BACKGROUND REDUCTION IN A CODED APERTURE MASK TELESCOPE

D. Bhattacharya, A. Owens, E. L. Chupp, P. P. Dunphy,
M. L. McConnell and A. Bui-Van

University of New Hampshire, Durham, NH 03824, USA

1. Introduction. In a previous paper presented elsewhere at this conference[1], we have evaluated the various background components detected by the University of New Hampshire Directional Gamma-Ray Telescope (DGT). It was found that the calculated energy-loss spectrum is in good agreement with that measured over Palestine, Texas at a mean atmospheric depth of 3 g cm^{-2}. Furthermore, the results indicate that the instrument is not optimally designed and that significant reductions in most of the background components may be readily achieved over the entire energy range of this instrument. Towards this end, we have begun the implementation of a number of relatively simple modifications to the present instrument in order to improve its sensitivity as well as its overall performance. The modified instrument is shown in Figure 1 and essentially retains the basic configuration of the original DGT [2].

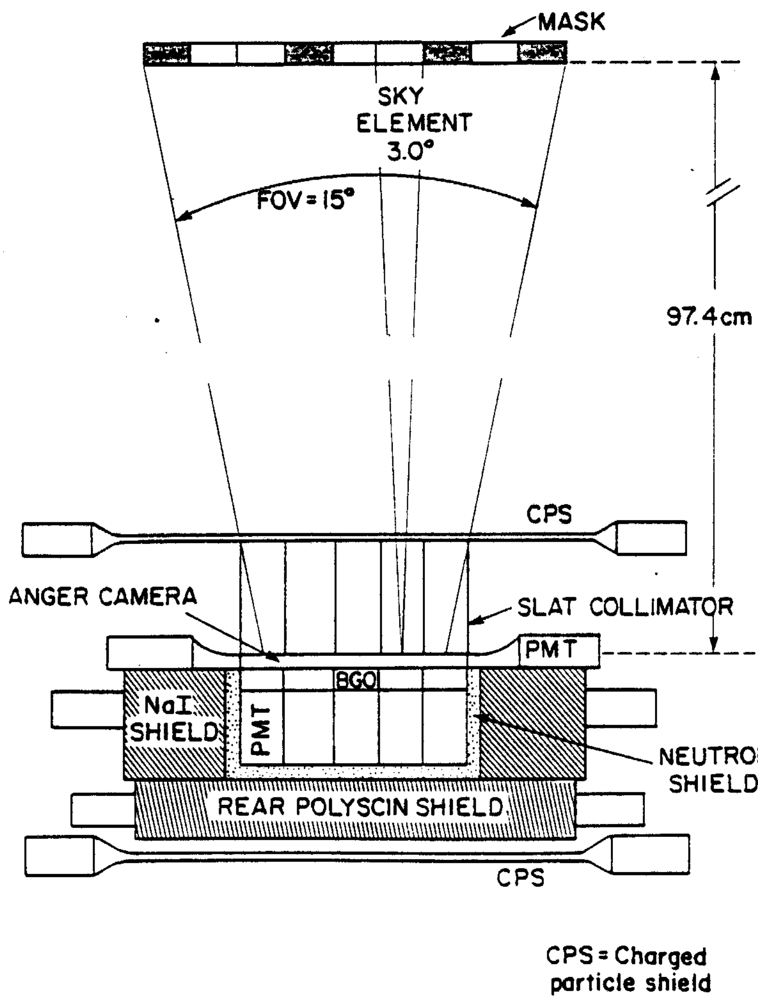

Figure 1.

A cross-sectional view of the modified DGT.

The principal modifications include: The reduction of the low-energy threshold of the instrument from 160 keV to 50 keV, the addition of a pre-collimator placed above the detection plane, a neutron jacket surrounding the central array, a thin sheet of plastic scintillator located above the pre-collimator which covers the forward aperture, and an Anger camera placed immediately above the BGO array. Although we have not explicitly included the properties of the Anger camera in the present calculations, it is anticipated that a significant reduction in the detector background would be possible at energies > 1 MeV by exploiting the kinematics of the Compton scattering process.

This would be achieved experimentally by requiring a two-fold coincidence between the upper gamma- camera and a signal from a spatially consistent crystal in the BGO array. Monte Carlo calculations are presently being carried out to determine the magnitude of this effect. In the following sections, we discuss the specific approaches employed to reduce each of the various background components.

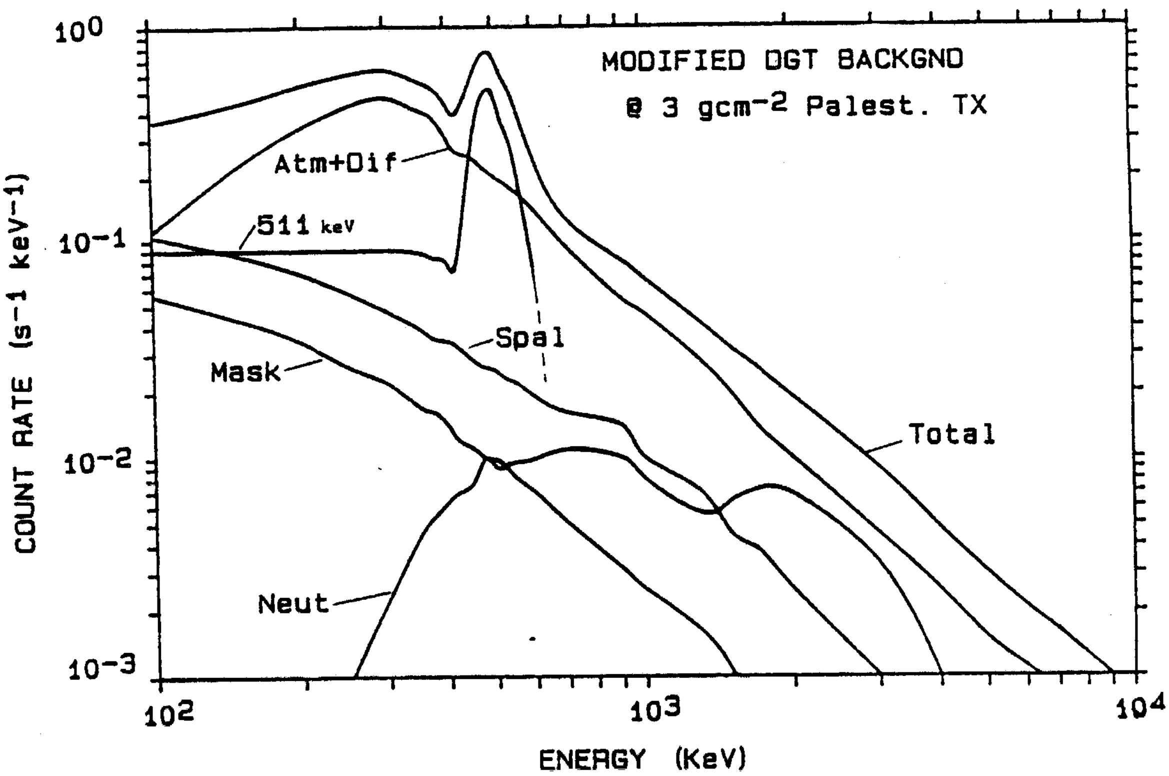

Figure 2.

The calculated background energy-loss spectrum for the modified DGT over Palestine, Texas at a residual atmospheric depth of 3 g cm^{-2}.

Atmospheric and Cosmic Component: A reduction in the counting rate due to the atmospheric and cosmic γ-radiation may be effected by pre-collimation of the forward aperture. This is achieved by the addition of a simple slat collimator. The pre-collimator consists of an inner 13 cm high boxed 'egg crate' composed of alternate strips of Cu, Sn, and Cu (of thicknesses 0.15, 1.0 and 0.15 mm, respectively) surrounded on the sides by a graded shield fabricated from alternate strips of Pb, Sn, and Cu of thicknesses 1.0, 1.0 and 0.5 mm, respectively. The use of this particular shield composition effectively eliminates the background due to flourescence in lead. The shield is virtually opaque for energies up to $\sim$ 100 keV and attenuates the diffuse component by a factor of $\sim$ 20 below this energy. Above $\sim$ 100 keV the transmission rises slowly to approximately 20% at 200 keV. Since almost 60% of the detector counting rate is due to γ-rays entering the forward aperture from outside the field of view of the mask, it is estimated that, in the energy region 50 to 200 keV, an overall reduction of a factor of $\sim$ 10 would be possible.

Neutron induced component: In the present instrumental design, the neutron induced count rate dominates the detector energy-loss spectrum at energies > 2 MeV. The principal contribution to this component arises primarily from neutron interactions within the central BGO array. Almost 90% of the resulting energy-loss spectrum is due to the inelastic scattering of the neutrons off germanium and bismuth nuclei, whereas only 10% arise from neutron capture processes [3]. This presents the real possibility of reducing the neutron induced counting rate by using suitable moderators and absorbers as described in Owens *et al.* [4]. It is estimated that a factor of ~ 2 reduction would be possible in the MeV range of the resulting energy-loss spectrum. It should be noted that in a NaI array the relative contributions due to inelastic scattering and neutron capture are approximately equal. Therefore the moderation of the incident spectrum would not affect the resulting counting rate as much, since the fast neutrons that were available for scattering proccesses are now available for capture instead.

Charged Particle and Mask Production Component: The contributions due to the atmospheric electrons and soft reentrant albedo protons may be significantly reduced by the inclusion of a simple charged particle shield above the forward aperture. Monte-Carlo calculations have shown [5] that this will have the added advantage of attenuating the contribution due to photon initiated secondary γ-ray production in the mask by a factor of approximately 2, since ~ 50% of these γ-rays are accompanied by a secondary electron of energy > 1 MeV.

Natural Radioactivity: Laboratory measurements have shown that almost all of the counting rate due to natural radionuclides emanates from the glass of the photomultiplier tubes in the BGO array. In particular, the presence of ^{40}K in the PMT tubes is evident in the DGT background spectrum by the strong line feature at 1.46 MeV. A comparison with similar tubes indicate that the problem is limited to the particular type of tube (EMI 9956) used in the DGT and therefore their replacement will virtually eliminate this component.

TABLE 1

Background Contributions to the Integral Detector Counting Rate

Component	160 keV–1 MeV *cts s^{-1} DGT	160 keV–1 MeV *cts s^{-1} Modified DGT	1 MeV–7 MeV *cts s^{-1} DGT	1 MeV–7 MeV *cts s^{-1} Modified DGT
Aperture + Leakage Atmospheric + Cosmic γ-rays	343	175	46	46
Neutron	15	6	56	20
Electron	7	0.07	10	0.1
Proton	0.07	0.007	0.5	0.05
Mask Production	16	9	4	2
Spallation	25	25	7	7
Lines	77	62	< 2	< 1
Natural Radioactivity	50	–	70	–
Total	533±100	277±70	193±48	70±25

*Multiply by 7.05×10^{-4} to convert to cts $cm^{-3}s^{-1}$

2. Results: Figure 2 shows the calculated background energy-loss spectrum for the modified DGT over Palestine, Texas at a residual atmospheric depth of 3 g cm^{-2}. These calculations were carried out using the same analytical procedures outlined in [1]. For comparison, the same paper shows the measured background spectrum of the original instrument. For completeness, Table I lists all the background contributions in two energy bands for the modified and original instruments. As can be seen in the table, we expect the overall reduction in the instrumental background to be approximately a factor of 2. A further reduction of a factor of two may be expected for a southern hemisphere flight, due to increase in geomagnetic rigidity ($R \sim 9.8$ GV as opposed to 4.5 GV for Palestine, Texas).

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References

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