E563

Annual Report on NAS8-35354

SPACE RADIATION STUDIES

including quarterly reports for the periods ending
February, May, August, and November 1988

Cosmic Ray Laboratory
The University of Alabama in Huntsville
Huntsville, AL 35899

TECHNICAL REPORT

Analysis of the gamma-radiation background measurements made by the Nuclear Radiation Monitor (NRM) flown on Spacelab-2 has proceeded. Current work was reported as a Space Sciences Laboratory Preprint, No. 88-136, appended to this report.

GAMMA RADIATION BACKGROUND MEASUREMENTS FROM SPACELAB 2

William S. Paciesas,* John C. Gregory,* and Gerald J. Fishman

SPACE SCIENCE LABORATORY
PREPRINT SERIES
NO. 88-136

*University of Alabama in Huntsville
Huntsville, Alabama 35899

GAMMA RADIATION BACKGROUND MEASUREMENTS FROM SPACELAB 2

William S. Paciesas and John C. Gregory
University of Alabama in Huntsville, AL 35899

Gerald J. Fishman
Space Science Laboratory, NASA/Marshall Space Flight Center
Huntsville, AL 35812

ABSTRACT

A Nuclear Radiation Monitor incorporating a NaI(Tℓ) scintillation detector was flown as part of the verification flight instrumentation on the Spacelab 2 mission, July 29 - August 6, 1985. γ-ray spectra were measured with better than 20 s resolution throughout most of the mission in the energy range 0.1 to 30 MeV. Knowledge of the decay characteristics and the geomagnetic dependence of the counting rates enable measurement of the various components of the Spacelab γ-ray background: prompt secondary radiation, Earth albedo, and delayed induced radioactivity. We summarize herein the present status of the data analysis and present relevant examples of typical background behavior.

INTRODUCTION

The usefulness of the Space Shuttle as a platform for high energy astrophysics experiments is highly dependent upon the spectrum and intensity of the ambient radiation background. The Nuclear Radiation Monitor (NRM) was developed to characterize the γ-ray, proton, electron and neutron environment inside the Shuttle payload bay during orbital operations. To this end, the NRM was included in the Verification Flight Instrumentation on the Spacelab 2 mission, where it operated continuously during the orbital portion of the flight. The data are currently being analyzed to distinguish among the various background components: primary radiation incident on the spacecraft (generally well-known from previous measurements) and secondary radiation from the spacecraft or the Earth's atmosphere. The secondary spacecraft radiation spectrum is difficult to calculate or predict because its production depends in a complex way on the composition and distribution of materials. Although this implies that the NRM measurements hold in the strictest sense only for Spacelab 2, other Shuttle missions may be sufficently similar to make the data relevant to other experimenters, either in instrument design or data analysis. Data from the NRM is available to other experimenters for this purpose.

EXPERIMENT DESCRIPTION

The NRM consists of a 12.7 cm diameter, 12.7 cm thick, NaI(Tℓ) central detector shielded on the front and side by a 1 cm thick plastic scintillator. The configuration resulted in a nearly omnidirectional response with an effective energy threshold of ~80 keV and an energy resolution of 9.0% at 662 keV. The NRM was installed in the payload bay of the Space Shuttle Challenger and operated during the Spacelab 2 mission (July 29 to August 6, 1985). The orbit for this mission was inclined at 49.5° and its altitude varied between 290 and 327 km. The NRM was mounted on a pedestal on pallet no. 3, approximately 1 m above and 1 m inside the payload bay sill, at least 2 meters away from any massive objects. The NRM thus had a representative "view" of the inside of the payload bay.

The data from the NRM consist of 510-channel spectra (dispersions of 1.5, 15 and 150 keV/channel) with 20.16 s time resolution and 16-channel rates with 5.25 ms time resolution. Separate plastic coincidence/anticoincidence spectra are accumulated simultaneously for each dispersion. The instrument and data system are described in more detail elsewhere[1].

DATA ANALYSIS

The data have been organized into two databases for efficient analysis. One of these combines the spectral data with livetime corrections and retains the inherent time resolution of 20.16 s. The other contains the 16-channel gamma ray and charged particle counting rates integrated over 0.504 s intervals. Figure 1 is an example of the available rate histories. Two different γ-ray energy ranges are shown together with the integral rate of events in the central detector in coincidence with the plastic scintillator (the latter are predominantly charged particle events). The characteristic sinusoidal modulation of the background results from the orbital position dependence of the cosmic ray secondary production in the atmosphere and the spacecraft. Significant increases over the basic orbital modulation are produced by at least two processes. In one case, passages through the South Atlantic Anomaly (SAA) region produce intense events which have a hard spectrum, smooth time structure, and durations of about 15 minutes. The other case is due to precipitating energetic electrons which produce bremsstrahlung x-rays by interacting with the atmosphere or the spacecraft. These events are seen only at high latitudes and have relatively soft spectra, as they are not prominent in the higher energy γ-ray channels. The electron events often feature rapid, complex temporal variation on timescales as short as 1 s, much faster than the proton events (an example of this is shown in Figure 3 of Ref. 1). Based on other studies of precipitating electrons at high latitudes (cf. Ref. 2), we conclude that the such rapid x-ray temporal structures reflect the time-variability of the electron flux rather than the spatial (orbital) motion of the detector.

Figure 2 shows a typical uncorrected spectrum at the time of an electron event compared with a spectrum taken at a background minimum. The softness of the bremsstrahlung spectrum is evident, the e-folding energy of the excess being ~100 keV. In contrast, the γ-ray spectra of SAA passages typically differ from those of low background regions in intensity but not in shape. The spectral

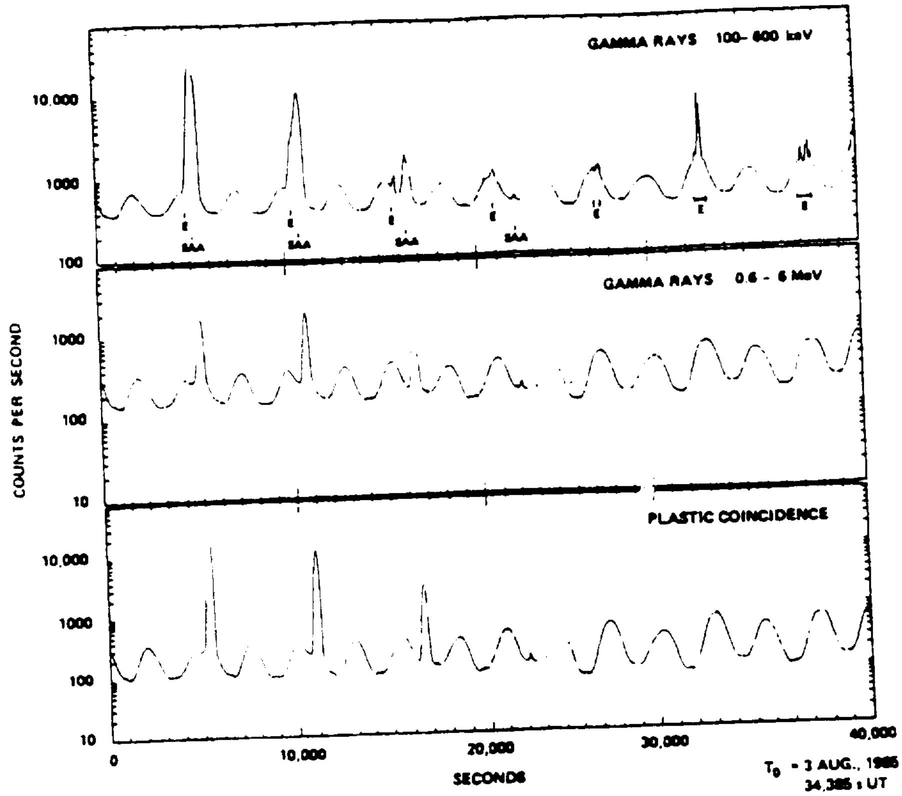

Figure 1. Background data from the NRM during the Spacelab 2 mission. Shown are the detected count rates in two γ-ray energy regions and the integral counting rate from the NaI in coincidence with the plastic (due mostly to charged particles). Several regions of increased background due to trapped electrons (E) and protons (SAA) are indicated, superimposed on the underlying modulation due to geomagnetic latitude variations. The data span ~7.5 orbits with 20.16 s time resolution.

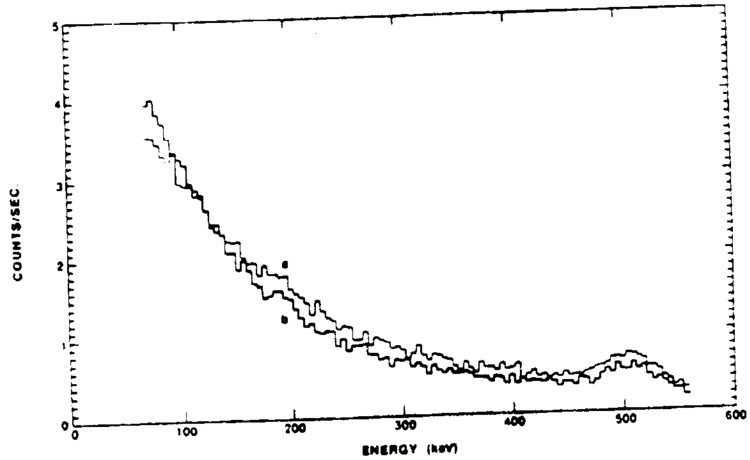

Figure 2. Spectrum of low energy γ-rays during an electron enhancement compared with a normal background spectrum. The energy scale is ~1.5 keV/channel.

distinction of proton enhancements shows up primarily in the highest-energy charged particle spectra.

The contribution of earth albedo to the background effects is illustrated best by examining data taken during an episode on July 31 in which the orbiter was rolled continuously for approximately one hour. Figure 3 shows the γ-ray rates in three energy intervals during this episode. Despite some interfering SAA passages, the roll rate of about one revolution per 300 s is readily apparent. The lowest energy channel shows the smallest effect and, more importantly, it is 180° out of phase with the higher channels, due to the fact that the sky-background spectrum is steeper than that of the earth albedo. Spectra taken at these two extremes are shown in Figure 4. The crossover point (where the earth and the sky have the same brightness) occurs at ~120 keV.

Cosmic rays, trapped protons, and energetic neutrons can also contribute to the γ-ray background by producing radioactivity in the detector and surrounding materials via spallation reactions. We attempted to measure such effects in the NRM by observing the spectral lines produced by activation of the central detector crystal. Though too weak to be seen in flight, the lines show up in post-flight spectra taken upder sufficiently low background conditions. Similar measurements on other heavy spacecraft have been interpreted[3,4] as evidence of a substantial flux of energetic neutrons, since the detected activity was too large to be explained by cosmic ray and trapped protons alone (the latter contributions are assumed to be much better-known than the neutron flux).

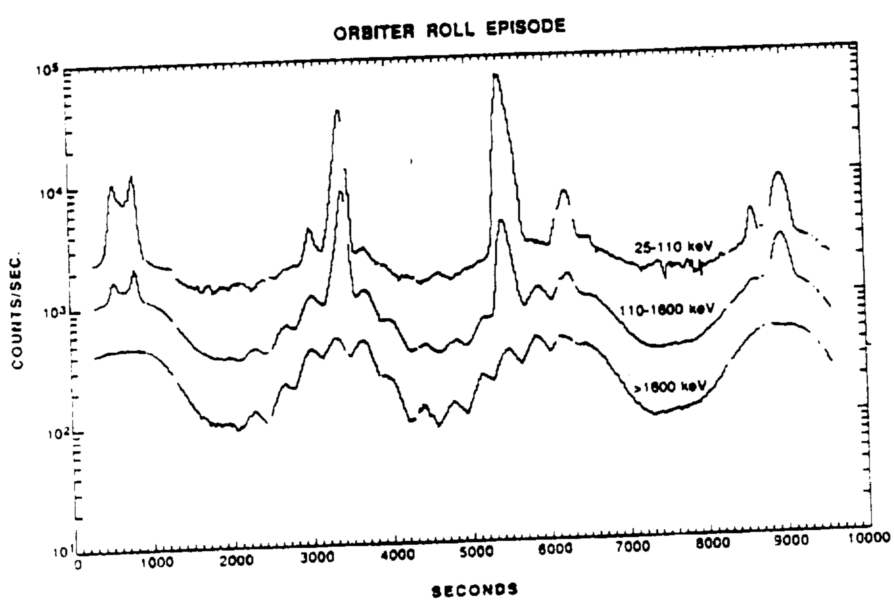

Figure 3. NRM γ-ray counting rates spanning an episode of orbiter roll. The roll period of ~300 s is superimposed on the orbital variations. The phase reversal due to the difference in spectral hardness between sky background and earth albedo is evident in the lowest energy band near the minimum of the orbital variation. The time resolution of the data is 20.16 s.

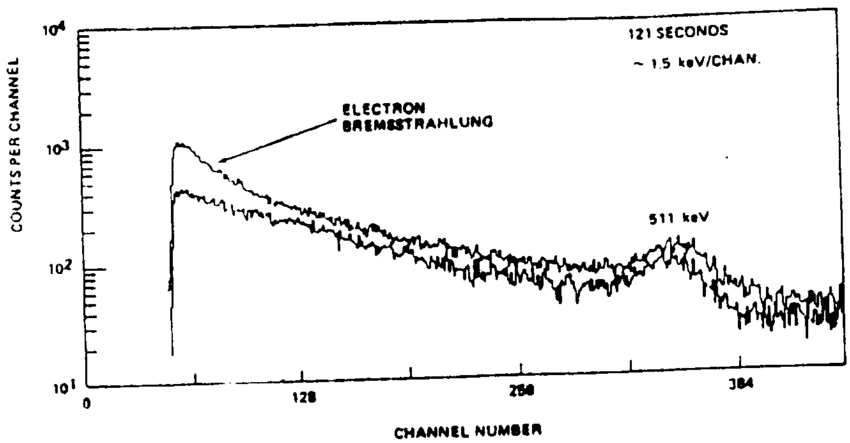

Figure 4. A comparison of background spectra taken during *a)* earth-pointing and *b)* sky-pointing intervals. The relative hardness of the earth albedo is evident.

The NRM was received at MSFC approximately three weeks after the end of the mission, at which time certain shorter-lived iodine spallation products such as ^{124}I ($t_{1/2}$ = 4.2 d) had decayed below detectability. With the NRM in a low-background counting facility at MSFC, we observed a γ-ray line which was consistent in energy and half-life with the most prominent line expected from ^{126}I decay within the detector (699 keV and 13 d, respectively; because the decay mode is electron capture within the detector, the apparent line energy is the sum of the ^{126}I γ-ray energy of 667 keV and the daughter tellurium K-shell binding energy of 32 keV). The line can be seen in figure 5, which shows spectra taken at various intervals after the end of mission. It is evident from the figure that the line at ~699 keV is decreasing in intensity relative to the other background lines. Extrapolation of these data back to the end of the mission implies an induced ^{126}I activity of ~0.5 decays/s/kg-NaI, with an uncertainty of ~50% due predominantly to systematic errors.

Similar measurements performed on Apollo 17[3] and the Apollo-Soyuz Test Project (ASTP)[4] are compared with the present result in Table I, from which it appears that evidence for neutron activation on Spacelab 2 is less strong than on the Apollo-17 and ASTP missions. More direct measurements of the energetic neutron fluence on Spacelab 2 by Parnell *et al.*[5] support this conclusion; their results imply an average energetic neutron flux of ~0.8 cm^{-2}-s, compared with values of 2 and 5 cm^{-2}-s derived for ASTP and Apollo 17, respectively[3,4]. Part or all of this discrepancy may be due to

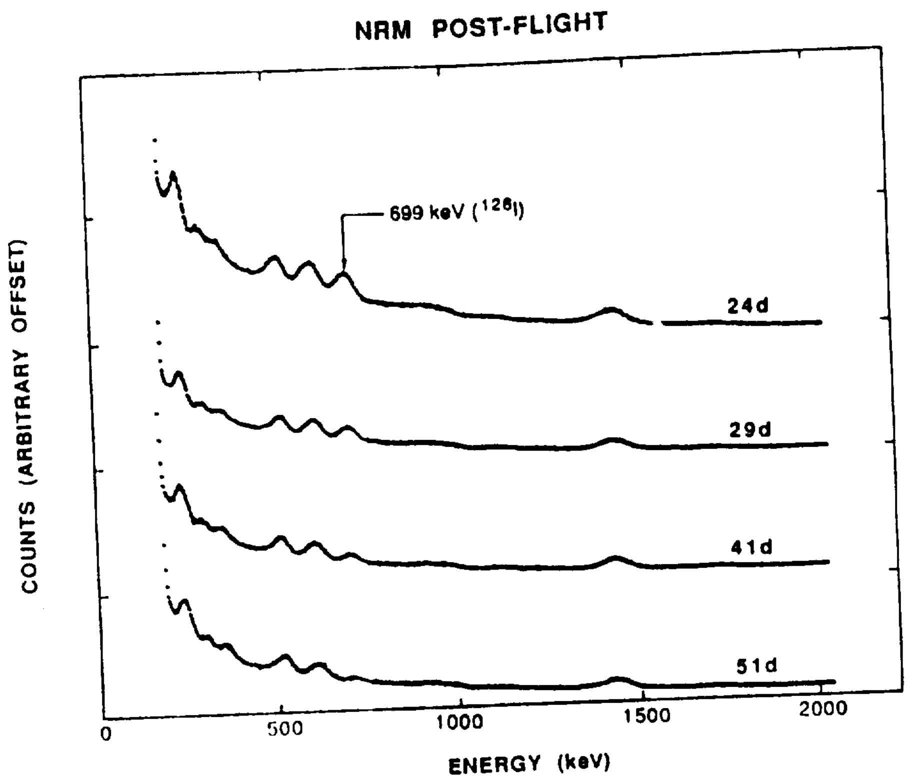

Figure 5. Post-mission γ-ray spectra accumulated at various intervals with the NRM inside a low-background shield. The line at 699 keV is identified with ^{126}I ($t_{1/2}$ = 13 d). The latter is produced in orbit by interactions of energetic neutrons and protons with ^{127}I in the central detector.

Table I. Measurements of ^{126}I Activity

Mission	^{126}I activity (decays/s/kg-NaI)
Apollo 17	5.0 ± 2.5
ASTP	~2.5
Spacelab 2	~0.5

different assumptions regarding the spectrum of the neutrons, which is poorly known. Nevertheless, the data are consistent with the conclusion that the energetic neutron flux on Spacelab 2 was a factor of 2 to 4 smaller than on ASTP and a factor of 5 to 10 smaller than on Apollo 17.

SUMMARY

We have seen spectral and temporal variations in the NRM γ-ray and charged particle event rates which may be used to distinguish among the major components of the radiation background on Spacelab 2. Further analysis of these variations will enable us to determine the contribution due to secondary radiation in the spacecraft, a result of importance not only for high energy astrophysics applications but also for other classes of experiments and materials such as photographic films and biological samples.

ACKNOWLEDGMENTS

We are grateful to the following people for the successful operation of the NRM: F. Berry, Jr., W. Selig, R. Austin, W. Hammon, S. Dothard, L. Wallace, R. Asquith, F. Emens, M. Teal, J. Gattis, R. Eakes, and C. Messer. We also thank T. Parnell for useful discussions regarding neutron fluence measurements.

REFERENCES

1. Fishman, G. J., Paciesas, W. S., and Gregory, J. C., *Adv. Space Res.* 7, (5)231 (1987).
2. Imhof, W. L. *et al.*, *J. Geophys. Res.* 91, 3077 (1986).
3. Dyer, C. S. *et al.*, *Space Sci. Instr.* 1, 279 (1975).
4. Trombka, J. I. *et al.*, ASTP Preliminary Science Report, NASA TM X-58173, p. 7-1 (1976).
5. Parnell, T. A. *et al.*, *Adv. Space Res.* 6, 125 (1986).