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COSMIC-RAY MONITORING OF THE MANNED STRATOLAB BALLOON FLIGHTS

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ABSTRACT

This note describes new observations made on emulsion blocks and skin monitors during Stratolab flights III and IV and, from this information, presents a re-evaluation of the results of the Manhigh II flight. A method for monitoring pilots for heavy primary hits on hair and skin structures is described utilizing nuclear emulsions placed in direct contact with the flat portions of the arms. Tracks of heavy primary traversals are plotted; and heavy primary thindown hits on the Stratolab IV and Manhigh II flights are compared and tabulated. The intensity of thindown hits was found to be not only dependent on altitude and geomagnetic latitude of the exposure but, also, markedly dependent on exposure time with the solar sunspot cycle. A sevenfold reduction in thindown intensity is indicated at the top of the atmosphere during periods of maximum sunspot activity; thus this natural amelioration of the cosmic-ray hazard should be considered in planning for manned exploration of the moon and planets.

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1. INTRODUCTION

A paucity of experimental observations exists on the biological action of primary cosmic radiation, both for experimental animals[1, 2] and man,[3] owing to the difficulties of maintaining a living environment for long periods near the top of the atmosphere. Since the flux of heterogeneous cosmic-ray particles arriving at the top of the atmosphere contains a group of multiply-charged stripped nuclei with charges as high as iron, and possibly greater, and these particles are characterized by very high rates of energy loss proportional to the square of their charge, the heavy nuclei have been suspect as a potential hazard to prolonged flight near or above the protective atmospheric layer. In particular, since the observation by Chase in 1954 of the greying of hair on mice exposed in the stratosphere for periods of about one day, it was deemed advisable to monitor the skin of pilots on high-altitude balloon flights in order to correlate changes of hair pigmentation with the passage of heavy primary cosmic-ray nuclei. This program was initiated on the Air Force Manhigh II flight piloted by Colonel D. G. Simons, and similar emulsion preparations were exposed on the arms of Lt. C. McClure, pilot of the Manhigh III flight.[4]

Because of the large collision cross section of the massive heavy nuclei the beam is largely attenuated either by collision or ionization processes in the uppermost 40 g cm^{-2} of air. Particles which escape catastrophic destruction by collision with air nuclei are slowed down by ionization, and shortly before reaching the end of their range they exhibit a maximum in their rate of energy loss which may reach as high as 10^5 ion pairs per micron of tissue for an iron nucleus. The terminal portions of the more highly charged members $Z \geq 6$, designated thin-down hits P_t, are further characterized that after passing through the maximum in their secondary delta-ray density the channel of biological

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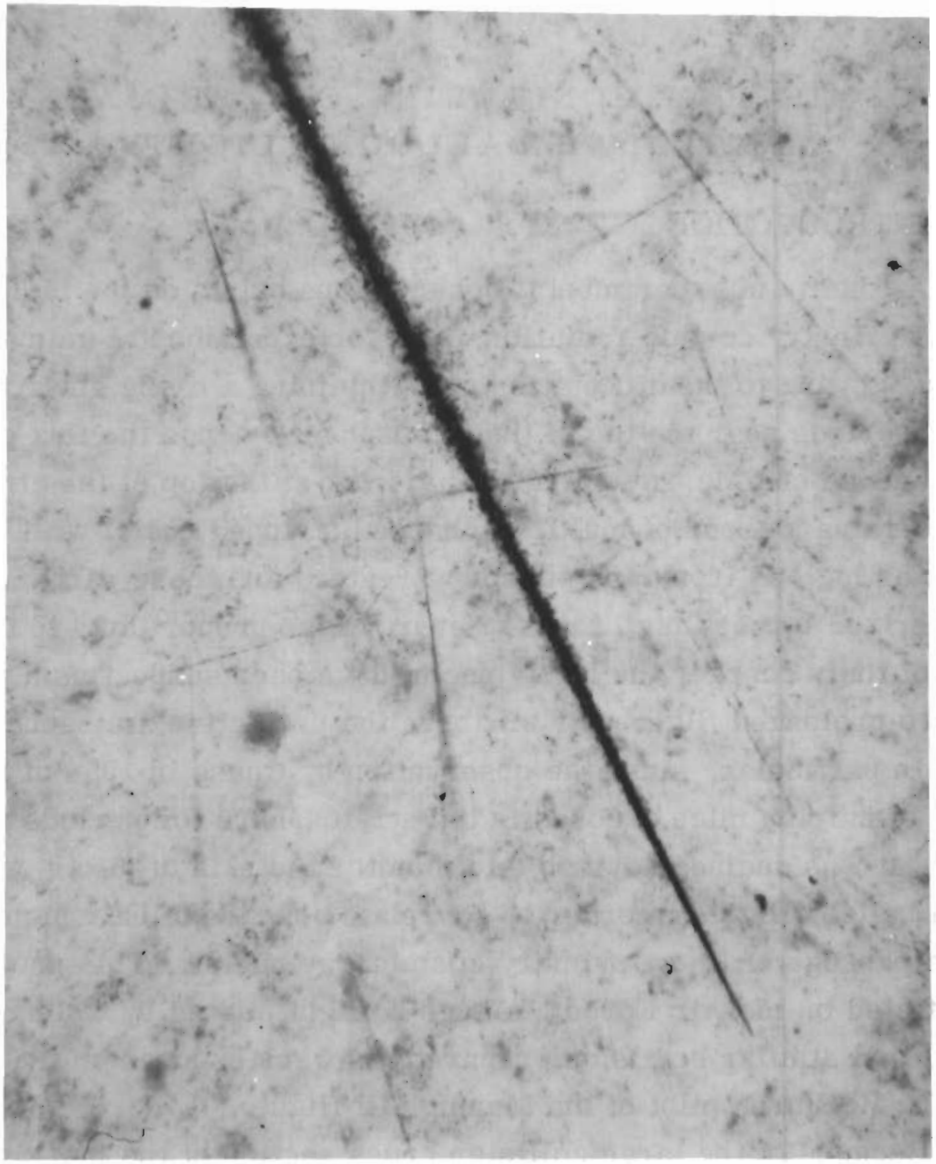

Fig. 1. Terminal portion of a heavy primary nucleus of charge Z = 23 ± 3 exhibiting characteristic tapering of the track as the particle reaches the end of its range. The track is 600 microns long.

action is reduced owing to the reduction in range of the knock-on electrons (delta rays) as the primary particle decelerates and its reduction in charge by electron capture when its velocity $\beta \leq Z/137$. These phenomena are readily recognized in emulsions exposed to cosmic radiation by a tapering of the track (illustrated in Fig. 1) as the

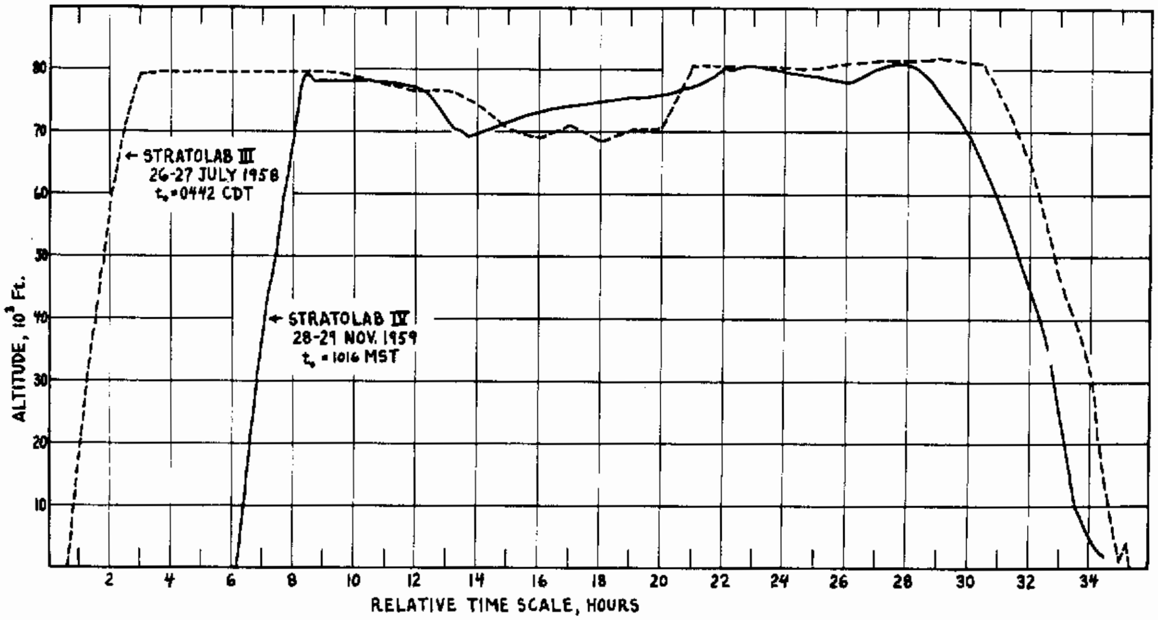

Fig. 2. Altitude profiles of Stratolab balloon flight III and IV.

particle approaches the end of its range.

The frequency of these tapered thindown hits is strongly dependent on the altitude within the atmosphere and, by extrapolation of existing data,[5] may be expected to become vanishingly small at about 70,000 ft. Since there are military planes capable of flying above this elevation and commercial flights may approach this level in the forseeable future, it is important to establish the boundary elevation at which the biologically effective thindown hits become negligibly small. Opportunity to explore this region was made possible by cooperation with the U. S. Navy Stratolab operation whose large two-manned capsule floats at average elevations below 80,000 ft, as shown by the balloon trajectories in Fig. 2.

Following the first exposure of an emulsion block on the Stratolab III flight launched at Crosby, Minnesota, arrangements were made with Commander M. D. Ross to make direct monitoring studies on hair pigmentation changes by mounting thin emulsions on his arms on subsequent flights. Skin monitors were placed on Cdr. Ross' arms prior to an attempted launch from the Stratobowl at South Dakota on

26 November 1958. As shown in Fig. 3, advantage was taken of existing skin pigmentation marks to orient the emulsion monitor with reference to hair structures. This exposure did not materialize because the balloon burst during the last stages of inflation. The experiment was repeated a year later; the emulsions were mounted in the identical positions (Fig. 4), and data were secured on localized heavy primary bodily traversals during the 28-hour flight of Stratolab IV launched on 28 November 1959.

The emulsion skin monitors were identical in construction with the set worn by Lt. McClure on the AF Manhigh III flight. They were recovered in excellent condition, proving for a second time that the sweat-proofing system was adequate. On being questioned after the flight, Cdr. Ross stated that their placement did not cause any discomfort and did not interfere with the fit of the space suit. The construction and development of the skin monitors is described in Appendices A and B.

As in the case of the Manhigh flights, star counts were made on emulsion blocks placed in the gondola and compared with that found in the skin monitor units. The star intensity is a measure of the nucleonic component of the cosmic radiation and is especially useful in the monitoring for biological effects, since the secondary protons and alpha particles originating from the star center create a local high-ionization density in the cell in which the target nucleus is disintegrated. A typical small star is shown in Fig. 5 located in about the same focal plane as the track of a fast iron nucleus. The star counts made in the emulsion blocks are shown in Table 2, page 11. Despite their lower altitude both Stratolab flights recorded an appreciably higher star intensity than that measured on the Manhigh II flight. Star counts made on Cdr. Ross' skin monitors gave a value of 1710 ± 50 stars cc^{-1} day^{-1}, which within the limits of statistical uncertainty is essentially the same as that recorded on the emulsion block flown on the same flight.

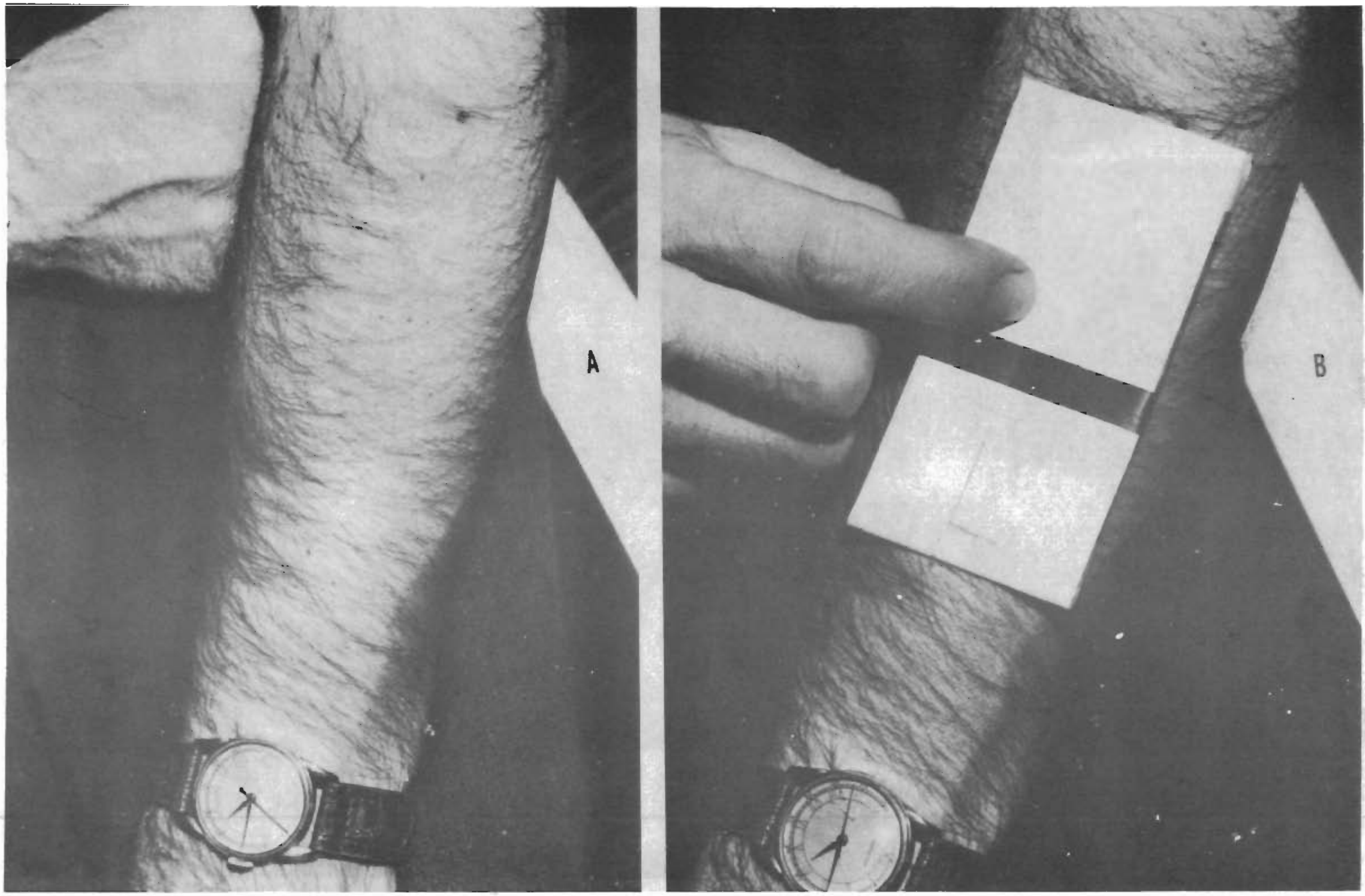

FIG. 3. Closeup view of Comdr. M. D. Ross' left arm (A) showing existing pigmentation marks, employed as orientation marks for the emulsion monitor (B).

FIG. 4. Cosmic ray emulsion monitors strapped to arms of Comdr. Ross, prior to flight of Stratolab IV on 28 November 1959.

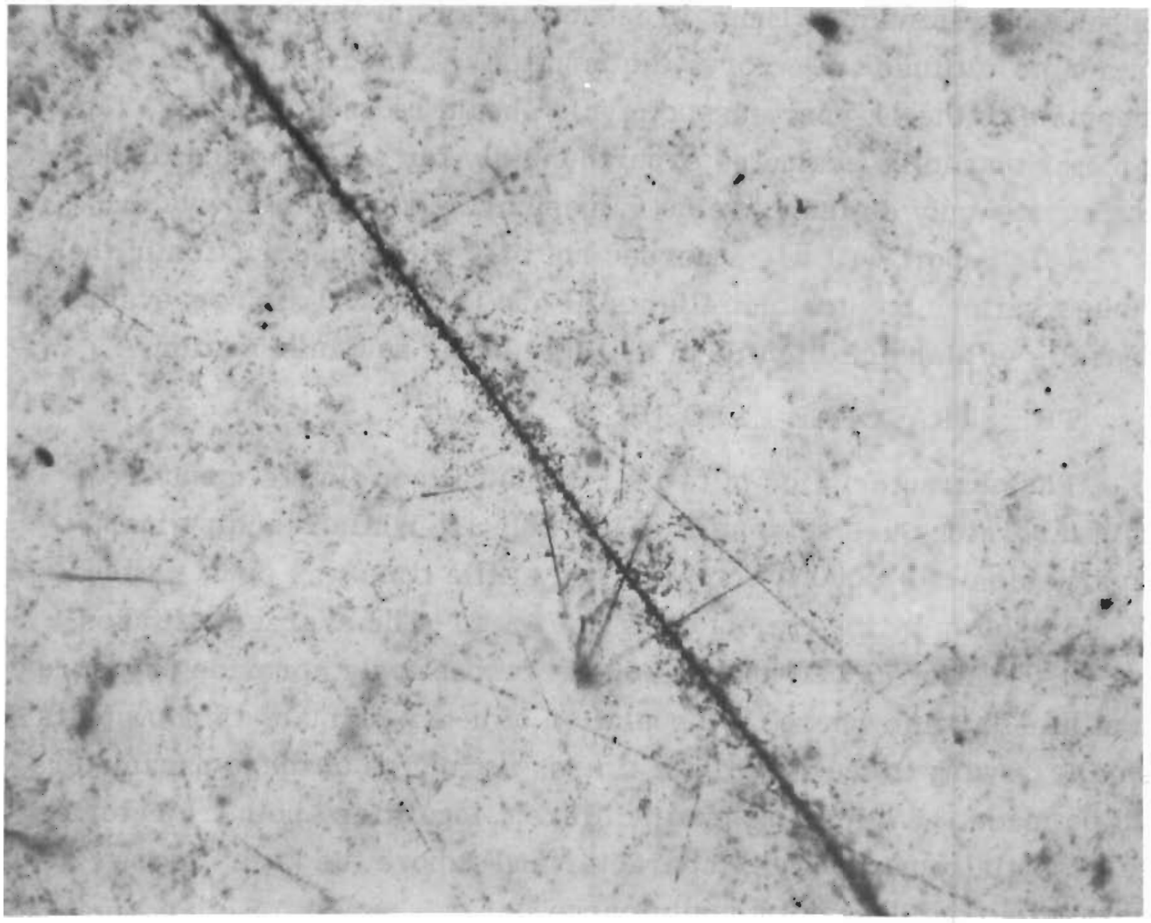

Fig. 5. Photomicrograph of a five-prong star produced by the disintegration of a silver or bromine atom in the emulsion as a result of interaction with a secondary cosmic-ray neutron. The heavy track was produced by the same particle whose terminal portion is shown in Fig. 1. The particular focal setting is at 35.6 mm from the end of the range, corresponding to a kinetic energy of 290 BEV.

An important result from the analysis of the manned Stratolab flights and other exposures secured during the IGY is that the intensity of thindown hits is not only dependent on altitude and geomagnetic latitude of the exposure but is also markedly dependent on exposure time within the solar sunspot cycle.[6] As shown in Fig. 6, counts of the thindown frequency for heavy primaries with charges $Z \geq 6$ made in 1958-1959, a period near sunspot maximum, are 2 to 4 times smaller than at corresponding exposures made in 1950-1955, a period near sunspot minimum. Thus, in estimating a total thindown dosage from a time-altitude trajectory, the function A or B of Fig. 7 appropriate to the 11-year sunspot cycle should be used. Ideally, this parameter should be evaluated experimentally for each manned flight as the curves only define extreme values during a particular cycle.

This report will be concerned not only with a description of the new observations on Stratolab flights III and IV but will also re-evaluate the results of Manhigh flight II in the light of the new information.

2. THE STRATOLAB EXPOSURES

The characteristics of two stratolab balloon flights monitored by this laboratory are summarized in Table 1. While reaching maximum altitudes of 81,000 ft comparatively little time was spent at the peaks, as shown by the trajectories in Fig. 2. The average altitudes above 60,000 ft of 77,520 and 75,780 ft, respectively, provide exposure data at an elevation where the population of heavy primary thindown hits is small. Owing to the long flight times, estimates of these parameters could be made. While launched in different localities, both trajectories were essentially northerly in character and "above the knee" in the geomagnetic cosmic-ray intensity curve.

The thindown counts were made in small blocks of emulsion whose weights and placement relative to the manned gondola are described in Table 2. The skin monitors strapped to the pilot's arms also exhibited a few thindown tracks, but because of the small volume of emulsion the counts were not adequate for an independent estimate.

3. HEAVY PRIMARY TRAVERSALS

The skin monitor emulsions strapped to the arms of Cdr. Ross during the Stratolab IV flight were developed by the special method described in Appendix B. The method commonly used by cosmic-ray physicists of mounting the emulsion sheet on glass prior to development is not suitable for these biological monitors, as the emulsion sheet is bent to the curvature of the arm and does not adhere well to a plane glass surface. However, if the sheet is developed unsupported,

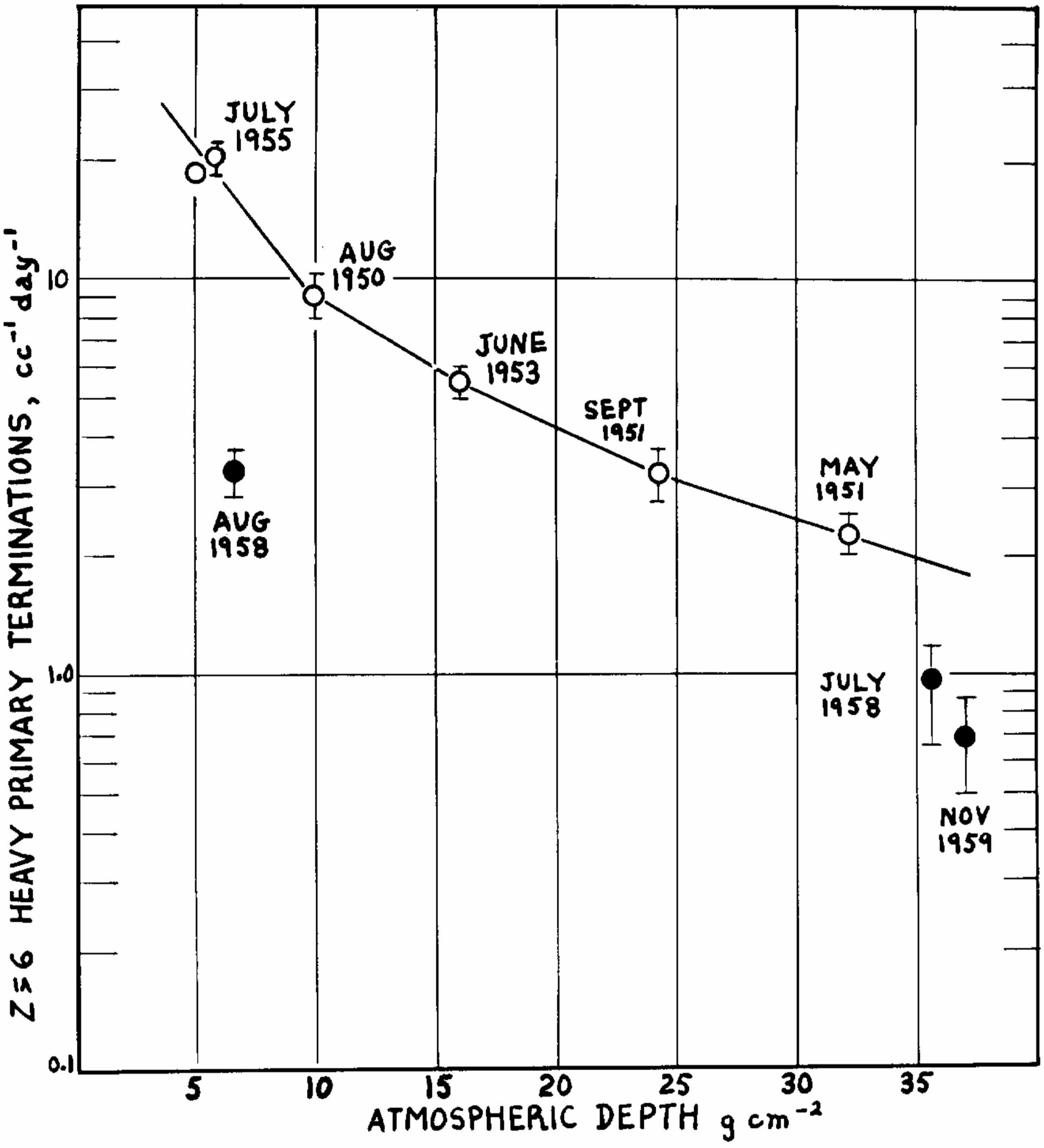

FIG. 6. Comparison of thindown frequencies in emulsions flown in the stratosphere during periods near maximum and minimum sunspot activities, at geomagnetic latitudes of about 55°N.

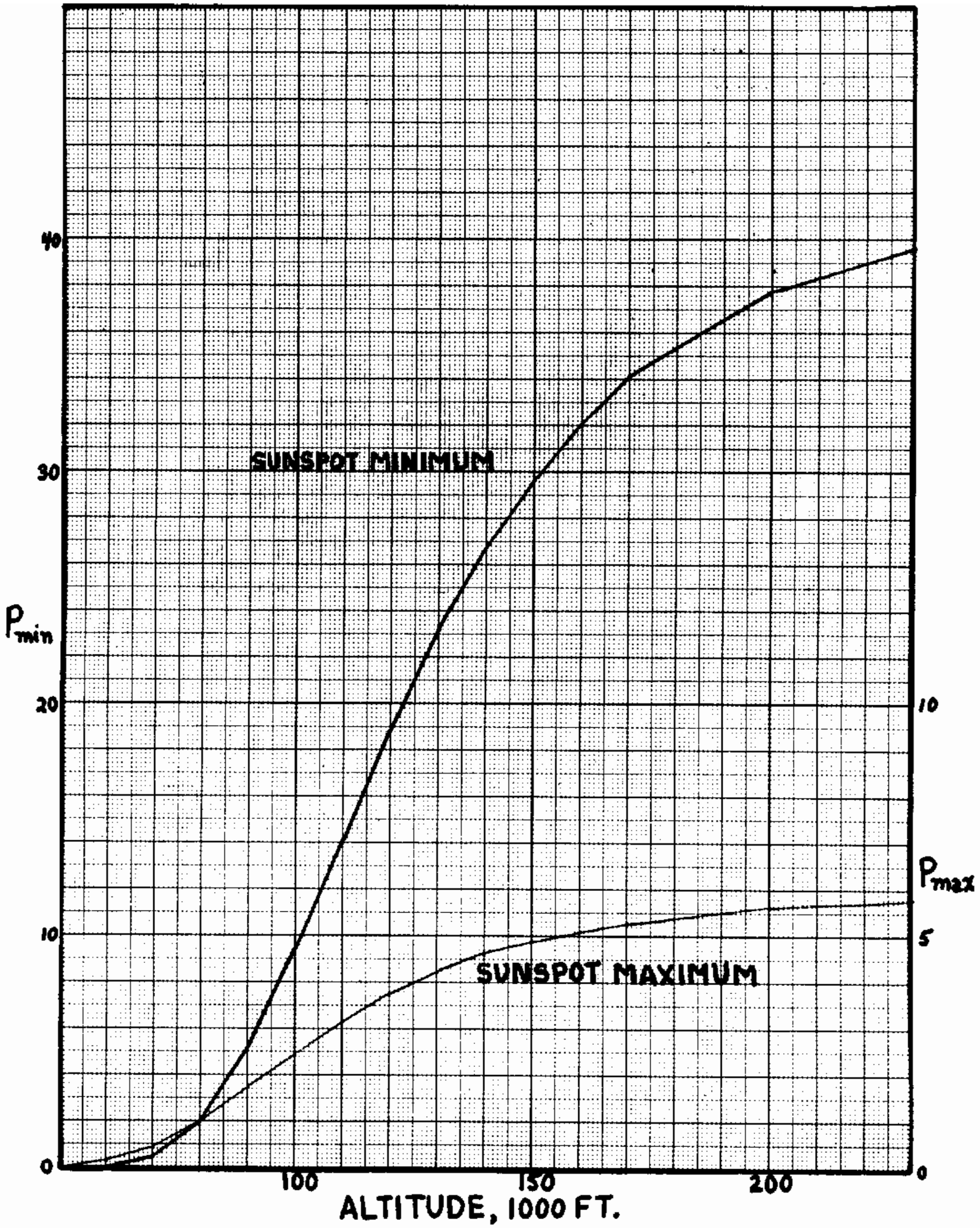

FIG. 7. Variation of thindown intensities with altitude for seasons of maximum and minimum sunspot activity.

Table 1. Flight Characteristics of Manned Balloons.

Flight	Stratolab III	Stratolab IV	Manhigh II
Launching Area	Crosby, Minn.	Stratobowl, So. Dakota	Crosby, Minn.
Date of Launching	26 July 1958	28 Nov 1959	19 Aug 1957
Pilot	M. D. Ross	M. D. Ross	D. G. Simons
Co-pilot	Lee Lewis	C. B. Moore	None
Total flight duration, hours	34.7	28.6	32.0
Hrs. above 60,000 ft	30.3	23.2	29.4
Maximum altitude, ft	81,000	81,000	101,000
Avg. Altitude ≥ 60,000 ft	77,520	75,780	87,000
Avg. atmospheric depth, $g\ cm^{-2}$	35.7	37.1	21.0

Table 2. Emulsion Block Characteristics Exposed on Manned Flights.

Flight	Stratolab III	Stratolab IV	Manhigh II
Location of block	outside gondola	inside gondola	inside gondola
Wt of block, grams	266.2	789.0	466.1
Vol. of block, cc	95.0	208.0	122.7
Area of emulsion sheets, cm^2	56.0	100.0	56.0
Emulsion types, Ilford	G5, K5	G5, K5	G5
Nuclear evaporation rate (Stars cc^{-1} day^{-1})	1569 ± 96	1653 ± 57	1170 ± 42
Stars on skin monitors (cc^{-1} day^{-1})	no count	1710 ± 50	1435 ± 54

as in the recommended procedure, little difficulty is subsequently encountered in mounting the processed gelatin to a permanent glass backing suitable for microscopy.

The developed preparations were examined for the tracks of heavy primary nuclei traversing the 600-micron thick layer of emulsion using 100 x magnification. Only the steep and more highly charged particles were tallied and their positions accurately noted. The plots of these trajectories (shown in Figs. 8 and 9) are a quantitative measure of all particles with nuclear charges $Z \geq 10$. Some tracks of nitrogen and oxygen nuclei are probably included, particularly if their angles of incidence were steep. The circles originally drawn on the cloth protecting the emulsions are reproduced on the emulsion plots and their centers provide an accurate reference point for correlating hair or skin pigmentation changes with the position of heavy primary traversals. In the graphical track plots, the position of the track closest to the skin is designated by a black circle.

In this system of monitoring, it is not practical to differentiate the velocities of the heavy primaries. Also, their absolute sense of direction is not known and some of the heavy particles may have penetrated backwards through the body before recording the tracks mounted on the arms. Only the nonrelativistic particles entering through the upper face of the skin monitors have opportunity to terminate their range within the confines of a hair follicle and thus produce a thindown hit. It is possible, however, that the more highly charged members of the beam with $Z \geq 16$ may deposit sufficient energy in traversing the follicle to cause the destruction of the pigmentation-producing cells even when moving at relativistic velocity.

4. HEAVY PRIMARY THINDOWNS

The experimental counts of the number of heavy primary thindown hits recorded in the emulsion blocks exposed on the Stratolab balloon flights and on Manhigh II are compared in Table 3. Owing to the greater average altitude of the Manhigh II flight, the thindown

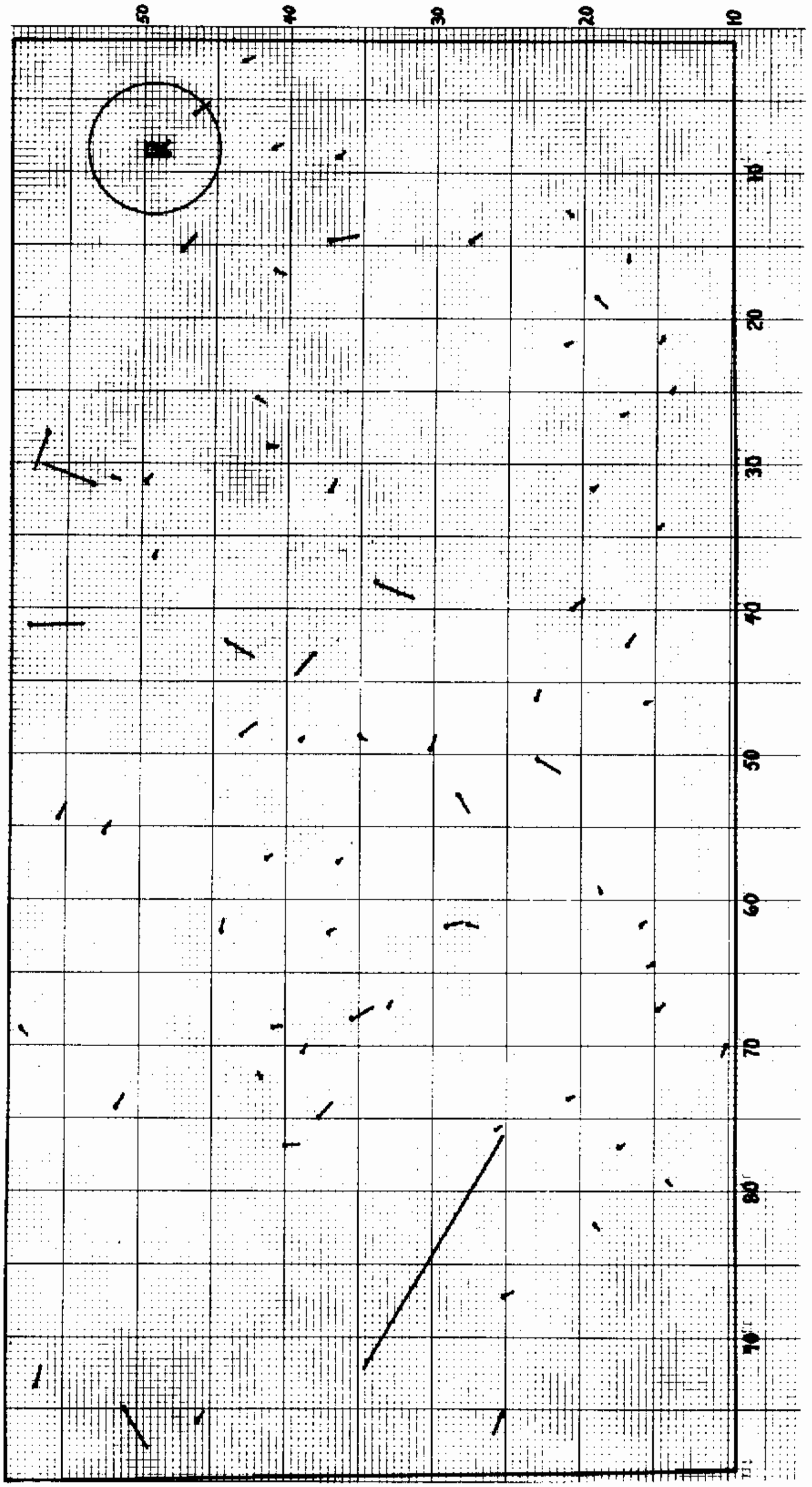

FIG. 8. Plot of positions of heavy primary traversals on Comdr. Ross' right arm.

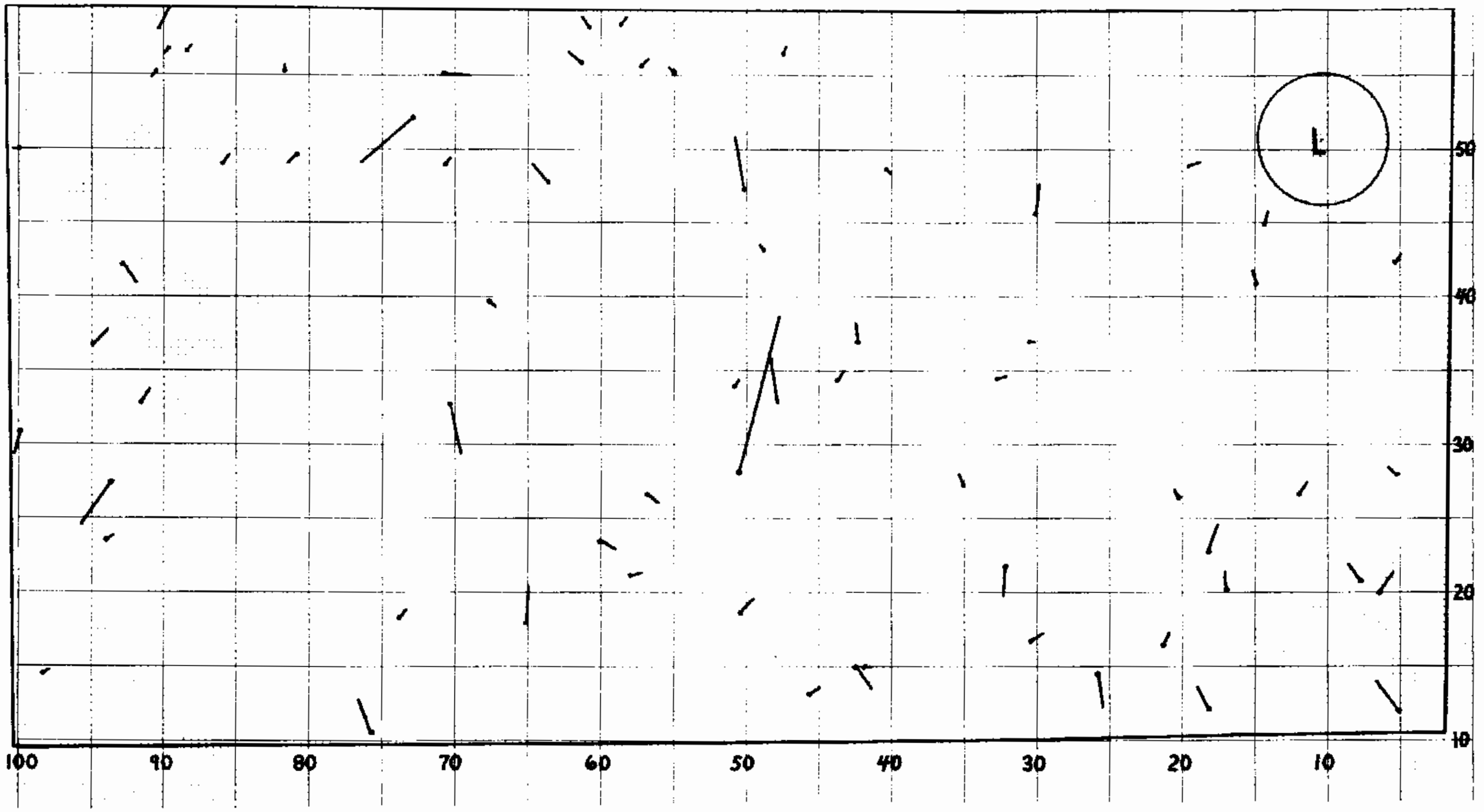

FIG. 9. Plot of positions of heavy primary traversals on Comdr. Ross' left arm.

Table 3. Heavy Primary Thindown Intensities Measured in Emulsions Blocks.

Flight	Stratolab III	Stratolab IV	Manhigh II
Date of Launching	26 July 1958	28 Nov 1959	19 Aug 1957
Avg. atmospheric depth for alt. $\geq$ 60,000 ft,g cm^{-2}	35.7	37.1	21.0
Vol. emulsion sampled, cc	17.3	32.0	8.9
No. of thindown tracks of $Z \geq 6$	21	21	28
Thindown intensity, cc^{-1} day^{-1}	0.96 ± 0.21	0.68 ± 0.19	2.6 ± 0.5
Sunspot numbers for days of flight	213-238	151-161	186-170
Avg. sunspot number for months of flight[7]	191	124	158

frequency is 4 to 3 times as great as on the Stratolab flights. At the time when the cosmic-ray report for Manhigh II was prepared, the effect of sunspot activity on the low energy heavy primary flux was not known and a value of 3.9 thindowns per cubic centimeter of emulsion per day of flight was estimated by interpolation of existing balloon data. The Manhigh II flight occurred during a period of high sunspot activity. Using curve P_{max} of Fig. 7 as a basis of estimating, the thindown frequency yields 1.64 per cc of emulsion per day. This estimate is about 37 percent low as compared with the experimental count in the emulsions of 2.6 ± 0.5 cc^{-1} day^{-1}.

The curves for the thindown variation with altitude shown in Fig. 7 were derived by fitting data from high-altitude balloon flights to Gross transformations of the form:

$$P = P_0 \left\{ e^{-x/k} + \frac{x}{k} \, Ei(-x/k) \right\} \qquad (1)$$

where P_0 represents the thindown intensity at the top of the atmosphere and $Ei(-x/k)$ is an exponential integral which allows for the opening up of the effective solid angle as the atmospheric depth x diminishes. The constant k is of the nature of an attenuation mean free path which attempts to describe the combined effects of collision loss and stoppage by ionization in the atmosphere. The magnitude of k is derived as a "best fit" to experimental data and the present study indicates that its magnitude varies with the sunspot cycle. If these preliminary observations are confirmed on future balloon exposures, the variation of k suggests that the flux not only varies in intensity but that the charge spectrum at low energies is also influenced by the solar cycle.

In view of the numerous factors which complicate the evaluation of the thindown intensity it is always best to determine this quantity by direct count per unit volume of emulsion. The scanning for thindown tracks, however, is a difficult, time-consuming procedure and the smoothed functions of Fig. 7 permit a rapid evaluation of this parameter from a knowledge of the time-altitude profile. The thindown intensities for times near solar maximum and minimum sunspot activity are expressed by:

$$P_{max} = 5.87 \{e^{-x/32} + \frac{x}{32} \mathrm{Ei}(-x/32)\} \qquad (2)$$

$$P_{min} = 40.6 \{e^{-x/16} + \frac{x}{16} \mathrm{Ei}(-x/16)\} \qquad (3)$$

These equations indicate a seven-fold reduction in thindown intensity at the top of the atmosphere during periods of maximum sunspot activity. This natural amelioration of the cosmic-ray hazard should be taken into consideration in plans for manned exploration of the moon and the planets.

ACKNOWLEDGMENT

Opportunity is taken to thank Commander M. D. Ross, USN, for the emulsion exposures on Stratolab flights III and IV. The thindown intensities were measured by Mr. Robert Filz. Observations of star frequency were made by Mr. K. Fukui, Mrs. D. Nastasi and Miss M. Higgins.

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APPENDIX A

SKIN MONITOR PREPARATION

The emulsion units worn by Lt. McClure and Cdr. Ross represent an improvement in design over those mounted on Col. Simons' arms. On the Manhigh II flight some sweat penetrated the flexible protective housing, causing adhesion of about 10 percent of the emulsion surface to the black paper wrapping. This difficulty did not occur on the Manhigh III flight, despite the excessively high body temperature of the pilot, owing to the incorporation of a layer of polyethylene sheeting between the emulsion and the black paper. This additional water proofing did not increase the bulk or rigidity of the monitor appreciably, and on post-flight questioning the pilots stated that the units did not cause discomfort or interfere with their operations during the flight. Since these special skin-monitoring devices may prove of utility on other manned flights near or above the top of the atmosphere a complete description of their construction follows:

a. Ilford G 5 unsupported emulsion sheets 600 microns thick are cut into rectangular pieces measuring 5 x 10 cm. In order to secure adequate pliability, the sheets should be maintained at 60 to 70 percent relative humidity for 1 or 2 hours. This does not reduce sensitivity appreciably, but permits fitting the final preparation to the contour of the arms and chest.

b. The emulsion is placed with its dull side uppermost between two sheets of thin polyethylene sheeting and covered with sheets of thin light-tight paper. The edges are rendered light-tight by sealing the periphery with a band of 10 mm wide black nylon adhesive tape. The unit is then wrapped in a sheet of waterproof "Parafilm" measuring 11 x 12 cm, overlapping and sealing the edges with cellulose adhesive tape. To prevent tearing of the thin "Parafilm" material, it is covered with a strip of white surgical adhesive plaster 5 x 20 cm. All identification and orientation marks are inscribed on the surgical tape surface.

c. A particularly useful orientation mark is to inscribe a circle 10 mm in diameter near a corner of the preparation. The compass needle should be pressed into the emulsion layer so as to produce a mechanical latent image. The large external circle defines the internal position of this point and is more readily visible on photographs of the preparation mounted on the body. The units for the right and left arm should be identified by an "R" and "L" mark, respectively.

d. The skin monitors should be placed on a relatively flat portion of the arm and oriented so that the edges are defined by characteristic skin pigmentation marks or by applied tattoo points. These serve to define the corresponding coordinate of the inscribed circle with reference to the skin.

e. The monitor is then fitted to the arm contour with the aid of two or three bands of 1-inch wide adhesive tape. The final tension should be applied by the pilot so as to feel comfortable and not to interfere with circulation of the blood. The rubberized sleeve of the pressure suit worn by the pilot is largely instrumental in keeping the monitor in place. The arms should be photographed before and after flight and the region under and adjoining the monitor should be carefully inspected, prior to flight, for the presence of background graying hair.

f. After flight termination and removal of the pressure suit, the skin monitor preparations are usually bathed in sweat. After removal they should be blotted between absorbent paper and allowed to "air dry" before being opened in the darkroom. Prior to development, appropriate identification marks should be inscribed on the emulsion proper. As is well known, pencil inscription marks on the upper emulsion surface make permanent markings on development.

g. The processed emulsion is examined microscopically for the characteristic tracks of heavy primaries, and the coordinates of the points where the tracks enter and leave the emulsion layer are plotted on graph paper. The distance between the two points represents the horizontal projection of the track and is proportional to the obliquity of the incident heavy particles. The steep tracks are most suited for correlation with changes in hair or skin pigmentation.

APPENDIX B

DEVELOPMENT OF 600-MICRON UNSUPPORTED EMULSIONS

CAUTIONS: All trays and glassware should be washed with water prior to use even if they appear clean. Use distilled water for preparing solutions. Lower 1-mm thick filter paper mats (C.S.S No. 470 Keene, New Hampshire) into solution slowly to displace all air bubbles prior to the immersion of the emulsion layers.

STAGE I: Fill tray with about 1 liter of distilled water. Insert mat. Deposit first layer of emulsion; cover with mat. Repeat until no more than four layers of 600-micron emulsion are contained per tray. Keep in refrigerator at 5°C for one hour.

STAGE II: Prepare 1 liter of developer per tray of following composition:

Amidol	2.0 grams
Sodium Sulfite, Na_2SO_3	10.0 grams
Potassium Bromide, K Br	0.6 grams
Distilled Water to 1 Liter	

Dissolve ingredients in about 100 cc water at 25°C. Filter into flask with liter mark, and dilute with water at 5°C. Chill to 5°C before use. Transfer emulsions to fresh trays and keep in developer solutions for one hour between filter paper mats.

STAGE III: Ionic environment hot stage - Composition per liter:

Sodium sulfate anhy., Na_2SO_4	50.0 grams
Sodium sulfite, Na_2SO_3	10.0 grams
Potassium Bromide, K Br	0.6 grams

Adjust to temperature of 15°C, then place solution in large plastic tank. Remove pellicles from Tray II, rinse in a separate dish of ionic environment, and place in plastic tank between mats. Maintain at 15°-18°C for 30 minutes.

STAGE IV: Transfer to trays containing 5 cc of glacial acetic acid per liter at 5°C for one hour.

STAGE V: Prepare solution of equal volumes of sodium thiosulfate (hypo) and water.

Composition of Hypo Stock:

Sodium Thiosulfate, C. P.	5 lbs
Sodium Sulfite, Na_2SO_3	24 grams

Dilute to 4 liters and chill to 5°C

Keep emulsions in this diluted bath until clear (1 or 2 days at 5°C).

STAGE VI: Transfer clear pellicles to 10 percent ammonium sulfate at 5°C in a temporary rinse dish. Transfer to trays of 10 percent ammonium sulfate and maintain for two hours at 5°C.

STAGE VII: Rinse emulsions in 5 percent ammonium sulfate and replace in trays for two hours. Repeat these 2-hour washes three times.

STAGE VIII: Aqueous Thiourea bath of following composition per liter:

Thiourea	10 grams
Citric Acid	10 grams
Ammonium acetate	30 grams

The ammonium acetate is added volumetrically from a stock solution made by dissolving 1 lb of solid ammonium acetate in 2 liters of distilled water.

132 cc of stock solution is equivalent to 30 grams of ammonium acetate.

Rinse emulsions in a portion of solution VIII and transfer to trays for two hours.

STAGE IX: Alcoholic thiourea of following composition per liter:

Thiourea	5 grams
Citric Acid	5 grams

66 cc of ammonium acetate stock

300 cc absolute alcohol

Dilute with water to 1 liter and chill to 5°C

Rinse emulsions in Stage IX and keep in trays at 5°C overnight.

STAGE X: Fill two cylindrical dishes with about 500 cc of 35 percent alcohol. Transfer emulsions to one dish, agitate momentarily, and then transfer emulsion sheets to the second dish. Repeat this operation for 15 minutes.

STAGE XI: Transfer emulsions to tray of 50 percent alcohol at 5°C and keep in refrigerator for three hours.

STAGE XII: Rinse emulsions in cylindrical dishes containing 60 percent alcohol for 15 minutes.

STAGE XIII: Transfer emulsions to tray of 70 percent alcohol at 5°C and keep in refrigerator for three hours.

STAGE XIV: Dissolve 50 cc of glycerine in absolute alcohol; chill to 5°C. Transfer emulsions to solution and leave trays at room temperature overnight.

STAGE XV: Clean both sides of each emulsion sheet with cotton moistened with absolute alcohol. Support emulsion on filter paper mat moistened with absolute alcohol during the cleaning operation.

STAGE XVI: Place sheets vertically in racks and allow to dry on edge in a room kept at 50 percent relative humidity. When thoroughly dry, the sheets become transparent.

STAGE XVII: Prepare solution composed of:

Alcohol	200 cc
Glycerine	50 cc
Distilled Water	750 cc
10 percent Aerosol	5 drops

When solution is at room temperature, immerse the dry processed gelatin sheet (only one at a time) and allow it to expand to its original emulsion size as indicated by fiducial marks. Transfer the gelatin sheets to a polyethylene slab with fiducial markings upright.

Remove globs of solution from upper surface by means of filter paper slightly moistened with Solution XVII. Transfer gelatin sheet to glass plates (Ilford treated glass) taking care to avoid inclusion of air bubbles.

Using a small camel's hair brush apply a film of gelatin solution along the edges where the emulsion makes contact with the glass. This gelatin solution is prepared as follows:

Add 1.5 grams of gelatin to 50 cc of distilled water and 2 drops of Aerosol wetting agent. Allow gelatin to imbibe water for one hour at room temperature. Heat to 60°C and when gelatin is dissolved cool to 25°C.

STAGE XVIII: Place glass mountings in drying box horizontally and allow to dry at relative humidity of 50 percent.

STAGE XIX: Clean dry gelatin with cotton moistened with equal volumes of xylol and absolute alcohol. Any adhering linters should be removed by pressing down and peeling off a strip of scotch tape.

Dip clean plate in a lacquer composed of 1 part of Duco cement and 2 volumes of acetone. Drain off excess fluid, support glass plate horizontally on three thumbtacks of equal height, and cover with evaporating dish whose inner walls are moistened with acetone. The film dries in about one hour and the preparation can then be examined with dry objectives. Oil immersion objectives can be employed after the lacquer film has hardened for one day.