CHAPTER VI
SUMMARY AND CONCLUSIONS

The work presented in this thesis has been carried out at the Physical Research Laboratory, and is a part of an extensive investigation program of the low energy photon component at balloon altitudes over Hyderabad ($\Lambda_n = 7.8^\circ N$, vertical cutoff rigidity 16.9 GV), India, near geomagnetic equator. The thesis describes in detail the following aspects of these investigations conducted by the author.

1. the diffuse cosmic X-ray measurements in the 20-200 Kev energy interval,
2. analysis of the background properties of the X-ray telescopes using NaI(Tl) as a detector at balloon altitudes in the 20-200 Kev energy range,
3. observations of low energy atmospheric gamma rays in the energy region 135-1123 Kev.

1. DIFFUSE COSMIC X-RAY MEASUREMENTS

A X-ray detector, incorporating a cylindrical NaI(Tl) crystal (2"x$\frac{3}{4}$"), surrounded by plastic anticoincidence shields and a collimator, was flown to an atmospheric
depth of 7.8 g cm$^2$ on 31 March 1968. The telescope had a semivertical opening angle of $20^\circ$, giving it a geometrical factor of 6.7 cm$^2$ sr. Spectral information in the 20-200 keV energy interval was obtained by means of an onboard seven channel pulse height analyser. The telescope suspended vertically, scanned a region of the celestial sphere hitherto known to be devoid of any discrete sources. The sun, which came partially in the field of view for the last half an hour of observation time, was comparatively quiet during the period, and no statistically significant increase in the counting rates due to this source was seen in the present measurement. It is therefore believed that the observed extraterrestrial radiation is due to the diffuse cosmic X-ray component only.

The data obtained from the flight has led to the following main conclusions.

1.1 The spectrum of the diffuse cosmic X-rays in the 20-130 keV energy interval from the region of the sky between declinations $37^\circ$ and $-3^\circ$ and right ascension $20^h30^m$ to $0^h20^m$ is found to be

$$\frac{dN}{dE} = 162E^{-2.4\pm0.3} \text{ photons cm}^{-2}\text{sec}^{-1}\text{sr}^{-1}\text{keV}^{-1}$$
1.2 The cosmic X-ray spectrum for the 20-130 Kev interval obtained in the present experiment, if extended to higher energies to derive the integrated intensity of photons of energy greater than 100 Mev, results in $10^{-5}$ photons cm$^{-2}$sec$^{-1}$sr$^{-1}$. This is an order of magnitude lower than the flux of $1.1 \times 10^{-4}$ photons cm$^{-2}$sec$^{-1}$sr$^{-1}$ measured by OSO-III at these energies. This means that these two components of the diffuse cosmic photon spectrum cannot be explained by the same generation mechanism.

1.3 The dependence of the intensity, $I$, of the secondary atmospheric background on the atmospheric depth, $X$, for depths smaller than 100 g cm$^{-2}$ can be well represented by a power law function of the type

$$I(x) = \text{Const } x^\alpha$$

with $\alpha$ lying between 0.4 and 0.5. This value of $\alpha$ appears to be slightly higher than those measured at high and mid-latitudes.

1.4 Evidence for the presence of extraterrestrial X-rays is obtained from observations at 20 g cm$^{-2}$ atmospheric depth itself from a 'color' index study. This is in contrast to 12 g cm$^{-2}$ whence only the effects of these radiations manifest themselves in the altitude - intensity profiles. Therefore the 'color' index approach seems to be a more
sensitive method for testing the presence of these extraterrestrial photons at small atmospheric depths.

2. NATURE OF THE SECONDARY ATMOSPHERIC BACKGROUND ENCOUNTERED.

The detailed analysis of the background properties of the X-ray telescope used in the present experiment has led to a break up of the contribution to the observed secondary background intensity at 7 g cm$^{-2}$ atmospheric depth over equatorial latitudes from different possible sources. These are summarised below:

<table>
<thead>
<tr>
<th>Nature of the background</th>
<th>Counting rate contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric X-rays in the 20-200 Kev range</td>
<td></td>
</tr>
<tr>
<td>a) those impinging through the forward opening</td>
<td>0.28 sec$^{-1}$</td>
</tr>
<tr>
<td>b) those leaking through the shields</td>
<td>0.20 sec$^{-1}$</td>
</tr>
<tr>
<td>Atmospheric gamma rays of energy greater than 200 Kev.</td>
<td></td>
</tr>
<tr>
<td>a) those falling on the crystal through the forward opening</td>
<td>1.60 sec$^{-1}$</td>
</tr>
<tr>
<td>filtration through shields</td>
<td></td>
</tr>
<tr>
<td>Nature of the background</td>
<td>Counting rate contribution</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>b) those falling on the shielding materials and get Compton scattered into the energy range 20-200 Kev and finally strike the detector.</td>
<td>2.0 sec⁻¹</td>
</tr>
</tbody>
</table>

Gamma rays resulting from the decay of \( \pi^0 \) mesons in the detector materials. \( \sim 10^{-3} \text{sec}^{-1} \)

Radiative capture of neutrons

- a) in plastic \( \lesssim 2.4 \times 10^{-2} \text{sec}^{-1} \)
- b) in \(^{206}\text{Pb}\) \( \lesssim 1.2 \times 10^{-3} \text{sec}^{-1} \)
- c) in \(^{127}\text{I}\) \( \lesssim 0.12 \text{sec}^{-1} \)

Star production due to neutrons

- a) in NaI(Tl) \( \lesssim 2 \times 10^{-2} \text{sec}^{-1} \)
- b) in Pb \( \lesssim 0.4 \text{sec}^{-1} \)

It is therefore clear that:

2.1.1. for the equatorial latitudes, almost all the background originates from the electromagnetic interactions, especially through the Compton scattering of photons of energy greater than 200 Kev with the scintillation crystal.
as well as the shielding materials, resulting in a flat nature of the spectrum of this background.

2.1.2 the background originating from nuclear interactions like $\beta^-$ decay gammas, radiative capture and star production of neutrons is found to be negligible and

2.1.3 the atmospheric X-rays in the 20-200 keV range play an insignificant role to the observed background rates over low latitudes, whereas they are quite important at high and mid-latitudes.

These features of the equatorial background lead to the following conclusions:

2.2.1 By suitable detector design, particularly by reducing the thickness of the scintillation crystal, an order of magnitude improvement in the value of the ratio of the intensity of cosmic X-rays to that of the secondary atmospheric background, compared to high latitudes, can be realized for X-ray telescopes flown on equatorial balloon flights. The resulting sensitivity is a factor of three better for equatorial latitudes. This fact is demonstrated by evaluating the performance of crystals of two different thickness i.e. 1.2 cms and 4 mms. Thinner crystals are shown to have superior background properties over thicker ones.
2.2.2 The shutter techniques employed in investigations at high and mid-latitudes for the separation of cosmic and atmospheric X-rays from CRIB are not very effective for equatorial measurements.

3. LOW ENERGY ATMOSPHERIC GAMMA RAYS IN THE ENERGY RANGE 135 K\text{eV} TO 1123 KeV

Investigation of the low energy atmospheric gamma rays in the 135-1123 Kev range over Hyderabad is made by an omnidirectional spectrometer consisting of a 2"x2" NaI(Tl) surrounded by a 4\text{T} plastic antishield. The detector was flown to an atmospheric depth of 6 g cm\text{^{-2}} on April 23, 1969. A twelve channel pulse height analyser was used to study the spectral details. The data obtained from this experiment have for the first time revealed the properties of these low energy gamma rays of atmospheric origin over low latitudes. The results obtained therefrom are given below.

3.1 In the energy range 135-1123 Kev, an intensity of 4.3 counts cm\text{^{-2}}sec\text{^{-1}} is observed at the transition maximum for these photons over Hyderabad. Its extrapolated intensity at the top of the atmosphere is 1.2 photons cm\text{^{-2}}sec\text{^{-1}} in the same energy interval. This is equivalent to an albedo energy radiation rate of 537 Kev cm\text{^{-2}}sec\text{^{-1}} away from the atmosphere.
3.2 The high altitude energy spectrum over Hyderabad is found to be

\[ \frac{dN}{dE} = 130E^{-2.2} \text{photons cm}^{-2} \text{sec}^{-1} \text{sr}^{-1} \text{kev}^{-1} \]

in the 135-380 Kev energy band at 6 g cm\(^{-2}\). For the entire energy range of 135-1123 Kev it is steeper with an index near 2.5. The nature of the spectrum does not show significant dependence on the atmospheric depth from 600 g cm\(^{-2}\) to the floating altitude of 6 g cm\(^{-2}\).

3.3.1 All the components of the gamma ray spectrum have a transition maximum around 120 g cm\(^{-2}\) over this latitude. The absorption length is also nearly same and its value in the equilibrium region is 200 g cm\(^{-2}\).

3.3.2 A comparative study of the absorption lengths measured for various secondary components over equatorial latitudes with those of the low energy photons does not lead to any conclusive evidence regarding their genetic association with electromagnetic or nucleonic components. Same situation results from a closer scrutiny of the depths of transition maxima for these components. Neutron induced effects in the crystal result in negligible contribution to the observed counts in the present experiment.
3.4.1 The presence of electron-positron annihilation line at 510 Kev in detectable intensities is apparent in the present experiment. Its intensity at the floating depth of 6 g cm$^{-2}$ is found to be 0.079±0.007 photons cm$^{-2}$sec$^{-1}$ whereas the observed value at the Pfotzer maximum is 0.24±0.02 photons cm$^{-2}$sec$^{-1}$. The extrapolated flux at the top of the atmosphere is 0.07 photons cm$^{-2}$sec$^{-1}$. The values of the absorption length and of the transition maximum for this component are the same as for the rest of the continuous spectrum.

3.4.2. The positron annihilation rate at the Pfotzer maximum is calculated to be 0.011 g$^{-1}$sec$^{-1}$ over Hyderabad; its production rate in a vertical column of 1 cm$^2$ area of the atmosphere is evaluated as 3.4 cm$^{-2}$sec$^{-1}$. This means that about 42 positrons result for every primary cosmic ray particle over this station.

3.5.1 The intensity of low energy photons show considerable latitude dependence. For gamma rays of energy greater than 300 Kev, the intensity reduces by a factor of seven from 1.3 GV to 16.9 GV cutoff rigidity at 6 g cm$^{-2}$. For 200 Kev photons, the latitude effect is less, the reduction being by about a factor of five only. This magnitude of variation appears also to be less than that
observed with ion chambers. As the ion chamber rates more or less reflect the nucleonic intensity, indications, though not very strong, are for the low energy photons not being associated with the nucleonic component.

3.5.2 The 510 Kev line also shows appreciable latitudinal variations in its intensity and its magnitude is nearly the same as that for the rest of the continuous spectrum.

3.6 A study of the dependence of the number of positrons per primary particle on the cutoff rigidity of the place reveals the interesting feature that its value i.e. 16 positrons/primary cosmic ray particle at high latitude increases steeply to 40e/primary at mid-latitudes and thence remain more or less constant (42e/primary) up to low latitudes. This points to the important role played by higher energy particles in the production of the atmospheric positrons. Further it implies that all primary particles with energy greater than about 3 EeV/nucleon are more or less equally efficient in the creation of these positrons.

3.7 The contribution of cosmic fluxes to the observed count rates of an omnidirectional detector of the type used here amounts to about 10% at 6 g cm$^{-2}$ over equatorial stations and its effect cannot be resolved from that of the atmospheric
photons in an experiment of the present nature.

4. The ionization rates measured in the atmosphere by flying the University of Minnesota continuous monitoring units a number of times have enabled to establish an accurate atmospheric depth - ionization rate relationship for Hyderabad.