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SONTRAC—A Low Background, Large Area Solar Neutron Spectrometer

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Abstract. SONTRAC is a scintillating fiber neutron detector designed to measure solar flare neutrons from a balloon or spacecraft platform. The instrument is comprised of alternating orthogonal planes of scintillator fibers viewed by photomultiplier tubes and image intensifier/CCD camera optics. It operates by tracking the paths of recoil protons from the double scatter of 20 to 200 MeV neutrons off hydrogen in the plastic scintillator, thereby providing the necessary information to determine the incident neutron direction and energy. SONTRAC is also capable of detecting and measuring high-energy gamma rays >20 MeV as a "solid-state spark chamber." The self-triggering and track imaging features of a prototype for tracking in two dimensions have been demonstrated in calibrations with cosmic-ray muons, 14 to ~ 65 MeV neutrons and ~ 20 MeV protons.

INTRODUCTION AND MOTIVATION

Neutrons above the nuclear binding energy are ubiquitous in cosmic ray interactions, whether those reactions occur on the surface of the Sun or in the earth's atmosphere. These secondary neutrons are difficult to measure because they lack charge, and thus, do not interact readily with detector material.

When high-energy charged particle reactions occur on the surface of the Sun, neutrons carry away information about the spectrum of ions that produced them. They can be used as diagnostic measures of the accelerated ion spectrum in solar flares (1,2). As illustrated in Fig. 1, gamma rays are produced efficiently by protons below 20 MeV and above 300 MeV. The intervening region of the proton spectrum is most effective in producing neutrons of comparable energy. To determine the proton spectrum in this region secondary neutrons must be measured. This measurement must take place from a space platform or a balloon. In either environment the background is high making the measurement difficult.

To perform these measurements neutron telescopes based on double scatters have been used (3-6). Because of its directional properties a neutron telescope one can reject

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much of the background, thereby enhancing the signal-to-noise ratio, making these instruments effective in high background environments. Such instruments have applications in other disciplines including atmospheric physics, radiation therapy and nuclear materials monitoring.

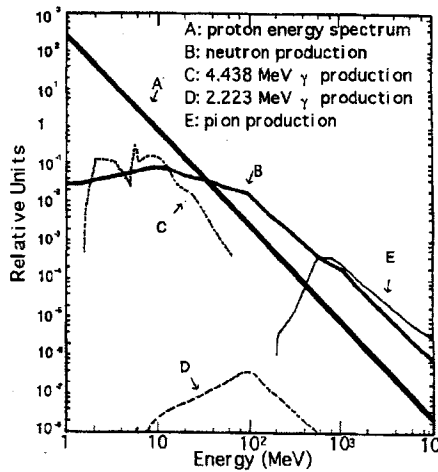


FIGURE 1. Spectrum-weighted emissions of solar flare gamma rays and neutrons.

TRACKING DETECTOR CONCEPT

We have been studying a tracking detector design for measuring neutrons in the difficult range of 20 to 250 MeV. The design is based around a closely packed bundle of square cross section plastic-scintillator fibers. The fibers are arranged in stacked planes with the fibers in each plane orthogonal to those in adjacent planes. This configuration allows one to record stereoscopic images of ionization tracks.

Neutrons undergo elastic scattering off hydrogen within the organic plastic-scintillator fibers, scattering at right angles with respect to the scattered proton at non-relativistic energies. The Bragg peak (greater ionization at the end of the track) is used to determine proton track direction. A second proton scatter of the neutron provides the spatial information that is necessary and sufficient to determine the incident neutron energy and direction. An image and spectrum of the neutron source can be constructed from these data. The angular and energy resolution of the instrument depend upon our ability to track the recoil protons and measure the scintillation light.

A functional diagram of an experiment utilizing the SONTRAC concept is shown in Fig. 2. The detector's spectroscopic, track detection and imaging components cover the entire light-emitting area of the fiber bundle and are duplicated in the orthogonal dimension (not shown). Scintillation light signal is collected and processed at both ends of the fiber bundle. At one end a signal above threshold from a photomultiplier tube (PMT) gates the trigger logic circuitry. At the other end, fiber-optic tapers and a pair of

image intensifiers demagnify, capture and hold the scintillation-light image of the track(s) for the CCD camera. The first image intensifier is always ON, holding the image for ~ 1 ms. The second image intensifier is normally in the gated-OFF condition. However, with the particle coincidence requirements satisfied, the track image and PMT pulse height data are acquired, combined with any auxiliary data and recorded.

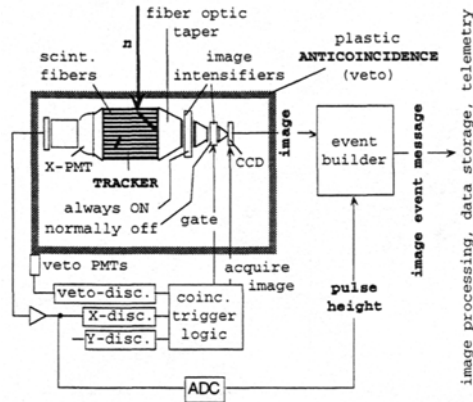


FIGURE 2. Complete instrument functional and logic diagram.

A 4π plastic scintillator shield surrounds the tracker to reject incoming cosmic rays. Other charged particles produced in the detectors cannot escape the detector volume without being registered. They represent lost energy and can be rejected.

The initial design of the SONTRAC instrument suffered at the time from a lack of affordable technology and existed in simulations only (7-9). Due to advancements in technology, we have been able to construct a simple prototype of the instrument to verify the concept and identify any fundamental technical limitations.

Fig. 3 is a schematic of the SONTRAC prototype operating at UNH. The prototype is a 10 cm long bundle of 250 μm -square (230 μm active), multicladd, organic, scintillating, plastic fibers (Bicron BCF-99-55) within a 12.7 mm square envelope. It is, therefore, limited to tracking in two dimensions. The fiber thickness was chosen such that a 10 MeV recoil proton traverses several fibers. The fiber pitch is 300 μm (including cladding and EMA) and the calculated range of a 10 MeV proton (50% of the proposed neutron threshold energy) is 1.25 mm (~ 4 fibers). The PMT is a bialkali photocathode device from Thorn EMI. Two 18 mm diameter, single-MCP, generation-2 image intensifiers from DEP are employed. The S20 photocathode for the first image intensifier was selected for its response to scintillation light. The P43 phosphor holds the image for ~ 1 ms. The second intensifier's photocathode (S25) and phosphor (P43) provide good spectral matches to the output of the first intensifier and the input to the CCD sensor, respectively. The CCD camera (Pulnix TM-9701) is an inexpensive, progressive scanning camera with digital readout and control, asynchronous external trigger and full frame shutter capability. The Matrox frame grabber and image processor operate within a Pentium PC.

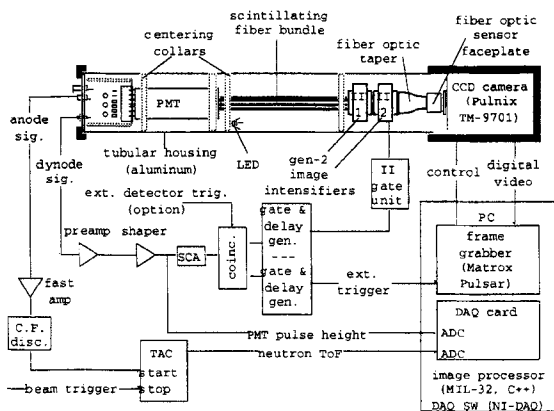


FIGURE 3. Prototype functional and logic diagram.

PROTOTYPE PERFORMANCE AND FLIGHT DESIGN

Tracks of recoil protons near our trigger threshold energy (14 MeV) have been published elsewhere (10). These data show that protons as low as ~ 10 MeV can be tracked over 4 or 5 fibers with a clear Bragg peak. The scintillation light also conforms to the expected distribution (within errors) of the ionization rate.

The SONTRAC prototype was also exposed to 20 MeV and 27 MeV neutrons and to ~ 20 MeV protons at the Crocker Nuclear Laboratory at the University of California at Davis. Additional measurements were made with ~ 65 MeV neutrons, although it was not possible to get a clean beam in the time available. Fig. 4 shows two CCD images of neutron interactions in the prototype fiber bundle. On the left is a double scatter event displaying two recoil proton tracks from a neutron (~ 65 MeV) incident from the top of the figure. On the right is a single proton recoil track from a 28 MeV neutron incident from the top left of the figure. The individual fibers are seen in the ionization tracks. Note that the Bragg peak is evident establishing the proton recoil direction. Gaps in the track images are due the ionizing particles traversing the passive cladding and EMA materials.

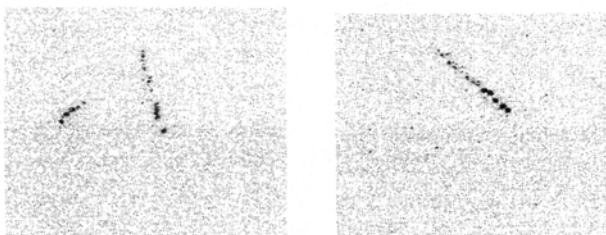


FIGURE 4. Double scatter of a ~ 65 MeV neutron (left) and a 28 MeV proton (right).

Fig. 5 is a cosmic-ray muon image recorded with the SONTRAC prototype, demonstrating the detector's ability to track minimum-ionizing particles. (The fiber

mask is shown for reference.) This is necessary to track conversion electrons in high energy gamma detectors. We calculate that ~ 4 photoelectrons/fiber are generated for amplification within the image intensifier.



FIGURE 5. A cosmic-ray muon track.

A sketch of a larger volume detector for particle tracking in three dimensions is shown in Fig. 6. It employs orthogonal layers of scintillating fibers in a $10 \times 10 \times 10$ cm bundle with one PMT (left) and one image intensifier/CCD chain (right) in each dimension. The fiber block would be surrounded by charged particle detectors to (1) reject cosmic ray protons and electrons and (2) to detect the escape of secondary charged particles from internal reactions. The flight instrument would occupy a space less than $50 \times 50 \times 20$ cm³ with a total mass less than 26 kg. We estimate that the proposed instrument will have an effective area for detecting and measuring 15 to 60 MeV neutrons of ~ 2 cm², approximately the same as that of the imaging Compton telescope, COMPTEL, a 1460 kg instrument (6).

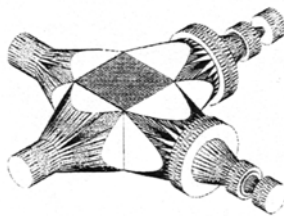


FIGURE 6. Sketch of a $10 \times 10 \times 10$ cm 3-d imager.

The typical energy resolution is on the order of 10% or better for the majority of neutron events. The angular resolution is largely determined by the pitch of the fibers, i.e., the uncertainty in the end points of the tracks. For a 45° scatter and 300 μ m fiber

pitch it ranges from 23° at 20 MeV to 5° at 50 MeV to 0.7° at 200 MeV. This angular resolution is the basis for our high signal-to-noise ratio and thus our good sensitivity.

CONCLUSIONS

We have demonstrated the important features of the SONTRAC instrument with a laboratory prototype. This will help to determine the engineering parameters important for the SONTRAC application (e.g., scintillating fiber pitch, light yields, gains, photocathode and phosphor selection, gating delays and intervals). Although the prototype is limited to tracking in two dimensions, we obtained self-triggered images of tracks of ~ 20 MeV protons, recoil protons from 14 to ~ 65 MeV neutrons and minimum ionizing tracks of cosmic ray muons. The track images and the associated pulse height information provide good resolution measurements of both the direction and energy of the incident radiation. An extension to 3-dimensional tracking promises to provide unprecedented measurement capabilities for studies in solar physics and other fields.

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