but which is not observed in the charged-particle reactions. A state at this energy and the alternative decay scheme are shown by the dashed lines in Fig. 2. All the alpha groups studied in the present experiment were of low intensity, and a weak group associated with a level at 3.10 Mev might not have been observed. It will be recalled that no group was found corresponding to the 3.16-Mev state. In the case of the inelastic proton scattering, if a peak associated with such a state at 3.10 Mev had an intensity greater than 3% of the one corresponding to the 3.16-Mev level, it would have been detected in the exposures at 50 and 90 degrees. In Fig. 1, an arrow marks the position a proton group would have if a state at 3.102 Mev were excited. The nonappearance of a group at this position might be explained on the basis of the high angular momentum required to excite Cr^{52} from its ground state, which has zero angular momentum, to the state formed in the beta decay which has been reported to have angular momentum of 6 units.[13] It should be pointed out that, while the assumption that a state exists at 3.10 Mev suffices to explain the discrepancy between the energy differences calculated from the charged-particle results and those observed in the beta-decay measurements, it does not explain why some evidence for the states established at 3.16, 2.97, 2.77, and 2.65 Mev was not found in the various decay studies.

The authors are indebted to Mrs. Mary Fotis for her very careful work in counting the tracks in the nuclear emulsions exposed during the present work.

[13] Huiskamp, Steenland, Miedema, Tolhoek, and Gorter, Physica **22**, 587 (1956).

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Study of Geomagnetic Cutoff Energies and Temporal Variation of the Primary Cosmic Radiation*

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The results of a series of 6 Skyhook balloon flights with combination Čerenkov-scintillation detectors, similar to ones previously described, are used to study spectral cutoffs as a function of latitude and to observe some aspects of temporal variations at high altitude of the alpha particles of the primary cosmic radiation. Observed cutoff energies are found to be in strong disagreement with geomagnetic theory. In one large cosmic-ray decrease the very low-energy portion of the cosmic-ray energy spectrum (300–600 Mev/nucleon) does not seem to be strongly affected.

I. INTRODUCTION

THE application of emulsion,[1–5] Čerenkov,[6–8] and Čerenkov-scintillation[9] techniques to the study of the flux and energy spectrum of primary cosmic-ray alpha particles has made helium the best known component of the primary radiation. Because of its abundance and because of its relative freedom from secondary effects, the helium component is an excellent one for the direct study of cosmic-ray temporal variations and geomagnetic effects at the top of the atmosphere. The Čerenkov-scintillation technique, which has been described in a previous article,[9] gives an absolute measurement of the primary alpha-particle intensity and energy spectrum. By carrying out measurements at a series of latitudes, the dependence of the energy spectrum on geomagnetic latitude can be studied. This technique is also well suited to the study of long-term temporal variations since it measures absolutely the intensity and energy spectrum. In addition, an electronic device of this type is uniquely suited to study short term temporal variations which occur during the course of a balloon flight or variations associated with changes in geomagnetic latitude along the balloon trajectory. At this time six successful Skyhook flights have been conducted by using the Čerenkov-scintillation method. This paper treats aspects of these flights dealing with temporal variations and changes due to varying geomagnetic latitudes of the energy spectrum and intensity of helium nuclei of the primary cosmic radiation.

II. EXPERIMENTAL APPARATUS

The experimental flight apparatus is identical to that previously described.[9] Briefly, the detector is a

* Assisted by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] C. J. Waddington, Phil. Mag. **45**, 1312 (1954).
[2] Fowler, Waddington, Freier, Naugle, and Ney, Phil. Mag. **2**, 157 (1957).
[3] C. J. Waddington, Nuovo cimento **3**, 930 (1956).
[4] P. H. Fowler and C. J. Waddington, Phil. Mag. **1**, 637 (1956).
[5] Shapiro, Stiller, and O'Dell, Bull. Am. Phys. Soc. Ser. II, **1**, 319 (1956).
[6] J. Linsley, Phys. Rev. **97**, 1292 (1955).
[7] N. Horowitz, Phys. Rev. **98**, 165 (1955).
[8] W. R. Webber and F. B. McDonald, Phys. Rev. **100**, 1460 (1955).
[9] F. B. McDonald, Phys. Rev. **104**, 1723 (1956).

three-element telescope (Fig. 1) containing a crystal scintillation counter, a Lucite Čerenkov counter, and a Geiger counter tray. The scintillation crystal and the Geiger counter tray are the defining elements of the telescope. For each particle which traverses these elements, the outputs from the Čerenkov counter and the scintillation counter are recorded. A notation is also made when a telescope event is accompanied by the triggering of more than one counter in the tray or by one of the ring of guard counters. The data are recorded on a continuously moving film with an accurate time base superimposed. These data are then reduced by measuring for each event the pulse height from the scintillation counter and from the Čerenkov counter. These measurements are recorded on a suitable two-dimensional data grid. The expected variation of Čerenkov pulse height *vs* energy loss in the scintillation crystal as β is varied from 1 to $1/n$ (n is index of refraction of the Čerenkov radiator) is shown in Fig. 2. For $\beta<1/n$, the theoretical Čerenkov pulse height is zero and the distribution will lie along the horizontal axis. The low-energy proton and alpha distributions will not overlap because of the short range of protons in this interval. Thus it is seen that excellent charge resolution should be maintained at all energies.

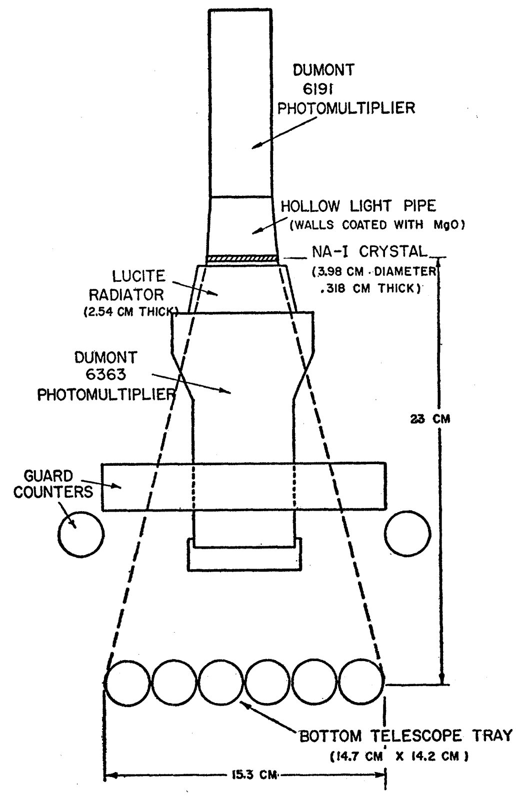

FIG. 1. Schematic drawing of telescope.

III. NEW DETERMINATION OF ENERGY SPECTRUM AT $\lambda=55°$

In I (reference 9) a determination was made of the alpha energy spectrum at $\lambda=55°$ from 285 to 883 Mev/nucleon. Amplifier saturation prevented the lower limit from being extended below 285 Mev/nucleon. At 320 Mev/nucleon the differential spectrum still appeared to be increasing toward lower energies. In an attempt to observe a cutoff in the spectrum at $\lambda=55°$ a Skyhook balloon flight (flight No. 8) was made on August 21, 1956 from Minneapolis, Minnesota. The time-altitude curve for this flight is included in Fig. 3. The data from this flight were transferred to a 40×40 array and studied by taking appropriate intervals of ionization and studying the Čerenkov distribution in these intervals. As in I the energy calibration is obtained by studying the ionization distribution of highly relativistic alpha particles (as defined by large pulses from the Čerenkov counter) and measuring the most probable energy loss of alpha particles at minimum

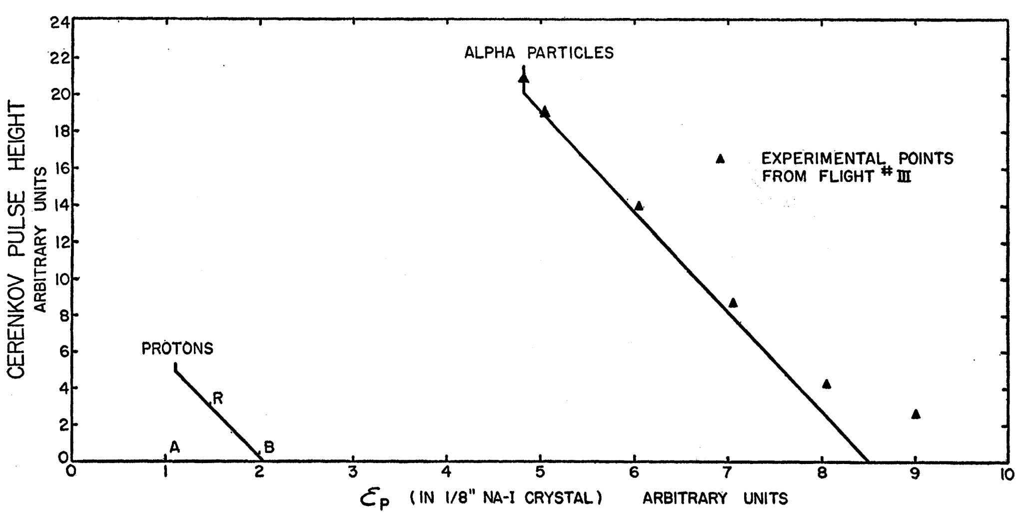

FIG. 2. Plot of Čerenkov pulse height in 1-in. Lucite radiator *vs* most probable energy loss for protons and alphas in a $\frac{1}{8}$-in. Na—I crystal.

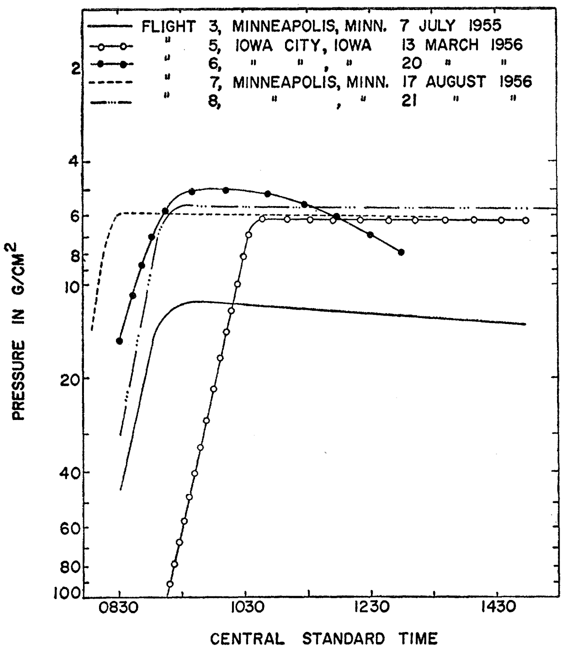

FIG. 3. Time altitude curves for flights III, V, VI, VII, and VIII.

ionization, $(E_p)_{\alpha\,\min}$. The selected intervals of ionization are then defined in terms of $(E_p)_{\alpha\,\min}$. It is necessary to know only the form of the dE/dx *vs* energy curve and not its absolute value. The uncorrected Čerenkov distributions for the various intervals of ionization are given in Fig. 4.

These intervals of ionization have been related to the corresponding kinetic energy and then corrected for energy loss by ionization to the top of the atmosphere. Table I summarizes the data and the necessary correction. Figure 5 gives the resulting differential and integral energy spectrum and shows for comparison the energy spectrum obtained on flight III, July 7, 1955 also from Minneapolis ($\lambda=55°$). In Fig. 4 it is seen that the Čerenkov pulse-height distribution does not go to zero for $\beta<1/n$ and that the alpha particles in the low-energy region have a well-defined distribution located in the region of low Čerenkov output. Investigation has shown that this is due to fluorescence in the Lucite or the photomultiplier tube.[10] This is not unexpected in view of the very large value of dE/dx for alpha particles of this energy. It indicates that below the Čerenkov threshold the detection system is acting as a double scintillation counter and for $\beta>1/n$ there is a small energy loss contribution. As in I, no use has been made of the theoretical dependence of Čerenkov light on β. It has been assumed only that the Čerenkov output decreases monotonically as β is decreased. The assumption is necessary only in the region where the Williams-Landau effect is large and the ionization distributions have a large width—i.e., $E>400$ Mev/nucleon. It was shown in I (reference 9) that this assumption was valid down to 320 Mev/nucleon. For $\beta<1/n$, (320 Mev), there is a suggestion that the "Čerenkov pulse height" again increases very slowly. This can be termed the ionization region of the Čerenkov counter in which the counter now behaves as a crude ionization detector. Comparison of the slow-proton and slow-alpha Čerenkov distributions in the region of $\beta<1/n$ show that the output from the Čerenkov counter does appear to vary in a linear manner with energy loss. However, in all cases, the Čerenkov counter is used only to give well-defined particle distributions for particles in a given energy-loss region and no additional use is made of this property.

It is now possible to extend with confidence the energy spectrum observation to the lowest observable energies (i.e., those particles which will just traverse the telescope). The well-resolved alpha peaks in the low-energy region indicate that alpha particles are present to the lowest observable energy. The curves in Fig. 4 have not been corrected for the pulse height distribution in the ionization detector but this correction has been applied to the energy spectrum data in Table I and Fig. 5. Even with these corrections it is observed that alpha particles of all energies down to the apparatus and atmospheric cutoff are present. However, due to the

TABLE I. Summary of α-particle data for flight 8.

Interval	Total energy loss in crystal in Mev	Energy interval defined at 6 g residual atmosphere; Mev/nucleon	Energy interval corrected to top of atmosphere; Mev/nucleon	No. of α counts in interval	No. of α counts with Landau-Williams correction	$J\alpha$ at 6 g/cm² (particles per m²-sec-sterad per unit interval)	$J_{0\alpha}$ at 0 g/cm² atmos depth particles per m²-sec-sterad per interval [m.f.p. = 45 g/cm²]	$dJ_{0\alpha}/dE$ (No. of α's per m²-sec-sterad Mev)
1	<5.92	>715	>730	865	1132	146	167	
2	5.92– 7.24	468–715	487–730	531	359	43.5	49.8	0.204±0.02
3	6.36– 7.68	405–608	427–625	396	270	34.9	38.6	0.195±0.02
4	7.24– 8.55	326–467	350–487	283	226	28.4	32.4	0.25 ±0.025
5	7.68– 9.43	272–405	298–427	324	282	35.2	40.4	0.304±0.03
6	8.99–10.74	220–295	249–316	137	128	16.0	18.2	0.27 ±0.03
7	10.74–12.50	170–220	204–249	93	84	10.5	12.0	0.26 ±0.04
8	12.50–16.00	120–170	161–204	60	47	6.0	6.8	0.16 ±0.025
9	14.25–16.88	110–142	153–179	30	24	3.1	3.4	0.13 ±0.03

[10] K. A. Anderson (private communication).

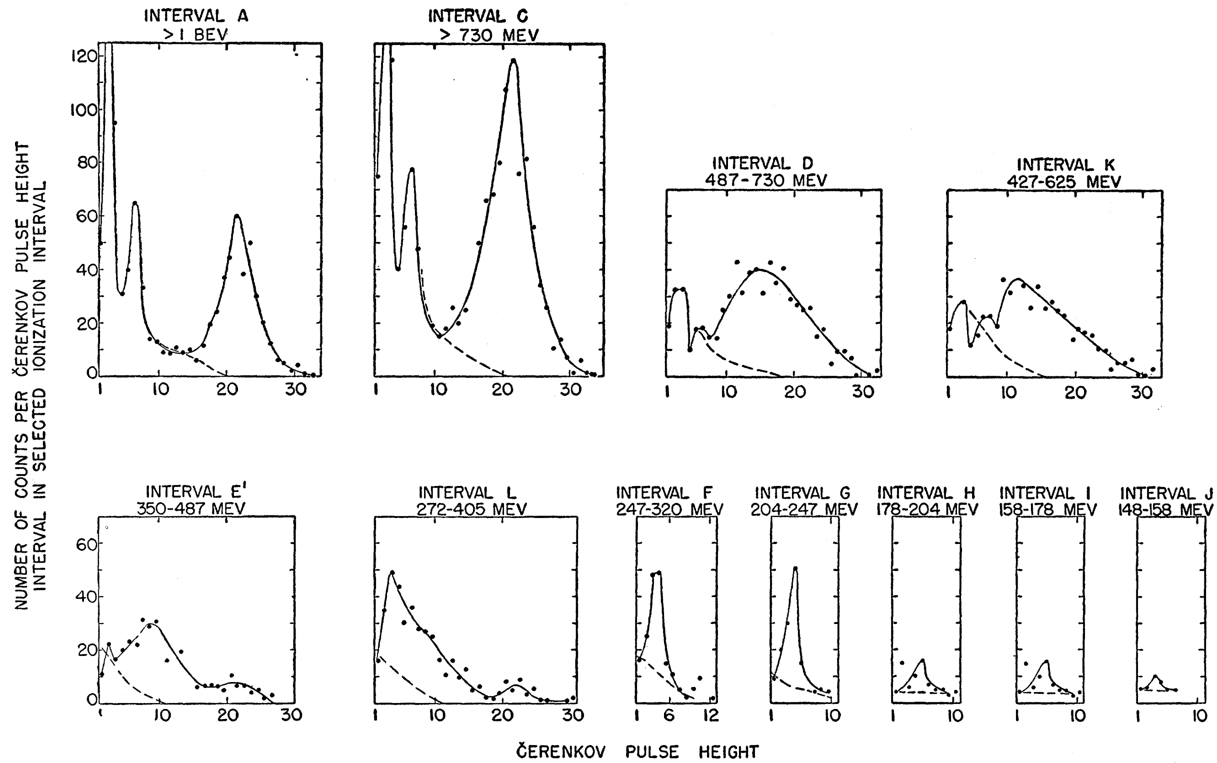

FIG. 4. The solid circles and lines give the uncorrected differential Čerenkov pulse-height data in selected ionization intervals. The dashed line represents the background counts in the interval. In *A* and *C* the off scale peak is due to slow protons, the second peak is the Williams-Landau "tail" from fast singly charged particles, and the third peak is the fast alpha peak. The ordinate represents the actual number of counts obtained while the balloon was above 6 g/cm² pressure altitude. Each energy interval has been corrected for ionization loss in the atmosphere.

width of the distribution, it is felt that the results are also consistent with an upper limit on the cutoff energy of 160 Mev/nucleon. The observed maximum of the differential spectrum in the region of 320 Mev/nucleon and its decrease at lower energy values are in excellent agreement with the results reported by the Minnesota group[2] based on a flight at Saskatoon, Canada ($\lambda = 62°$)[2] and with those of Waddington at $\lambda = 55°$ (Minneapolis, Minnesota). Waddington's[3] experiment clearly showed that alpha particles were present down to the lowest

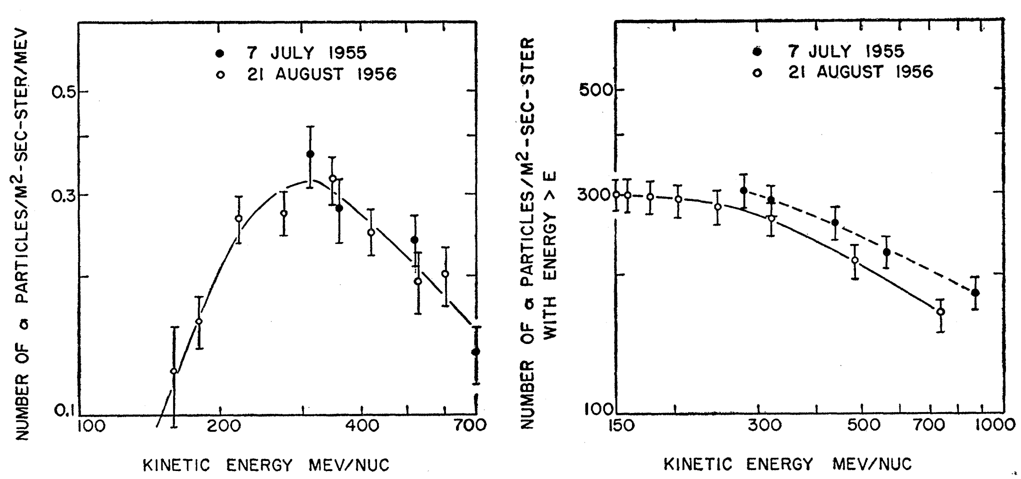

FIG. 5. Differential and integral energy spectrum for primary alpha particles. The open circles are for flight 8, August 21, 1956, and the solid circles are for flight III, July 7, 1955. Amplifier saturation prevented the extension of the flight III data to lower energies.

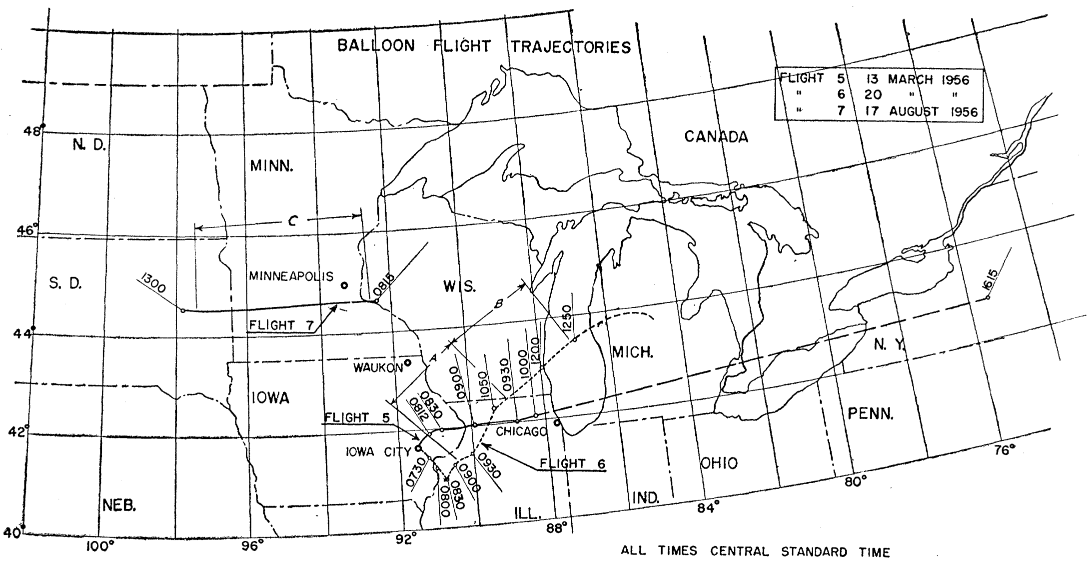

FIG. 6. Trajectories of flights 5, 6, and 7. Periods A, B, and C (see Fig. 7) are indicated along the trajectories.

observable energy. The data presented here fully confirm his results. The calculated geomagnetic cutoff at $\lambda=55°$ is 325 Mev/nucleon. Thus there exists a clear contradiction between the results obtained in this experiment and the predictions of standard geomagnetic theory. It will be shown later that the occurrence of the maximum in the differential spectrum near the expected value of the geomagnetic cutoff does not appear to be of significance. The resolution of the detectors at low energies is such that the "rounding" of the differential spectrum could not be produced by the width of the distributions obtained from the scintillation counter. It is not known, of course, whether the shape of the differential spectrum is due to a geocentric modulation mechanism or whether it represents the actual cosmic-ray energy spectrum at large distances from the earth.

IV. GEOMAGNETIC CUTOFF IN THE INTERVAL $\lambda=51°-55.5°$ N

On March 20, 1956, a flight (flight 6) was made from Iowa City, Iowa ($\lambda=52°$) to measure the flux of He, Li, Be, B, and C using the technique described in the previous section. The only modification was a compression of the alpha-particle distribution by a factor of 8 in order to study the higher Z groups. This made the detailed study of an energy spectrum difficult. However, one feature of flight 6 provided an ideal opportunity for the study of variations due to changing geomagnetic latitude during the course of a balloon flight. The trajectory of this flight is shown in Fig. 6 and the time-altitude curve is given in Fig. 3. During the period at altitude the balloon moved from the southern part of Iowa into central Michigan. The Li, Be, B, and C data will be published in a separate paper. The telescope counting rate for alpha particles is approximately 450 counts/hr. It should be possible to observe small values of $dJ/d\lambda$, especially if these changes are confined to a limited energy interval. The data were studied in the usual manner, by dividing them into intervals of ionization. Because of the scale compression, a significant distribution could not be obtained in the low-energy Čerenkov region; therefore, only the total numbers of counts in each ionization interval are tabulated. The data are divided into two 2-hour intervals which are indicated on the balloon trajectory in Fig. 6. The number of alpha counts per interval of ionization for the two periods is given in Fig. 7. Also included in this figure is the result of subtracting interval A ($\lambda=51.6°$ N) from B ($\lambda=52.6°$). This subtraction gives the pulse-height distribution of the particles which are present in B and absent in A. When the distributions are subtracted, there remains a small but well-defined group of particles with a mean energy of 225 ± 25 Mev/nucleon. This value is the geomagnetic cutoff energy at $\lambda=52.2°$. The calculated value based on conventional geomagnetic theory is 450 Mev/nucleon. The flux of new particles coming in between 51.6° N and 52.6° N is $22\pm3/m^2$-sec-sterad at the top of the atmosphere. On the basis of the previously derived energy spectrum (Sec. III), this increase in flux corresponds to a change in cutoff energy (making the arbitrary assumption of a sharp cutoff) of 200 to 250 Mev/nucleon. This range of energies is in agreement with the pulse height distribution of Fig. 7. The presence of counts below the instrument cutoff indicates that there exist background events which cannot be corrected by the method used previously in flights III and VIII. This uncertainty is removed by the subtraction of the two periods. That this results in a well-defined group of particles gives added confidence that the method is a valid one.

Identical apparatus was flown from Minneapolis, Minnesota, on August 17, 1956 (flight 7). A comparison of the alpha ionization distributions obtained in this flight (the pressure altitude curves of flights 6 and 7 were almost identical, see Fig. 3) during periods A and B is also shown in Fig. 7. There is a small but apparently finite increase between $\lambda=52.6°$ N and $\lambda=53.5°$ N. The observed increase of new alpha particles shown in part (iii) of Fig. 7 is in agreement with the energy spectrum data of Sec. III. The mean kinetic energy of this group of particles appearing between $\lambda=52.6°$ and 53.5° N is 160±15 Mev/nucleon. This value of 160 Mev/nucleon is the geomagnetic cutoff energy at 53.2° N. The increase in alpha-particle flux is 9±2 particles/m^2-sec-sterad. From the previous energy spectrum data of Sec. III this change in alpha flux defines an energy interval of 210 to 140 Mev/nucleon and is in agreement with the observed differential distribution of Fig. 7. The agreement between periods B and C in the kinetic energy interval 450–190 Mev/nucleon would seem to indicate there did not exist an observable temporal variation in the low-energy region. (See Sec. V.)

There does not appear to be appreciable overlap between the differential particle distributions at $\lambda=52.2°$ and at 53.2° as shown in Fig. 7. The overlap that does exist can be accounted for by the width of the ionization distribution.[11] This would seem to indicate the existence of a relatively sharp cutoff in the latitude range 51 to 54° N. It is important to note, however, that there might be alpha particles at $\lambda=52.2°$ N below the mean cutoff energy of 240 Mev/nucleon since a differential technique has been used. However, comparison with flight 8 (Sec. III) reveals that the number of counts in period A below 240 Mev/nucleon is in agreement with the background counting rate of flight 8 in this energy interval.

One additional estimate of the alpha cutoff energy at $\lambda=52.4°$ N can be obtained from flight V (launched at Iowa City, Iowa, March 13, 1956). The differential and integral spectrum data for this flight are discussed in Sec. V. The method outlined in that section gives a vertical alpha-particle cutoff at 52.4° of 220±30 Mev/nucleon. The three measured values of geomagnetic cutoff energies are summarized in Table II. It is seen that a shift in latitude coordinates of approximately 4° would bring the data into agreement with geomagnetic theory. This is identical with the shift proposed by Waddington and Fowler[4] to bring the 41° N (Texas) alpha data into agreement with alpha measurements over Europe. Such a shift is completely outside the errors involved in calculating geomagnetic coordinates and experimental errors in measuring cutoff energies and would seem to imply the existence of some perturbing mechanism in the vicinity of the earth.

[11] A. G. McNish, Terrestrial Magnetism and Atmospheric Elec. **41**, 37 (1936).

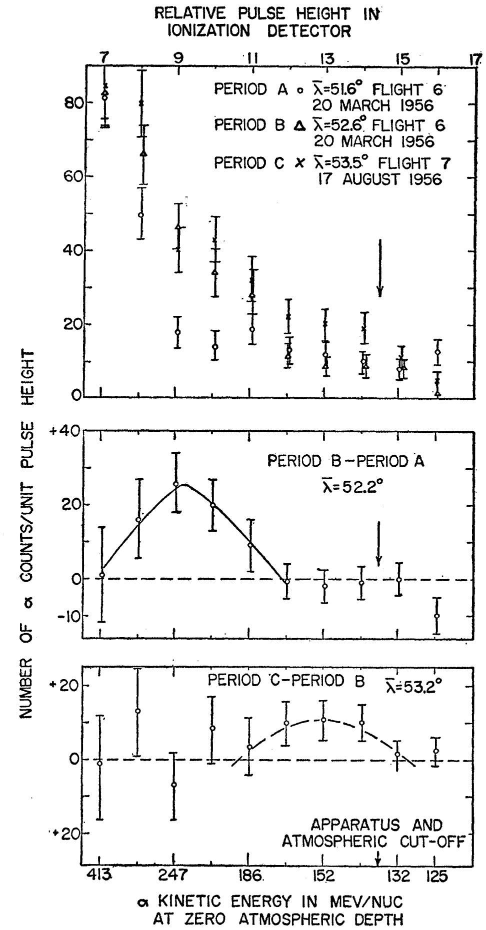

FIG. 7. Part (i) gives the total number of counts per unit ionization interval in the low-energy alpha region. There exists a small but appreciable fraction (25%) of background counts which can be removed by comparing different latitude intervals. This is done in parts (ii) and (iii) and gives the number and energy distribution of new particles coming in between the two mean latitudes.

V. SOME OBSERVATIONS ON TEMPORAL VARIATIONS AT HIGH ALTITUDES

The flights to be discussed can be divided into three intervals of time centering around July 7, 1955, March 13 and 20, 1956, and August 17 and 21, 1956 (see Fig. 3). Flight V launched from Iowa City, Iowa on March 13, 1956, is of greatest interest. This flight proceeded along a due east trajectory with an average velocity of 110 miles/hour. However, it will be shown later that there was not an appreciable change in geomagnetic latitude. The alpha differential and integral energy spectra derived from this flight are shown in Fig. 8 along with a comparison spectrum from flight III ($\lambda=55°$, July 7, 1955). The method of analysis is similar to that described in Sec. III. The most striking

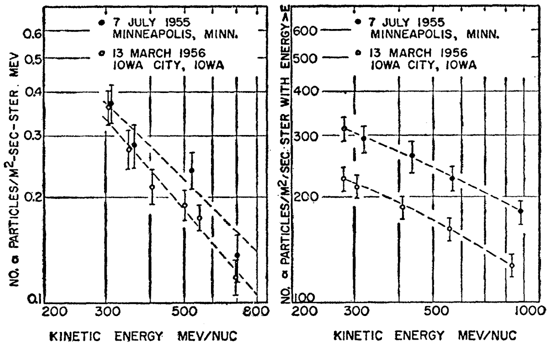

FIG. 8. Differential and integral alpha energy spectrum for flight V (March 13, 1956) and flight III (July 7, 1955). The absence of points below 270 Mev/nucleon is due to amplifier saturation.

feature of the integral spectrum is the large decrease in the total flux. The errors shown in Fig. 8 are for absolute measurements; relative errors are approximately 0.6 of the indicated errors. For energies greater than 700 Mev/nucleon there is a 36±12% change in the flux of alpha particles. However, the differential spectrum of this flight which covers only the energy sensitive region of the detector, is only slightly below the differential spectrum obtained from flight III (July 7, 1955, Minneapolis) and there is good agreement at the low-energy end of the spectrum. The small change in the low-energy region means that the 33% change in alpha flux occurred primarily with particles having kinetic energy *greater than* 800 Mev/nucleon. This result is in disagreement with an extrapolation of neutron monitor results to low energy since these detectors generally show a greater percentage change at high latitudes than at low latitudes. However, owing to atmospheric absorption, sea level neutron measurements cannot give information on the behavior of primary cosmic radiation in the energy region below 1 Bev/nucleon and so the energy dependence observed at high altitudes is not necessarily in disagreement with the neutron results. Nevertheless, since they provide a continuous record, neutron monitors remain a most valuable technique in the study of time variations. The neutron history[12] of the period centering around March 13 and 20, 1956 flights V and VI) is given in Fig. 9 where the average hourly counting rate at the University of New Hampshire's Mt. Washington Station, for the period February 1 to April 10 has been plotted. These flights occurred 21 and 28 days after the extremely large solar flare event of February 23, which would be far off scale on this plot and immediately followed what could be characterized as a large Forbush decrease. The proton counting rate is 25% below the $\lambda=55°$ rate. However, one expects a change of approximately 10% in the total counting rate[13] between $\lambda=52°$ and 55°; thus, there appears to be only a 15% change in the singly charged particle counting rate. It was not necessary to correct for latitude effects in the alpha-counting rate since all energies considered were well above the geomagnetic cutoffs described in Sec. IV. It thus appears that the percentage decrease in the alpha flux was greater than the change in proton flux by approximately a factor of two. However, the latitude dependence of the proton flux is based on data obtained with thin-wall Geiger counter telescopes and must be regarded as tentative until the Čerenkov-scintillation apparatus or a detector of comparable thickness can be flown at this geographical position on a normal day. The good agreement of dJ/dE at both latitudes 52 and 55° (flights V and VIII) in the vicinity of the maximum of the differential spectrum would indicate that the position of the maximum at 320

TABLE II. Summary of measurements of geomagnetic cutoff energies.

Flight No. and date	Period	Geographic coordinates of end points of selected periods[a]	Geomagnetic latitude defined by periods[b]	Mean geomagnetic latitude defined between two selected periods	Measured cutoff energy between selected periods in Mev/nucleon	Calculated mean cutoff energy between selected periods in Mev/nucleon	Shift in coordinates necessary to bring measured cutoff energies into agreement with calculated energies
VI March 20, 1956	*A*	41°30′ N–90°43′ W 42°36′ N–88°09′ W	51° N–52°16′ N				
				A–B 52°16′ N	225±25	455 Mev	4°15′
	B	42°36′ N–88°09′ W 43°43′ N–87°00 W	52°16′ N–53°30′ N				
				B–C 53°10′ N	160±15	400 Mev	5°
VII August 17, 1956	*C*	44°34′ 92°40′ W 44°30′ 97°43′ W	54° N–53° N				
V March 13, 1956	*D*	42°12′ N 87° W 42°40′ W 75°30′ W	51°40′ N 53°05′ N	*D* 52°23′ N	220±30	445	4°

[a] See Fig. 6.
[b] See reference 11.

[12] J. A. Lockwood (private communication).
[13] John Winkler and K. A. Anderson (private communication).

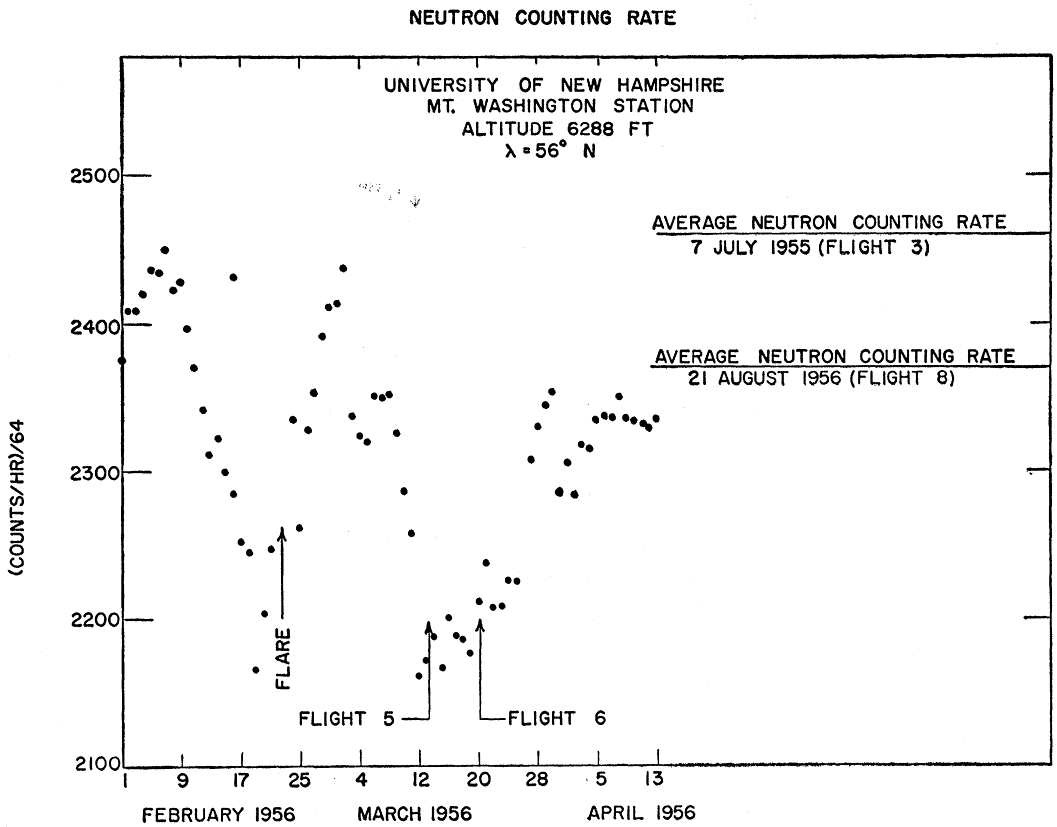

FIG. 9. University of New Hampshire Mt. Washington neutron monitor counting rate for periods February 1, 1956 to April 15, 1956. Also indicated on this figure is the neutron counting rate for July 7, 1955 (flight III) and August 21, 1956 (flight 8). The large event of February 23, 1956 would be far off scale on this plot.

Mev/nucleon at $\lambda=55°$ is not related to the calculated geomagnetic cutoff value of 325 Mev/nucleon at that latitude.

The absence of data below 278 Mev/nucleon in Fig. 8 is due to amplifier saturation in the ionization channel which prevents any direct measurement of a cutoff in the spectrum at this latitude. During flight preparation it was felt that since the theoretical cutoff at this latitude was greater than 425 Mev/nucleon, the saturation point of 280 Mev/nucleon would provide an ample margin of safety. Since it now appears that the low-energy portion of the spectrum was not strongly affected by the decrease, an estimate of the cutoff can be obtained by comparing the total number of counts in flight V due to events with energy loss greater than alpha particles of kinetic energy 280 Mev/nucleon (i.e., $E<280$ Mev) with the energy spectrum obtained in flight 8 (see Sec. III) if an appropriate background correction is included. This procedure leads to a value for the vertical cutoff of alpha particles at 52.4° of 220+25 Mev/nucleon.

The He, Be, B, and C flights of March 20, 1956, and August 17, 1956, also provide information regarding changes in the alpha differential spectrum. These data indicate on March 20 the flux of alpha particles with energy >700 Mev/nucleon was $18\pm9\%$ lower than on August 17. However, the data given in Fig. 7 indicate no appreciable difference in the low-energy region except in the vicinity of 160 Mev/nucleon and this is attributed to latitude variations. The University of New Hampshire's Mt. Washington neutron record indicated that the neutron level on March 20 was 8% below that of August 17.

The low-energy differential points in Fig. 8 have a probable error of $\pm12\%$ and the observed flux change is $33\pm10\%$. The data indicate that the low-energy particles are not affected more strongly than the higher energy particles ($E>800$ Mev/nucleon) by the mechanism leading to the cosmic-ray decrease of March 13–20. Indeed the data suggest there was a large diminution of the intensity of particles with energies greater than 800 Mev/nucleon and that particles with energies less than 450 Mev/nucleon were not strongly affected. However, the accuracy of the experiment is such that one cannot definitely conclude that there was no decrease in the low-energy portion of the spectrum. It is important to realize that what is referred to here as the high-energy portion of the spectrum means only $E>800$ Mev/nucleon.

It is felt that the conclusions reached in the previous

TABLE III. Comparison of a flux and neutron monitor counting rate at Mt. Washington, New Hampshire, and Sacramento Peak, New Mexico.

Flight No. and date	No. of α's/m²-sec-sterad with $E>700$ Mev/nucleon [No. in parentheses gives % change from Flt. III]	No. of α's/m²-sec-sterad with $E>280$ Mev/nucleon [No. in parentheses gives % change from Flt. III]	No. of α's/m²-sec-sterad in interval 280–450 Mev/nucleon. [No. in parentheses gives % change from Flt. III]	Neutron counting rate (counts/hr) at Sacramento Peak, New Mexico. No. of counts/hr averaged over period of flight. [No. in parentheses gives % change from July 7, 1957][a]	Neutron counting rate (counts/hr) at Mt. Washington, New Hampshire. No. of counts/hr/64, averaged over period of flight. [No. in parentheses gives % change from July 7, 1955][b]
III July 7, 1955	203±16	305±25	50±6	23 680±100	2461±15
V March 13, 1956	142±14 (36±12%)	227±2.3 (30±14%)	49±6 (2±16%)	21 344 (10.5%)	2175 (13%)
VIII August 17, 1956	176±15 (12±12%)	270±2.5 (12±14%)	48±6 (4±16%)	22 272 (6%)	2369 (4%)

[a] See reference 18.
[b] See reference 14.

discussion put a very strong constraint on the type of modulation mechanism existing in the period March 13 to March 20, 1956. At the present time we have not reached any conclusions regarding the nature of this mechanism. The energy dependence of the observed temporal variations would not appear to be in agreement with the recent geocentric mechanism proposed by Parker.[14] However, it might be possible to explain this type of variation on the basis of a cavity model such as proposed by Meyer, Parker, and Simpson,[15] Morrison,[16] and Davis.[17] A cavity would tend to provide a storage mechanism which is more efficient for low-energy primaries.

The average levels of sea level neutron intensity on July 7, 1955 and August 21, 1956 are also included in Fig. 9 and the corresponding alpha fluxes and neutron counting rate levels are shown in Table III. There appears to be roughly a 3% change in alpha flux for each 1% change in the sea level neutron counting scale.

The flight of March 13, 1956, is also of interest for the study of short-term temporal variations. Figure 10 gives a plot of counting rate *vs* time for protons, portions of the alpha differential spectrum, and neutron data from Climax and Mt. Washington. While the balloon is moving East in an approximate great-circle trajectory and constant geomagnetic latitude, the form of the proton curve eliminates any large change due to small changes in geomagnetic latitude. The data show a 17±4% increase in protons, a 25±7% change in fast alphas ($E>600$ Mev/nucleon), and no change in alphas with energies between 300–600 Mev/nucleon. Unfortunately this flight terminated just as an appreciable increase of alphas was noted (Fig. 10) so this component might have shown changes at a later time. The total flux changes are clearly reflected in corresponding changes in the neutron monitor counting rates.[18] There does not appear to be any marked solar activity on the date of this flight which could be associated with the observed increase.

[14] E. N. Parker, Phys. Rev. **103**, 1518 (1956).
[15] Meyer, Parker, and Simpson, Phys. Rev. **104**, 768 (1956).
[16] P. Morrison, Phys. Rev. **101**, 1397 (1956).
[17] L. Davis, Phys. Rev. **100**, 1440 (1955).

VI. REMARKS

In view of the experiments of Simpson *et al.*[19] which indicate that the "cosmic-ray" equator and the geomagnetic equator do not coincide and the results of Waddington and Fowler[4] and the present paper which indicate that the cosmic-ray cutoff energies are not in agreement with the predictions of geomagnetic theory, it would appear that standard geomagnetic theory is not applicable to cosmic rays without additional magnetic fields or a perturbing mechanism in the vicinity of the earth. The "knee" previously observed in the spectra of the high-Z component of the primary cosmic radiation by Ellis, Gottlieb, and Van Allen[20] should perhaps be reinterpreted in the light of the new, effective geomagnetic cutoffs which are found in the present work. However, the measurements of Ellis *et al.* were made in the summer of 1953 (near sun-spot minimum) and it is possible that effective cutoffs vary with solar activity.

The observed variation of the energy spectrum would seem to require a mechanism which can contain the very-low-energy portion of the cosmic radiation while modulating the cosmic rays above this energy. From the neutron data we also know that the very-high-energy cosmic rays ($E>10$ Bev/nucleon) are not as strongly affected as those in the range 800 Mev/nucleon to 10 Bev/nucleon. These two observations place very strong constraints on the type of modulation mechanism which can produce these effects. It is suggestive that the effect of the increase measured during flight 5 (March 13, 1956) in the midst of a large Forbush decrease was to enhance those portions of the spectrum

[18] J. A. Simpson (private communication).
[19] Simpson, Katzman, and Rose, Phys. Rev. **102**, 1648 (1956).
[20] Ellis, Gottlieb, and Van Allen, Phys. Rev. **95**, 147 (1954).

which had been most heavily depleted and would tend to indicate that the same mechanism caused both changes.

SUMMARY AND CONCLUSIONS

The alpha-particle differential energy spectrum has been extended down to 150 Mev/nucleon. A maximum in the differential spectrum is observed in the vicinity of 325 Mev/nucleon in agreement with that reported by other observers. At the present time it is not known whether the observed shape of the differential spectrum is due to a local modulation mechanism or whether it represents the cosmic-ray energy spectrum at large distances from the earth. The position of the maximum in the differential spectrum at 325 Mev/nucleon is not a function of latitude for $\lambda > 52°$ N. The measured geomagnetic cutoffs in the region 51°–55° are consistent with calculated values for latitudes 4° higher. The increase in flux in this latitude range is in agreement with the energy spectrum data obtained at 55°. The cutoff would appear to be a sharp one although our evidence on this point is not conclusive. The measured shift in geomagnetic coordinates is much greater than the experimental errors and would seem to imply the existence of a perturbing mechanism in the vicinity of the earth. The observed long-term temporal variations agree very well with the sea-level neutron data. There would appear to be roughly a 3% change in alpha flux for each 1% change in the sea-level neutron counting rate. The Forbush decrease centering around March 13, 1956, was studied in great detail. There appeared to be a larger decrease in the alpha flux than in the proton flux. Alpha particles in the energy region 600–300 Mev/nucleon did not appear to be strongly affected by the decrease while those with energies greater than 800 Mev/nucleon changed by 36% from previous measurements during a "quiet" cosmic-ray period (July 7, 1955). An increase observed during the course of the flight was also recorded by sea level neutron counter.

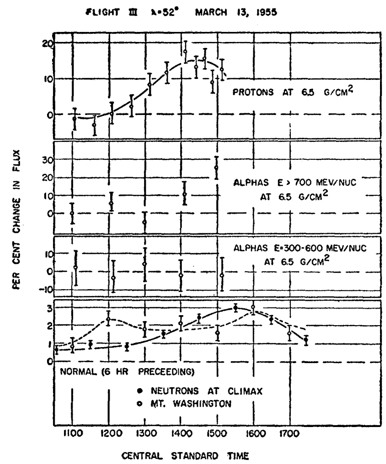

FIG. 10. Plot of protons, portions of the alpha-particle energy spectrum, and Climax and Mt. Washington neutron data *vs* time for flight V (March 13, 1956).

Again the high-energy alphas showed the greatest change while particles below 700 Mev/nuceon did not seem to show any appreciable change.

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