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THE DEVELOPMENT OF A SEGMENTED N-TYPE GERMANIUM DETECTOR, AND ITS APPLICATION TO ASTRONOMICAL GAMMA-RAY SPECTROSCOPY

N. Gehrels*, T.L. Cline, B.J. Teegarden, J. Tueller+, NASA/Goddard Space Flight Center

M. Leventhal, Bell Laboratories

C.J. MacCallum, Sandia National Laboratories

P. Ryge, Princeton Gamma-Tech, Inc.

Extensive calculations and simulations have shown that the instrumental background in a coaxial germanium photon detector flown at balloon altitudes or in space, can be substantially reduced by segmenting the outer contact. The contact is divided into horizontal strips around the side of the detector, giving it many characteristics similar to that of a stack of planar detectors. By choosing different segment coincidence requirements in different energy ranges, one can obtain a factor of ~ 2 increase in sensitivity to spectral lines between 40 keV and 1 MeV, compared with an unsegmented detector. The reverse electrode configuration (using n-type germanium), with the p contact outside, is preferred for this application due to its thin dead layer and resistance to radiation damage in space. We are currently developing a small two-segment n-type detector to serve as a prototype for larger multi-segment devices. Results of this development effort and of detector tests will be presented.

* NAS/NRC Research Associate; + Univ. of Maryland

N. Gehrels
Code 661
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
(301) 344-6546

DISCLAIMER

SUMMARY

A study of the instrumental background observed in shielded germanium photon detectors at balloon altitudes has led to a better understanding of its origin. It has been found that many of the components of the background can be reduced, and in some cases almost eliminated, by segmenting the outer side contact of a coaxial germanium detector and applying various coincidence requirements between signals from the segments.

The segmentation concept is illustrated in Figure 1. The high-resolution spectroscopic signal is taken from the inner unsegmented anode (n-type detector), while the signals from the outer cathode are used to determine in which segment or segments the event occurred.

At low energies ($\lesssim$ 100 keV), only events in the top segment are accepted. Almost all incident photon events are retained due to the approximate unit efficiency for their absorption in the top segment, whereas, the volume dependent component of the detector background is reduced by a factor of $\frac{\text{detector volume}}{\text{1 segment volume}}$. We are considering a detector of dimensions 6.5 cm length by 6.5 cm diameter divided into 7 segments, surrounded by a 15 cm thick NaI scintillation, and with a field-of-view collimated to 3° x 3°. For this case, the volume-dependent component of the background increases from half the total background at 40 keV to almost all of it at 100 keV. Since the volume-dependent component is reduced by a factor of 7, the segmentation results in a net background reduction ranging from a factor of 3.5 at 40 keV to a factor of ~ 7 at 100 keV. The detector sensitivity to spectral lines, which is defined as the minimum line flux detectable at a given significance level in a given observation time, scales like the square

root of the background divided by the detector efficiency. The segmentation, therefore, improves the sensitivity by a factor of ~ 2 between 40 and 100 keV.

At intermediate energies (~ 300 keV to ~ 1 MeV) the background is dominated by β^- activation of the detector by interactions of atmospheric protons and neutrons with the germanium atoms. We have calculated the contribution of different nuclear interactions to this component by integrating the neutron and proton spectra observed at balloon altitudes with the best available interaction cross-sections for each germanium isotope. All possible β^--emitter final states were considered, amounting to more than a hundred for each germanium isotope; the total number of integrations performed and production rates calculated were over 1000 (> 100 β^- emitters, 5 Ge isotopes, 2 incident particles). The new result obtained from this effort is that the β^- component of the background is due almost entirely to β^- decays to a nuclear ground state, without an accompanying gamma-ray. The electrons emitted in these decays have ranges less than ~ 1 mm, so that the decays can be considered localized.

In the intermediate energy range, the detector is operated in a multisegment mode, which requires more than one segment for a valid event. Photons between 300 keV and 1 MeV interact in the detector primarily via Compton scattering, and therefore tend to deposit energy in more than one segment; the β^- decays occur predominantly in a single segment and are therefore vetoed, as illustrated in Figure 2. The net gain in sensitivity is shown in Figure 3. The plotted sensitivities are for 3σ detections of narrow ($\lesssim$ 3 keV FWHM) spectral lines from an 8-hour balloon observation at ~ 24° latitude and 3.6 g/cm^2 atmospheric depth. The segmentation improves the sensitivity by more than a factor of 2 at 800 keV.

We are currently developing a small (~ 4 cm diameter) two-segment n-type high-purity germanium detector to serve as a prototype for larger multi-segment devices. Results of this development effort and of detector tests will be presented.

SEGMENTED N-TYPE GERMANIUM DETECTOR

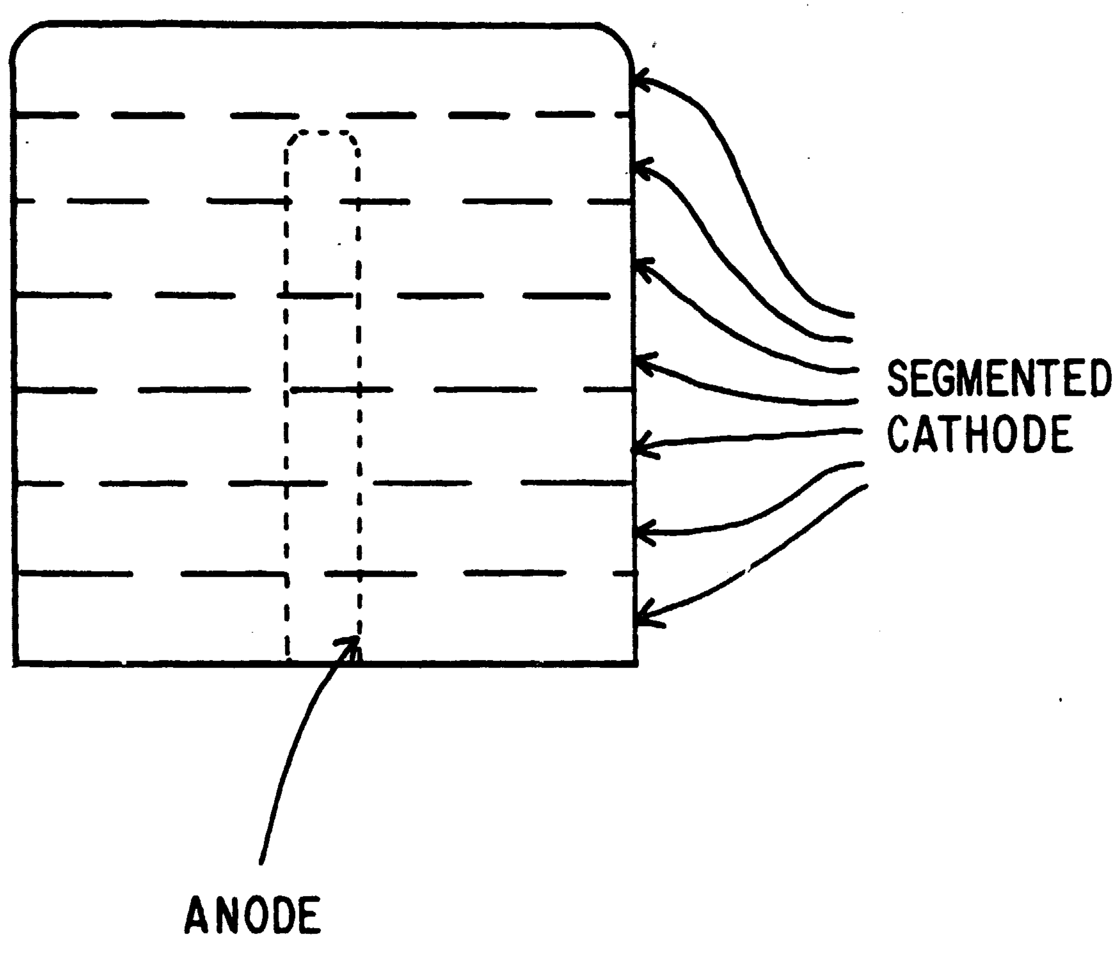

FIGURE 1

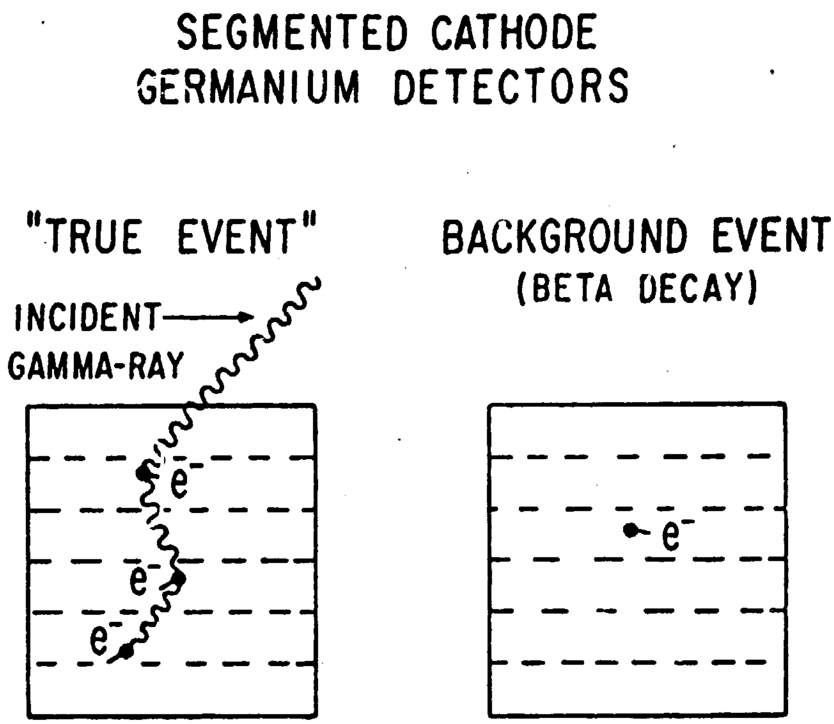
SEGMENTED CATHODE
GERMANIUM DETECTORS
"TRUE EVENT"
INCIDENT
GAMMA-RAY
e⁻
e⁻
e⁻
BACKGROUND EVENT
(BETA DECAY)
e⁻

FIGURE 2

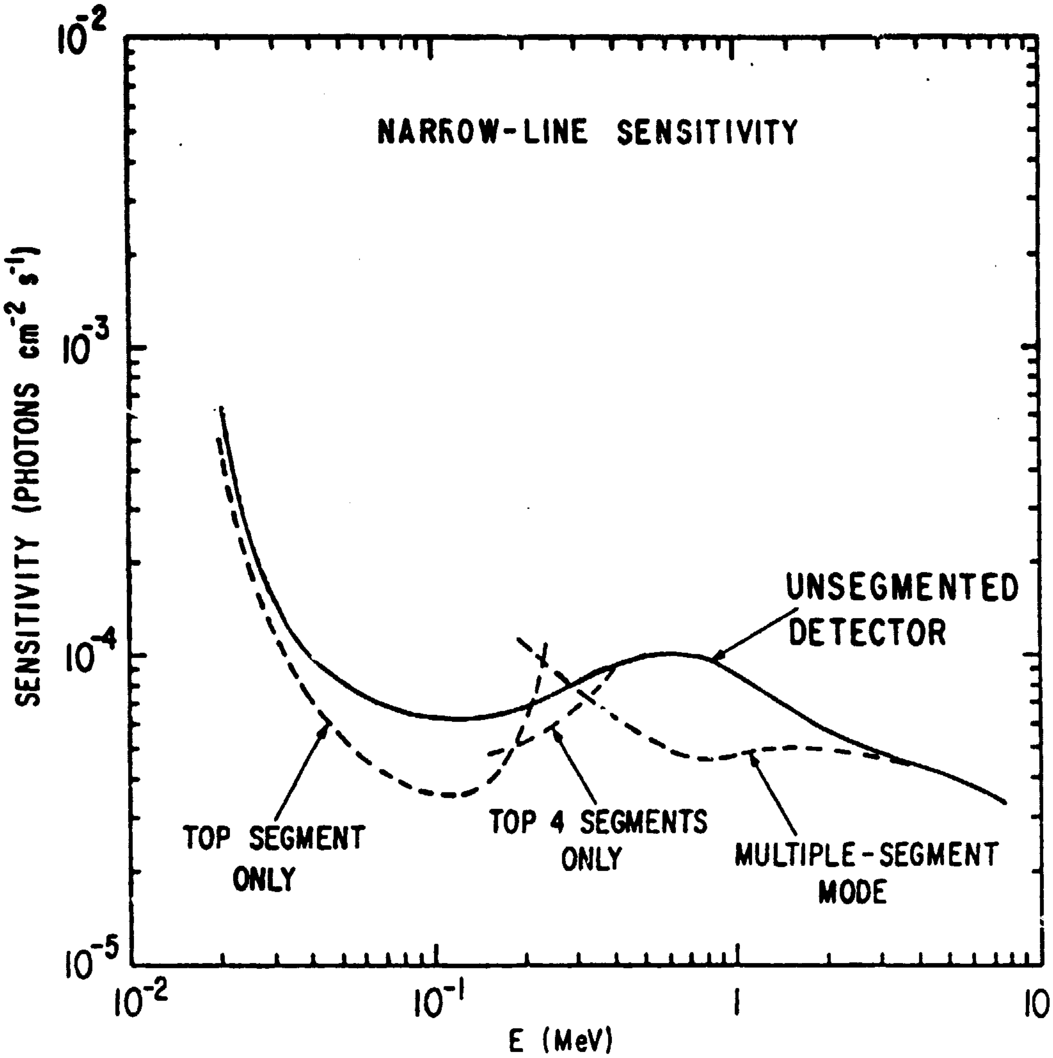
NARROW-LINE SENSITIVITY
SENSITIVITY (PHOTONS cm⁻² s⁻¹)
10⁻²
10⁻³
10⁻⁴
10⁻⁵
UNSEGMENTED DETECTOR
TOP SEGMENT ONLY
TOP 4 SEGMENTS ONLY
MULTIPLE-SEGMENT MODE
10⁻²
10⁻¹
1
10
E (MeV)

FIGURE 3