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# II-2-2. The Cosmic Ray Neutron Density at High Altitudes*

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Our group at New York University has been making a series of measurements of cosmic ray neutrons at high altitudes during the past several years. This work, which is of interest in connection with the problems of A) isotope production, B) the neutron albedo and C) the energy balance, has been conducted using balloons and sounding rockets.

The instrumentation used on all these flights was rather similar. It consisted of $BF_3$-filled unmoderated proportional counters. At least two such detectors are carried aloft in each experiment. They are identical in all respects, except that the filling gas in one counter is enriched in the $B^{10}$ isotope, while the other counter contains gas depleted in this isotope. From a study of the difference of the two counting rates, one obtains[1] the slow-neutron density (that is, the density of those neutrons having less than 1 kev of energy). This technique also permits an evaluation of the counting rate due to "background" radiation; this radiation includes all those events other than neutrons which liberate as much ionization within the counter as does the $B^{10}$ (n, alpha) reaction.

The balloon flights have shown[2] that the slow-neutron density rises to a maximum at the 100 millibar level. The slope of this increase, which depends on the latitude[3], is approximately 160 gm/cm$^2$. At higher altitudes, the density decreases rapidly, with a slope of about 4 gm/cm$^2$, at least up to 122,000 feet. The density of slow neutrons at that altitude is $5\times10^{-8}$ neutrons/cm$^3$ at a conventional geomagnetic latitude of 55°N, and represents the average of 4 hours counting at ceiling.

It is also of interest to examine the behavior of the background radiation. This background of highly ionizing events in

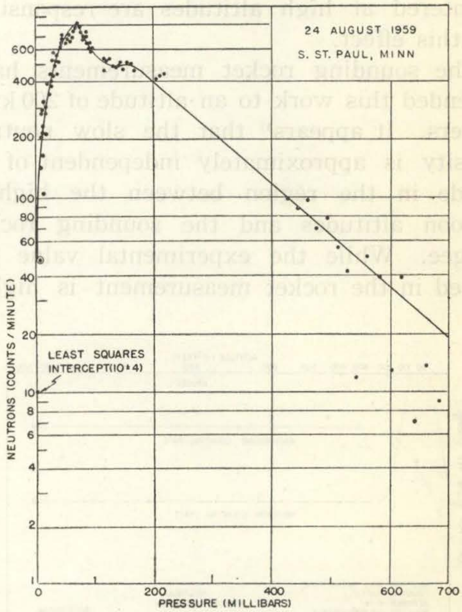


Fig. 1. Slow neutron counting rate as a function of altitude. The least squares intercept is equivalent to $5\times10^{-8}$ neutrons/cm$^3$.

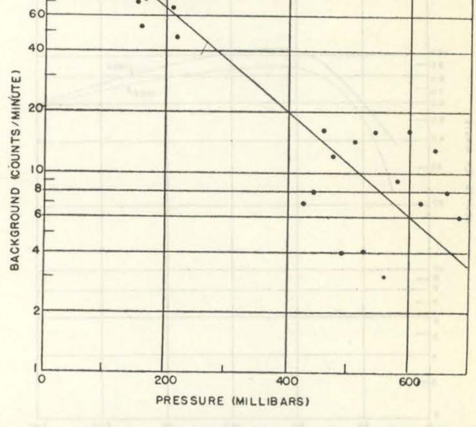


Fig. 2. Background counting rates a function of altitude. It is believed that the increase in slope above 63,000 feet is due to heavy primaries.

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the counter increases exponentially to about 63,000 feet with a derived mean free path of 152 g/cm$^2$. The increase is much sharper at higher elevations; the mean free path up to 122,000 feet becomes 15 gm/cm$^2$. We believe that the heavier nuclei which are encountered at high altitudes are responsible for this effect.

The sounding rocket measurements have extended this work to an altitude of 200 kilometers. It appears[4] that the slow neutron density is approximately independent of altitude in the region between the highest balloon altitudes and the sounding rocket apogee. While the experimental value obtained in the rocket measurement is higher than that noted above, this discrepancy can be explained through local production and moderation, and through the fact that slow neutrons are gravitationally trapped in the vicinity of the earth. Thus, it would appear that the slow-neutron density just outside the earth's atmosphere is $5\times10^{-8}$ neutrons/cm$^3$.

The background radiation flux appears to level off to a value of $0.019\pm0.001$ particles/cm$^2$·sec above 100 kilometers. This value is in good agreement with the flux obtained from the balloon flights. This flux can be explained in terms of the combination of heavy primaries, stars formed in the walls of the counters, as well as secondary radiation produced in the body of the rocket.

There is a little data on the time-variations of the slow neutron component at high altitudes. It appears[1] that the neutron density was about 12% lower in 1958, the period of maximum solar activity, than it was in 1954, when the sun was relatively quiet. However, this question requires a much more detailed investigation.

Some work has also been done on the energy spectrum of slow neutrons at balloon altitudes. At altitudes below the Pfotzer maximum, the spectrum is independent of altitude[5], but hardens sharply at higher altitudes. The index here is the "cadmium ratio," which is the ratio of the counting rate of a bare counter to that of an identical counter which is shielded by cadmium. This ratio drops sharply at altitudes above 60,000 feet, and begins to approach unity at 135,000 feet.

Several investigators have made[6,7,8] high altitude measurements using moderated counting systems. Such systems employ $BF_3$ counters which are surrounded by hydrogeneous substances, in an attempt to examine the variations of the fast-neutron flux. It should be pointed out, however, that a moderated counter detects neutrons produced in the moderator itself as well as those produced in the atmosphere. It is not possible to separate these two effects in such an experiment. It can therefore be said that an unambiguous determination of the fast-neutron flux at high altitudes has not yet been made. We are presently planning a series of such experiments, but no data are as yet available.

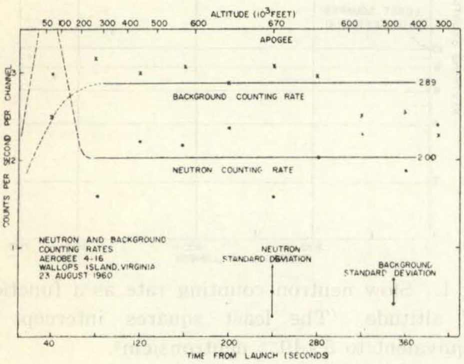


Fig. 3. Neutron and background rates.

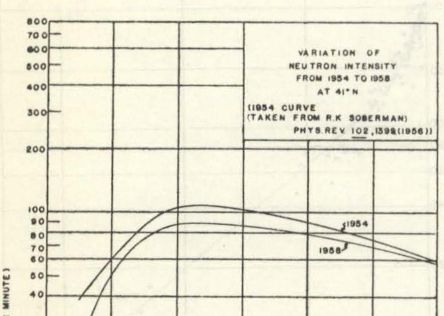


Fig. 4. The curves for 1954 and 1958.

### References

1) R. C. Haymes: Phys. Rev. **116** (1959) 1231.
2) R. C. Haymes and S. A. Korff: Phys. Rev. **120** (1960) 1460.
3) R. K. Soberman: Phys. Rev. **102** (1956) 1399.
4) W. P. Reidy, R. C. Haymes and S. A. Korff: Bull. Amer. Phys. Soc. **6** (1961) 361 (A). Detailed paper to be published shortly.
5) H. A. Bethe, S. A. Korff and G. Placzek: Phys. Rev. **57** (1940) 573.
6) S. J. Bame: private communication.
7) W. N. Hess and A. J. Starnes: Phys. Rev. Letters, **5** (1960) 48.
8) S. A. Korff and R. C. Haymes: J. Geophys. Res. **65** (1960) 3163.


### *Discussion*

**Rose, D.C.:** The curves you show of rocket measurements show about the same counting rate for neutrons and background. Can you say that the neutron intensity you are measuring is of the same order as the background of heavily ionizing particles realizing of course that there is a difference in efficiency.

**Korff, S.A.:** Assuming a thermal neutron goes through the counter on an average path, efficiency would be around ten percent. About 30 counts per minutes were recorded at the top of the atmosphere. Hence the flux passing through the counters was roughly 300 per minute. On the other hand, the background counting rate was 400 per minute. If the neutrons were, on the average, faster than thermal, the efficiency is reduced proportionally inversely to the velocity you assume, and the counts correspond to more neutrons. The order of magnitude of the fluxes could therefore be the same. However, it must be recalled that this experiment does not determine the average neutron energy.

**Bagge, E.:** In your 2nd slide which showed the difference between $n$-measurements with enriched and without enriched boron, there was a fine structure in the curve for intensities below that of maximum neutron intensity. Would you think that this fine structure is of physical significance and if so, what physical significance you attribute to it?

**Korff:** Yes, the fine structure has significance. The peak at the Pfotzer maximum is due to the neutrons and highly ionizing events such as stars and heavily ionizing primaries at very high elevations.