LOW ENERGY GAMMA-RAY MEASUREMENTS OVER HYDERABAD, INDIA

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Received August 8, 1970

ABSTRACT

The results of the first low energy gamma-ray (0·2 to 1 MeV) measurements at equatorial latitudes conducted by two-balloon flights over Hyderabad, India (7·6° N GM), are presented. The energy resolution of the detectors was sufficient to detect the γ-ray peak at 0·5 MeV due to the electron-positron annihilation. The flux of the 0·5 MeV photons was found to be $0 \cdot 090 \pm 0 \cdot 012$ photons/cm^2 sec at an atmospheric depth of 10 gm cm^{-2} and $0 \cdot 048 \pm 0 \cdot 011$ photons/cm^2 sec at the top of the atmosphere. Comparison of our results with those obtained at higher latitudes, show the existence of a considerable latitude variation of the 0·5 MeV flux, about a factor of 4 between 55° and 7° latitudes at an altitude of 10 gm/cm^2.

INTRODUCTION

A PRECISE estimation of the gamma-ray flux at different altitudes and latitudes is of vital importance both in gamma-ray astronomy studies and in the study of the energy balance in the atmosphere. The general features of low energy gamma-rays in the atmosphere at mid and high latitudes have been studied by several workers (Jones, 1961) and the references therein, Anderson (1961), Northrop and Hostetler (1961), Vette (1962), Peterson (1963), Chupp *et al.* (1967, 1969), Haymes *et al.* (1969) and Peterson (1969). A prominent feature of the low energy gamma-ray spectrum at mid and high latitudes conducted at balloon altitudes using omnidirectional detectors, is the peak at 0·5 MeV generally attributed to the gamma-rays from the electron position annihilation.

Due to the expected strong latitude dependence of the γ-ray flux, it is extremely important to extend these observations to equatorial latitudes particularly for estimating the general background gamma radiation, which is of great interest to gamma-ray astronomy. In this paper, we describe

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in detail the results of first such studies conducted from India and compare these results with the results from mid and high latitudes to provide an estimate of latitude effect of the gamma-ray spectrum. These studies were performed on two balloons launched from Hyderabad, India (Geographic latitude 17·3° N, longiude 78·5° E) one at 0652 hrs. IST on April 1, 1968 and the second at 0706 hrs. IST on March 22, 1969.

FLIGHT AND EXPERIMENTAL DETAILS

The first experiment performed on April 1, 1968, used a 2665 m^3 balloon which reached a ceiling altitude of 22 mb. The pressure was measured by an onboard aneroid element and was also checked independently by radar tracking. Continuous data from launch to instrument release at 1230 hrs. IST, were obtained. The second flight on March 22, 1969 was conducted with a 1·5 million cubic foot balloon, which reached a ceiling of 8 mb at 0940 hrs. IST. The pressure was measured by a Wallace Tiernan pressure gauge and was checked by radar tracking. Data from Launch upto 1040 hrs. were obtained during this flight, by which time the balloon had drifted beyond the telemetry capability, due to the then prevailing high velocity winds.

The physical arrangement of the detectors used in the two flights is shown in Fig. 1. The earlier flight was conducted with a NaI (Tl) crystal, 12·7 cm. in diameter and 1·27 cm thick, which was viewed by a RCA 8055 photomultiplier. The later flight was performed with a Na I (Tl) crystal of a diameter of 3·81 cm and thickness of 2·54 cm, viewed by a RCA 6199 photomultiplier. Both the detectors were surrounded on all

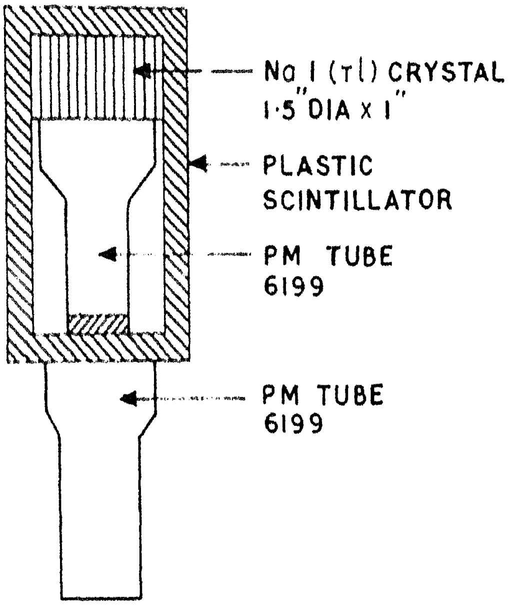

FIG. 1. Sketch of the detecr to (1969).

sides by 1 cm thick plastic anticoincidence scintillators which were viewed by suitable photomultipliers. The energy resolution of both the photon detectors was about 18% at 511 KeV. Adequate care was taken in these experiments to see that all dense materials such as batteries were more than two feet below the detector, to minimise the contribution from the secondary γ-rays produced in the surrounding material. Each instrument was encased in a 2″ thick styrofoam box to provide thermal insulation.

The pulses from the photon detector were amplified and pulse height analysed into ten contiguous differential energy channels and one integral channel above the final threshold. The pulse height analyses (PHA) was inhibited whenever a pulse, corresponding to an energy deposition of $>$ 300 KeV, occurred in the anticoincidence shield. The differential energy channels of the PHA system in the first flight were adjusted in the ranges 180–225, 225–330, 330–370, 370–450, 450–475, 475–498, 498–560, 560–620, 620–740 and 740–940 KeV and for the second flight in the ranges 191–244, 244–339, 339–424, 424–476, 476–524, 524–552, 552–610, 610–689, 689–848 and 848–1060 KeV. The systems were checked with a laboratory pulse height analyser for energy linearity and calibration using Na^{22} (511 KeV) and Cs^{137} (661 KeV) gamma-ray sources. The relative widths of the channels were determined accurately by using a linearly rising ramp type pulse generator and measuring the times for which each channel responded. All the data from the flights were transmitted to ground using FM/FM telemetry.

DATA ANALYSIS

The omnidirectional geometrical factors (G_0) for the two detectors computed using the formula

$$G_0 = \frac{\pi}{4} L D \left(1 + \frac{D}{2L}\right)$$

where L is the thickness and D is the diameter of the crystal, were 76 cm^2 and 13·3 cm^2 respectively.

The efficiencies ϵ (E) of the detectors were calculated for a broad parallel beam using the formula

$$\epsilon(E) = 1 - e^{-\mu(E) L}$$

where μ (E) is the absorption coefficient (White, 1957) for γ-radiation of energy E, and L is the thickness of the crystal. The calculated efficiencies were further checked with the values obtained by Miller *et al.* (1957) from

Monte-Carlo calculations. The efficiencies are found to be 0·32 and 0·54 for the two crystals respectively. The photofractions have been estimated using the empirical relationships given by Steyn and Andrews (1969) based on the data of Miller *et al.* (1957) which are found to be 0·54 and 0·49 respectively. The photopeak efficiencies given by the product of the efficiency and the photofraction for each detector for 0·5 MeV photons incident normally on the crystal are found to be 0·17 and 0·27 for the 1968 and 1969 detectors respectively.

BACKGROUND GAMMA-RAY SPECTRUM

Figure 2 shows the plot of γ-ray count rate dependance on atmospheric depth for various differential energy channels. The counting rates in all the energy channels show an increase with altitude, upto the Pfotzer maximum at about 110 gm/cm^2 with practically the same absorption length of about 210 gm/cm^2 suggesting a common origin for the secondary components of different energies. Figure 3 shows the differential counting rate

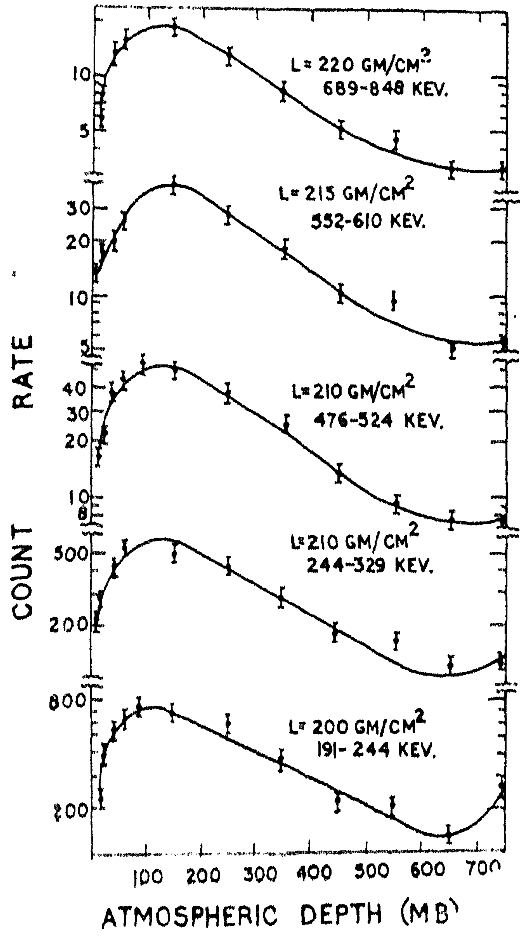

FIG. 2. Counting rates *versus* atmospheric depth (1969 experiment).

spectrum plotted against the energy loss in the crystal for both the 1968 and 1969 flights at altitudes corresponding to 22 gm/cm^2 and 10 gm/cm^2 respectively. In Fig. 4 is plotted the differential energy loss spectrum obtained in our flights as a function of energy, along with the results from other workers. Due to lack of precise knowledge of spectral details to the highest energies, needed for deconvoluting the data with detector efficiency and resolution, no attempt has been made to derive the true photon spectrum from the counting rate spectrum.

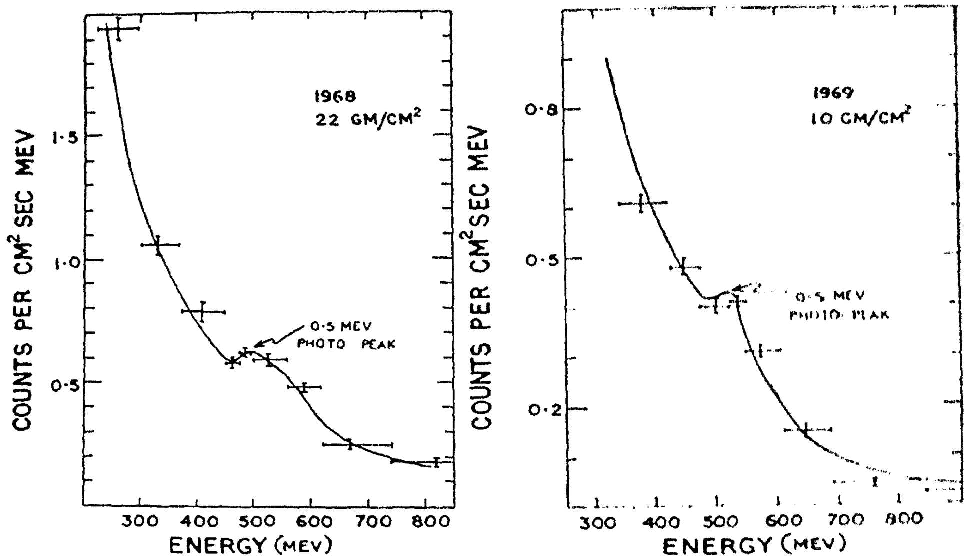

FIG. 3. Differential counting rate spectra (at 22 gm/cm^2 in the 1968 experiment, at 10 gm/cm^2 in 1969 experiment).

In spite of some uncertainty in comparison due to the failure to take into account the differences in efficiencies, certain important general conclusions can be drawn from a comparison of our results with those of other workers obtained at mid and high latitudes. It is quite clear from Fig. 4 that the gamma-ray flux obtained in our experiments are consistently lower than the corresponding values obtained at higher latitudes. The flux at 300 KeV, as obtained from extrapolation of 1969 observations to a depth of 6 gm/cm^2 of 1969 data, is found to be lower by a factor of 2·4 ± 0·3 as compared to that observed at Minneapolis (Peterson, 1963). This factor goes up by a factor of two, if either the revision of Minneapolis data (Peterson, 1969) or the recent observation of Haymes *et al.* (1969) are considered. However, the observed latitude effect exhibited by γ-ray flux seems to be less than that observed for ion chamber intensity, which is 6·3 ± 0·4 times lower at Hyderabad than at Minneapolis, as seen from Neher's (1967) latitude survey at 5 gm/cm^2. Smaller latitude variation of the gamma-ray spectrum may be indicative of the high energy nucleonic component of cosmic rays being primarily responsible for the production of low energy γ-rays.

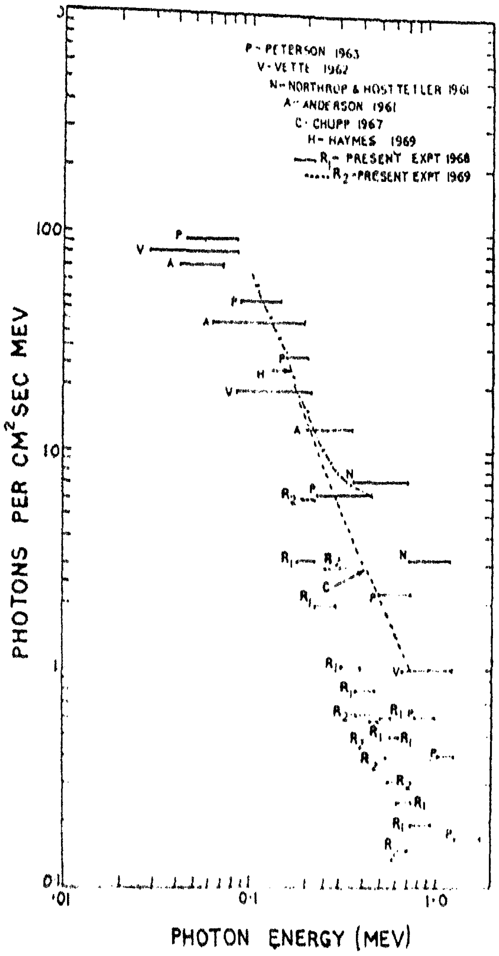

FIG. 4. Low energy gamma-ray spectrum along with other observations.

COSMIC CONTRIBUTION

Even though most of the gamma-rays observed at balloon altitudes are produced by cosmic ray interactions in the atmosphere, a small contribution from gamma-rays of cosmic origin does exist (Fazio, 1964; Clark *et al.*, 1968). During intense solar flares, the Sun is also known to produce γ-rays of this energy, even though such occasions are very rare (Peterson and Winckler, 1959; Kondo, 1968; Takakura *et al.*, 1969). Both our balloon flights were characterised by days of low solar activity, the C_p values on these days being 1·2 and 0·6 respectively, and hence the data have been used to estimate the contribution due to cosmic background.

Cosmic gamma-ray flux which is incident over a solid angle of 2π will get attenuated in the atmosphere depending on the zenith angle of arrival and the attenuation coefficient. The per cent (effective solid angle/2π)

cosmic gamma flux incident on the crystal at an atmospheric depth of X gm/cm^2 can be estimated by using the expression

$$P(E) = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi/2} e^{-XA(E)\sec.\theta} \operatorname{Sin}\theta \, d\theta \, d\phi$$

where A (E) is the mass absorption coefficient of air at energy E.

Assuming the differential number spectrum of cosmic γ-ray flux given by Gorenstein *et al.* (1969), the predicted gamma-ray flux entering the crystal has been computed as a function of energy. The cosmic flux, thus calculated, is expressed as a percentage of the observed counting rate at different energies and is shown in Fig. 5. It should be noted that we have not considered either the efficiency and resolution of the detector or the effect of compton scattering of the primary gamma radiation in the atmosphere in these calculations. However, it is evident that the contribution from cosmic origin to the low energy gamma-ray flux at balloon altitudes is not insignificant at low latitudes and form nearly a third of the measured flux at these energies.

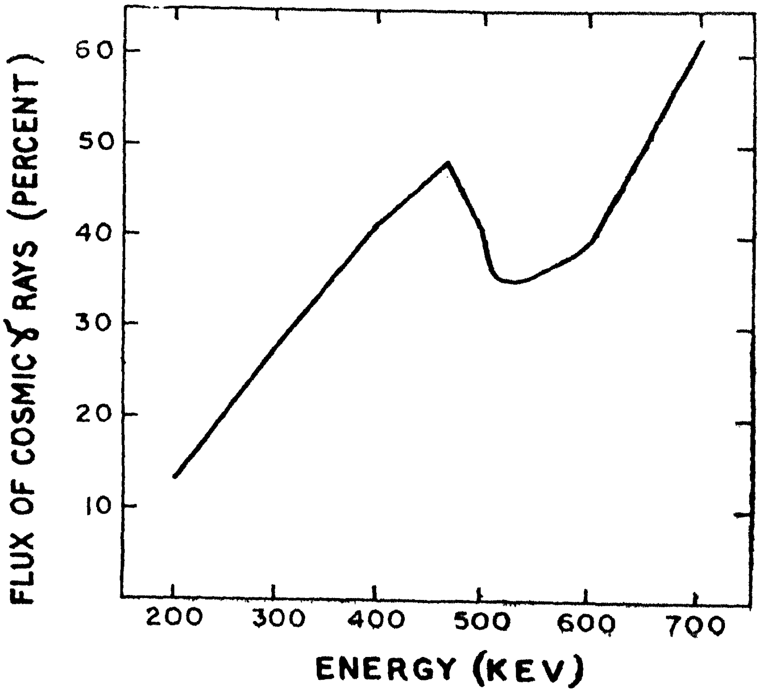

FIG. 5. Expected cosmic flux expressed as percentage of the observed counting rate at different energies.

0·5 MeV PHOTOPEAK

The gamma-ray peak at 0·5 MeV is well resolved in both the flights as can be seen from Fig. 3. The strength of the 0·5 MeV photopeak is estimated using the formula,

$$F = R/\epsilon\, G_0 \text{ counts/cm}^2 \text{ sec}$$

where R is the area (counts) between the observed spectrum and the background spectrum, and ϵ is the photopeak efficiency at 0·51 MeV for the crystal used. The counts (R) have been determined as follows. The observed counting rates in the channels, which do not contain any contribution from the 0·5 MeV line, have been fitted to a power law spectrum, as the data clearly indicate such a spectrum. Superimposing the spectral fit for the background spectrum, on the actual spectrum obtained from the observational data, the contribution due to the singularity at 0·5 MeV is estimated from the difference in the area between the two curves.

The values of the flux of 0·5 MeV photons corrected for the appropriate photopeak efficiency have been computed from the data at several depths in the atmosphere for both the flights in 1968 and 1969 and are shown in Fig. 6. The values of 0·5 MeV photon flux are found to be 0·14 ± 0·01 photons/cm^2 sec at a depth of 22 gm/cm^2 in the 1968 experiment, and 0·086 ± 0·012 photons/cm^2 sec at a depth of 10 gm/cm^2 in the 1969 experiment.

SOURCE STRENGTH OF 0·5 MeV γ-RAYS

The source strength (S) of the 0·5 MeV photopeak gamma-rays at transition maximum at equaitorial latitudes can be estimated from the relation (Peterson, 1963), $S = F\mu$, where F is the photon flux and μ^{-1} is the source thickness ($\mu = 0{\cdot}085$ cm^2 gm^{-1} in air for 0·5 MeV γ-rays). From the data in 1969, the source strength at transition maximum is found to be 0·034 photons/gm sec.

The rate of positron production (N), in a vertical column of atmosphere of 1 cm^2 area derived by using the expression

$$N = \tfrac{1}{2}\mu \int_0^{1000} F(x)\, dx$$

where F (x) is the photon flux at an atmospheric depth x gm/cm^2, is found to be 3·3 positrons/cm^2 sec in 1969.

ALTITUDE DEPENDANCE OF 0·5 MeV PHOTOPEAK

For meaningful comparison of data from different experiments at different epochs, all the observational values have to be reduced to the same depths of the atmosphere. The observed flux of 0·5 MeV peak from our experiments, show a linear relationship with atmospheric depth (Fig. 6) for the range of altitudes considered. The observed data have been fitted by least squares method and these fits have been used for deriving extrapolations to different depths. The value of 0·5 MeV flux (0·094 ± 0·010 photons/cm^2 sec) at 10 gm/cm^2 in the 1968 experiment, obtained from such an extrapolation, is consistent with the 0·5 MeV flux value (0·086 ± 0·012 photons/cm^2 sec) obtained at the same depth from 1969 data, within the experimental errors, the mean being 0·090 ± 0·012 photons/cm^2 sec.

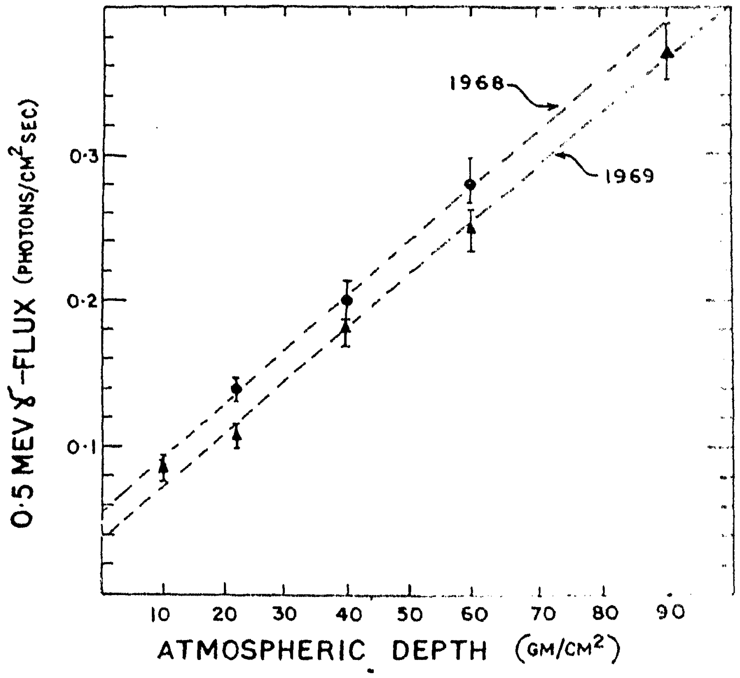

FIG. 6. 0·5 MeV flux as a function of atmospheric depth.

From the above fits for the altitude dependance of 0·5 MeV flux, the values of the flux at the top of atmosphere, were found to be 0·057 ± 0·006 and 0·039 ± 0·009 photons cm^{-2} sec^{-1} for the 1968 and 1969 observations respectively, which are consistent within experimental errors. The slight difference between the values obtained an year apart cannot be attributed to any time variation, particularly, in view of the uncertainty in the extrapolation of 1968 data from 22 gm/cm^2 to the top of the atmosphere. The mean value of the flux of 0·5 MeV photons at the top of the atmosphere over 7·6° N latitude is 0·048 ± 0·011 photons cm^{-2} sec^{-1}.

Table I gives the values of 0·5 MeV flux at three depths, 10 gm/cm^2, 4 gm/cm^2, 0 gm/cm^2 obtained from different measurements, along with the epoch of their observations. Extrapolation of the observations by other workers have been made by using the altitude dependance given by the individual authors (Peterson, 1963; Chupp *et al.*, 1967).

TABLE I

Sr. No.	Year of observation	Experimentor	Geomagnetic latitude °N.	0·5 MeV flux at 10 gm. $cm.^{-2}$ (extrapolated)	0·5 MeV flux at 4 gm. cm^{-2} (extrapolated)	0·5 MeV flux at zero depth atmosphere (extrapolated)
1	1961	Peterson *et al.* (1963)	55	0·36 ±0·03	0·26 ±0·03	0·18 ±0·02
2	1962	Frost *et al.* (1966)	55	~0·7	~0·6	..
3	1963	Bocelet *et al.* (1963)	41	~0·5	..	..
4	1966	Chupp *et al.* (1967)	41	0·42 ±0·05	0·29 ±0·04	0·25
5	1967	Chupp *et al.* (1969)	41	0·27 ±0·04	0·188±0·02	0·131
6	1968	Chupp *et al.* (1969)	41	0·26 ±0·04	0·18 ±0·02	0·125
7	..	Peterson (1969)	55	≃0·34	≃0·28	0·16
8	1968	Present experiment	7·6	0·094±0·010	·07 ±0·01	0·057±0·006
9	1969	do.	7·6	0·086±0·012	·05 ±0·01	0·039±0·009

LATITUDE VARIATION OF 0·5 MeV PHOTOPEAK

For any quantitative study of latitude variation, observations have to be corrected for time variation, as various observations may relate to different epochs. From a large number of observations, Chupp *et al.* (1969) have conclusively shown that the correlation between the 0·5 MeV flux and solar activity during 1967–68 is not significant. Further, since the change in solar activity from 1967–1969 is quite small, we estimate that the correction for any time variation should be quite small compared to the experimental uncertainties, and hence we have neglected the effect of time variation for estimating the latitude variation. Accurate calibration and precise estimates of efficiency of the detectors, are essential prerequisities, in any intercomparison of different experiments. Due to lack of such precise estimates, the results in the past, numbered 1 to 4 in Table I, are not reliable. In fact, Peterson (1963) and Chupp (1967) themselves have recently revised their previous observations (Peterson, 1969, private communication; Chupp *et al.*, 1969), even though such revisions are *ad hoc* in nature. In view of better accuracies of observations made after 1967, only these (numbered 5 to 9 in the table) have been utilised for a meaningful comparison of 0·5 MeV flux. It is seen that the values of 0·51 MeV flux obtained by Chupp *et al.* (1969) at about 40° N geomagnetic latitude and by Peterson (1969) at about 55° N are consistent within each other, though they show a small latitude variation.

Figure 7 shows the plot of 0·5 MeV flux observations numbered 5–9 as a function of geomagnetic latitude along with the variation of ion chamber intensity at 5 and 10 gm cm^{-2} atmospheric depths. The latitude variation of ion chamber intensity shown in the figure, pertains to the data obtained in 1965, and is typical of the latitude variation in other years. From the figure, it is clear that the 0·5 MeV flux exhibits a large latitude effect. It can be seen that the 0·5 MeV flux at 10 gm cm^{-2} increases by factors of 3·0 ± 0·6 and 3·8 ± 0·8 with geomagnetic latitude from 7·6° N to 41° and 55° N respectively, whereas the ion chamber intensity at the same atmospheric depth varies by 5·0 ± 0·5 and 9·5 ± 1·0 respectively over the same latitudes. Similarly, the 0·5 MeV flux at an atmospheric depth of 4 gm cm^{-2} shows an increase with latitude, by

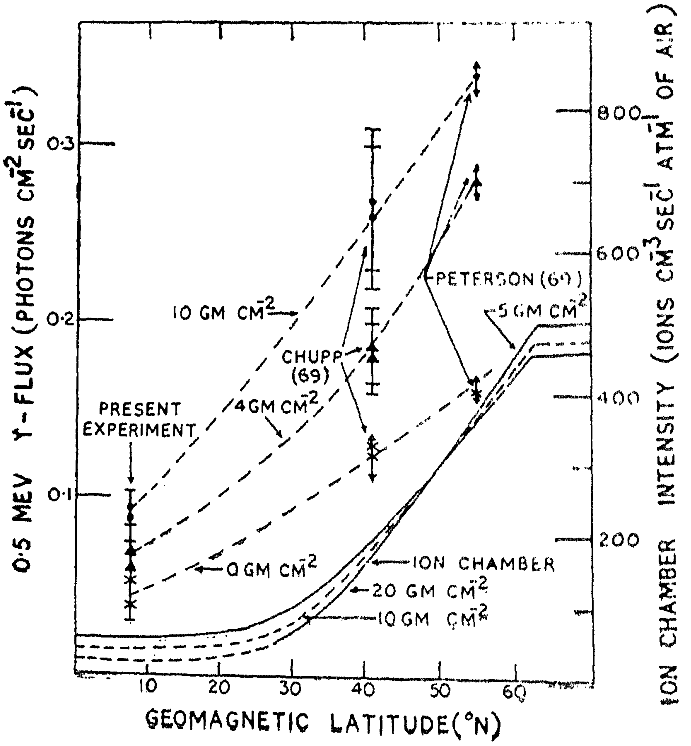

Fig. 7. 0·5 MeV flux and ion chamber intensity *versus* geomagnetic latitude.

factors 3·0 ± 0·6 and 4·2 ± 0·8, whereas ion chamber intensity shows a variation of about 10 and 20 respectively over the same latitudes mentioned above. It is also interesting to note that the latitude effect of 0·5 MeV gamma-rays at 10 gm/cm^2 and at 4 gm/cm^2 are practically the same.

In spite of the relatively few number of observations of the 0·5 MeV flux and the uncertainties involved in comparison, the results definitely indicate a much lower latitude effect, than that exhibited by ion chamber data, which is also consistent with the latitude variation exhibited by the general gamma-ray spectrum. This behaviour, along with the fact that the latitude variation of 0·5 MeV flux does not seem to vary appreciably with altitude, indicates that the 0·5 MeV flux is primarily due to the high energy nucleonic component of cosmic rays.

The values of 0·5 MeV flux, extrapolated to the top of the atmosphere, also exhibit a latitude variation by a factor of about 3 over 50 degrees latitude. Any cosmic contribution to the 0·5 MeV gamma-ray flux should not show any latitude variation. Hence the 0·5 MeV gamma-ray flux obtained by extrapolation to zero depth of atmosphere should be mainly attributed to albedo flux from the atmosphere.

CONCLUSION

In conclusion we list the following important conclusions derived from the first observations of gamma-ray flux in the energy range 200–1000 KeV at equatorial latitude.

(*a*) The gamma-ray spectrum in the energy range 0·2 to 1 MeV, as well as the flux of 0·5 MeV photopeak, due to annihilation of positrons and electrons show a large latitude effect.

(*b*) Nearly a third of the gamma-ray flux in this energy range observed at an altitude of 10 gm/cm^2 over Hyderabad is of cosmic origin.

(*c*) The flux of 0·5 MeV gamma-ray photons at 10 gm/cm^2 and at 0 gm/cm^2 over 7·6° N geomagnetic latitude is found to be 0·090 ± 0·012 photons/cm^2 sec and 0·048 ± 0·011 photons/cm^2 sec respectively.

(*d*) The latitude effect of 0·5 MeV gamma-ray photons at 10 gm/cm^2 and at 4 gm/cm^2 do not appreciably differ from each other indicating that these photons are due to the high energy nucleonic component of cosmic rays.

(*e*) The flux of $0 \cdot 5$ MeV photons at 4 gm/cm^2 over 41° N and 55° N geomagnetic latitudes show an increase by factors of $3 \cdot 0 \pm 0 \cdot 6$ and $4 \cdot 2 \pm 0 \cdot 8$ respectively over the flux at $7 \cdot 6$° N latitude. Even though the latitude effect exhibited by the $0 \cdot 5$ MeV photons is quite significant, the effect is much smaller than that exhibited by the ion chamber intensity which shows an increase by factors of 10 and 20 respectively over the same latitude range and at same depth.

ACKNOWLEDGEMENTS

The authors wish to thank Messrs. K. S. V. Seshadri, K. S. B. Manian and D. P. Devgan, for their help in the construction of payload and during flight operations and Mr. S. P. Agrawal for useful discussions. The help of Drs. G. S. Gokhale, R. T. Redkar and their group, in launching the balloons and providing pressure data is gratefully acknowledged. The research was supported by the funds from the Department of Atomic Energy, Government of India.

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