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EFFECTS OF ENERGETIC PARTICLES ON PHOTOMULTIPLIERS IN EARTH ORBITS UP TO 1500 KM

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ABSTRACT

This paper discusses the response of several types of photomultipliers to energetic particles in terms of observed background current. Examples are drawn primarily from photometers for observation of the earth's airglow on two Polar Orbiting Geophysical Observatories, OGO-2 and OGO-4; brief reference is made to other OGO photometers. The largest background current was observed on OGO-2 from an EMR 541E, a sapphire end-window tube with S-20 photocathode. At a maximum of the inner electron belt, cathode current exceeded 10^{-9} amperes at about 1500 km. On OGO-4 with the same type tube, added shielding, and an orbit not exceeding 925 km, current was reduced to about 6 x 10^{-12} amp. At the same time another photomultiplier (EMR 641E) of the side window type with CS 7056 glass, S-20 cathode and similar shielding showed only 7 x 10^{-15} amperes. Several components were noted in the background current, with the most prominent due to the inner radiation belt and a component with the latitude distribution characteristic of cosmic rays. Estimated instantaneous proton and electron fluxes are compared with background current in order to obtain an approximate responsivity to energetic particles.

I. INTRODUCTION

Low brightness thresholds for measurement by spacecraft photometers are generally limited by levels of photomultiplier background or "dark current". For low orbits near the equator these levels can be reasonably constant and not very different from the laboratory. For higher orbits, DC background, effected by energetic particles, can increase regularly by up to 5 orders of magnitude depending on the type of photomultiplier and position in orbit. In this paper we will show examples of flight data, review laboratory simulation and conclude that for the inner electron belt in particular, the cathode-window combination, the shielding, and high voltage power supply should be considered with care.

II. BACKGROUND CURRENT AND THE ELECTRON BELTS

A Polar Orbiting Geophysical Observatory, Figure 1, launched on October 14, 1965 and July 28, 1967, included two airglow photometers: one in the mainbody of the spacecraft which measured airglow above and below the spacecraft through selected interference filters, and a second photometer in an appendage outside the spacecraft which scanned the horizon at 6300A.

After the first launch, it was noted that there was a large variable DC background or dark current in the mainbody photometer data, Figure 2. The effect was largest at low latitudes when at altitudes near 1500 km. The L value, given for each of the maxima, identifies the geomagnetic shell at the satellite. If we approximate with a dipole field, the L value gives the earth radii at the point where the shell crosses the equator. The L value further distinguishes between the lower portion of the outer electron belt where L is about 4, and the maximum of the inner belt at an L of about 1.25. During the other half of the orbit, Figure 3, the satellite was at much lower altitudes with perigee of about 420 km. Here can be seen the maxima near L = 4, but the very large equatorial increase is not present. Note that in one of the three orbits there is a substantial

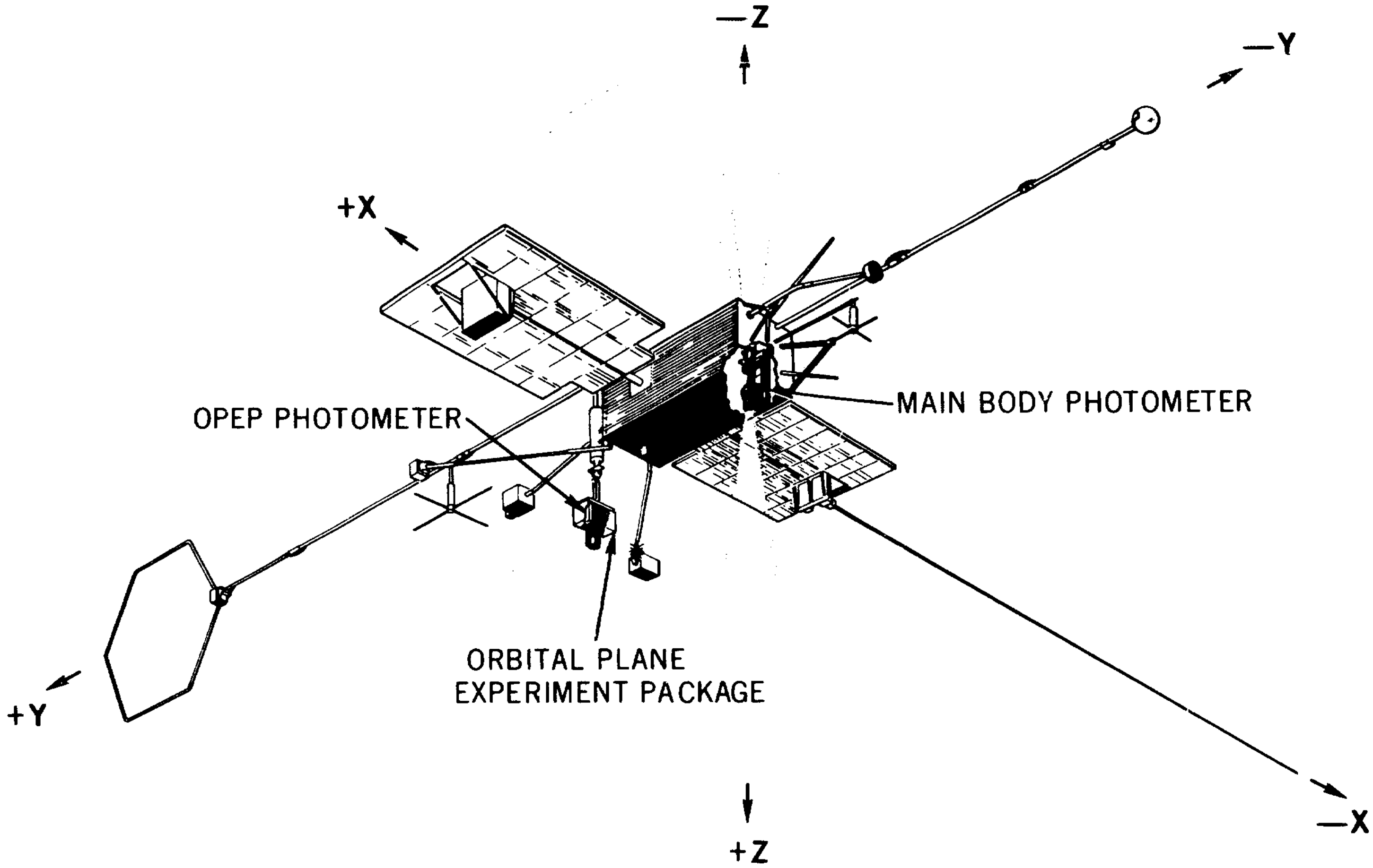

Figure 1–The location of the Main Body and horizon scanning (OPEP) photometers in the spacecraft. When properly oriented, the +Z axis pointed toward the center of the earth, and the −Y axis toward the solar azimuth.

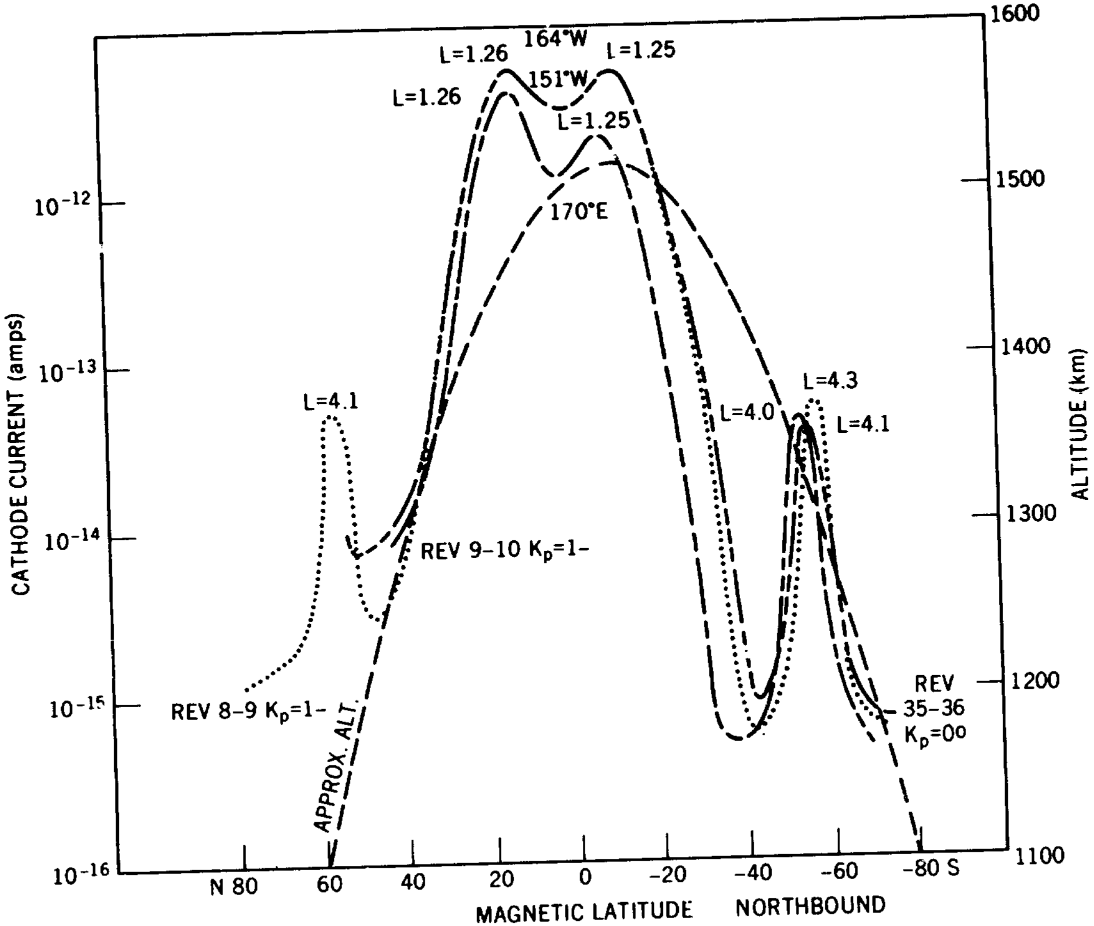

Figure 2-The background or dark current shows two small maxima at about L = 4 where the outer belt extends as "horns" to relatively low altitudes. The prominent maximum of the inner belt is reached twice at about L = 1.25. K_p is the geomagnetic index.

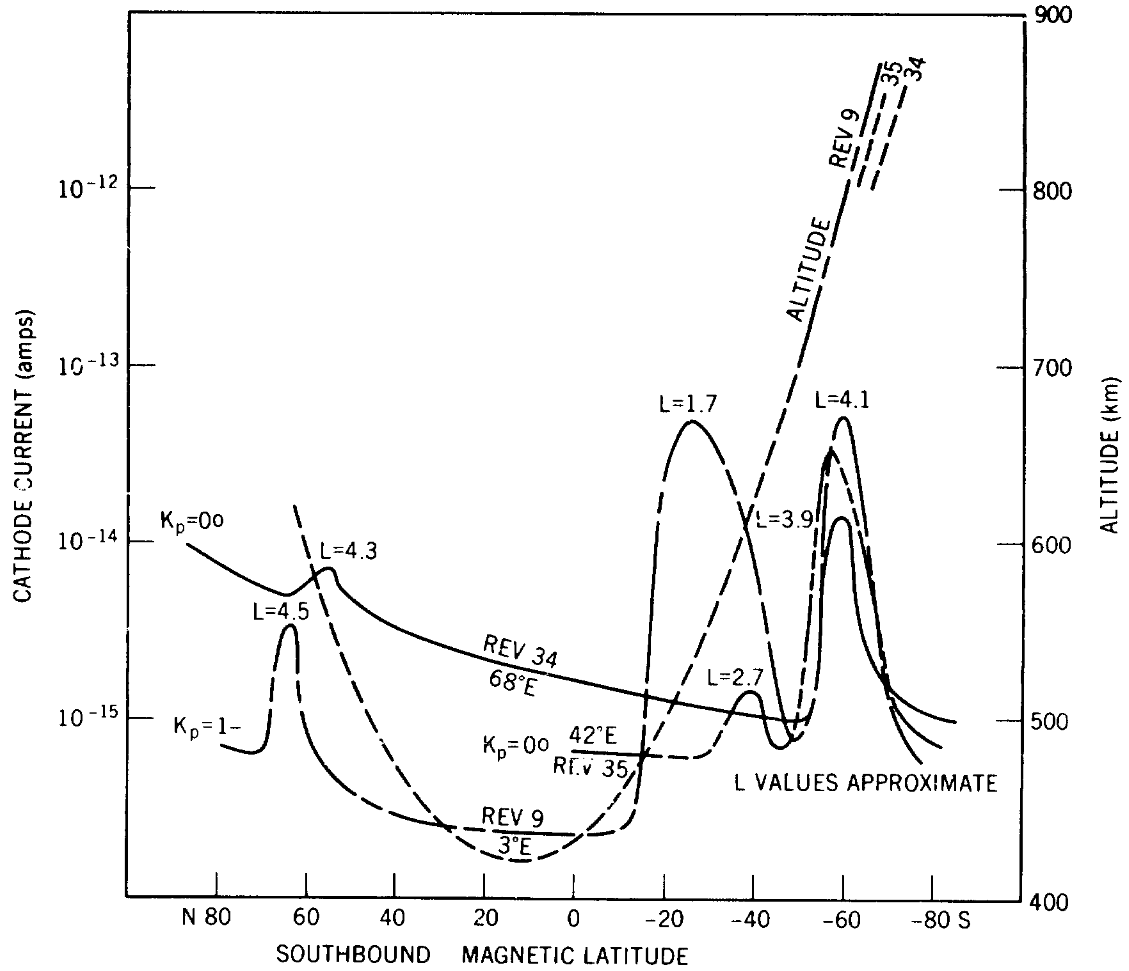

Figure 3-In lower portions of the orbit the outer belt can still be seen, but the inner belt is only prominent in the South Atlantic.

increase at L = 1.7. This happens to be at a longitude of 3^{o} East near the South Atlantic Magnetic Anomaly. Small enhancements, corresponding to those just described, were also seen in the horizon scanning photometer; most important, the increase here was 4 to 5 orders of magnitude less. Let us then consider those contrasting details of these two photometers which contribute to the difference of response.

III. SOURCES OF BACKGROUND SIGNAL

In the mainbody photometer, the photomultiplier was an EMR 541E-05M, 1 inch diameter tri-alkali cathode on a sapphire window. The electrometer design included a feedback loop which lowered the anode voltage when the current exceeded 4×10^{-7} amp and thus limited anode current to less than a microampere. This instrument depended on the spacecraft for shielding which is shown for the spacecraft horizontal plane in Figure 4.

Although geometrically different, the horizon scanner was similar electronically and used similar materials in mirrors, lens and filter. The important differences were (a) the photomultiplier EMR 641 E was a side window type using Corning 7056 glass as a window, (b) the opaque tri-alkali cathode, not deposited on the window was shielded by .12 to .20 inches aluminum over .08 inches tungsten. The spacecraft appendage provided thin additional shielding.

Details of construction and circuitry can be found in Reference 1 which also includes a description of certain laboratory tests conducted for the purpose of simulating and possibly eliminating the unwanted effects of the earth's radiation belt. Although electrons of the inner belt have energies up to about 5 MEV, typical energy for simulation was taken at 2.6 MEV, With this energy it was confirmed that the main body instrument was 4 to 5 orders of magnitude more sensitive to electron irradiation than was the OPEP photometer. About 95% of the unwanted signal came from the cathode-window combination and most of the rest from the first and second dynodes.

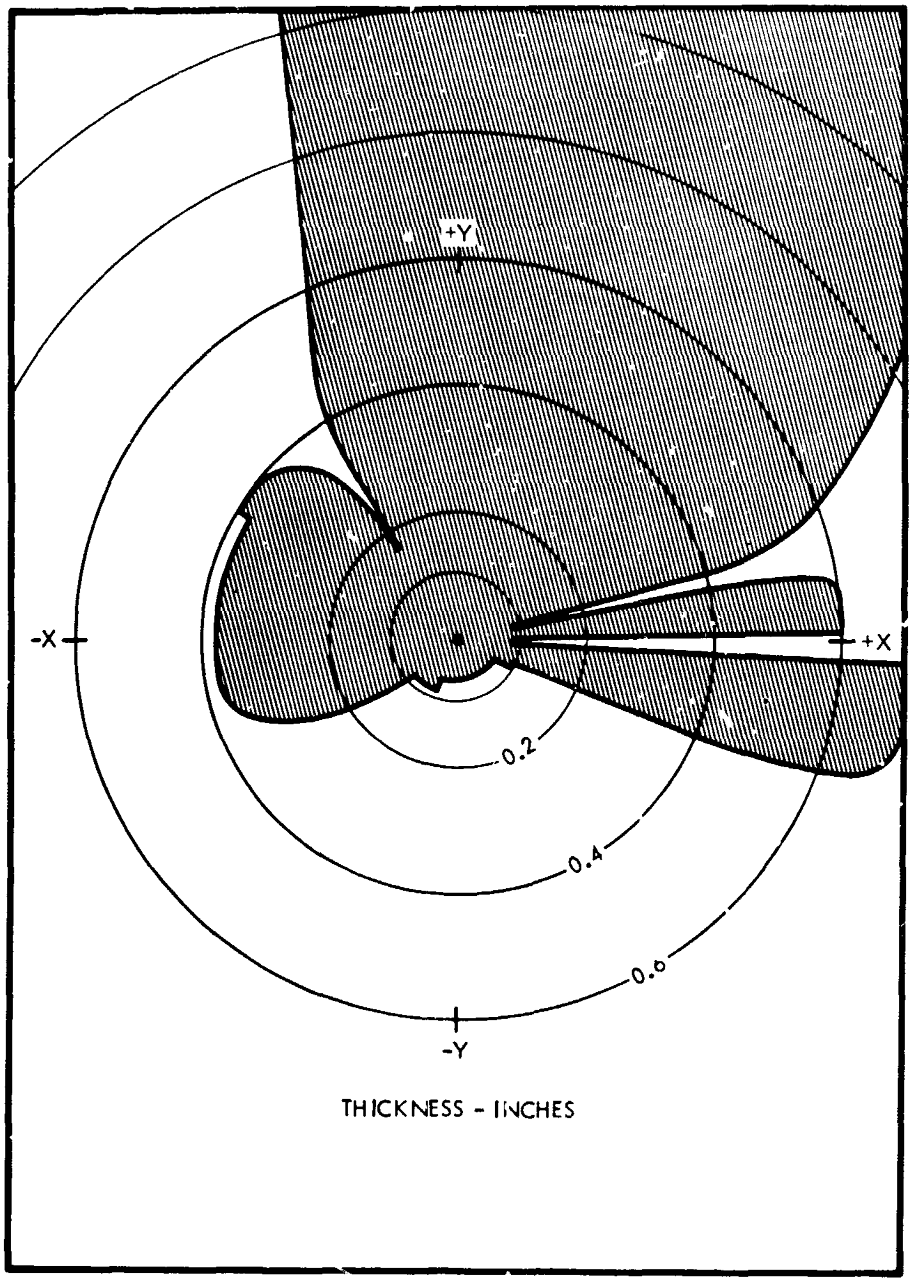

Figure 4–The material in the X-Y plane of the spacecraft between the photomultipliers and space. Most of the material is aluminum, and the dimensions shown include the .040" thick magnesium housing around the photomultiplier.

Further isolation and analysis has not been attempted. It is to be noted that it is difficult to use enough shielding to reduce to a negligible number the energetic electrons which penetrate to the photomultiplier window. Their energy loss appears as both Cerenkov radiation and bremstrahlung; additional loss may appear as both fluorescence and phosphorescence. The real environment, however, is complicated by shielding as well as secondary electrons and x-rays originating in nearby parts of the spacecraft.

Examples discussed here were not complicated by thermal background. Temperature sensors in each photometer confirmed that thermal dark current was near and generally below laboratory levels with negligible variation through the orbit.

IV. RESPONSIVITY TO ENERGETIC PARTICLES OF THE RADIATION BELTS

G. Stassinopoulos of the Goddard Theoretical Division ran a computer analysis of some early OGO-II orbits which included predicted instantaneous electron and proton fluxes based on the Hendricks-Cain field model for epoch 1960. Although the examples chosen occurred during a period of geomagnetic activity, the cathode currents seem, nevertheless, rather typical, especially for the inner belt. The predicted instantaneous fluxes are plotted in Figure 5 along with the background cathode current of the main body photomultiplier (sapphire windowed tube). Absolute accuracy of both fluxes, aside from effects of geomagnetic acitvity, is estimated to be within a factor of two. It is clear from the upper decades that the electron flux is the prime contributor. The peak around 60° S is primarily electron flux. However, the part marked "very noisy" between 35° and 40° may show components resulting from proton flux.

Figure 6 shows the dark current under the last two conditions - an increase about 60° S due to the electrons of the outer belt and superimposed on the other increase is much noise, probably corresponding to the effects of individual protons.

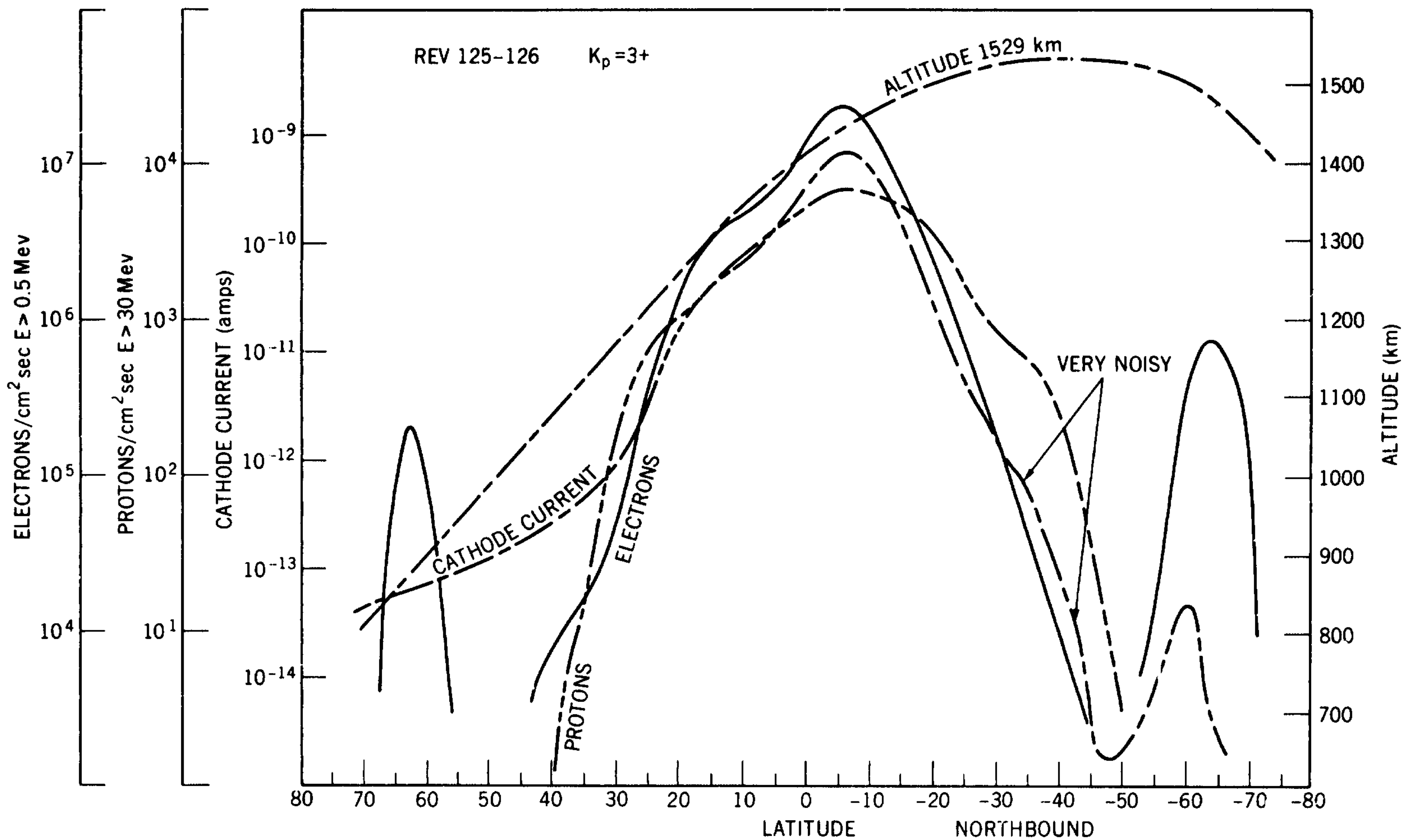

Figure 5–A plot of background cathode current for the EMR 541 E 05M photomultiplier plotted against predicted electron and proton fluxes for a northbound polar orbit. In the upper decades electron flux is the prime contributor. The part marked "very noisy" between 35 and 40° S. may show components resulting from proton flux.

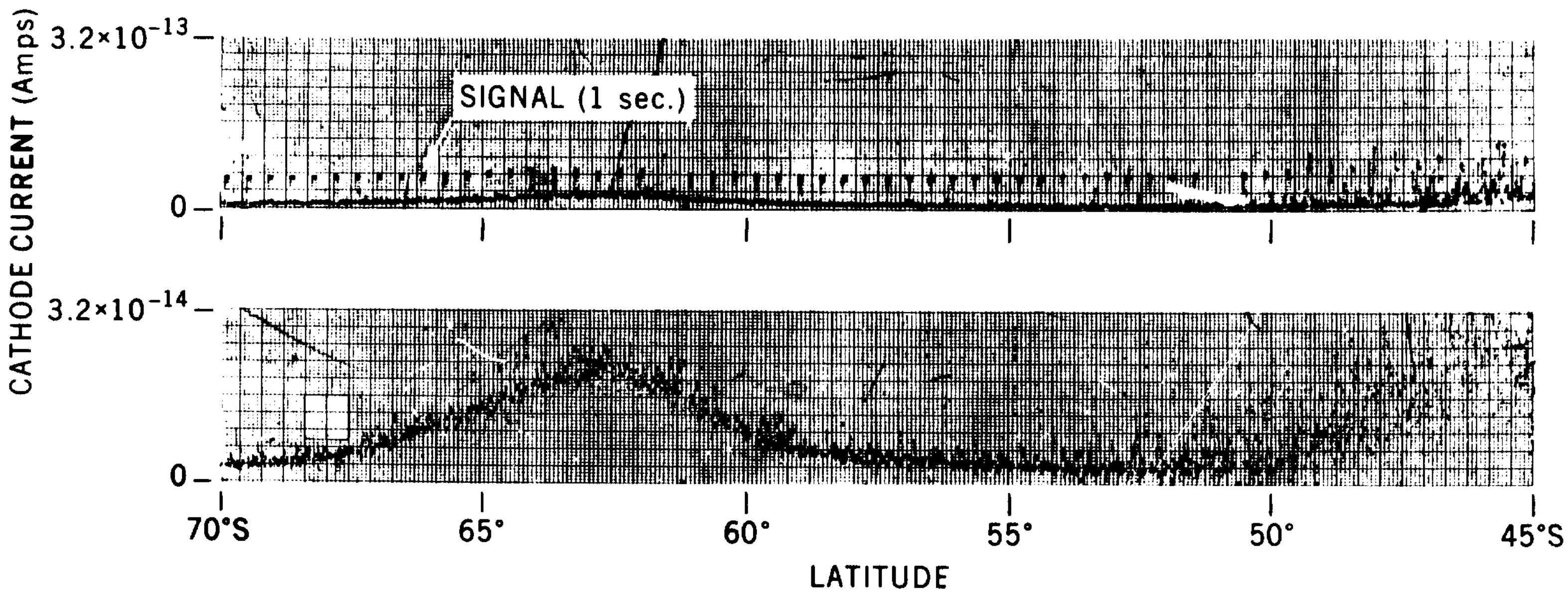

Figure 6–A strip chart example of the plot in Figure 5 taken at a time when the down shutter was closed and the up shutter open. The signal of one second duration appears every eight seconds. Notice the change in character of the background at what appears to be an onset of proton flux between 50° and 45°S.

With the background source localized to the cathode-window, it is interesting to compare our photomultipliers with others. Charles Wolff [2], of this Laboratory discusses an image dissector on OGO-I also using a tri-alkali (S-20) cathode deposited on Corning 9741. With a minimum shielding of 1.2 gms/cm^2, he noted a maximum of 1.3×10^5 counts/sec cm^2 when passing through the inner belt, which had at that time an estimated flux of about 10^8 electrons/cm^2 sec above 0.5 MEV. This is low, and comparable with our OPEP photometer.

Also, on OGO-II and adjacent to our mainbody photometer, were two EMR photomultipliers in the UV airglow spectrometer of Dr. Charles Barth, now of the University of Colorado [3]. These photomultipliers (EMR 541) were very similar in construction to those in our main body photometer except for window and cathode. One had a CsI cathode on 3/8 in. diameter LiF window; the other had a CsTe cathode on a 1 in. diameter sapphire window. The tube with the sapphire window was about 220 times as sensitive to the inner radiation belt as the other tube. There was no extra shielding above typical instrument and spacecraft structure. Spectral responses of these and other UV cathode-window combinations have been reported by Dunkelman, et.al. [4].

To complete a comparison of photomultipliers, mention should be made of the laboratory study by Dressler and Spitzer [5]. With pulse counting techniques, background comparison was made of 13 EMR 541 type window-cathode combinations. Excitation originated in a ^{60}Co gamma source which produced .6 MEV secondary electrons by Compton scattering. With events analyzed as a large pulse followed by a train of pulses, comparison between cathode-window combinations is made in terms of pulses per event as well as pulse rate. Evidence is presented that Cerenkov excitation for the sapphire window can not account for both the large and the many small pulses. They suggest that the observed train of pulses may be associated with direct excitation of electrons in the solid by energetic electrons.

V. OTHER EFFECTS BY ENERGETIC PARTICLES-MAINBODY PHOTOMETER

In addition to the effects of the radiation belts in regions of low dark current, sharp spikes appeared, Figure 7. These appear similar in quality to those described by Young [6], and gave the background a latitude dependence which is best shown with a plot of "dark current" from OGO 4, Figure 8.

OGO 4 had additional shielding (.234" aluminum over .040" tungsten) similar to the horizon scanner, reducing the effects of energetic electrons. The enhancements seen over the poles are characteristic of cosmic ray particles and the flattening above 60 degrees magnetic latitude is characteristic of galactic cosmic rays in particular. This polar enhancement can also be seen on the dark current world map, Figure 9. The correlation of the polar enhancement with magnetic coordinates is here particularly clear.

VI. CONCLUSIONS

Examples here can be used to estimate background changes for DC or charge integrating photometers using sapphire windows and S-20 cathodes. Some improvement should then be possible with chopper and tuned amplifier or pulse counting techniques. Regardless of these improvements, in the inner belt high anode currents may damage tubes if fixed high voltage is maintained, or taking our results directly, with variable high voltage (Sweet circuit) the sapphire tube does not suffer appreciable degradation.

The flight data reviewed here confirm the laboratory results of Dressler and Spitzer which indicated that the tri-alkali cathode, sapphire window was most susceptible to high background in the radiation belts. The relative order of comparison between cathode-window combinations seems in agreement; however, the range of difference is less extreme for the gamma excitation and may also reflect an advantage to be gained with pulse counting techniques.

For our photometers, simulation of the inner belt

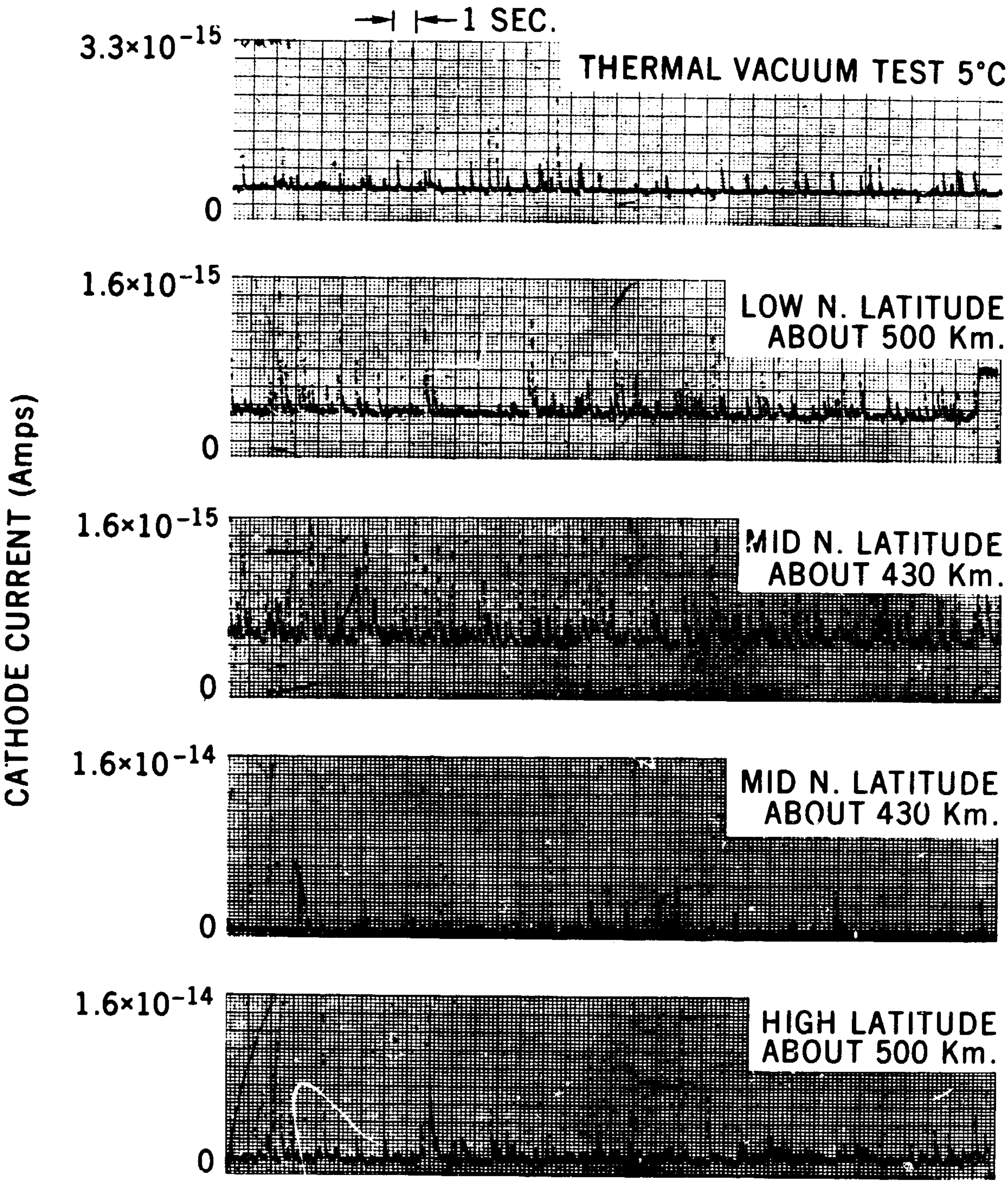

Figure 7–Strip chart examples showing the quality of background current in the lower portions of the OGO II orbit. The sharp spikes are attributed to cosmic ray particles which as expected show a latitude dependence.

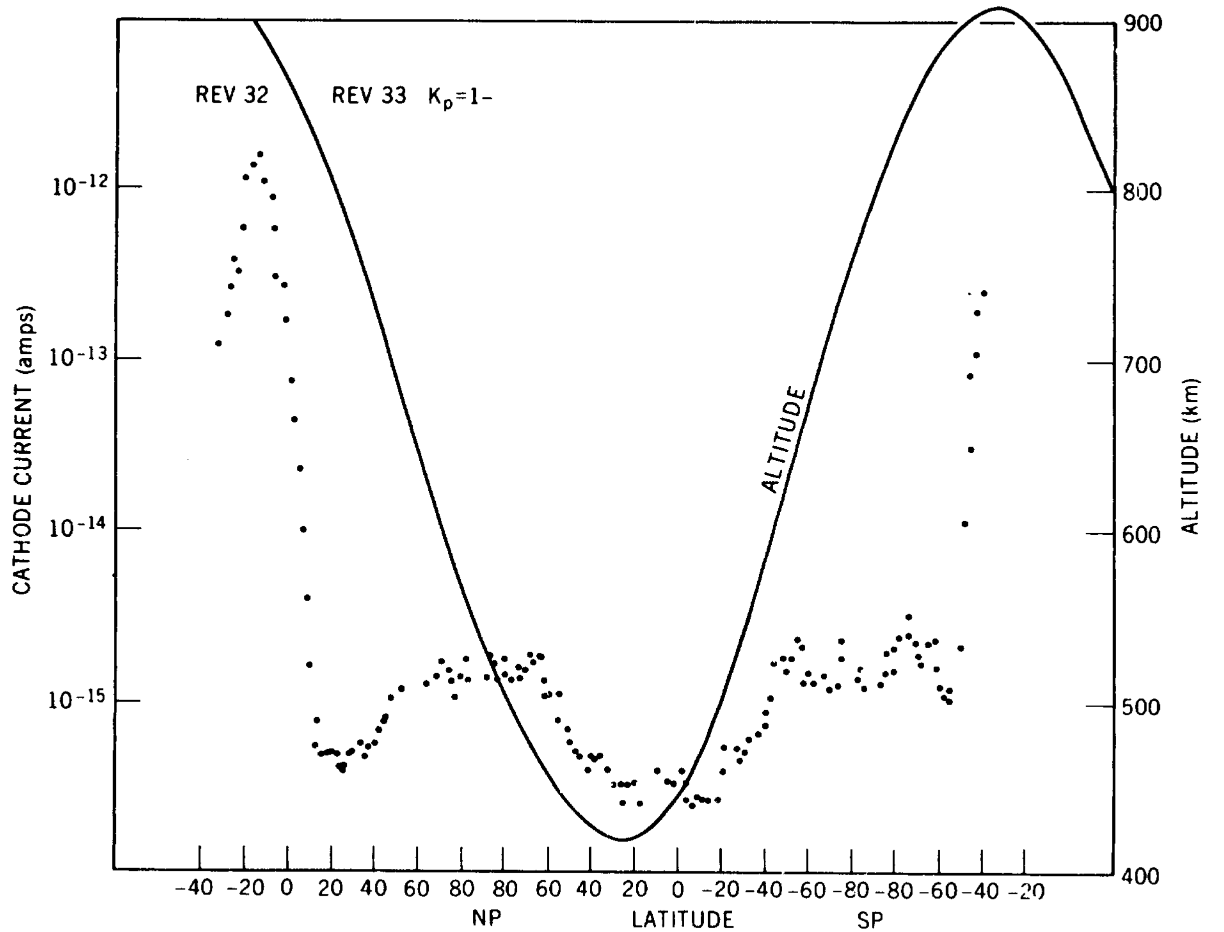

Figure 8–Dark current values from OGO IV where the extreme values, or spike tops, have been eliminated in the data reduction program. Nevertheless the enhancement over the poles, as a plateau at greater than 60° latitude, is characteristic of galactic cosmic rays and can be seen for both north and south polar regions. Equatorial crossings occur, from left to right, at 5.5°E. 173°E, and 19°W (not shown).

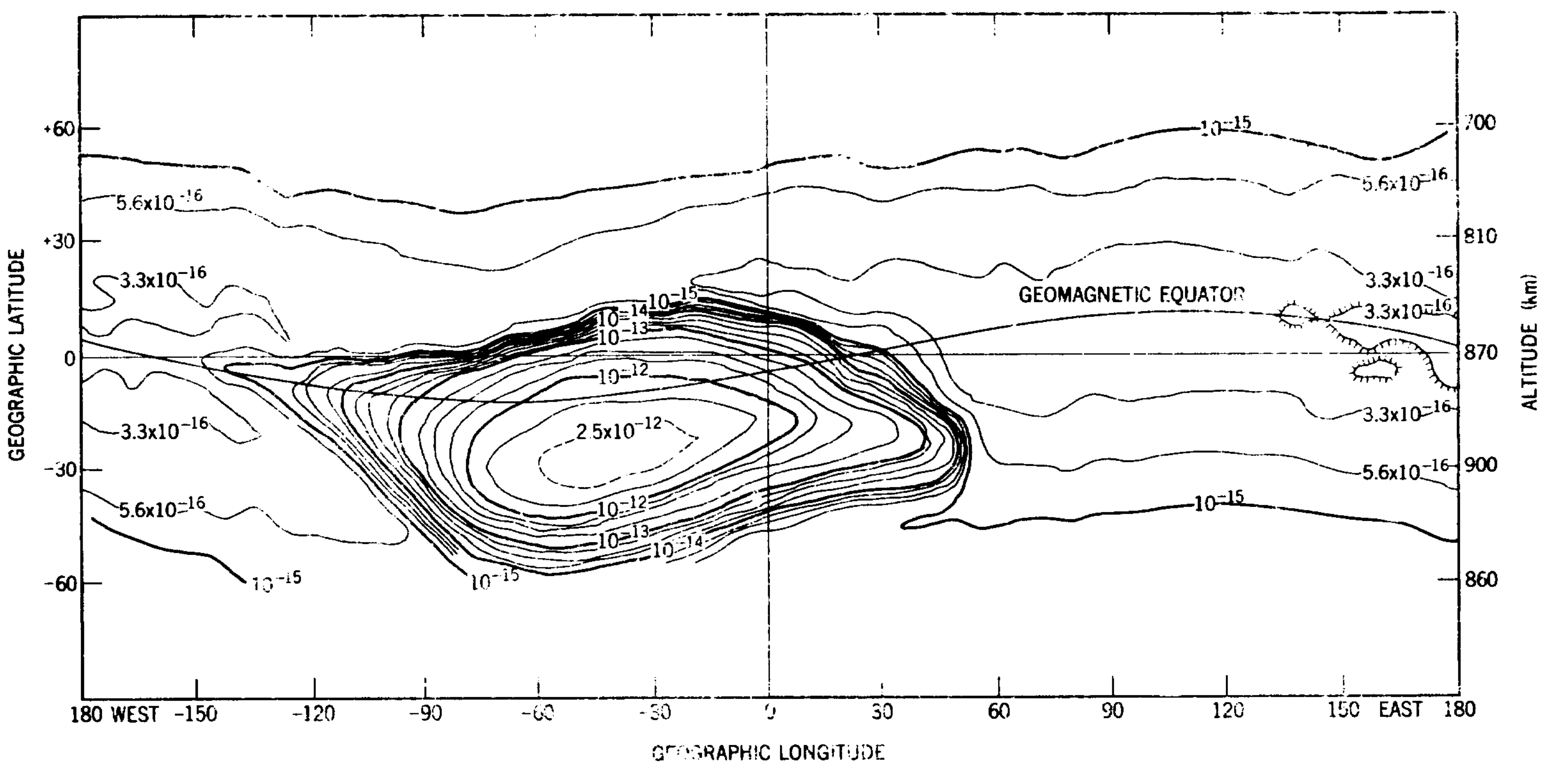

Figure 9-A world map drawn from background cathode current values over the period 1 to 9 September 1967. The profile of Figure 8, taken from July 30 data, is seen again here at +5.5° and −19° longitude The dependence of the polar plateau on magnetic coordinates is clearly evident.

with 2.6 MEV electrons appeared to be successful using the van de Graff accelerator at the Grumman Aircraft Corporation, {1, 7}. Further, results indicated the improvement resulting from added shielding on the OGO IV main body photometer was reasonably well predicted and approached, two orders of magnitude. Figure 4 shows extreme directional variation of shielding which was difficult to evaluate for simulation.

For purposes of the airglow experiment the enhanced background was always treated as an undesirable effect to be reduced or eliminated. However, it is apparent that this variable, often discarded in the data reduction process, can contain useful information on the energetic particle environment. A prelaunch calibration of responsivity to energetic particles could improve the value of this type of data. Whether for energetic particle study or the estimation of low brightness thresholds, further study is needed to better predict background levels. Although one assumes the near earth environment, results could conceivably be applied to radiation belts in the vicinity of Jupiter where assistance to the experimenter might be considerable.

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