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Primary Cosmic Radiation

Status Report for period ending

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polycarbonate and two mylar polyesters. In addition there was a layer of Ilford G5 nuclear emulsion, 200 micron thick on 10 mil mylar. Total thickness of such a sandwich was 0.40 gm/cm^2; total area of one layer was 7.8 m^2 of detector area and 1.5 m^2 inactive area (mostly the supporting framework). Three sandwich layers were used, with 1/8 inch aluminum absorber between.

Barndoor II had two sandwich layers. Each sandwich layer contained Ilford G5 emulsion 90 micron thick on 10 mil mylar and 13 plastic sheets: 4 of 10 mil cellulose nitrate, 2 of 8 mil cellulose acetate, 2 of 8 mil cellulose acetate buterate, 3 of 10 mil lexan polycarbonate and 2 of 10 mil mylar polyester. Total sandwich thickness was 0.75 gm/cm^2, and total detector area 13.8 m^2. No additional absorber was used.

Recognition of altitude tracks (as opposed to ascent and descent tracks) was accomplished on Barndoor I by moving the A layer above the B layer. On Barndoor II, the separation between the two layers was much less, and the extrapolation from the B to the A layer correspondingly easier. (This is complicated by the difficulty in getting large areas of plastic to stay quite flat.)

The data for these two flights are shown in Table I.

Table I
Balloon Flight Data

Flight	Date	Mean Altitude at ceiling (mb)	Time at ceiling (hrs)	Mean geomagnetic cut-off rigidity
Barndoor I	23 Sept. 1967	4.0	15	5.0 GV
Barndoor II	24 May 1968	3.5	14	5.0 GV
Barndoor III	19 Sept. 1968	3.6	40	5.0 GV

Both flights were launched from the N.C.A.R. Balloon Base in Palestine, Texas, and the cut-off rigidities listed in the Table have been derived from the Quenby-Wenk (1962) tabulations, and represent the midpoints of the ceiling portions of the flights. This suffices for an indication of the cut-off, but we return to this point in detail in a later section, since the conclusions to be drawn from an analysis of the heaviest tracks depends on the cut-off values.

(b) Etching and Developing of Tracks

The nuclear emulsions were developed by a standard procedure, but we describe the plastics processing in somewhat more detail since this is not as well known.

The etching solution is 6.25 N sodium nydroxide; this attacks the latent tracks at a higher rate than it attacks the overall free surface. Cellulose nitrate sheets were etched for 4 days at 23°C. In this time, about 10% of the sheet thickness (about 25 micron) is removed, and the tracks appear as holes with about 50 micron diameter - easily seen with a magnification of 25X under a stereo-microscope. Longer etching times have been found to reduce the optical clarity of the sheets and also increase the number of flaws which are rendered visible. Lexan polycarbonate was etched for 36 hours at 70°C, removing about 15% of the thickness (or a total of 75 micron from both surfaces). Experience with lexan exposed to low energy heavy ions (at the Yale and Berkeley linear accelerators and to low energy cosmic rays at northern latitudes) has shown that these etching conditions permit automatic detection for particles whose rates of loss of energy equal those of relativistic particles with charge $Z \gtrsim 75$.

(c) Scanning

Optical scanning of plastics is tedious for very large areas, Stereo-microscopes whose magnification can be adjusted over a factor or three range have been used for checking the efficiency of mechanical scanning.

There are two methods of mechanical scanning. In the first, a plastic sheet is placed on a flat metal plate, and a probe is passed over the top surface of the plastic. The probe is maintained at a potential of a few thousand volts above that of the plate; the presence of an etched track which goes through the plastic is quite easily seen through the resulting spark discharge. The locations of such sparks are marked, and then examined with a stereomicroscope so that plastic defects are quickly rejected. This method is quick and has permitted us to scan our large areas rapidly. (The total area of each flight (over 20 m^2 together) was filled by sheets of about 12" x 15" so that several hundred sheets needed to be examined.

The second method of mechanical scanning depends on the passage of a fluid through the track, from one side of the plastic to the other. Penetration is demonstrated optically by the fluid's participation in a chemical reaction. Here again, flaws which have etched through are also rendered visible and must be rejected after optical examination.

While these two methods will quickly lead us to those tracks which have been etched completely through the plastics, the optical scanning is still needed for the detection of tracks only partially etched. These appear, under the microscope, as two cones, each with its base at a surface, and with the two apexes not quite or barely touching. These will be produced by particles whose rate of loss of energy is just about at the threshold for that plastic.

In all flights, the top layer was the one which was shifted at ceiling, and the initial scanning was therefore carried out in the next sandwich layer. The plastic selected for primary inspection was one of the cellulose nitrate layers. This was made in Japan and is referred to by its trade name, Daicel. After location of etched tracks and flaws in the Daicel 'B' layer, the flaws were optically rejected and the continuation of each track located in the neighbouring emulsion 'B' layer. From the observed azimuthal angle and projected

In layout, Barndoor III was essentially the same as Barndoor II. The same frame was used for the support of the emulsions and plastics, and the major difference arose through the use of about 20 different plastics which were chosen for a variety of sensitivity tests. For instance, some were irradiated by x-rays prior to the flight, some have been irradiated after flight - this to simulate the possible effects of exposure of the plastics to the earth's trapped radiation during an extended satellite flight.

(d) Preliminary Results from Barndoors I and II:

All of Barndoor I has been scanned and our present analysis rests on the tracks found in that flight. In Barndoor II, the lexan sheets have been scanned to locate the very heaviest tracks and two were found. The identification of these two tracks is discussed later, and the scanning of the other plastics has not yet been carried out.

On Barndoor I, there were two cellulose nitrate layers: one was the Daicel which was estimated to be the most sensitive, and the other was made in this country by Nixon-Baldwin. To anticipate somewhat, it has indeed turned out that the Nixon-Baldwin registers particles with Z above about 35, while the Daicel appears to have a threshold region between $Z = 28$ and $Z = 32$.

The first scanning was in the Daicel B layer. Tracks found there were checked in the emulsion B layer (to confirm that they were indeed tracks and not plastic defects) and in the Nixon-Baldwin B layer. Then the various possible altitude and ascent locations in the A layer were examined, and the particle appropriately classified. When a particle had been confirmed as being recorded at altitude, ionization measurements were carried out ant these are described later.

The breakdown of the tracks found, into the various categories, is best described in a diagram (Fig. I). Finally length, an extrapolation was made to the 'A' layer. In Barndoor I, this involved looking at each of four possible positions and selecting only those recorded in the altitude regions. With a three inch separation between the A and B layers and having to deal generally with very steeply dipping tracks, the four positions of the A layer during flight result in the specification of four regions in which to look for tracks from the B layer; each of these small areas is about 1.5 cm x 1.5 cm, but the correct track is usually quickly and unambiguously located. In Barndoor II, the A and B layers were almost in contact, and the areas to be searched were much reduced. In addition, there were only two positions of the A layer -- an altitude position and another for both ascent and descent.

There is a further complication in the case of Barndoor I: there is sufficient matter in the path of a particle that a fast particle may not have sufficient charge to produce an etchable track in the A layer, yet will have lost enough energy by the time it reaches the B layer that it will be recorded there. Particles going upwards could also register in B but fail to reach A, although this is highly unlikely for very heavy particles. For a particle having sufficient energy to penetrate both the B emulsion and B Daicel layers and leave tracks, a miniumum charge of Z = 10 is needed, yet such a particle would not register in the A layer Daicel. For penetration through the A and B layers and registration in the plastics, a slow particle with Z as low as 18 could be recorded.

Barndoor III was one of three spectacularly successful flights in September (the other two were by Fowler) each was about 40 hours at ceiling. Starting with Barndoor III, the collaboration between G.E. and W.U. has been extended to include the University of Bristol. The program will be immensely strengthened through this close co-operation. One layer of emulsions from Barndoor III has been developed here; another will be sent to Fowler, so that a standardised development can be followed and identification more easily checked. One layer of lexan has been etched here, and a daicel layer is to be done next.

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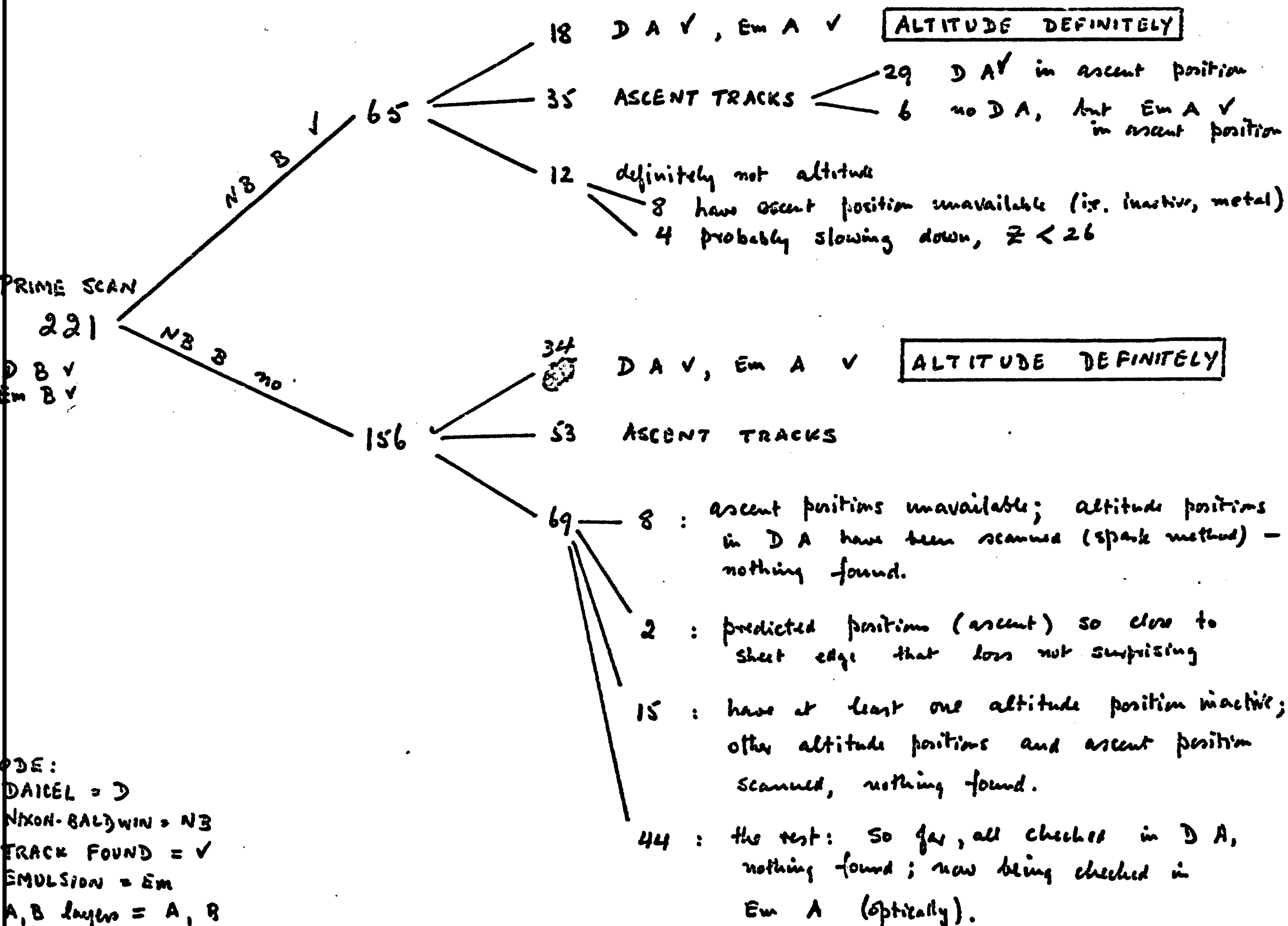

PRIME SCAN
221
D B ✓
Em B ✓
NB B ✓
65
18 D A ✓, Em A ✓
ALTITUDE DEFINITELY
35 ASCENT TRACKS
29 D A✓ in ascent position
6 no D A, but Em A ✓ in ascent position
12 definitely not altitude
8 have ascent position unavailable (ie. inactive, metal)
4 probably slowing down, Z < 26
NB B no
156
34 D A ✓, Em A ✓
ALTITUDE DEFINITELY
53 ASCENT TRACKS
69
8 : ascent positions unavailable; altitude positions in D A have been scanned (spark method) — nothing found.
2 : predicted positions (ascent) so close to sheet edge that loss not surprising
15 : have at least one altitude position inactive; other altitude positions and ascent position scanned, nothing found.
44 : the rest: So far, all checked in D A, nothing found; now being checked in Em A (optically).
CODE:
DAIEL = D
NIXON-BALDWIN = NB
TRACK FOUND = ✓
EMULSION = Em
A, B layers = A, B

in Barndoor 1, 32 altitude tracks have been confirmed, but this number may be increased as a certain group of tracks are re-examined. These special tracks have been detected in the Daicel B layer, in the emulsion B layer but not in the Nixon-Baldwin B. layer. To date, their corresponding tracks have not been found in any of the available altitude positions in the A layer, and these are being re-examined. On the other hand, in the A layer, no Daicel tracks have been found in any of the anticipated positions by the spark scanning. This means that if there is a track in the Daicel A layer, it has not etched through, and location of un-connected cones is difficult. The matching places in the emulsion A layer are being scanned; it would appear that any tracks in this category must have charge less than about Z = 35, the Nixon-Baldwin threshold, since no tracks have been seen in that plastic.

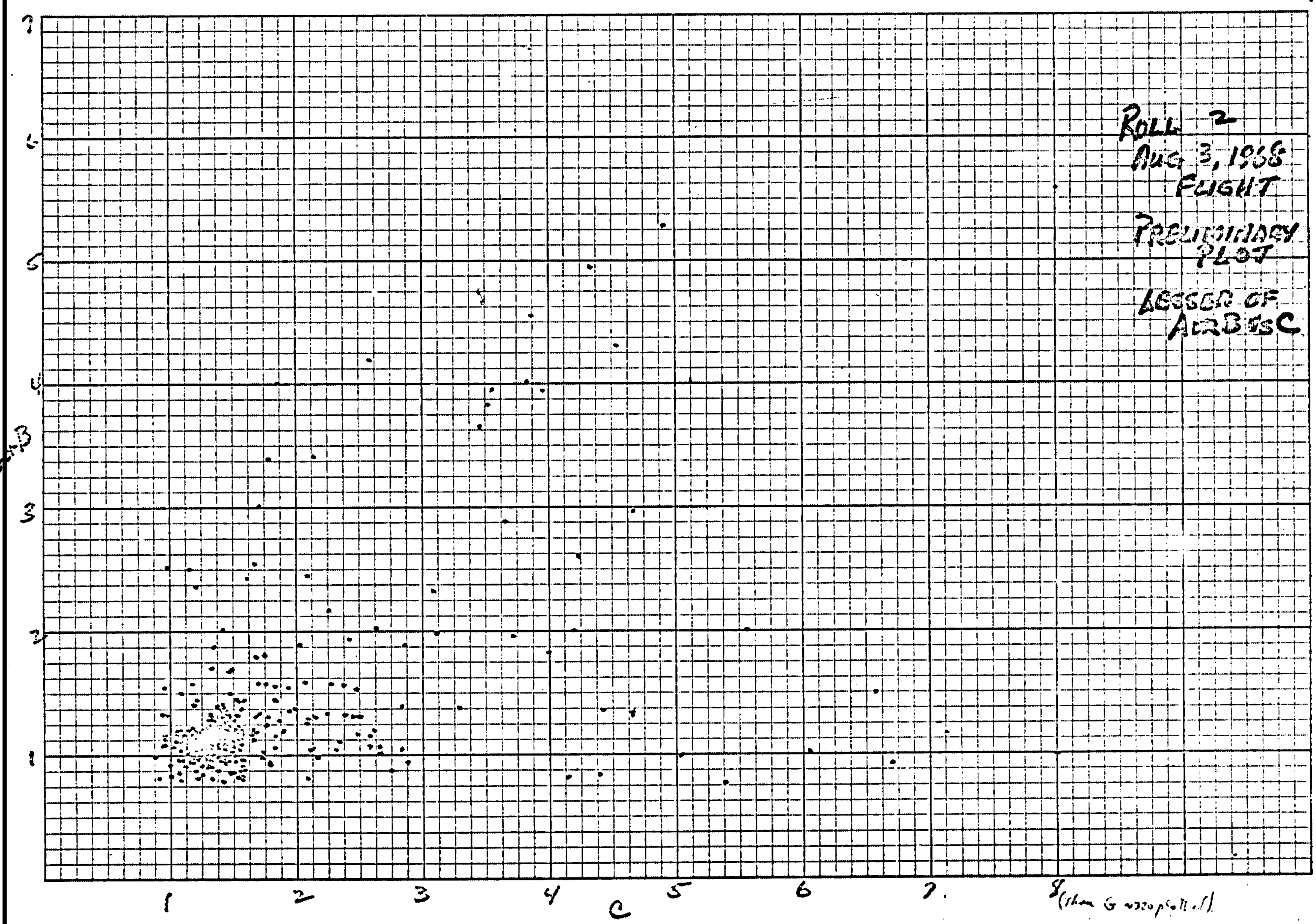
In a 10-hour flight, we accumulate about one Fe track per square cm. Extensive optical scanning will therefore yield immense numbers of Fe tracks and the selection of tracks with Z only slightly more than 26 will be impossible. We rely on the Daicel for the detection of particles as close to Fe as possible. Repeated spark scanning of Daicel sheets has always yielded the same tracks: 36 sheets have been checked and in these 130 completely etched tracks have been repeatedly found. Of these, 102 had been found by visual scanning but none had not already found by the spark method. We consider the spark method to be 100 % efficient.

Efficiency of optical scanning in the Daicel layers has been checked, and the table below summarises the results.

Table II

	Observer A	Observer B	Total Tracks
through tracks	32	34	36
not through	24	39	46

Here "through" tracks are those which etched completely through,


ROLL 2
AUG 3, 1968
FLIGHT
PRELIMINARY
PLOT
LESSER OF
A or B vs C
B
C
1
2
3
4
5
6
7
8

the various techniques. Fowler, in Bristol, also uses a densitometer but with a different choice of ionization parameter for charge identification.

At this stage, flux values to be quoted are based as follows:

$Z \geq 60$: three tracks from Barndoors I and II, using Lexan scanning
$Z \geq 35$: 18 tracks, Barndoor I only: tracks recorded in Nixon-Baldwin, with apparent threshold at $Z \sim 35$. (One of the three with $Z \geq 60$ is included in these 18.)

The flux values are:

$J_{60} = 8.6 \times 10^{-7}$ particles/m^2 . ster. sec
$J_{35} = 1.4 \times 10^{-5}$ particles/m^2 . ster. sec

In addition, we have 34 tracks recorded at altitude and seen in the Daicel but not the Nixon-Baldwin. These appear to have charges less than 35 (by direct measurement) but the present uncertainty in the registration efficiency of the Daicel precludes the calculation of a flux value. These values should be compared to the flux of Fe nuclei at the same location, about 0.25 particles/m^2. ster. sec.

Work continues with the measurement and calibration of tracks already found, as well as the scanning of further areas of plastic.

(f) Theoretical studies associated with the VVH experiment.

The examination of the physical processes involved in the propogation of VVH particles, from sources to the Earth, through interstellar hydrogen, requires an understanding of the same sorts of processes now so well known in the charge region below Z = 26. We require knowledge of the mean free paths and fragmentation parameters for the various components of the radiation. These must be deduced from laboratory studies. No high energy beams of heavy ions are available, and instead we must start with the radiochemical studies of the fission and spallation of heavy nuclei under extended proton bombardment in the Gev range. A detailed study is in progress, and will form the body of a Ph.D. thesis which should be completed early in the new year. General patterns of the charge spectrum to be expected are now emerging from these calculations. Different injection spectra have been assumed and followed through various distances in hydrogen (different densities have also been considered). The effect of the relativistic time extension has been included for the heavy unstable nuclei. As more experimental data are accumulated, the theoretical studies can be directed towards particular regions of the spectrum which seem to be the most sensitive discriminators between the different injection spectra assumed.

II. Scintillation-Cerenkov Counter Experiment: Particles with $1 < Z \leq 26$

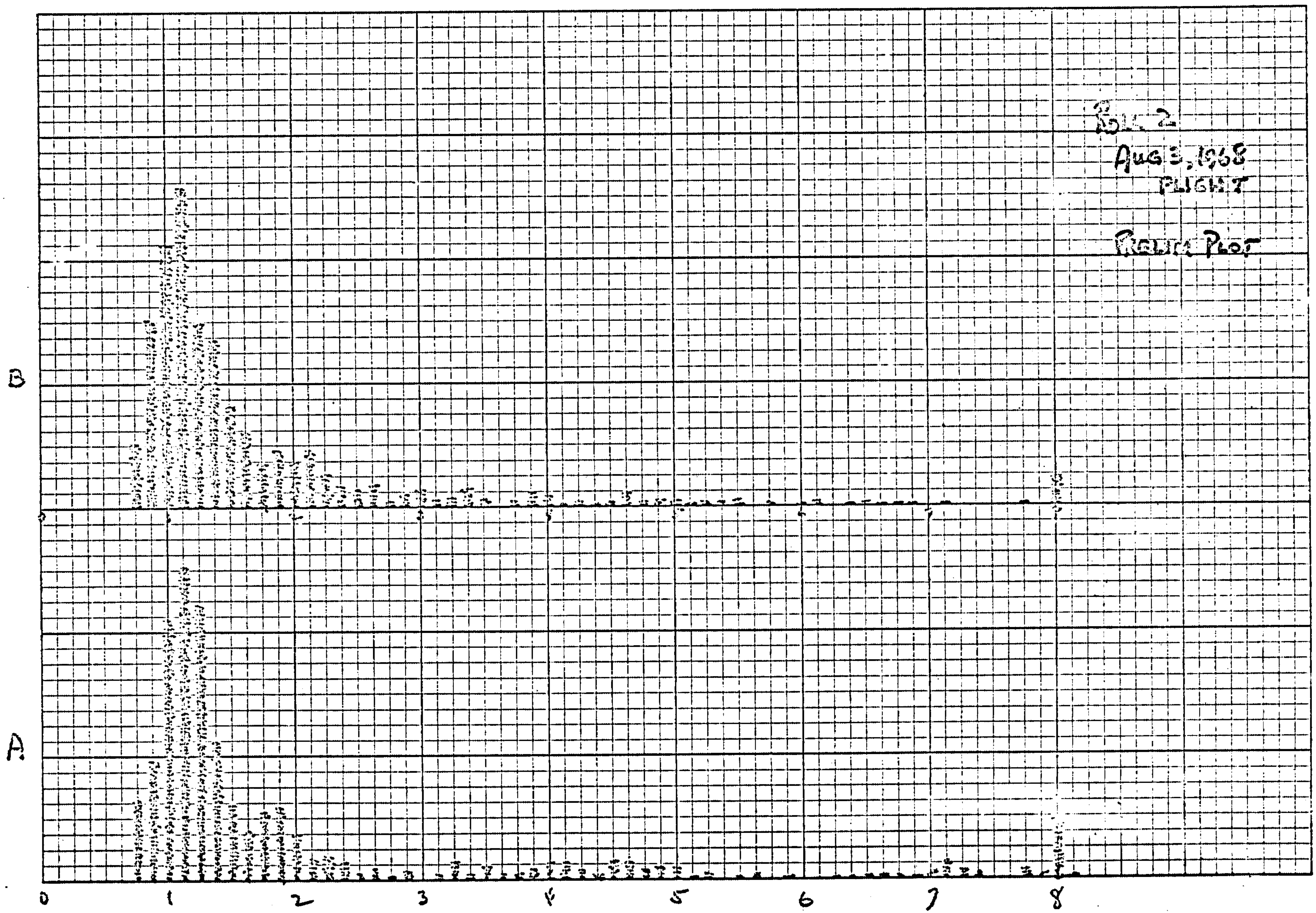
This experiment is designed to examine the more conventional part of the charge spectrum. Scintillation counters (NaI crystals) and plastic crenkov counters are each viewed by four photomultipliers. A small spark chamber above helps to define the zenith angle of each particle's traversal and thus allow a correction to be made for path length through the counters.

In a successful balloon flight, from Palestine, on August 3rd, 1968, the experimental package was held at an altitude of close to 127,000 ft. (3.5 mb) for 7.7 hours. During this time, the equipment operated in two modes. For the first four hours, all particles whose pulse heights were greater than or equal to that of a relativistic He nucleus triggered the system: counts were recorded at the rate of 130/minute. For the second part of the flight, the triggering was shifted to require a cerenkov pulse corresponding to relativistic Li or heavier, together with the scintillators being set to require a pulse slightly greater than the most probable pulse expected for a relativistic He-nucleus. In this mode the counting rate was about 23/minute.

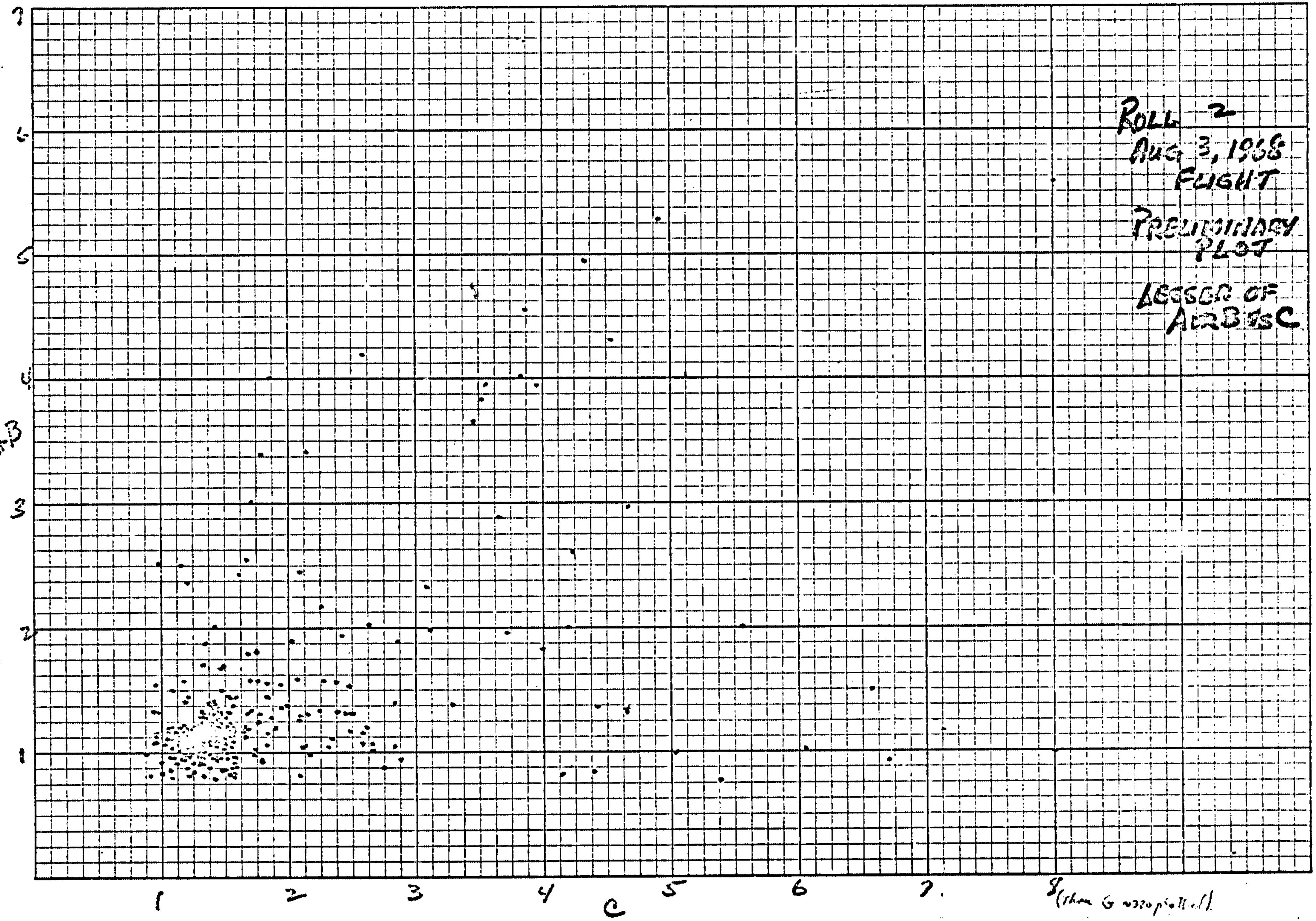
Close to 35,000 events were recorded on a little more than 100 ft. of 35 mm film which was recovered after the flight in the relatively undamaged package, southeast of El Paso. About 700 of these events have been read directly from the film and are being used to test the computer programs for reading and analysing. These data have also been plotted by hand to give an idea as to how the analysis would go. Eventually, the reading of the film will be via a computer-controlled flying-spot scanner. The programming is well under way and indications are that when it is fully operative, it will take about 1 hour of computer time to convert the dots on the film to actual hexidecimal numbers stored on a disc for reduction and analysis. The film advance mechanism is under construction.

Considerable thought has been put into the question of analysis and the associated program. The A and B detectors are identical NaI scintillators; what kind of bias is introduced by taking the mean pulse height? or by taking the lesser of the two? or what bias is introduced by the rejection of events in which the two scintillators do not yield pulse heights within some predetermined mutual agreement? Problems such as these, together with the inclusion of effects in the third (Cerenkov) counter, are being examined. Monte Carlo calculations have been performed with the Landau fluctuation distributions, but other forms of analysis may only emerge after the data has been analysed in one way. We expect that all of the parameters will be well determined within the next few months and that a well resolved charge spectrum should then be obtained.

Further, there has been consideration of possible improvements which might be incorporated in the system. This would be chiefly in the area of the spark chambers. The


Aug 3, 1968
FLIGHT
B
A
0
1
2
3
4
5
6
7
8

K+E 8 X 8 TO THE INCH 46 0540
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



problem encountered there was to make the chamber spark in one and only one place if one particle passed through it, yet to spark in five places if five particles were present. The early results seem to indicate that for multiple events, the chamber sometimes recorded nothing. We are considering replacing the digital spark chamber with a digital scintillation chamber, which would have the same resolution as the spark chamber, consume the same power (phototubes instead of high voltage pulsing circuits) and cost about the same as the spark chamber. The scintillation chamber would have an efficiency of 99.9% for a particle in one strip, 99.8% for seeing particles in each of two strips, 99.7% for seeing particles in each of three strips, etc. Design study continues on this problem.

The figures which follow show the results of the preliminary analysis of about 10 minutes' data. In Fig. 1, there are displayed the outputs of the A and B scintillators for the 1st half of the flight: the large helium peak is notable, and smaller peaks are beginning to build up. The electronics converted the data to a square-root so that the ordinate in these figures is linear with charge over the range for which pulse height is proportional to Z^2. Figure 2 shows a cross-plot of the smaller of the pulses from the A and B counters vs. the Cerenkov signal, and again the He peak is notable.

III. Analysis of data from older flights:

The work on the 1965 IQSY has been completed. Two papers have so far appeared:

"An Apparently High fluc of Primary Cosmic Ray He-Nuclei at 41°N Mag" by M. W. Friedlander and J. Klarmann, Planetary Space Sci. 15, 619 (1967).

III. Analysis of data from older flights (cont'd)

"Flux of Primary Cosmic Ray Particles with $Z \geq 3$", by S. A. Fody, M. W. Friedlander, H. Hasegawa and J. Klarmann, Plan. Space. Sci. 16, 253 (1968).

and a third paper is in the manuscript stage: "The Relative Abundances of Cosmic-Rays with $Z \geq 3$", by S. A. Fody, M. W. Friedlander, H. Hasegawa, J. Klarmann and W. Wells.

In addition, much of this is included in the Ph.D. thesis of S. A. Fody, completed in September 1968.

M. W. Friedlander

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Principal Investigator