NEUTRON-INDUCED 2.2 MEV BACKGROUND IN GAMMA RAY TELESCOPES

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1. Introduction. Neutron-induced gamma ray production is an important source of background in Compton scatter gamma ray telescopes where organic scintillator material is used. Most important is deuteron formation when atmospheric albedo and locally produced neutrons are thermalized and subsequently absorbed in the hydrogenous material. The resulting 2.2 MeV gamma ray line radiation essentially represents a continuous isotropic source within the scintillator itself. Interestingly, using a scintillator material with a high hydrogen-to-carbon ratio to minimize the neutron-induced 4.4 MeV carbon line favors the np reaction.

The full problem of neutron-induced background in Compton scatter telescopes has been previously discussed (1). In this paper we will present results of observations with the University of California balloon-borne Compton scatter telescope (2,3) where the 2.2 MeV induced line emission is prominently seen.

2. Observations. The neutron-induced 2.2 MeV line feature has consistently been present in the background gamma ray spectra measured with the University of California Compton scatter telescope. Figure 1a shows a typical energy spectrum accumulated over a period of 34 hours during a balloon flight from Palestine, Texas in September, 1978. The cutout (Fig. 1b) shows a 1/2 hour accumulation of the line feature at 2.13 MeV with a 0.98 MeV FWHM with the continuum background subtracted. In addition to an expected shift downward in the mean energy from 2.23 MeV due to some loss in event energy from the second scintillator, there was a systematic drift (3.3% or 70 keV) in the mean energy of this 2.2 MeV line feature over the duration of the balloon flight.

Each of the telescope's 56 scintillator cells was calibrated prior to the flight with gamma ray reference sources. During the flight LED light sources in each cell are used to normalize the photomultiplier gains to the pre-flight calibration. The systematic drift referred to above was due to the temperature related drift of the telescope's LED-pulser system which wasn't compensated.

The observed count rates for the 2.2 MeV gamma rays are given in Table 1 for two different geomagnetic vertical cutoff rigidities. With the University of California telescope, the 2.2 MeV line feature is also observed in the upward-moving background spectrum. The upward-moving line feature is approximately four times as intense as the downward moving but is effectively separated from the latter with time-of-flight.

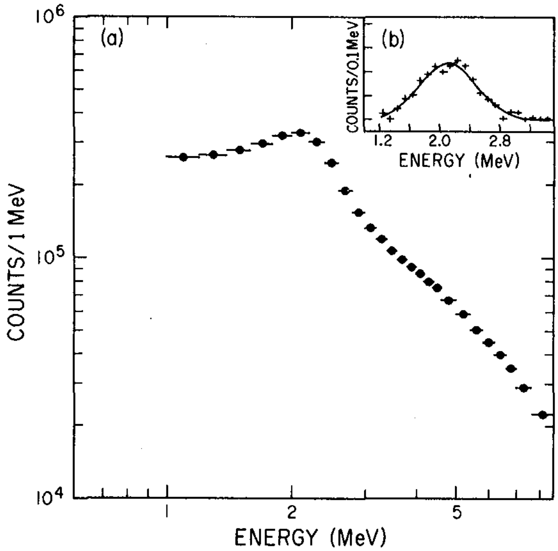

Fig. 1(a) Count rate spectrum of downward moving gamma rays at 4 g/cm^2. (b) Line feature at 2.13 MeV mean energy with continuum background subtracted.

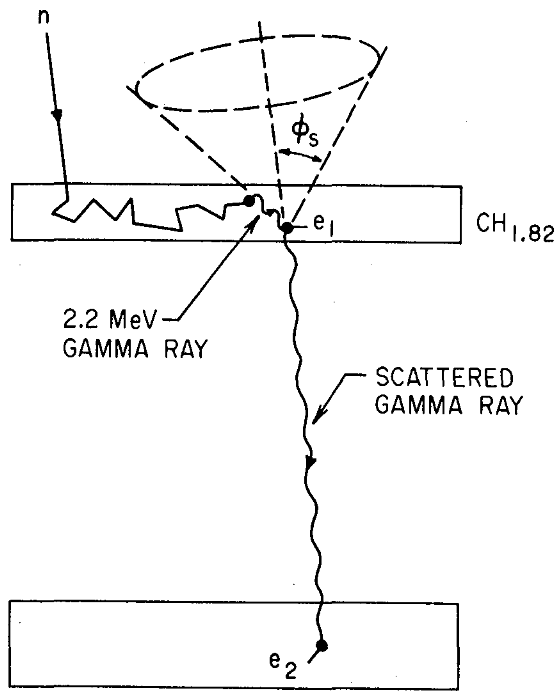

Fig. 2 Typical neutron thermalization and absorption to produce background 2.2 MeV events.

Table 1. Measured Count Rate of 2.2 MeV Induced Gamma Rays

Vertical Cutoff (GV)	Photons/sec
4.5 GV (Palestine, Texas)	2.1
9.0 GV (Alice Springs, Australia)	1.4

3. Calculations. The basic process for detecting a neutron-induced 2.2 MeV photon and misidentifying its direction of origin with a celestial source within the field-of-view of the telescope is shown in Figure 2. First, atmospheric neutrons incident on the large 100 x 100 x 12.5 cm^3 upper scintillator array filled with a mineral oil-based liquid scintillator (H/C = 1.82) are moderated by the hydrogen and carbon until they either escape the boundaries of the array or are absorbed by the hydrogen. Most of the absorbed neutrons are thermalized first ($E_n \approx 0.025$ eV).

The fraction of incident isotropic neutrons which actually are absorbed has been calculated with a Monte Carlo code. These results are summarized in Table 2. Typically, about 20% of the incident neutrons are absorbed; they have an exponential absorption time distribution with a mean time of about 140 μsec.

Table 2. Thermalization and Absorption of Isotropic Neutrons Incident on a 100 x 100 x 12.5 cm^3 Scintillator (H/C=1.82)

E_n(MeV)	Percent Thermalized	Percent Absorbed
10	25	14
1	43	23
0.1	42	22
0.01	40	20

Near the top of the earth's atmosphere the cosmic ray albedo neutron flux is relatively insensitive to float altitude changes typical of balloons. Thus the 2.2 MeV gamma ray production rate in the large scintillator array is constant. Using a value of 0.1 neutron/cm^2-sec for this flux (4) at 9 GV, the production rate is approximately 250/sec for the upper scintillator array. At 4.5 GV this rate should be larger by a factor of 2.1. It is primarily neutrons above 10 keV that produce this flux due to the flatness of the albedo spectrum below this energy.

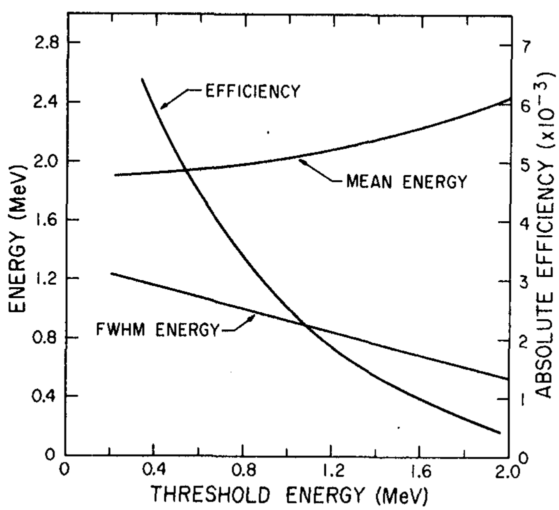

Fig. 3 2.2 MeV gamma ray detection efficiency as a function of energy threshold. Also shown are the variations in mean energy and FWHM.

The actual counting rate for the induced 2.2 MeV γs depends on the double scatter efficiency of the telescope which, in turn, is very sensitive to the energy thresholds in the two scintillator arrays. We have used our gamma ray Monte Carlo transport code to calculate this efficiency for 2.2 MeV photons distributed uniformly throughout the upper scintillator array with an isotropic angular distribution. These results are shown in Figure 3 as a function of the summed energy threshold for the upper and lower scintillator arrays. For a 1 MeV threshold the expected rate is 0.6/sec compared with the observed rate of 1.4/sec at 9 GV. In the above calculation we have neglected the non-negligible downward neutron flux due to the atmosphere remaining above the balloon and any locally produced neutrons in the telescope itself.

The efficiency and, therefore, the count rate is a very sensitive function of the threshold. Also affected by the threshold are the mean energy assigned to the 2.2 MeV peak and the FWHM of the line feature. This is because the threshold energy is comparable both to 2.2 MeV and the energy resolution of the telescope.

Since the production rate of induced 2.2 MeV γs is constant the telescope count rate of these events is a sensitive function of the photomultiplier tube gains. For example, a gain increase of 10%, which is effectively an energy threshold reduction by the same amount, will account for a count rate increase of 16% while the mean energy of the line changes by 7.8% or 160 keV.

The induced 2.2 MeV line emission poses a limitation for observing this same line feature from celestial gamma ray sources. The importance of this line emission in astrophysical processes is illustrated by its dominance in the Sun's solar flare gamma ray emission. Based on our measured count rate of this line feature, our minimum detectable flux for 2.2 MeV line emission is $2.2 \times 10^{-4} \gamma/cm^2$-sec at the 4 sigma level for six hours of observation at 9 GV.

4. Conclusions. The sensitivity for observing 2.2 MeV line emission from celestial sources will be limited by the neutron-induced background at this energy. This will be especially true of gamma ray telescopes which use substantial amounts of organic scintillator materials. This source of background cannot be removed with pulse shape discrimination techniques in the organic scintillator because of the relatively long time delay between the initial neutron scatter and its absorption by hydrogen. Any positive detection of 2.2 MeV line emission will be in addition to the ever-present induced emission.

Gamma ray telescopes which do not use organic scintillator as their primary detection element but do use large quantities for charged particle shields will also see this background unless precautions are taken. Compton scatter telescopes with improved angular resolution will have somewhat improved sensitivity because valid event circles can be better correlated with known source directions.

The 2.2 MeV background line feature, however, can be used for energy calibration purposes if needed or, which is preferred, used for verification that the calibration and gain-control methods are stable with respect to long term drift.

5. Acknowledgments. We wish to acknowledge NASA grant NGR-05-008-022 for support of this research.

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