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No. 54

RADIATION STUDIES FROM NUCLEAR EMULSIONS AND METALLIC COMPONENTS RECOVERED FROM POLAR SATELLITE ORBITS

Herman Yagoda

March 1961

GEOPHYSICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
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ABSTRACT

Two blocks of Ilford G5 emulsion measuring 10 x 15 cm and each weighing 772 ± 2 grams have been recovered from polar satellite orbits. The one launched on Discoverer XVII was exposed to the intense solar radiation associated with the 3+ flare of 12 November 1960. By means of a special developing technique conducted at pH 6.50, which resulted in a 30-fold reduction in grain growth, it was possible to suppress the intense background of solar protons and discern the tracks of very highly charged heavy primary nuclei that stopped by ionization in the emulsion. The frequency of this category of particles with charges $Z \geqslant 11$ is estimated at 13 ± 3 cc^{-1} day^{-1}. A similar measurement on the Discoverer XVIII emulsions, which were placed in orbit on 7 December 1960 during a period of relatively normal solar activity, yielded a termination rate for nuclei with charges $Z \geqslant 6$ of 8.65 ± 0.93 cc^{-1} day^{-1}. These measurements indicate that the flux of the heaviest galactic primaries remained essentially unaltered during the giant solar flare. Examination of the flare-irradiated emulsions at very high magnification shows the presence of a much larger flux of nuclei which appear to be of charge $Z = 6 \pm 2$ on the basis of tentative ionization-range identifications. A comparison of the Discoverer XVIII emulsion measurements with data from a balloon flight at 140,000 ft elevation, launched at Minnesota on 29 July 1960 and which recorded 7.8 ± 1.2 heavy primary terminating tracks cc^{-1} day^{-1}, indicates that the flux of slow heavy primaries does not increase appreciably while the satellite is orbiting over the polar regions during quiescent solar conditions.

Preliminary estimates of star production in the Discoverer XVIII emulsions show that nuclear disintegrations with three or more associated tracks accumulate with a frequency of about 6700 ± 500 cc^{-1} day^{-1}. This is about twice as large as can be anticipated from counter data and emulsions flown in rockets from sites whose geomagnetic latitudes extended between the equator and the polar regions. The slope of the integral star prong spectrum indicates a component of low-energy star-producing radiation which probably originates in the fringes of the lower Van Allen belt that the satellite grazed during apogee.

The aluminum, iron, and lead inside the satellite capsules are being analyzed by radiochemical techniques for long-lived radioactive spallation products. Preliminary reports from the Harvard Astrophysical Observatory, the Brookhaven National Laboratory and the Enrico Fermi Institute, where these studies are being conducted, indicate greatly increased yields of radionucleides in the metallic components of the satellite capsule exposed to the flare as compared with iron and stone meteorites. The yield of tritium is particularly high and the ratio of H^3/Ar^{37} observed suggests that primary tritium nuclei may be accelerated during the 3+ solar flare.

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RADIATION STUDIES FROM NUCLEAR EMULSIONS AND METALLIC COMPONENTS RECOVERED FROM POLAR SATELLITE ORBITS

1. INTRODUCTION

Blocks of Ilford G5 emulsion measuring 10 x 15 x 1.3 cm containing 772 grams of sensitive material have been flown into polar orbits by means of the Discoverer recoverable satellite. Two of these units have been retrieved in excellent condition as a result of successful air-catches of the ejected instrument capsule. Data on the orbiting characteristics of these vehicles are summarized in Table 1. The first exposure secured on Discoverer XVII proved of exceptional interest because the vehicle was launched shortly after the occurrence of a large solar flare (Class 3+) when the radiation level above the atmosphere was several thousand times greater than the normal cosmic-ray background. As a consequence of this intense irradiation in the initial stages of the exposure, the emulsions appear to have lost their electron sensitivity; and, by severe underdevelopment, it was possible to discern the tracks of multiply-charged particles, particularly when moving at low velocities, when their rates of energy loss are very high. The special methods of photographic processing are described in Section 3.

As a result of the large radiation dosage originating from the solar flare, macroscopic quantities of spallation products could be isolated from the metallic components of the satellite capsule by utilizing techniques identical with those employed in the analysis of meteorites. These measurements were made by Dr. E. Fireman and co-workers at the Smithsonian Astrophysical Observatory. Additional radiochemical measurements were made by Dr. O. A. Schaeffer, C. R. W. Stoenner and R. Davis of the Brookhaven National Laboratory and Dr. A. Turkevich of the Enrico Fermi Institute. A brief summary of these observations is presented in Section 5.

One of the main advantages of an exposure in a polar-orbiting satellite is that the vehicle provides a trans-atmospheric exposure which

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(Author's manuscript approved 13 March 1961)

TABLE 1. Orbital Parameters of Discoverer Satellites

Vehicle:	Discoverer XVII	Discoverer XVIII
Launched	2042 UT 12 Nov 1960	2020 UT 7 Dec 1960
Recovered	2230 UT 14 Nov 1960	2300 UT 10 Dec 1960
Number of Orbits	31	48
Orbiting period, minutes	96.44	93.67
Apogee, km	993 ± 4	638 ± 23
Perigee, km	188 ± 3	239 ± 6
Total time in orbit	2.075 days	3.124 days
Time spent $\geqslant 50°$ N geographic latitude	0.908 days	1.367 days
Time spent $\geqslant 55°$ geomagnetic latitude	0.766 days	1.217 days
Latitude of Apogee	20° S	20° S
Latitude of Perigee	18° N	15° N

surveys cosmic-ray intensities over all geomagnetic latitudes and tends to average out all longitudinal asymmetries if a sufficiently large number of orbits are executed prior to re-entry. A map showing the regions sampled during the first 16 orbits of Discoverer XVII is shown in Fig. 1. Owing to the continuous sensitivity of the emulsion, the medium provides an integrated average of these complex geomagnetic variations. Nevertheless, by comparing some average parameter (such as star formation or the frequency of terminating heavy primary tracks with a series of point values secured by balloons or vertical rocket probes) it is possible to note large deviations from the norm which thereby indicate an anomalous intensity somewhere along the orbit. The average values secured by the emulsion recordings are of interest *per se* in such fields as the evaluation of the radiation hazards of manned flight near the top of the atmosphere and in problems associated with the estimation of the total cosmic-ray energy influx into the atmosphere. Since the geographic position and the magnitude of apogee and perigee vary with different satellite launchings, a comparison of the results of these integrated exposures provide additional information for estimating geophysical asymmetries.

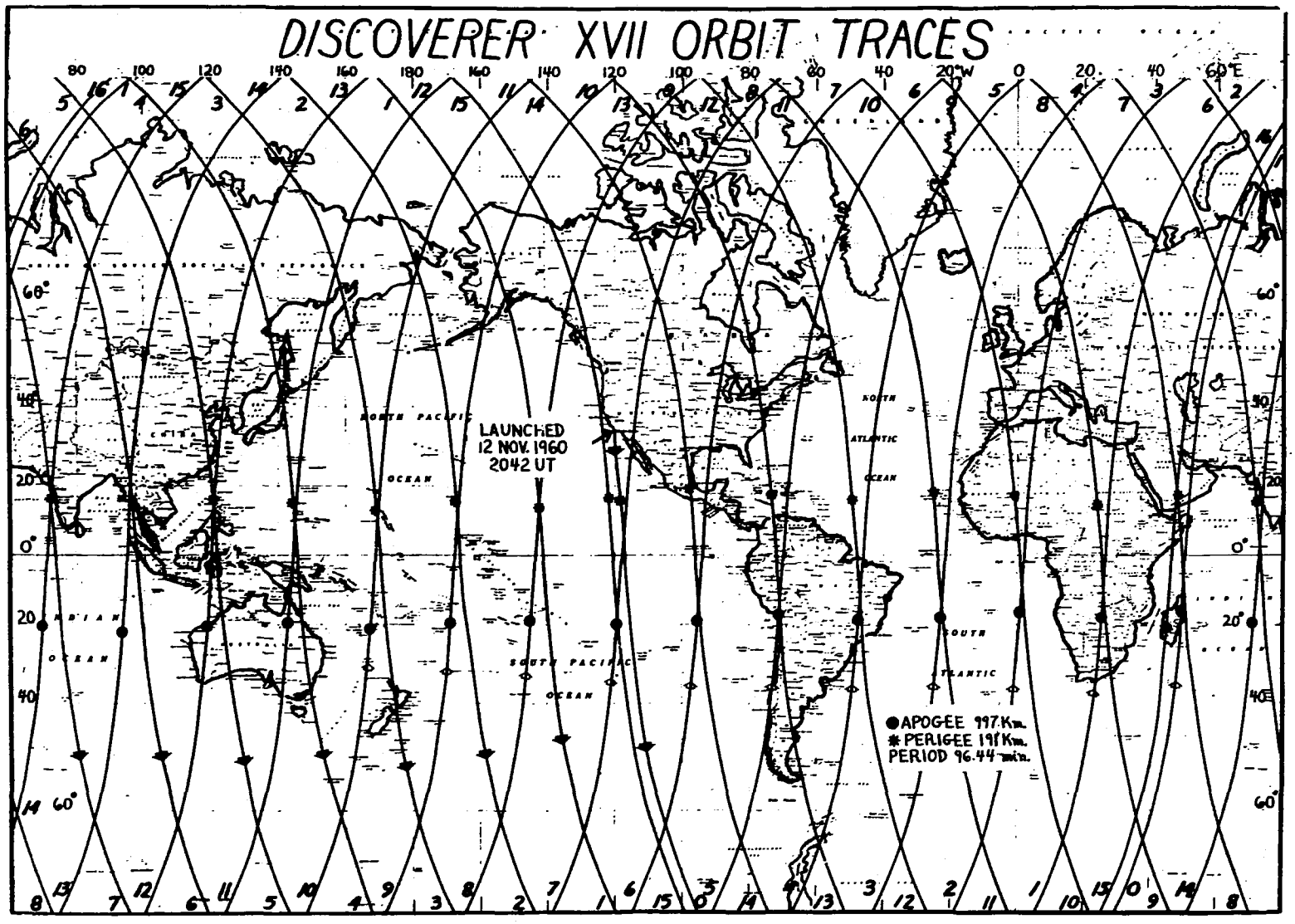

FIG. 1 Map showing the first 16 orbits executed by the Discoverer XVII satellite. (Courtesy of the Lockheed Tracking Group.)

By locating the emulsion block adjacent to a thin window, an opportunity is offered to study new components of the cosmic radiation possessing large collision cross-sections such as the anti-proton or conceivably heavier anti-nuclei which are ordinarily removed from the flux by interactions in the upper layers of the atmosphere. In the present experiments the minimum absorber paths in condensed matter were 2.2 g cm^{-2}, and the windows in front of the emulsion blocks subtended frontal solid angles of approximately 3.0 and 6.2 steradians in Discoverer XVII and XVIII, respectively.

The intense radiations of the trapped radiation belts severely limits the utility of satellite emulsion-block exposures. The lower Van Allen belt in equatorial regions starts with an appreciable intensity at an elevation of about 600 km. Satellite orbits whose apogees exceed this lower boundary will expose the emulsions to high fluxes of trapped protons whose intensity is roughly doubled with each additional 100-km increment in altitude. Owing to the 993-km apogee of Discoverer XVII, even in the absence of the concomitant solar flare, it is estimated that 25×10^6 proton tracks per cm^2 would record while the satellite was at elevations $\geqslant$ 900 km. This estimate of the Van Allen track contribution, based on emulsion studies with Thor [1] and Atlas rockets, [2] is about 140 times greater than the anticipated track background from primary galactic cosmic radiation.

By placing the satellite in a nearly circular orbit with an apogee $\leqslant$ 600 km and limiting the orbiting time to less than 3 days, excessive blackening of the emulsion block can be avoided. This ideal situation was almost realized on Discoverer XVIII whose apogee was 638 ± 23 km and which spent 3.124 days in orbit.

2. THE FLARE OF 12 NOVEMBER 1960 IN RELATION TO THE DISCOVERER XVII EXPOSURE

On 12 November 1960 a bright area on the sun at heliographic latitude 27°N reached a great intensity in H alpha radiation at 1325 UT with maximum intensity at 1330 UT. A photograph of this flare area taken at Sacramento Peak Observatory at 1437 UT is shown in Fig. 2. Neutron monitors registered a slow increase in counting rate at 1340 UT, reached a peak in about 2.5 hours, and then decreased until

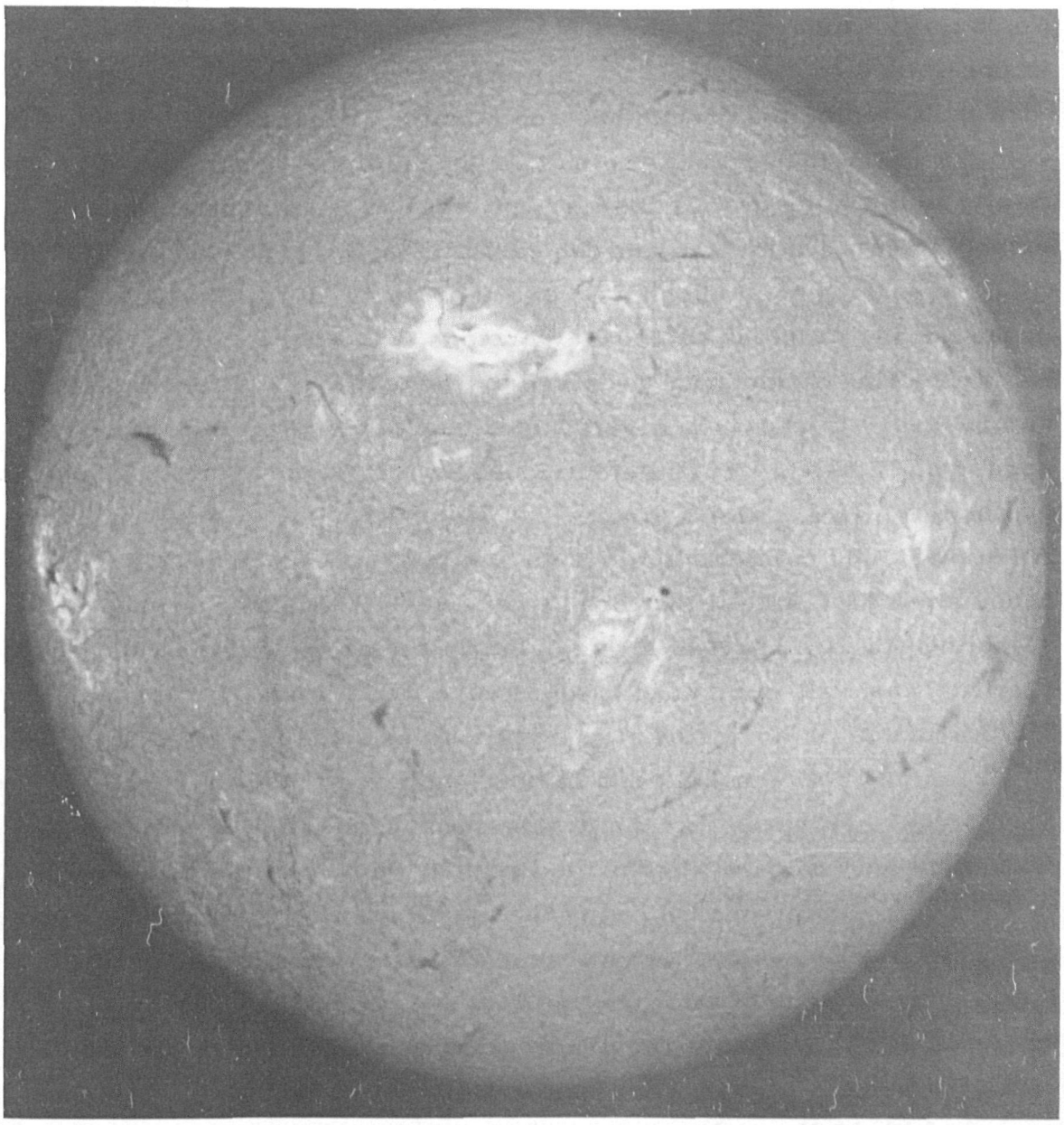

FIG. 2 Photograph of sun showing the flare area on 12 November 1960 taken at the Sacramento Peak Observatory.

a sudden rise occurred about 1900 UT and reached its maximum intensity at 2005 UT (t_{max}).

The Discoverer XVII was launched from Vandenberg Air Force Base, California at 2042 UT and, as shown in Fig. 3, was above the sensible atmosphere at about 2045 UT. On the basis of t_{max} = 2005 the satellite missed the peak of the cosmic storm by 40 minutes. It is possible, however, that t_{max} at high altitudes may be greater than indicated by the ground neutron monitors because of the smaller velocity of the low-energy proton component and their greater difficulty in diffusing across the lines of force in the magnetic bottle extending between the sun and the earth. The spread in the arrival time, according to Simpson,[3] is of the order of 10 to 15 minutes even in the energy range of 1 to 10 Bev protons.

The flux of radiation received by the satellite between launching and recovery is shown in Fig. 4 based on Geiger counter data recorded on Explorer VII and emulsions flown in balloons at atmospheric depths between 3.9 and 6.0 g cm^{-2}. The reading at 2330 UT by Van Allen of 21,000 particles cm^{-2} sec^{-1}, when the Explorer VII and Discoverer XVII satellites were at very nearly equal elevations and sampling the same part of space, clearly indicates that the recovered satellite was still immersed in an intense radiation field at about 3 1/2 hours after launching. In emulsions exposed in a balloon on 12 November between 2130 and 2320 UT at 5.3 g cm^{-2} pressure, E. P. Ney[5] estimates that the dose corresponded to 0.85 R per hour.

The smooth curve in Fig. 4 was constructed on the assumption that the flux diminishes following the maximum inversely as the square of the time as shown by Dorman[6] and Winckler[7] in the case of other 3+ flares. Integration of this function between time of launch and recovery suggests that the capsule received a total bombardment of 2×10^9 particles per cm^2. Van Allen[4] estimates that during the perturbed period of 12-16 November, at a geographic latitude of about 48°N at 1000 km altitude over North America, the integrated omnidirectional intensity of protons (E > 30 Mev) and alpha particles (E > 120 Mev) exceeded 10^9 per cm^2.

In evaluating the probable dosage received by the Discoverer XVII

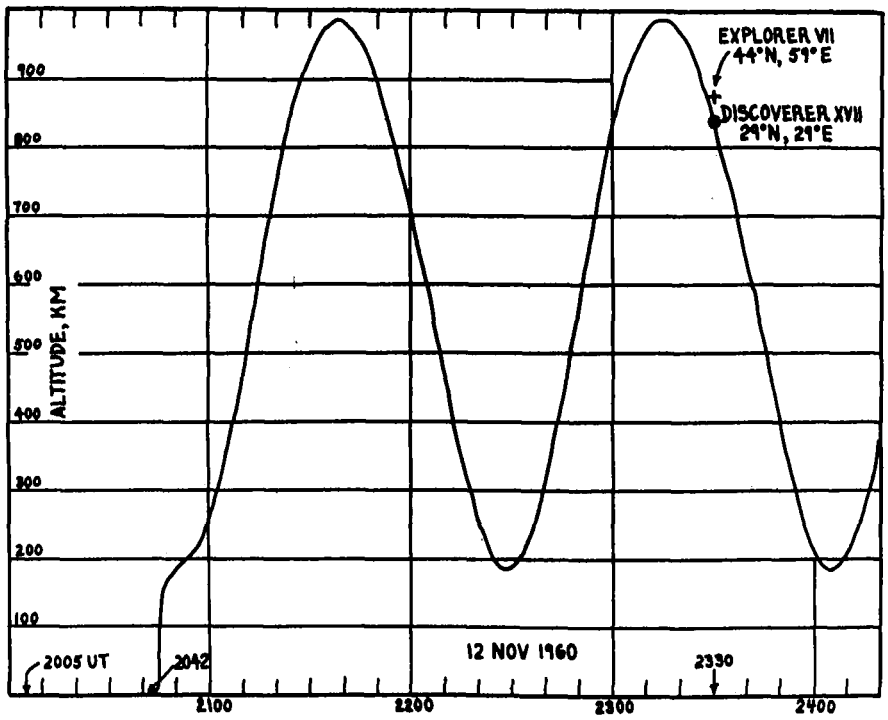

FIG. 3 Altitude profile of the Discoverer XVII satellite as a function of universal time for the first two orbits.

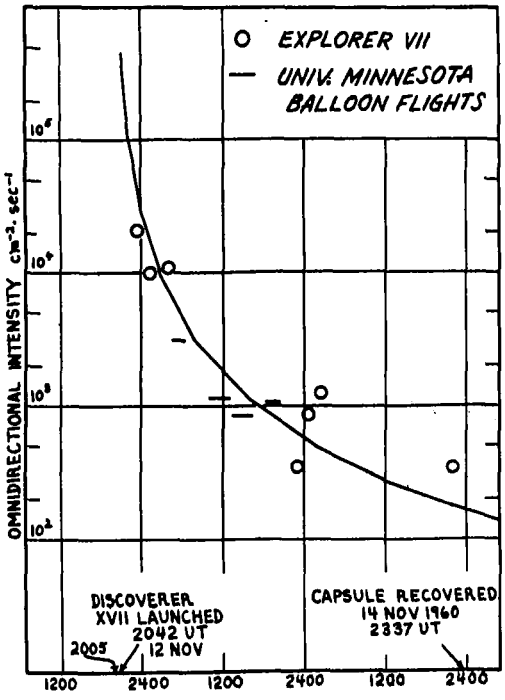

FIG. 4 Radiation flux incident on the Discoverer XVII satellite as a function of time between launching and recovery of the capsule.

satellite an observation reported by Pomerantz[8] is pertinent. Comparing neutron-counter monitors located at Thule, Greenland and McMurdo Base, Antarctica, shows that the counting rate near the South Pole exceeded that at the North Pole by 3 percent. This asymmetry was doubtless of greater magnitude above the atmosphere. Since the satellite sampled both polar regions, dosages based on northern hemisphere observations may be underestimated.

3. PHOTOGRAPHIC PROCESSING OF SATELLITE EXPOSED EMULSION

Owing to the high track densities encountered in long duration satellite exposures, it is not possible to use conventional development techniques. These procedures aim at high grain densities such that even singly-charged relativistic particles at the minimum of ionization are outlined by a grain density of 20 ± 5 grains per 100 microns. By altering the concentration of the active amidol developing agent and proper control of temperature and pH of the solution, it is possible to delineate the track of a given ionizing particle with a greatly reduced grain density, particularly along that portion of its trajectory where it is moving at its highest velocity. Thus, by sacrifice of information on fast singly-charged particles, it is possible to secure quantitative information on slow singly-charged particles and fast multiply-charged nuclei when the over-all track population is very high.

The composition of the developer solutions used in the processing of 600-micron-thick emulsions from the Discoverer satellites is shown in Table 2. For comparative purposes an isothermal procedure for processing emulsions exposed in the stratosphere for 14 hours is included. The component emulsion layers are processed unsupported by glass so that they are free to swell and the solutions have access to both faces. After fixation and washing, the sheets are restored to their original size by dehydration in a graded series of alcohol solutions, as described in earlier publications.[9, 10, 11]

As an index of the strength of development secured by these novel methods a count is made of single silver grains or blobs per unit volume of emulsion. For this purpose a control emulsion is used which accompanies the main block to the satellite-launching base and whose main

TABLE 2. Composition of Developing Solutions

Exposure	XVII	XVIII	Balloons
Amidol, grams	0.5	1.0	1.0
Sodium Sulfite, Na_2SO_3	2.5	4.5	5.0
Sodium Bisulfite, $NaHSO_3$	2.5	0.5	none
Potassium Bromide, KBr	2.0	0.5	none
Water	1 liter	1 liter	1 liter
pH of Developer	6.50	7.15	7.40
Water Pre-soak, hours	2.0	1.5	1.0
Water Temperature	5°-1°C	5°-1°C	5°C
Developer Temperature	1°-5°C	1°-5°C	5°C
Time at 1°C, hours	1	1	none
Time at 5°C, hours	2	4	16
Single grains, cc^{-1}			
In Control Emulsion*	20×10^6	320×10^6	600×10^6

*The control emulsions accompany the main block to and from the launching grounds but are not flown in the vehicle.

purpose is to serve as a correction for star production during aeroplane flights from and to the laboratory. As shown in Table 2 the grain concentrations indicate that the emulsions exposed on Discoverer XVIII were underdeveloped 2-fold as compared with the normal balloon plate developing procedure. Figure 5 shows the track structures resulting from this procedure. Although the trajectories are densely crowded, it is possible to follow individual proton tracks with oil immersion objectives for 13 minutes from the end of their range, at which point the 62 Mev particles produce a grain density of 55 grains per 100 microns. The tracks of very heavy nuclei are readily discerned against the dense proton track background at moderate magnifications.

Measurements of the single grain background in the control plate accompanying the Discoverer XVII emulsion block indicate that it was underdeveloped 30-fold as compared with the normal processing procedure. It is doubtful whether this represents a quantitative index for the satellite-exposed emulsions which were developed simultaneously.

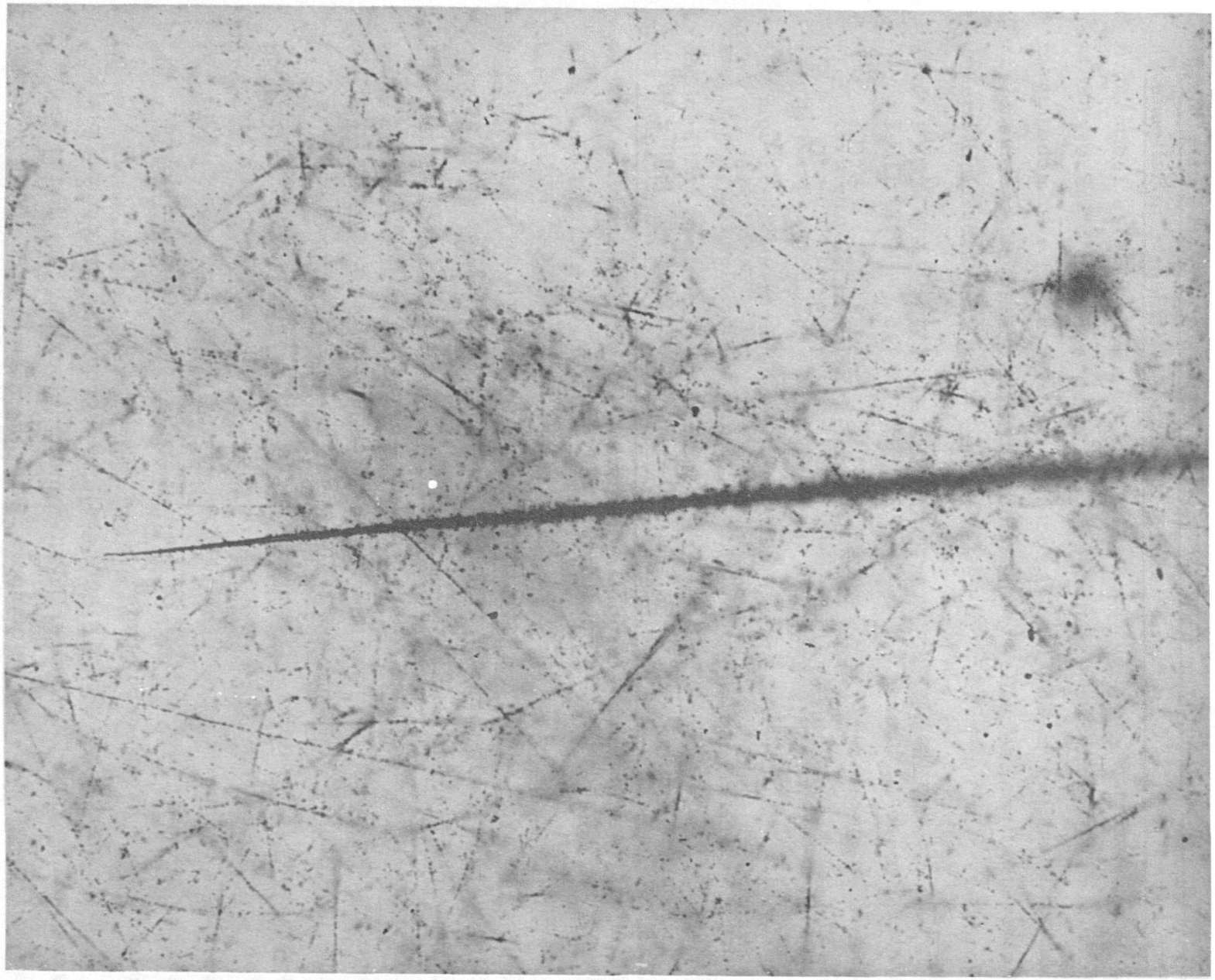

FIG. 5 Photomicrograph of track structures in the Discoverer XVIII emulsion block. While underdeveloped, particles of high linear energy transfer produce tracks of essentially the same characteristics as in fully developed Ilford G5 emulsions.

As indicated in Section 2 the intense radiation exposure during the early stages of the flare greatly reduced the primary sensitivity of the recording medium. While the non-irradiated control shows distinct tracks of protons and alpha particles, there is no evidence of similar structures on the orbited emulsions.* As shown in Fig. 6 the emulsions flown through the solar flare show a dense background of random grains, estimated at $2.5 \times 10^{10} cc^{-1}$. These silver grains were formed, despite the exceedingly low development potential, because of multiple hits received by the larger sized or more sensitive silver bromide grains. Slow multiply-charged particles of high linear energy transfer record solid tracks readily visible despite the heavy background. When these enter the block at small angles to the emulsion plane, the track can be followed for several millimeters. When they stop by ionization, the tapering of the track width is evident (Fig. 7); this is a property characteristic of very highly charged particles as they approach the end of their range.

Assuming that the track shown in Fig. 7 has a charge of 16 ± 3, as is indicated by observations on the track profile in the thindown region, then its grain density of 1360 grains per millimeter at 6 mm of range indicates that a proton of 1-mm range would be delineated by only 25 grains. This extrapolated trajectory is too tenuous to be discerned as a track under the prevailing background. However, it is reasonable to assume that the random background of 2.5×10^{10} single grains per cc originated from a multiplicity of such phantom proton tracks. If this interpretation is correct, between 0.5 to 0.8 Mev are required to produce a background grain. This energy absorption

*Prior to development, marked areas on the control and one of the Discoverer XVII emulsions were exposed to 5 Mev alpha particles from a polonium source. The tracks could be discerned clearly in the fog-free control, delineated by 80 grains per 100 microns. Similar structures could not be recognized unambiguously in the flare-irradiated sample, although occasionally clusters of 4 to 5 grains extending for 15 microns would appear in linear array among the high background of random grains. Since these experimental latent images were developed without an intervening fading period, it seems certain that alpha particles did not record resolvable tracks in the Discoverer XVII block.

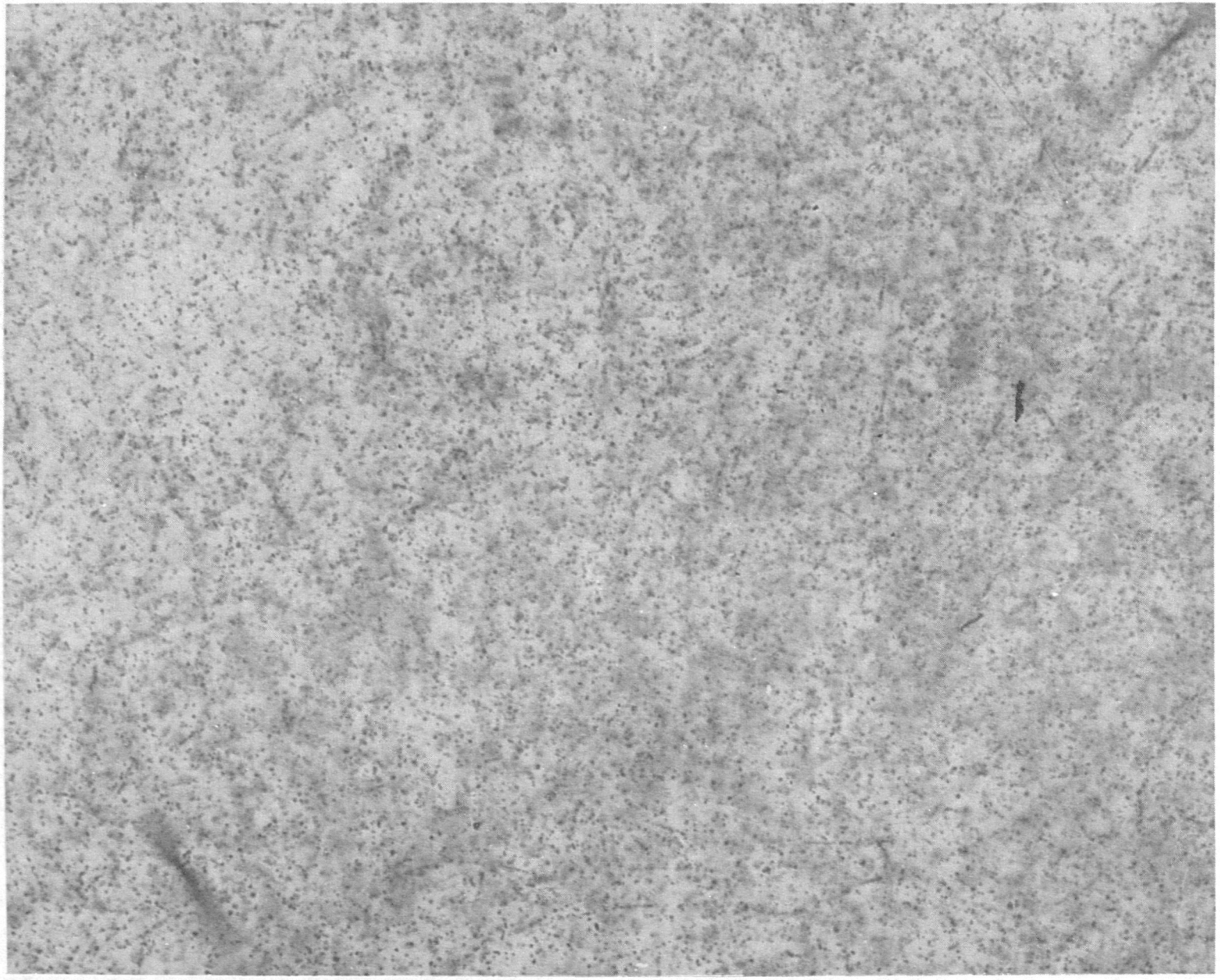

FIG. 6 Photomicrograph showing dense single grain background in the Discoverer XVII emulsions irradiated by the solar flare protons. Despite the noise, the tracks of two steep heavy nuclei are readily evident in the upper right-hand and lower left-hand corners.

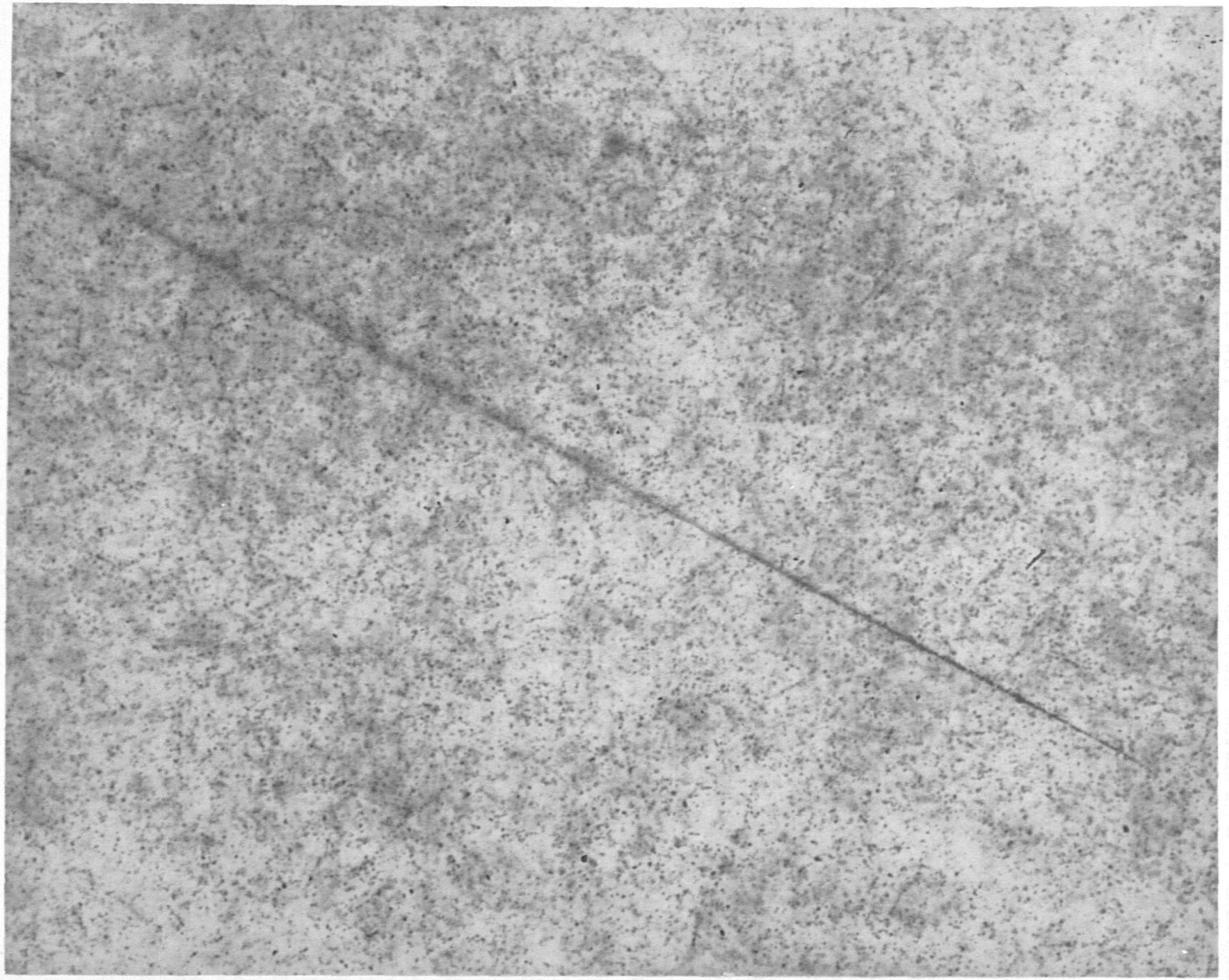

FIG. 7 Photomicrograph of a heavy primary nucleus which makes a small angle with the emulsion plane and terminates its range. The track length shown is 320 microns, and this scale of magnification also applies to Fig. 5 and 6.

corresponds to a radiation dose of 50 to 80 rads. The biomedical unit (Item F in Fig. 9, page 18) contained dosimeters which indicate that the capsule of Discoverer XVII was subject from about 30 to more than 100 rads according to preliminary estimates made by G. W. Crawford.[12]

4. PRELIMINARY COSMIC-RAY OBSERVATIONS ON ORBITED EMULSIONS

The question as to whether a geomagnetic cutoff exists for the low-energy component of the heavy primary beam has not been resolved by balloon exposures because of difficulties in the launching and recovery operations in the polar regions. Another experimental difficulty resides in the large collision cross-section and small ranges of the more massive particles which necessitates that the measurements be made in the absence of appreciable atmosphere or condensed matter. The Discoverer XVIII emulsions orbited above geomagnetic latitude $\lambda \geqslant 55°$ for 1.217 days (Fig. 8) and one face of the emulsion block had an absorbed path of 2.2 g cm^{-2} over a large solid angle, so that most of the requirements were fulfilled.

As an index of the low-energy flux the number of particles of charge $Z \geqslant 6$, which stop by ionization in unit volume of emulsion, is tallied. These particles have a characteristic taper in the emulsion (see Fig. 5) which permits their ready recognition in a dense population of tracks of lesser charge. At the present time about 4 percent of the block has been sampled which yields an average intensity of 10.5 ± 1.1 cc^{-1}, as shown in Table 3. This corresponds to a termination frequency P_t of 8.65 ± 0.93 cc^{-1} day^{-1} on the basis of orbiting time at geomagnetic latitudes $\geqslant 55°$.

This value is compared in Table 4 with the results of a similar set of measurements made in emulsions flown at an atmospheric depth of 2.2 g cm^{-2} at an essentially constant geomagnetic latitude of 58° N. Within the limits of statistical fluctuation, the satellite and the balloon detectors show identical termination frequencies of heavy nuclei with $Z \geqslant 6$. This can be interpreted that no additional heavy particles arrive near the polar regions with energies sufficient to reach the emulsion block.

Careful examination of the Discoverer XVIII emulsions at 1000X magnification has revealed a body of stars with prong count $N_h \geqslant 3$

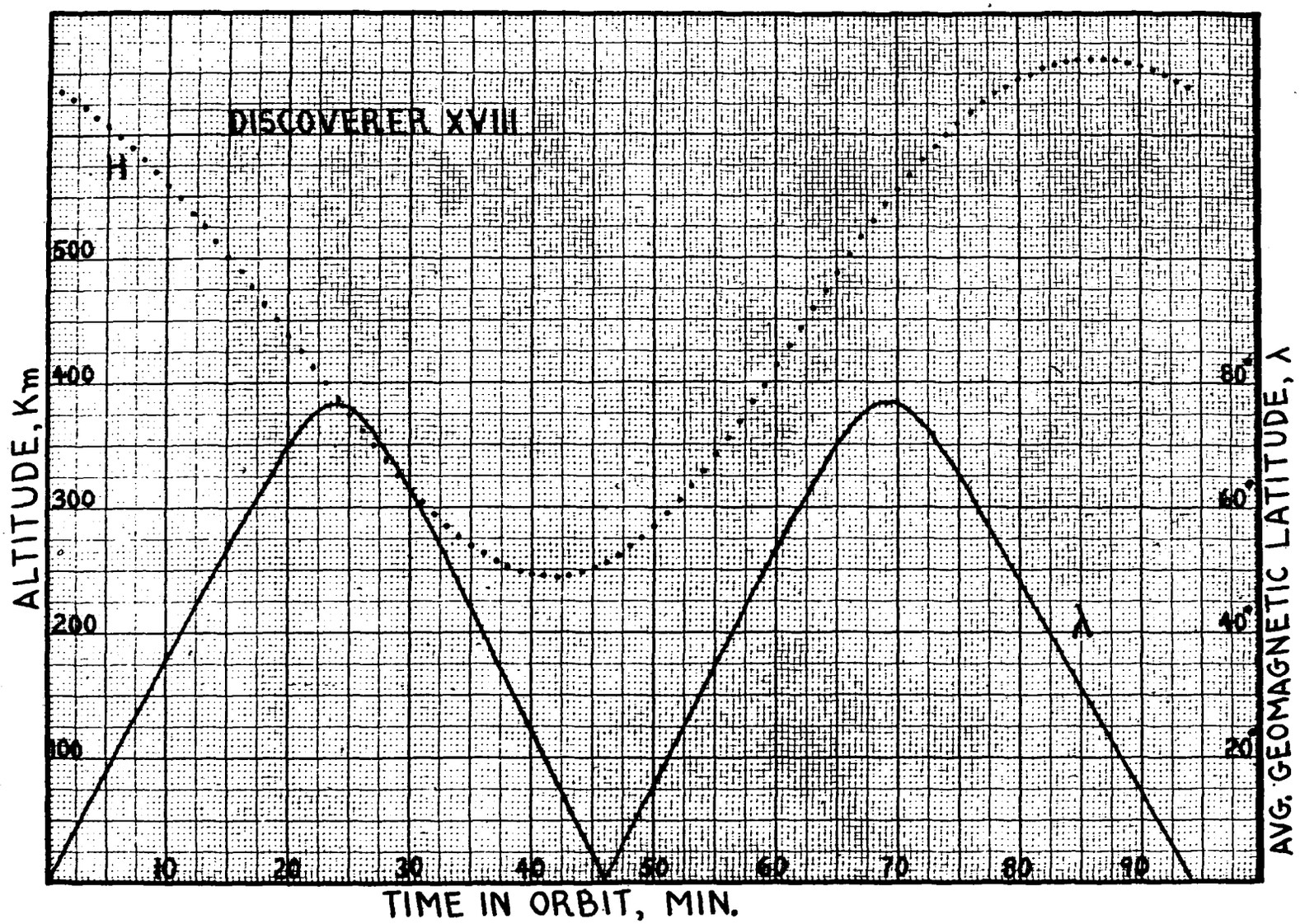

FIG. 8 Altitude and geomagnetic latitude profiles for an average orbit of Discoverer XVIII. (Constructed from data furnished by Space Track, Bedford, Massachusetts.)

TABLE 3. Population of Heavy Primary Terminations in Discoverer XVIII Emulsion Block

Plate Number	No. of Particles With $Z \geq 6$	Volume Scanned, cc	Terminating Tracks per cc
7	20	1.78	11.2
10	36	3.56	10.1
12	30	2.82	10.6
Total	86	8.16	10.5 ± 1.1

TABLE 4. Comparison of Termination Frequency of $Z \geq 6$ Nuclei in Balloon and Satellite Emulsions

Flight	Date	Altitude km	Terminations cc^{-1} day^{-1}
532 Bemidji*	29 July 1960	42.5	7.78 ± 1.15
533 Bemidji	5 Aug 1960	42	8.60 ± 1.04
Disc. XVII	12-14 Nov 1960	188-993	Not Established
Disc. XVIII	7-10 Dec 1960	239-638	8.65 ± 0.93

*Balloons launched at Bemidji, Minn., USA, geomagnetic latitude 58°N

corresponding to a production rate of 6700 ± 500 cc^{-1} day^{-1} on the basis of total orbiting time. This frequency is about twice as large as can be anticipated from emulsions flown in vertical rocket probes[13] when their star populations are normalized to the vertical intensities[14] measured by Geiger counts flown above the atmosphere between the Equator and the North Pole. Since the prong spectrum shows a predominance of small stars the excess nuclear evaporation rate may possibly originate from the flux of energetic trapped protons which can reach the emulsions when the satellite is near apogee.

The irradiated emulsion block from Discoverer XVII represents a potentially invaluable medium for the study of the heavy primary component of the radiation associated with 3+ solar flares. At the present time definitive conclusions cannot be made because of the absence of absolute

ionization criteria. The heaviest thindown tracks exemplified by the track in Fig. 7 occur with a frequency of 13 ± 3 cc^{-1} day^{-1}. Our preliminary estimates of the ionization in this unusual medium suggests that this termination frequency, made at low magnification, may only represent the abundance of the very heaviest nuclei of $Z \geqslant 11$. More detailed examination with oil immersion objectives reveals a much higher population of tenuous tracks that enter the faces of the emulsion and stop by ionization. Depending on the acceptance criteria and position in the block, these occur with a frequency some 3 to 50 times greater than the $Z \geqslant 11$ group. The top sheet of the block facing the thin window area exhibits a particularly large number of terminating tracks whose population varies between 500 to 1000 cc^{-1}. Most all of these enter the front face of the emulsion. This asymmetry in the flux strongly indicates that the incident particles are rapidly attenuated by ionization loss and are arriving with relatively small kinetic energies, of approximately 100 Mev per nucleon if these be carbon or oxygen nuclei.

The relative frequency of the different nuclear species must await a formal charge analysis. One of the promising features in this difficult problem is that individual grains can be resolved and their number n can be tallied even at distances fairly close to the end of the range R. For long flat tracks the differential grain density, when plotted against ionization loss as a function of range, exhibits a linear response which indicates that the radiation-damaged medium is still functioning as a quantitative tool. Likewise the integrated grain count log n, when plotted against log R, yields a series of straight parallel lines for tracks of different optical density.

5. RADIOCHEMICAL ANALYSIS OF THE DISCOVERER CAPSULES

The relative position of the several metallic components of the satellites which are being analyzed for long-lived radioactive spallation products and induced radioactivities is shown in longitudinal cross-section in Fig. 9. The outer ablation material was not recovered. The aluminum flange (D in Fig. 9) was beneath the thinnest layer of ablation material and was exposed to the interaction of protons with kinetic energies $E \geqslant 27.5$ Mev as shown

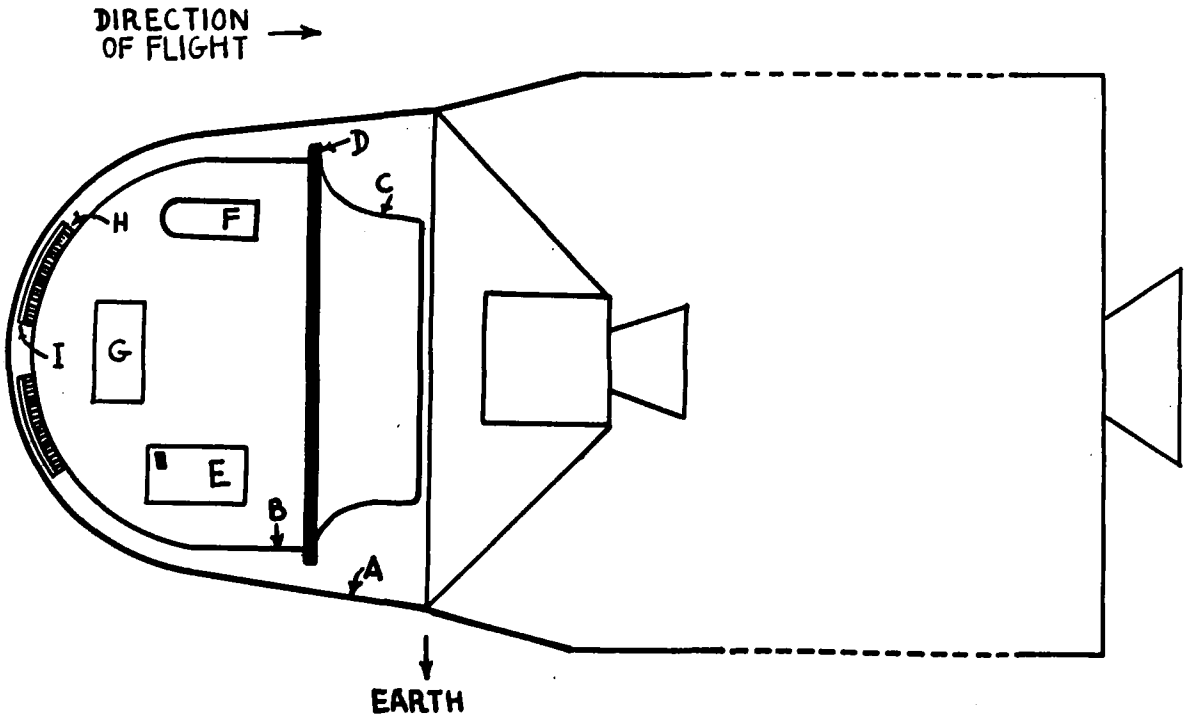

FIG. 9 Sketch of Discoverer satellite capsule showing positions of principal components whose induced radioactivities are under investigation. The components are: A - ablation material; B - gold-plated aluminum capsule; C - fiberglass plastic cover housing the parachute; D - aluminum flange; E - emulsion block; F - biomedical specimans; G - storage battery with stainless steel housing composed of 70 Fe, 20 Cr, and 10 Ni; H - lead spherical segment, 6.35 mm thick; and I - aluminum spherical segment, 1.6 mm thick.

in Table 5. This tabulation only records the absorber paths for radiation passing through the thin front windows. Particles approaching from the rear traverse a complex mass of absorbers. Some average estimates are pertinent. Rays parallel with the longitudinal rocket axis encounter 68 g cm^{-2}, which at the battery (G) subtend a solid angle of 0.063 steradians. Radiation entering the rear of the capsule at wider angles encounter an average absorber mass of 21 g cm^{-2}. At the battery position, this encompasses a solid angle of 3.4 steradians. The spherical lead segment (H) and its aluminum support (I) were only onboard Discoverer XVII. Otherwise, the orientation of the other components were identical on both flights.

The second capsule was recovered 28 days after the occurrence of the large solar flare of 12 November 1960. In view of this short period and

TABLE 5. Minimum Energies of Charged Particles Required to Reach Capsule Components

Item	Min. Range g cm^{-2}	Min. Kinetic Energy, Mev Protons	Tritons	Alpha	C^{12}
B-capsule	0.95	27.5	42.5	112	53*
D-flange	0.95	27.5	42.5	112	53*
E-emulsion	2.20	45.0	70.0	185	88*
F-biomedical	2.64	50.5	78.0	205	
G-battery	2.14	44.5	70.0	180	
H-lead**	3.03	55.0	86.0	223	
I-cover**	2.60	50.0	77.5	203	

*The kinetic energies for C^{12} are expressed per nucleon.
**Items H and I were only onboard the Discoverer XVII satellite.

the additional flares which occurred on 15 and 20 November[15] it is possible that Discoverer XVIII was not exposed to an entirely normal cosmic ray environment. Particles ejected from the sun during the November flares may have been trapped in orbits and still circulating at the time of the second satellite launching. Where comparative data is available, however, the indications are that the satellite launched during the flare exhibits a tritium and argon-37 production rate greatly in excess of that observed in the post-flare vehicle.

Owing to the complex radiochemical isotope separations and the slow counting rates characteristic of long-lived nucleides, final results are not available at present. The significance of the tentative measurements can be surmised from the following abstracts prepared by the groups cooperating in the analyses.

TRITIUM IN RECOVERED SATELLITE MATERIAL

E. L. Fireman, J. DeFelice, and D. Tilles
Smithsonian Astrophysical Observatory

The radioactive isotope tritium (12.4-year half-life) was measured in iron and in lead from the Discoverer XVII satellite. This satellite was exposed to the solar flare of 12 November 1960. The tritium content of the iron was 50 ± 3 decays/kg min, and of two lead samples it was 7.5 ± 0.2 and

24.0 ± 0.5 decays/kg min. The tritium production rate averaged over the 50 hours that the satellite was in orbit was 150,000 tritons/kg min in the iron, and 23,000 and 75,000 tritons/kg min in the lead samples. The largest tritium production rate measured in iron meteorites or in the iron phase of stony meteorites is 300 tritons/kg min. The iron from the Discoverer XVII contained over 500 times more tritium than would be expected from the action of cosmic rays. The ratio of tritium to argon-37 production is 2500 in the Discoverer XVII iron compared to a ratio of 40 in iron targets bombarded by 160 Mev protons and a ratio of 15 in iron targets bombarded by 1 Bev protons. The large tritium content probably results from tritium in the flare itself.

ARGON-37 IN RECOVERED SATELLITE MATERIAL

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The amount of the radioactive isotope argon-37 (34-day half-life) was measured in iron and in lead from the Discoverer XVII satellite and in iron from the Discoverer XVIII satellite. Both were in polar orbits; the Discoverer XVII was exposed to the solar flare of 12 November 1960 while in orbit. At the time of recovery, iron in the Discoverer XVII satellite contained 2.5 ± 0.3 argon-37 decays/kg min corresponding to an average production rate of 58 ± 7 argon-37 atoms/kg min. In the Discoverer XVIII satellite the argon-37 production was less than 10 argon-37 atoms/kg min in iron covered by only 0.95 g/cm^2 of shielding. The argon-37 production rate in the iron meteorite Aroos was 23 atoms /kg min which is lower than the rate observed in the iron from Discoverer XVII but higher than that of Discoverer XVIII. The argon-37 production rate in the lead of Discoverer XVII was 4 atoms/kg min or less. The results indicate that the flare produced an appreciable amount of argon-37 in iron but not in lead.

ARGON-37 PRODUCED IN STAINLESS STEEL FROM DISCOVERER XVII AND XVIII AND ITS RELATION TO METEORITES

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Brookhaven National Laboratory

Argon-37 production rates were obtained on pieces of a stainless steel battery case carried by Discoverer XVII and XVIII. During the

flight of Discoverer XVII a solar flare of Importance 3+ occurred, with associated increases in cosmic-ray neutron intensities. The argon-37 activities observed were as follows: Discoverer XVII, 3.2 ± 0.4 dis. min^{-1} kg^{-1}; Discoverer XVIII, 1.1 ± 0.3 dis. min^{-1} kg^{-1}. The latter value approximates that expected from the normal cosmic-ray proton intensity outside the Earth's atmosphere. The greater argon-37 activity found in Discoverer XVII resulted from solar flare protons. Argon-37 is a high energy spallation product with a threshold of about 200 Mev. From the production cross-section as a function of the energy, and the observed argon-37 in Discoverer XVII, the high-energy flare proton intensities can be evaluated. The results obtained can be related to argon activities observed in meteorites.

INDUCED RADIOACTIVITIES IN Pb CARRIED ON DISCOVERER XVII

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A sheet of lead 7 g/cm^2 thick carried in the nose cone of Discoverer XVII was obtained from the Geophysics Research Directorate. From one portion of the entire thickness of the lead a bismuth fraction was isolated and examined for x-rays resulting from electron capture decay of Bi^{205} (14 d) and Bi^{206} (6 d). A small but real counting rate was observed whose decay was compatible with a 14-d half-life. Extrapolating back to the time of recovery the activity would correspond to 0.5 dpm of Bi^{205}/g of Pb. From the known excitation functions of the p, xn reactions on lead isotopes, one can conclude that this Bi^{205} activity resulted largely from protons of between 50 and 100 Mev. Bi, Hg, and Tl were isolated from a surface sample 1 g/cm^2 thick. The measurements on the thallium fraction indicated less than 0.06 dpm of Tl^{202}/g of Pb at time of recovery. The mercury fraction showed a β activity compatible with 0.004 dpm of Hg^{203}/g of Pb at time of recovery. The bismuth samples are being counted by x-v coincidences. The implications of these results with respect to the intensity and spectrum of the solar flare protons will be discussed.

RADIOACTIVITY PRODUCED IN AgBr EMULSION BLOCK CARRIED ON DISCOVERER XVII

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Scintallation - spectroscopy measurements on an emulsion block (containing 330 g Ag) from Discoverer XVII, which was flown during a period of high solar cosmic-ray activity on 12 November 1960, reveal a gamma-ray spectrum attributable to 8.4-day Ag^{106}. The disintegration rate, corrected to a probable production time of 2100 UT, 12 November 1960, is 14 d/sec. If one assumes a (p, pn) cross-section of 100 mb, this corresponds to a total dosage within the emulsion of about 1.6×10^8 protons/cm^2. An attempt to measure the gamma spectrum of 40-day Ag^{105} was unsuccessful, allowing the assignment of an upper limit on the disintegration rate of 1 d/sec at the time of production. A search for 1.3-year Cd^{109} is under way.

SOLAR FLARE INDUCED RADIOACTIVITY IN DISCOVERER XVII

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The radioactivity induced in materials of the recovered satellite Discoverer XVII is being examined. This satellite was orbiting the Earth for two days at the time of the solar flare of 12 November 1960. Samples of bismuth isolated radiochemically from a lead sheet on the satellite (which was shielded from cosmic rays by only a few grams per square centimeter of material) have been found to emit x-rays in the 70 kv region. Part of this radioactivity has been identified by x-ray-v coincidence counting to be due to 15.3-day Bi^{205}. The specific activity of the top surface of the lead at the time of recovery of the satellite was a few disintegrations per minute of Bi^{205} per gram of lead. On the assumption that protons are responsible, a time-integrated flux of 5×10^7 particles per cm^2 incident on the lead and having an energy between 20 and 50 Mev would account for the observed amounts of Bi^{205}. This calculation is based on the known cross-sections of (p, xn) reactions on separated lead isotopes.

6. CONCLUSIONS

The emulsion blocks recovered from the two satellites contain a wealth of information on galactic cosmic rays, trapped protons from the lowest fringes of the inner radiation belt, and what appears to be a heavy corpuscular component associated with the 3+ solar flare of 12 November 1960. The unwieldy concentration of tracks in the Discoverer XVIII emulsions and the altered sensitivity of the block irradiated by the flare make it very difficult to unravel the data. However, from the preliminary results of Discoverer XVIII, it would appear that further useful cosmic-ray information could be secured by means of emulsions provided the altitude of apogee could be reduced and the recovery operation was initiated after 15 to 20 orbits.

In contrast with the ideal requirements for the emulsions, exposures of long duration are advantageous in the study of radioactive spallation products. In satellite vehicles designed for prolonged orbiting periods it would be desirable to expose portions of purified and de-gassed metals, rather than to depend on the structural members of the capsule.

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