Slow-Neutron Intensity at High Balloon Altitudes*

R. C. HAYMES AND S. A. KORFF
New York University, University Heights, New York, New York
(Received June 22, 1960)

In order to extend measurements of cosmic-ray neutrons to top balloon altitudes, a flight was conducted on August 24, 1959, in which our system of identical counters filled with enriched and natural $B^{10}F_3$ was used. An altitude of 122 000 feet at a geomagnetic latitude of 55°N was attained, corresponding to 4-mb pressure, which is considerably higher than previous measurements. The counting rate dropped to about 1% of the maximum rate, which occurs at 60 000 feet. If one extrapolates this curve to the top of the atmosphere, one obtains an upper bound for the slow-neutron albedo of 0.03 neutron per cm²-sec. The background due to highly ionizing events in the counters increased exponentially to about 63 000 feet, with a derived mean free path of 152 g/cm². The background continued an exponential increase up to 122 000 feet, but with a mean free path of 15 g/cm².

I. INTRODUCTION

THE purpose of the experiment described herein was to extend measurements of the cosmic-ray neutron density to regions near the top of the atmosphere. Previous investigations[1–3] have been limited to altitudes below 90 000 feet, or approximately 15 millibars.[4]

The experiment has determined the density of those neutrons in the $1/v$ region at altitudes up to 122 000 feet, or 4 millibars. It is not possible to directly determine the flux of these neutrons from the data without additional information on the neutron energy spectrum.

It is of interest to measure the slow-neutron density at these high balloon altitudes for several reasons. The first of these concerns itself with the question of the rate of production of the C^{14} isotope in the atmosphere. The neutron balance in the atmosphere has been studied by Korff and others. Korff[5] has pointed out that C^{14} is produced by at least two processes, only one of which is measured by BF_3 counters, so that the numbers of neutrons determined from the radiocarbon measurements is greater than that measured by counters. The evaluation of the totals measured by counters at all altitudes including the highest, bears importantly on this problem. The second reason for this high-altitude measurement is the question of the origin of the Van Allen belts of radiation girdling the earth at several earth radii. Several investigators[6–9] have suggested that the trapped radiation is caused by the decay of neutrons in the space surrounding the earth. According to this view, these neutrons are created in the earth's atmosphere by the primary cosmic radiation, and some fraction diffuse back outward into space. It is obviously of interest to measure the source strength for this process. A measurement such as this will thus set an upper bound to the rate of production of protons in the Van Allen belts by this process.

II. EXPERIMENTAL METHOD

The experimental technique has already been described in detail by our group.[1] It employs two sets of proportional counters. One set is filled with BF_3 enriched to 96% B^{10}, while the other identical set utilizes the natural isotopic enrichment, which is 19% B^{10}.

A total of 4 counters[10] was carried aloft on this flight. Two were of the enriched type, and the others were of the "regular" variety. Each counter's wall thickness was 0.41 gm/cm² of aluminum, and had an active length of 53.5 cm. The diameter was 5 cm and the filling pressure was 25 cm of mercury. The counters had a

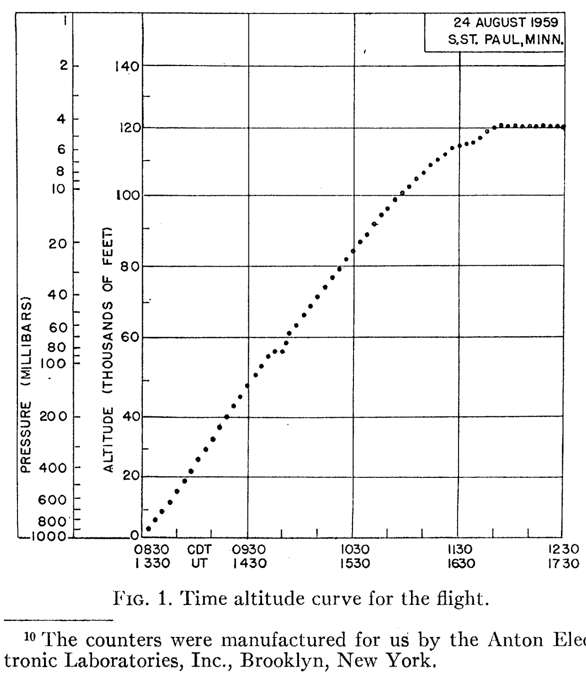

FIG. 1. Time altitude curve for the flight.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

1 R. C. Haymes, Phys. Rev. **116**, 1231 (1959).
2 R. K. Soberman, Phys. Rev. **102**, 1399 (1956).
3 W. N. Hess, H. W. Patterson, R. Wallace, and E. L. Chupp, Phys. Rev. **116**, 445 (1959).
4 U. S. Extension to the I. C. A. O. Standard Atmosphere (1958).
5 S. A. Korff, Nuovo cimento **8**, 796 (1958).
6 W. N. Hess, Phys. Rev. Letters **3**, 11 (1959).
7 S. F. Singer, Phys. Rev. Letters **3**, 188 (1959).
8 R. Karplus and A. J. Dessler, Phys. Rev. Letters 4, 271 (1960).
9 P. J. Kellogg, Nuovo cimento **11**, 48 (1959).

10 The counters were manufactured for us by the Anton Electronic Laboratories, Inc., Brooklyn, New York.

common operating point of 2300 volts, so that a single high voltage supply sufficed for their operation.

III. EXPERIMENTAL RESULTS

The balloon[11] was launched at 1328 U. T. on August 24, 1959 from South St. Paul, Minnesota, at a conventional geomagnetic latitude of 55°N. The trajectory was almost exactly east-west, so that latitude corrections are negligible.

The time-altitude curve is shown in Fig. 1. The altitude was measured by a hypsometer,[1] and also by an aneroid transducer.[11] The aneroid system failed at 57 000 feet, but previous experience[1] has shown the hypsometer to be quite accurate at the high altitudes.

A curve of the slow-neutron density versus atmospheric pressure is depicted in Fig. 2. This curve is proportional to the difference of the counting rates of the two sets of counters. It shows the counting rate that a counter filled with 100% B^{10} would yield in the presence of no background.

Figure 3 plots the neutron density as a function of a linear scale of altitude rather than pressure. The standard deviations are not indicated because the high counting rates reduced them to negligible size. The point at maximum altitude represents the data obtained from 3 hours at ceiling and is therefore also quite reliable.

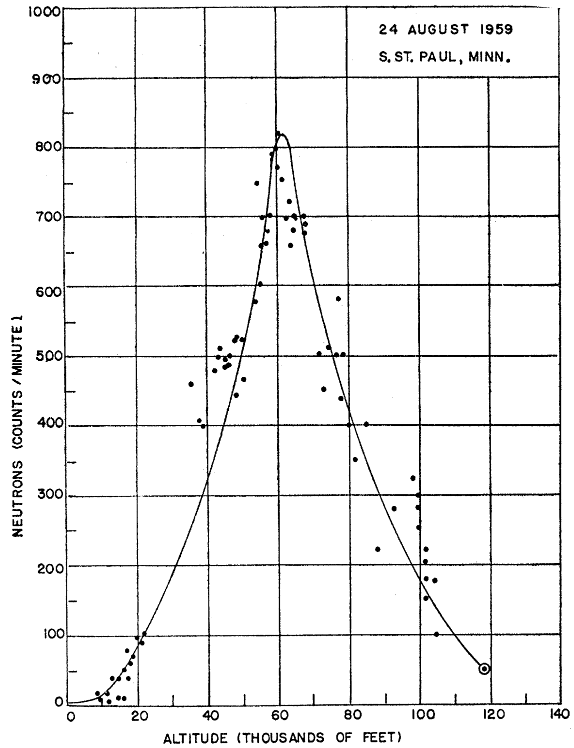

FIG. 3. Slow-neutron density as a function of altitude. The high altitude point represents three hours at ceiling.

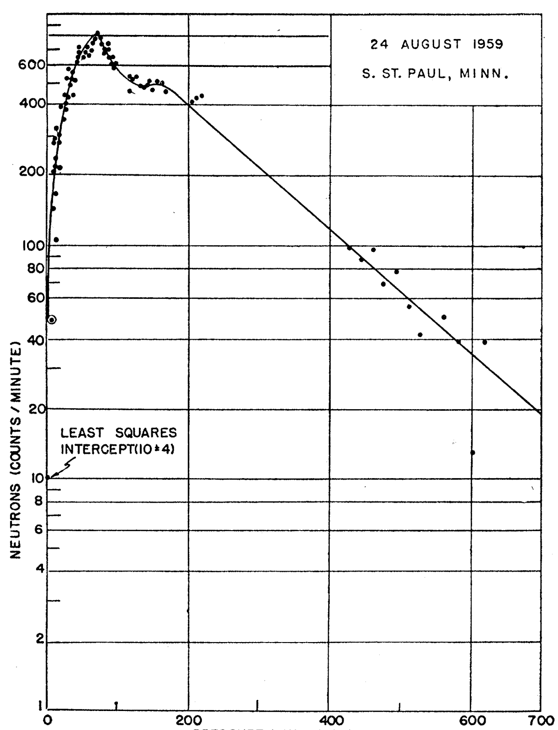

FIG. 2. Slow-neutron density vs atmospheric pressure. This curve has been corrected for background.

Figure 4 portrays the increase of the background radiation detected by the system with increasing altitude. Real BF_3 counters count all those events which form ionization equal to or greater than 2 Mev, the bias.

It is of interest, in the analysis of such flights, to determine if the geomagnetic field, ionosphere, etc., were disturbed during the flight. It appears[12] that this was a "normal" (i.e., neither "disturbed" nor unusually "quiet") day. The geomagnetic storm and related events of August 20–21, 1959 had ended before the flight was launched.

IV. DISCUSSION

As can be seen from Figs. 2 and 3, the counting rate at 122 000 feet is approximately 1% of the maximum rate. The maximum occurs at 60 000 feet, in agreement with previous observations,[1,2] and depends on the latitude. This 1% value appears to be in good agreement with the calculations of Hess, Canfield, and Lingenfelter.[13] These investigators solved a diffusion equation for those neutrons leaking out of the atmosphere.

[11] The 5-million cubic foot balloon and flight control instrumentation were manufactured by Winzen Research, Inc., Minneapolis, Minnesota.

[12] U. S. National Bureau of Standards, Central Radio Propagation Laboratory Report, CRPL-F182 (unpublished).

[13] W. N. Hess, E. H. Canfield, and R. E. Lingenfelter, University of California Radiation Laboratory Report, UCRL-5899, March 1960 (unpublished).

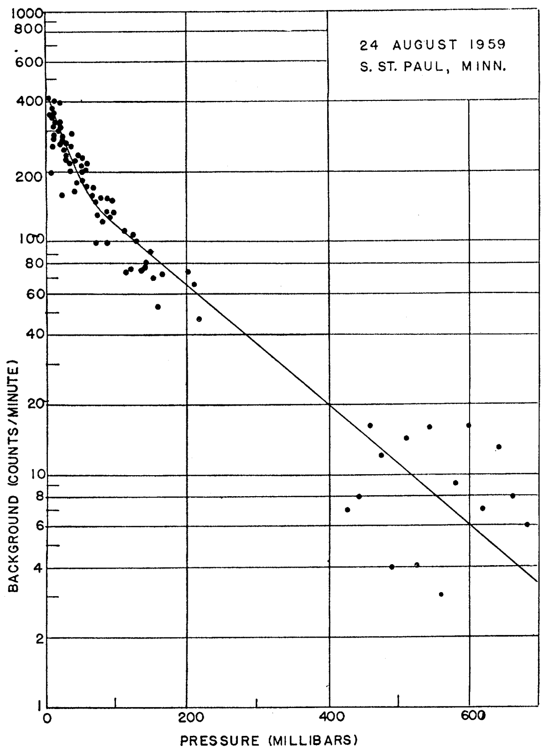

FIG. 4. Background radiation as a function of atmospheric pressure. This system detects those events which liberate more than 2 Mev in the counter.

It should be emphasized that this experiment detects only neutrons with less than 10 kev of energy. It is possible that the fast-neutron component will play an important role in the generation of the Van Allen belts, but such neutrons will not be detected by this apparatus.

Figure 3 shows that the neutron density continues to slowly decrease with increasing altitude, ever at the highest altitude achieved (122 000 feet). If one performs an exponential extrapolation to zero pressure ("infinite altitude"), one obtains the point shown in Fig. 2 at 10 ± 4 counts per minute. This point represents an extrapolation of the exponential curve found in the region from 16 to 4 millibars.

This point then represents an upper bound for the slow-neutron albedo. If one assumes an average energy of 0.2 ev for those neutrons detected by this system, then the flux would be 0.03 neutron per cm^2-sec at the top of the atmosphere.

This very low flux implies that a substantial fraction of the neutron albedo may be in the fast neutron component. As noted before, this experiment detects only those neutrons with less than 10 kev of energy. Our group is planning an extension of these experiments to determine the energy dependence of the albedo.

It is interesting to note that Fig. 4 shows the background steadily increases with altitude. This background, which consists of heavily ionizing events, is presumably due to star formation in the walls of these aluminum counters. The change of slope at 65 mb probably is evidence for two components of the star producing radiation. The two mean free paths derived from the slopes are 152 g/cm^2 and 15 g/cm^2. These could be fast neutrons and protons.[14] It is interesting to note that the lower-altitude figure (152 g/cm^2) is in excellent agreement with the 142 gm/cm^2 absorption mean free path that was determined for the neutron component.

V. ACKNOWLEDGMENTS

The authors would like to express their appreciation to F. Lapeter, J. Kohl, E. Christman, F. Hajnal, and Mrs. R. Mendell for their assistance during the flight and in the reduction of the data.

[14] J. J. Lord, Phys. Rev. **81**, 901 (1951).