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Energetic neutrons and gamma rays measured on the Aryabhata satellite

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Abstract. An experiment to measure energetic neutrons and gamma rays in space was launched in the first Indian scientific satellite, *Aryabhata,* on April 19, 1975. From this experiment, the first measurements in space of the Earth's albedo flux of neutrons of energy between 20 and 500 MeV have been made; the values obtained for two mean geomagnetic vertical cut-off rigidities of 5·6 and 17·0 GV are $(6\cdot 3 \pm 0\cdot 4) \times 10^{-2}$ and $(1\cdot 4 \pm 0\cdot 3) \times 10^{-2}$ neutrons cm^{-2} sec^{-1} respectively. These measurements confirm that protons arising from cosmic ray albedo neutron decay, can adequately account for the protons in the inner radiation belt. Observations on gamma rays of energy between 0·2 and 24 MeV have enabled the determination of the total background gamma ray flux in space as a function of latitude. This in turn has permitted useful information on the diffuse cosmic gamma rays. We have also observed four events that showed sudden increases in the gamma ray counting rates between 0·2 and 4·0 MeV. Observational details of these events are given.

Keywords. Energetic neutrons; gamma rays; Aryabhata Satellite.

1. Introduction

" Energetic neutrons and gamma rays from the Sun" was one of the three scientific experiments on board the first Indian Scientific Satellite *Aryabhata*, launched on April 19, 1975. The experiment worked satisfactorily until the 41st orbit when the electrical power for the three experiments failed. Though it was not possible to realise the major scientific objective of the experiment, namely, to detect solar neutrons expected to be emitted at times of intense solar flares, we have made the first measurements on the flux of neutrons of energy greater than 20 MeV at satellite altitude as a function of latitude. These have been compared with measurements of other workers made at balloon altitudes. The present results confirm that the cosmic ray albedo neutrons can well account for the protons seen in the inner radiation belt. Furthermore, observations on the flux of gamma rays over the geographic latitude range of 0°–50° at the satellite altitude have enabled us to set useful upper limits for the flux of diffuse cosmic gamma rays of energy between 0·2 and 24 MeV. Reference is also made to the observation of four events associated with sudden increases of gamma ray fluxes over time periods of 1–2 sec.

2. Experimental details

2.1. *Principle of detection*

Neutrons of energy between about 20 and 500 MeV can best be detected with high efficiency through the low energy evaporation and knock-on charged particles they produce as a result of nuclear interactions they induce in an inorganic scintillator CsI (Tl); in contrast to this, gamma rays interact in the crystal giving rise to fast electrons. Due to the significant difference in the ionisation loss dE/dx for fast and slow particles in such crystals, the pulse shape for each type of interaction is different. It is known that the derivatives of pulses of identical shapes, irrespective of their amplitudes, will cross the time axis at a fixed point (Mathe and Schlenk 1964). This cross over time T which is characteristic of the particle is measured in addition to its total energy E released in the crystal; and from a cross plot of T and E the two types of events can be reliably separated. The high degree of specificity of the experiment to identify neutron induced events individually amidst the abundant gamma rays using the Pulse Shape Discrimination (PSD) technique has already been demonstrated in balloon experiments (Daniel *et al* 1970; Joseph 1970). Furthermore, the thickness of the crystal is chosen such that gamma rays are recorded with a minimal efficiency without unduly affecting that for neutrons. At energies below a few MeV almost all events are due to gamma rays, because firstly, the steep gamma ray spectrum will lead to very high fluxes at lower energies, and secondly, the chances of neutron induced nuclear interactions to release less than a few MeV in charged particles become more and more unlikely. Thus, it is possible to sample reliably low energy gamma rays without taking recourse to the PSD technique.

From a consideration of our knowledge on the energy release spectrum due to neutrons of varying energies, particularly from extensive work carried out in nuclear emulsions, and the threshold energy of 4 MeV set for neutron events in the present experiment, it can be easily shown that the energy range of neutrons to which the present experiment is sensitive is about 20–500 MeV. In order to convert the neutron counting rate, seen in the present experiment, into flux values the following information is used: (i) the variation with energy of the cross section for inelastic interaction of neutrons in the detector crystal; (ii) the energy release spectrum as a function of neutron energy; (iii) the angular and energy distribution of particles emitted from neutron induced nuclear interactions; and (iv) an assumed energy spectrum for neutrons appropriate to its origin. It is however, important to note that the calculated flux is not very sensitive to the assumed energy spectrum. The neutron flux is then obtained from the relation

$$F = \frac{N\langle\lambda\rangle}{V} \text{ neutrons cm}^{-2}\text{ sec}^{-1} \tag{1}$$

where N is the observed counting rate per second corrected for the selfgating effect in which a fast particle produced in the nuclear interaction triggers the 4π charged particle shield, $\langle\lambda\rangle$ is the appropriate mean interaction mean free path in the crystal, and V is the volume of the CsI(Tl) crystal.

In the case of gamma rays the counting rates are reduced to photon fluxes using the unfolding factor calculated as a function of energy (Peterson 1975).

2.2. *The detector system*

The detector system consists of a CsI (Tl) crystal of diameter 12·54 cm and 1·27 cm thick coupled to a 12·5 cm photomultiplier tube (RCA C31029) completely enclosed in a plastic scintillator anticoincidence shield viewed by four photomultipliers of 3·8 cm diameter (2 of type RCA 4461 and 2 of type RCA C70132 A).

Selection of a neutral event is carried out by putting the CsI (Tl) pulse in anticoincidence with the charged particle shield pulse. Neutral events which release between 0·2 and 4 MeV are analysed in three energy channels (0·2–0·4; 0·4–1·0; and 1·0–4·0 MeV) without recourse to PSD technique and scaled down appropriately (scale factors are 8, 4 and 16 respectively); they are all classified as Low Energy Gamma rays (LEG–1, LEG–2 and LEG–3 respectively). Neutral events which release more than 4 MeV in the crystal are subject to the PSD technique and the cross over time and energy release are each analysed by a 64 channel pulse height analyser which enables the separation of individual neutron and gamma ray events. The counting rate of events which result in coincident pulses (COIN) in the charged particle shield and the main detector, scaled down by a factor 64, were also continuously monitored.

The total weight of the experiment was 20 kg. The weight of the whole satellite was 358 kg.

2.3. *Orbit performance*

The satellite had a near circular orbit with the following parameters: perigee: 563 km; apogee: 619 km; period: 96·36 minutes; and inclination: 50·71 degrees. During the time when the experiment was on, only real time telemetered data received over two ground stations, one at Bear's Lake in USSR, and the other at Shriharikota (SHAR) in India, were available. The data accumulated over 11 passes covered a useful time period of about 90 minutes; the results described in this paper are based on the analysis of this data. During this period the instrument maintained a temperature between 3° C and 23° C.

The near circular orbit at the mean altitude of 590 km is generally below the inner radiation belt except over the region of the South Atlantic Anomaly where the trapped particle flux is significant even at this altitude. It is now well known that nuclear gamma ray emission induced by interactions of trapped protons in the main detector crystal and surrounding material slowly decays with time and data recorded from orbits not passing through the South Atlantic Anomaly region are considered to be relatively free from effects of induced radioactivity. This effect does not affect the neutron events but it is observed to have a significant effect on the gamma ray counting rates at energies < 5 MeV. In view of this, for the analysis of low energy gamma rays we have included only passes which clearly avoided the South Atlantic Anomaly.

3. Data analysis and results

A careful examination of the data obtained with regard to: (*a*) the latitude dependence of the various counting rates, (*b*) the separation of neutron and gamma ray events based on the analysis of the two-dimensional matrix, E vs. T and (*c*) the level of various counting rates, compared to that expected from calculations and

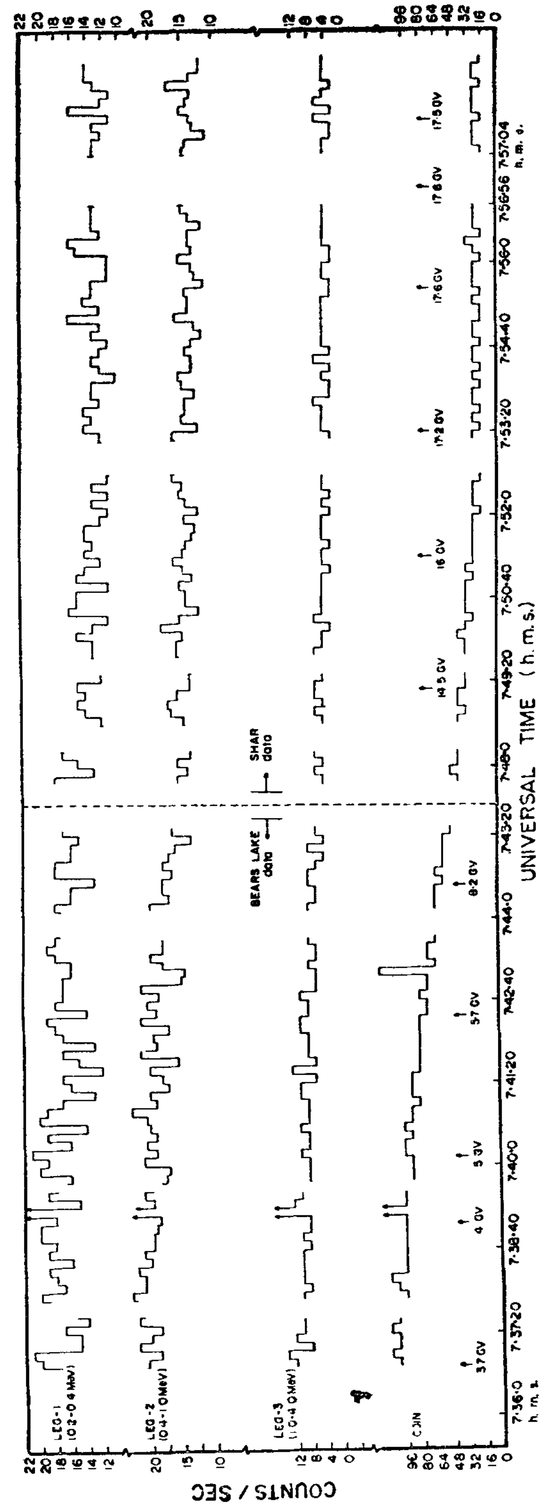

Figure 1. The counting rates for three low energy gamma ray channels (LEG–1), LEG–2 and LEG–3) and for the charged particle coincidence channel (COIN) observed in an orbit covering a wide latitude range.

earlier balloon measurements, clearly demonstrated that the instrument performed satisfactorily during this period. As an example, we have plotted in figure 1 the counting rates LEG-1, LEG-2, LEG-3 and COIN as a function of time (and vertical geomagnetic cut-off rigidity) for orbit 16 for which we have extensive data from both the ground stations; the profiles of the counting rates as a function of latitude are in excellent agreement with our expectations. Secondly, in figure 2 we display the energy release spectrum of high energy neutron and gamma ray events obtained from the *E-T* plots based on data obtained from several orbits. This again demonstrates clearly the different spectral shapes for the two kinds of events consistent with our expectations; they are also consistent with our earlier balloon experiments (Daniel *et al* 1970) where a similar detector system and PSD technique were employed.

3.1. *Neutron fluxes*

The background neutron counting rate recorded by the instrument in orbit should be essentially due to: (i) splash albedo neutrons from the Earth's atmosphere having been produced in nuclear interactions by cosmic rays in collisions with air nuclei and (ii) neutrons produced from the cosmic ray bombardment of the spacecraft material. Since we cannot separate the two in a straightforward manner, we have summarised in table 1, the measured total background neutron flux between 20 and 500 MeV for two different mean geomagnetic vertical cut-off rigidities. (We would like to state here that since the energy release spectrum due to monoener-

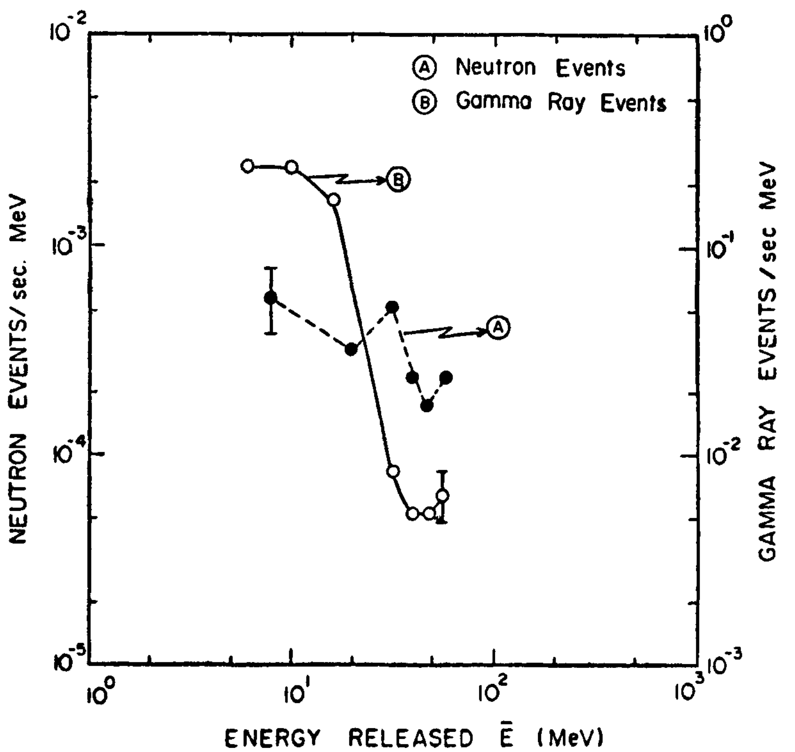

Figure 2. Energy release spectrum for high energy neutron events and high energy gamma ray events.

getic neutrons is known to be very broad, we have not attempted to construct an energy spectrum for the neutrons). Also shown in this table are the values calculated from the albedo measurements of White *et al* (1973) and Kanbach *et al* (1974) from balloon experiments suitably extrapolated for the same energy interval using a differential power law in energy with an exponent—1·8. The errors given for the results from the present experiment relate to those of statistical fluctuation only. The agreement between the results of the balloon experiments and the present satellite experiment in table 1 should be considered to be quite satisfactory bearing in mind the different methods of detection and evaluation of neutron flux and the difference in the configuration of local matter. Also, on the basis of our balloon experiment (Daniel *et al* 1970) with the detector in stowed and extended positions, and the calculated contribution from local production in the spacecraft, the local production of energetic neutrons is likely to be $\lesssim 10\%$ of the total counting rate.

The understanding of the origin of trapped protons of energy > 10 MeV in the inner radiation belt has been a subject of considerable interest since the first rocket observations of Freden and White (1962) and Naugle and Kniffen (1963). The early calculation of Lingenfelter (1963) on the flux of energetic neutrons produced in the upper atmosphere to account for the radiation belt protons as due to Cosmic Ray Albedo Neutron Decay (CRAND) was found to be too small by a factor of 20–50. However, balloon experiments carried out subsequently (Daniel *et al* 1970; Heidbreden *et al* 1970; Preszler *et al* 1972; Eyles *et al* 1972; White *et al* 1973; Kanbach *et al* 1974) established that the measured leakage flux of neutrons above 20 MeV was larger than that calculated by Lingenfelter, suggesting that CRAND could be the origin of the radiation belt protons. More recently, the improved calculations of Armstrong *et al* (1973) and Claflin and White (1974) have clearly shown that the leakage flux of neutrons determined from balloon experiments is adequate to explain the origin of the energetic protons in the inner belt. However, so far there has been no direct satellite observation to confirm the fluxes extrapolated from balloon experiments to the space well above the top of

Table 1. Comparison of the present measurements with those available from balloon experiments for neutrons of energy 20–500 MeV.

Mean geomagnetic rigidity	Method	Flux (neutrons cm^{-2} sec^{-1})	Authors
4·5 GV	Double scattering—Balloon measurement	$1 \cdot 7 \times 10^{-1}$	White *et al* (1973)
4·5 GV	Double scattering—Balloon measurement	$1 \cdot 8 \times 10^{-1}$	Kanbach *et al* (1974)
5·6 GV	PSD technique—Satellite measurement	$(6 \cdot 3 \pm 0 \cdot 4) \times 10^{-2}$	Present experiment
17·0 GV	PSD technique—Satellite measurement	$(1 \cdot 4 \pm 0 \cdot 3) \times 10^{-2}$	Present experiment
16·9 GV	PSD technique—Balloon measurement	$(1 \cdot 6 \pm 0 \cdot 4) \times 10^{-2}$	Daniel *et al* (1970)

the Earth's atmosphere. The present experiment fulfils precisely this need and confirms that CRAND is the primary source of energetic protons in the inner radiation belt.

We also have data from passes during local day and night over equatorial latitudes. From the absence of any detectable differences in the counting rates between these, we are able to set an upper limit of 2×10^{-2} neutrons cm^{-2} sec^{-1} at energies between 20 and 500 MeV for the quiet time emission of neutrons from the sun. This may be compared with the upper limit of 2×10^{-2} neutrons cm^{-2} sec^{-1} obtained by Forrest and Chupp (1969) between 20 and 120 MeV, and the very much better upper limit of 2×10^{-3} neutrons cm^{-2} sec^{-1} obtained for the energy range 20–500 MeV from balloon experiments of White *et al* (1973).

3·2. *Gamma ray fluxes*

Of the data on gamma ray intensities obtained from orbits for which tracking was possible from both ground stations, some had passed through the South Atlantic Anomaly showing enhanced counting rates in the low energy gamma ray channels (particularly 0·4 to 1 MeV) arising from the well-known induced radioactivity effect (Fishman 1972; Dyer and Morfill 1972). In figure 1 the observed counting rates are shown for the three low energy gamma ray channels and the coincidence channel observed over the two ground stations covering a cut-off rigidity from 3·7 GV to 17·5 GV for one of the clean orbits.

The counting rates of gamma rays measured in the present experiment will include contributions from the following sources:

(*a*) albedo produced by cosmic ray bombardment of the Earth's atmosphere;
(*b*) local production by cosmic ray bombardment of the body of the satellite;
(*c*) radioactivity induced in the CsI (Tl) detector and in the material surrounding the detector by trapped protons;
(*d*) diffuse cosmic gamma rays; and
(*e*) there will also be a contribution of bremsstrahlung gamma rays resulting from trapped electrons interacting in the vicinity of the detector.

Contributions from sources (*a*) and (*b*) are dependent on the geomagnetic latitude while those from (*d*) will be latitude independent. The effect of source (*c*) will depend on the trajectory of the spacecraft with respect to the radiation belt, and in particular, whether the satellite passed through the South Atlantic Anomaly just prior to the orbit under consideration. Effects arising from (*e*) are of no concern to us in the present experiment since we have no recorded data while the satellite was passing through the Anomaly.

In order to study the energy spectrum of gamma rays measured in space, and its latitude dependence, we have summarised in figure 3, the present observations for a mean geomagnetic latitude $\bar{\Lambda} \approx 39°$ and the equatorial region corresponding to mean vertical cut-off rigidities of 5·6 and 17 GV respectively. The latitude effect is clearly seen from this figure. For a comparison with other satellite measurements, we have also shown in this figure data obtained from COSMOS-163 (Golenetskii *et al* 1971) and OSO-1 (Peterson 1967). While the COSMOS-163 results are in good agreement with our measurements, the OSO-1 values are significantly higher even after allowing for the higher latitude of 42° in their experiment. As explained by the authors, this effect is most likely due to the fact that

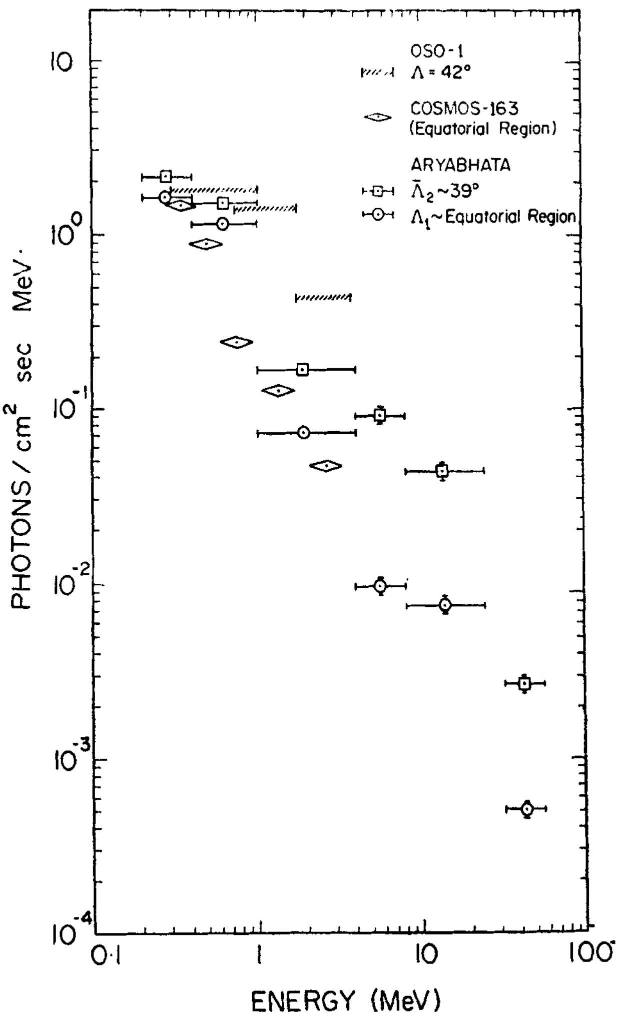

Figure 3. The photon spectrum for the gamma ray background, over high latitude ($\bar{\Lambda} \approx 39°$, $\bar{R}_c \approx 5\cdot6$ GV), and over equatorial latitudes ($\bar{\Lambda} \approx 0°$, $\bar{R}_c \approx 17$ GV) observed in the present experiment on Aryabhata Satellite ($\sim$ 600 km altitude). The data from OSO–1 ($\sim$ 550 km altitude) and COSMOS-163 (apogee: 660 km., perigee: 250 km) satellites are also shown.

the OSO–1 detector system was in the proximity of a large amount of matter in the body of the satellite.

The high energy data beyond about 24 MeV in figure 3 could be an underestimate of the true flux of gamma rays because of the selfgating of high energy gamma rays which is an effect resulting from the triggering of the anticoincidence shield by a secondary electron from a genuine gamma ray induced event. Using the method discussed by Forrest (1967), it is estimated that such a reduction in flux will be less than about 15% for gamma rays of energy of about 24 MeV.

3.3. *The latitude effect*

In table 2 we have summarised the ratios of counting rates of different types of events measured over two mean vertical cut-off rigidities $\bar{R}_1$ and $\bar{R}_2$. It is known that the ratio of the number of primary cosmic ray particles arriving over a station with $R_1 \approx 5\cdot6$ GV to that with $R_2 \approx 17$ GV is close to 5·5 (Waddington 1960; Webber 1967 and references therein; Agrawal *et al* 1965; Daniel and Srinivasan, 1965) though this is likely to vary somewhat with the solar cycle. The ratio of $4\cdot6 \pm 0\cdot9$, obtained in the present experiment for energetic neutrons of 20-500 MeV, is within errors same as that for primary particles, thereby revealing that the production of albedo and local neutrons in this energy range bears a direct relation to the integral flux of primary particles. The coincidence counting rate (COIN) relates to all charged particles of energy greater than about 50 MeV. The value of $3\cdot9 \pm 0\cdot2$ for the COIN ratio is somewhat low and if this effect is genuine, it can in principle be due to the slowly increasing multiplicity of created particles with increasing energy of primary cosmic rays inducing nuclear disintegrations in the body of the satellite.

In the case of gamma rays, the ratios of counting rates at energies below 4 MeV summarised in table 2 relate to only those orbits which clearly avoided the South Atlantic Anomaly; at higher energies we have used other orbits as well. From table 2 there is evidence that at gamma ray energies of 0·2–4 MeV the ratios of counting rates increase with energy though they are all significantly below that for the primaries; at still higher energies there is clear indication that the ratios reach a value close to that for the primary particles. Such a effect can in principle arise from the following: (i) an increasing effective multiplicity of the secondary component with increasing energy of the primary particles; (ii) delayed induced radioactivity and (iii) the existence of a diffuse cosmic gamma ray component. Any

Table 2. Latitude effect for various types of events

Sl. No.	Type of event	The ratio of the flux over high latitude ($\bar{R}_1 = 5\cdot6$ GV) to that over low latitude ($\bar{R}_2 = 17$ GV)
1.	Gamma rays	
	0·2–0·4 MeV	1·33±0·06
	0·4–1·0 MeV	1·40±0·07
	1·0–4·0 MeV	2·36±0·14
	4·0–8·0 MeV	9·4 ±1·5
	8·0–24 MeV	5·7 ± 0·6
	32–56 MeV	5·25±0·5
2.	COIN	3·9 ±0·2
3.	High energy neutrons (20 MeV to 500 MeV)	4·6 ±0·9
4.	Primary cosmic rays	5·5

effect due to (i) is likely to be small because calculations on the production of secondary gamma rays in the energy interval 1–20 MeV for small atmospheric depths clearly show that the latitude effect between $\bar{R}_1 = 5\cdot5$ GV and $\bar{R}_2 = 17$ GV is close to 5·5, the value for the primary particles (Daniel and Stephens, 1975). Furthermore, the effect due to (ii) which is relevant to the energy range 0·2–4·0 MeV is also likely to be small since for the present analysis we have selected only clean orbits. From these considerations, it seems very strongly suggestive that the depression of the ratios of gamma ray fluxes for energies below 4 MeV in table 2 is primarily due to diffuse cosmic gamma rays.

3.4. *The diffuse cosmic gamma rays*

It is clear from section 3.3 that it is possible to deduce the flux of the diffuse cosmic gamma rays from observations made at satellite altitude as a function of latitude; the procedures followed are described in this section and the results obtained are summarised in table 3.

For gamma rays of energy less than 4 MeV we have calculated the flux of the cosmic component by following two procedures. In the first, we have adopted the procedure due to Golenetskii *et al* (1971) in which we first express the observed counting rate of gamma rays at any given latitude as

$$n_{\mathrm{obs}} = n_c + n_s \tag{2}$$

where n_c denotes the contribution due to the constant cosmic component and n_s that due to the latitude sensitive secondaries, both albedo and locally produced. It is known that for the rigidity range of concern to us here, namely, $R = 4$–17 GV,

Table 3. Cosmic gamma ray flux

Energy range MeV	Cosmic gamma ray flux: Photons $cm^{-2}\,sec^{-1}\,Sr^{-1}\,MeV^{-1}$			Remarks
	$\alpha = 1$	$\alpha = 1\cdot5$	Using latitude effect	
0·2–0·4	$1\cdot4\times10^{-1}$	$2\cdot2\times10^{-1}$	$2\cdot4\times10^{-1}$	
0·4–1·0	$5\cdot3\times10^{-2}$	$1\cdot1\times10^{-1}$	$1\cdot7\times10^{-1}$	*Aryabhata* satellite (present work)
1·0–4·0	$2\cdot6\times10^{-3}$	$5\cdot7\times10^{-3}$	$8\cdot0\times10^{-3}$	
0·3–0·4	$6\cdot5\times10^{-2}$	$1\cdot3\times10^{-1}$	..	
0·4–0·6	$3\cdot5\times10^{-2}$	$6\cdot9\times10^{-2}$	..	COSMOS–163 data Golenetskii *et al* (1971)
0·6–1·0	$8\cdot8\times10^{-3}$	$2\cdot0\times10^{-2}$	..	
2·0–3·7	$1\cdot5\times10^{-3}$	$3\cdot1\times10^{-3}$	..	
4·0–8·0		$<1\cdot6\times10^{-3}$		*Aryabhata* satellite (present work)
8·0–24		$<1\cdot2\times10^{-4}$		Using observed value over equatorial latitude
32–56		$(8\cdot2\times10^{-5})$		with average rigidity cut-off 17 GV

the primary flux F can be written as $F = A \cdot R^{-1.5}$ where A is a constant. Since the quantity n_s in eq. 2 can also be written as a function of R, we have

$$n_{obs} = n_c + kR^{-\alpha} \tag{3}$$

where k is a constant and α the index defining the dependence of n_s on rigidity The investigation of Golenetskii *et al* seems to suggest that α has a value lower than 1·5. In the present investigation we made use of the observations for the three low energy channels for which there is a significant lowering of the latitude effect compared to that expected for the primaries, and plotted n_{obs} as a function of $\bar{R}$ for values of R between 3·7 and 17·5 GV, and for two values of α, namely, $\alpha = 1$ and 1·5. From this we obtained the value of n_c by a method of extrapolation and therefrom the values of the cosmic flux; these are given in table 3 for the energy intervals 0·2–0·4 MeV, 0·4–1·0 MeV and 1–4 MeV. It should be noted that since there could still be a small residual effect due to the Anomaly the true flux values of the cosmic component could be somewhat smaller than the values obtained here.

In the second method, we made use of the observed fluxes for two mean geomagnetic latitudes corresponding to cut-off rigidities $\bar{R}_1$ and $\bar{R}_2$ having values of 5·6 and 17 GV respectively for the three low energy channels. We further made use of the calculated ratio of 5·5 for the secondary gamma rays at these energies for the two cut-off rigidities concerned here (Daniel and Stephens 1975) and estimated the flux of the cosmic gamma rays assuming that the value of n_s for $\bar{R}_1$ is 5·5 times that for $\bar{R}_2$. The values thus obtained are also given in table 3 and are found to be consistent with those obtained by the earlier method for $\alpha = 1\cdot5$. (We would like to stress here that in this case the two methods are not independent.)

Owing to the limited data available at higher energies, we have not been able to use the above methods meaningfully for gamma rays of energy in excess of 4 MeV. However, extreme upper limits for the flux of cosmic gamma rays at these energies were obtained by assuming that all the observed counting rates over the equatorial latitude are due to the cosmic component. The results of these calculations are also included in table 3.

The results obtained from the two methods for the lowest energy channels 0·2–0·4 MeV and 0·4–1·0 MeV are consistent with those obtained by other authors (for a summary *see* Daniel and Lavakare, 1975). In the energy interval 1·0–4 MeV, if the value of α, as discussed by Golenetskii *et al* (1971), is close to 1, then the diffuse gamma ray flux obtained therefrom will be inconsistent with the existence of a shoulder in the energy spectrum of the diffuse cosmic gamma rays as claimed by Trombka *et al* (1973). In the energy interval 4–24 MeV, the counting rates over the two geomagnetic latitudes exhibit a ratio consistent with that for primary particles indicating thereby that if there is a contribution from the cosmic component it has an effect less than that due to statistical and other possible experimental errors. This would mean that the true flux of the cosmic component should be very much smaller than the values given in table 3 thus again providing evidence against the existence of the shoulder in the cosmic gamma ray spectrum. As for the energy interval 32–56 MeV no useful inference can be made because of the uncertainty in the selfgating effect.

3.5. *Sudden gamma ray increases*

In the course of analysing the entire data, we observed four clear events of sudden and large increases of gamma ray counting rates ($\gtrsim 10\,\sigma$) in all the three low energy channels. From a very careful and systematic examination of the nature of the increases, and the information we had on the functioning of the experiment in the laboratory during the various tests and in orbit, we could not find any evidence or reason to explain them as due to instrumental effects. We have, therefore, summarised the main features of these events in table 4 (*see* figure 1 for event No. 4 which occurred at 073920 U.T.). However, the frequency of the events observed by us, namely, 4 in about 90 minutes of integrated time over many orbits is very much higher than that for the class of gamma ray bursts first discovered from work with Vela Satellites (Klebesadel *et al* 1973) and now well confirmed. Of the four events two of them lasted for a period $1 \lesssim t \lesssim 2$ seconds and the other two for $t \approx 1$ second. Also, events 1 and 3 did not show any increase in the coincidence counting rate while 2 and 4 were associated with such increases An examination of the energy spectra constructed using the counting rates from the three channels exhibit shapes similar to genuine events observed by other workers. Though we are unable to understand presently what these events are due to, we have included a brief description of them so that other workers may examine their data for time coincident events in their experiment.

Table 4. Main features of the sudden gamma ray increase events

Event No.	Orbit No. U.T. (hr., mt., sec) and date	Latitude	Longitude	*dN/dE* photons/cm² sec keV 0·2–0·4 MeV	0·4–1 MeV	1–4 MeV	Total energy erg/cm²	Remarks
1.	16 SHAR 07, 49, 33 20–4–1975	+28	77·18 E	2·12 $\times 10^{-3}$	5·05 $\times 10^{-3}$	1·63 $\times 10^{-3}$	1·7 $\times 10^{-5}$	No increase in COIN
2.	3 B.L. 10, 55, 26 19–4–1975	+32·87	31·86 E	20 $\times 10^{-3}$	11·1 $\times 10^{-3}$	3·6 $\times 10^{-3}$	4 $\times 10^{-5}$	Increase in COIN
3.	15 B.L. 06, 03, 46 20–4–1975	+47·64	66·91 E	18·6 $\times 10^{-3}$	3·14 $\times 10^{-3}$	..	3·7 $\times 10^{-6}$	No increase in COIN
4.	16 B.L. 07, 39, 20 20–4–1975	+48·66	38·02 E	19 $\times 10^{-3}$	10·8 $\times 10^{-3}$	3·65 $\times 10^{-3}$	4 $\times 10^{-5}$	Increase in COIN

4. Conclusion

The high energy neutron gamma ray experiment on the first Indian Scientific Satellite, *Aryabhata*, performed satisfactorily in the first few orbits until the electrical power to the experiment failed.

Because of the limited data available, the primary scientific objective of the mission could not be achieved; however, interesting results have been obtained on high energy neutron and gamma ray background in space at 600 km altitude.

The high energy neutron observations have provided, for the first time, the albedo neutron fluxes at satellite altitude. The results essentially corroborate the recent measurements at balloon altitudes and support the CRAND theory for the origin of inner radiation belt protons.

The gamma ray background measurements and their latitude effect have given useful upper limits on diffuse cosmic gamma ray flux in the energy range 0·2–24 MeV. These results add further doubts for the existence for a shoulder in the energy spectrum of the diffuse gamma rays at energies between 1 and 20 MeV.

Four events of sudden increases in the gamma ray counting rates have been observed. On the basis of our present knowledge of gamma ray bursts of the type discovered by Klebesadel *et al* (1973), we are unable to understand the origin of these events though to the best of our knowledge we cannot explain them to be of instrumental effects.

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References

Agrawal P C, Damle S V, Gokhale G S, Joseph G, Kunte P K, Menon M G K and Sunderrajan R 1965 *Proc 9th Int. Con. Cosmic Rays* **1** 457
Armstrong T W, Chandler K C and Barish J 1973 *J. Geophys. Res.* **78** 2715
Claflin E S and White R S 1974 *J. Geophys. Res.* **79** 959
Daniel R R and Srinivasan N 1965 *Nuovo Cimento* **35** 3
Daniel R R, Gokhale G S, Joseph G and Lavakare P J 1970 *Acta Phys. Acad. Sci. Hung.* **29** Suppl. 2 697
Daniel R R and Stephens S A 1975 *Rev. Geophys. Space Phys.* **12** 233
Daniel R R and Lavakare P J 1975 *Pramāṇa* **5** 107
Daniel R R and Lavakare P J 1975 *Proc. 14th Int. Conf. Cosmic Rays* **1** 23
Dyer C S and Morfill G E 1971 *Astrophys. Space Sci.* **14** 243
Eyles C J, Linney A D and Rochester G K 1972 *Plant Space Sci.* **20** 1915
Fishman G J 1971 *Astrophys. J.* **171** 163
Fieden S C and White R S 1962 *J. Geophys. Res.* **67** 25
Forrest D J and Chupp E L 1969 *Solar Phys.* **6** 339
Forrest D J 1969 Ph.D. Thesis, University of New Hampshire, USA
Golenetskii S V, Mazets E P, Ilinskii V N, Aptekar R L, Bredor M M, Guryan Yu A and Panov V N 1971 *Astrophys. Lett.* **9** 69
Heidbreden E, Pinkau K, Reppin C and Schonfelder V 1970 *J. Geophys. Res.* **75** 6347
Joseph G 1970 Ph.D. Thesis, University of Bombay, India
Kanbach G, Reppin C and Schonfelder V 1974 *J. Geophys. Res.* **79** 5159
Klebesadel R W, Strong J B and Olson R A 1973 *Astrophys. Lett.* **182** L85
Lingenfelter R E 1963 *J. Geophys. Res.* **68** 5633
Mathe G Y and Schlenk B 1964 *Nucl. Instr. Methods* **27** 10
Naugle J E and Kniffen D A 1963 *J. Geophys. Res.* **68** 4065
Peterson L E 1967 UCSD-SB-68-1
Peterson L E 1975 private comm.
Preszler A M, Simnett G M and White R S 1972 *Phys. Rev. Lett.* **28** 982
Trombka J I, Metzger A E, Arnold J R, Matheson J L, Ready R C and Peterson L E 1973 *Astrophys. J.* **181** 737
Waddington C J 1960 *Prog. Nucl. Phys.* **8** 3
Webber W R 1967 *Handb. Physik* XLVI/2 181
White R S, Moon S, Preszler A M and Simmett G M 1973 *Space Res.* **13** 683