ATMOSPHERIC NEUTRONS ON SNOW FIELD AT MIZUHO STATION, ANTARCTICA

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Abstract: Cosmic-ray-produced atmospheric neutrons with energies of less than 1 MeV were observed on the snow field at Mizuho Station (70.7°S, 44.3°E, 2230 m elevation), East Antarctica. Five-month recordings of the two BF_3 proportional counters, which were installed about 70 cm above and below the snow surface respectively, show that atmospheric neutron fluxes observed at air-snow boundary are between the two expected fluxes at air-soil and air-water boundaries. The attenuation of neutrons in very deep snow cover is intermediate between that in snow cover on soil, that is, a snow-soil interface, and in water, equivalent to a water-water interface. This work suggests an application to estimation of water equivalent depths of a snow cover accumulated on a permanent snow field, or on a glacier, using atmospheric neutrons.

1. Introduction

One of the current problems concerning atmospheric neutrons produced by cosmic radiation is the so-called interface effect of transition from air to soil, water and metal near the earth's surface (KASTNER *et al.*, 1970; O'BRIEN *et al.*, 1978). This effect is characterized by two different spatial distributions of neutron fluxes with respect to altitude and zenith, depending on the neutron energy. The former was investigated for slow neutrons of less than 1 MeV by helicopter experiments (KODAMA *et al.*, 1980) and the latter was measured for 10–100 MeV fast neutrons by the recoil proton method (PRESZLER *et al.*, 1974). Most of these measurements were carried out under a common environment of air-soil boundary. But there are few similar measurements near the air-water boundary. Since the influence of air-water boundary on the behavior of atmospheric neutrons is considered to be reproduced equivalently at an air-ice, or air-snow boundary, neutron measurements on the Antarctic snow field are available for studies of the air-water interface problem.

One related problem is found in the ground albedo neutrons which are produced in soil and scattered upward into the air. Their flux amounts to as large as 40% of the total neutron flux for both slow and fast neutrons (KODAMA, 1983). Meanwhile, the total neutron flux on the air-water boundary is lower than that on the air-soil boundary, by about 30 and 50% for slow and fast neutrons, respectively (KODAMA *et al.*, 1980; O'BRIEN *et al.*, 1978). This is interpreted qualitatively by the lesser production and higher absorption of neutrons in water. However, the total and albedo neutron fluxes for an infinite depth snow cover are unknown. This is also directly concerned with an application of cosmic-ray snow gauge of KODAMA (1980) on an ice field or glacier. Whether the same attenuation curve of neutrons as for snow cover over land holds there or not is not yet confirmed.

There are two experimental advantages for atmospheric neutron measurements on the Antarctic continent. Since the Mizuho Station (70.7°S, 44.3°E), East Antarctica is located at 2230 m elevation, atmospheric neutron fluxes are expected to be five times the sea level flux owing to the altitude dependence of the cosmic ray nucleonic component, and also the latitude effect gives 1.6 times the Tokyo flux at Mizuho Plateau (KODAMA, 1979). These two effects favorably improve the counting statistics. The other advantage is the ease of maintenance of instruments, even though some special devices are necessary for stable operation at low atmospheric temperature. It is of interest to measure atmospheric neutrons above and below the snow field, in the light of the air-water interface effect, particularly the depth dependence in the snow field, in which no sand or rock is found until a considerably deeper depth.

2. Measurements

The instrument used for neutron detection is a high-pressurized BF_3 counter ($20\phi \times 715$ mm, 1200 Torr) surrounded by 2-cm thick polyethelyne cylinder. The whole is contained in an air-tight aluminum cylinder ($80\phi \times 1185$ mm) together with the associated electronic assembly. Two detectors were prepared and carried to Mizuho Station via Syowa Station. As is indicated by marks A and B in Fig. 1, one detector was placed at point A, about 70 cm above the snow surface about 100 m apart from

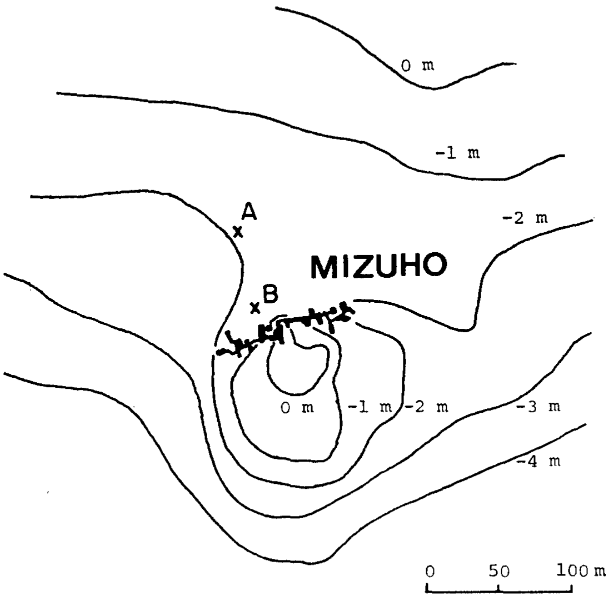

Fig. 1. Arrangement of two neutron sensors at points A and B near Mizuho Station, whose huts are indicated by black mosaic pattern.

the Mizuho observation huts, and another at B, about 70 cm under the surface near the huts. The accumulated counting rates of pulse singnals from the detectors were recorded by a digital printer twice a day. The snow cover thickness over detector B was read by a snow scale once a day.

Continuous observations started in April 1982, but no reliable data were acquired during the winter season, because of electrostatic noise induced by blizzards on the coaxial cables between the outdoor detectors and the indoor recorder. Since November 1982 when most of the cables sank enough below the snow surface and wind speeds became less than 10 m/s, normal operation of detector B was achieved with a shorter cable, but detector A with a longer cable only operated normally after several more months. Daily plots of counting rates from detector B on the snow surface are shown in Fig. 2, where snow cover depths measured by the snow scale are also shown. Counting rate fluctuations of detector B are very much larger than the statistical uncertainty represented by circle size, covering the range from 32000 to 38000 counts/day. In particular, the origin of a transient decrease followed by gradual recovery which occurred in December is not yet identified, because no corresponding variations appear in both the snow cover depth and the primary cosmic ray intensity measured by the Tokyo NM-64 cosmic ray neutron monitor, as seen in Fig. 2. Counting rates from detector A under the snow surface were 16286±271/day on a 9-day average during December to January 1983.

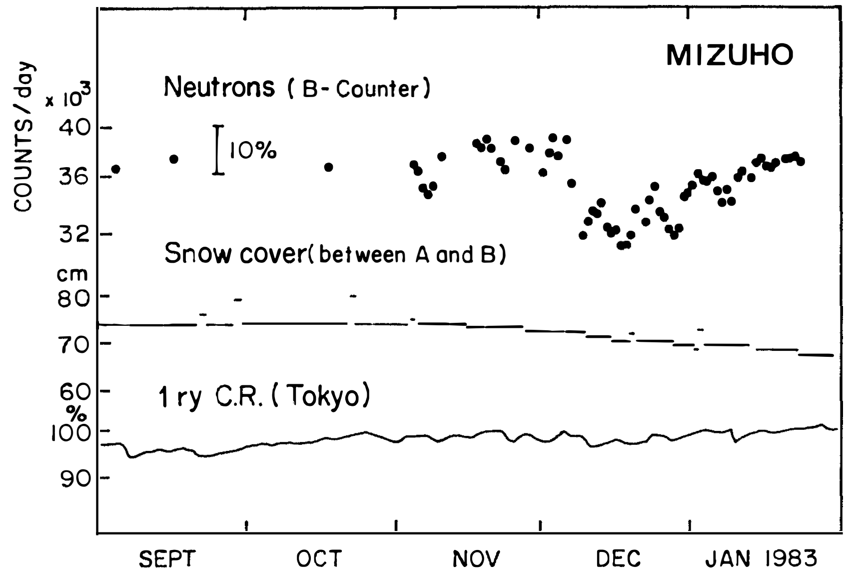

Fig. 2. Day-to-day variations of atmospheric neutron counts over the snow field, snow cover depths and primary cosmic ray intensity measured by the Tokyo NM-64 cosmic ray neutron monitor.

3. Discussion

Now let us estimate the expected neutron flux at Mizuho from the sea level flux at middle latitude. Counting rates obtained in Tokyo, prior to transportation of the present apparatus to Antarctica, were 5530 counts/day 3 m above the ground (in

1012.6 mb), from a 8-month running operation. Assuming both a latitude factor of 1.6 and altitude factor of 5.0 between Tokyo and Mizuho, an expected daily count of 44240 at Mizuho is deduced. Hence, the observed flux of detector B, that is 32000 to 38000, is lower than the expected flux on land, even if the upper limit is taken.

In general, atmospheric neutron fluxes at the air-water boundary are relatively lower than those at the air-soil boundary owing to lesser production and larger absorption of neutrons in water. According to the measurements on Lake Yamanaka (13 m in maximum water depth), the neutron flux on the lake surface is about 30% less than on land (KODAMA *et al.*, 1980). This reduction rate gives an another expected count of 31000/day at Mizuho, which is lower than the lower limit of the Mizuho observed fluxes. After all, the atmospheric neutron flux on the snow surface at Mizuho Plateau is between two expected values on land and on a lake. This is explained by the slightly smaller absorption of neutrons in snow due to smaller density effect. If one considers spatial distributions of atmospheric neutron fluxes in terms of downward and upward components, fractional rates of both components for each of different three boundary conditions can be summarized as shown in Table 1, where the total flux is normalized to unity at the air-soil boundary.

Table 1. Fractional rates of atmospheric neutron fluxes, normalized to unity for total component at the air-soil boundary.

Component	Boundary		
	Air-soil	Air-water	Air-snow
Downward	0.6	0.6	0.6
Upward (Albedo)	0.4	0.1	0.2–0.3
Total	1	0.7	0.8–0.9

Next, let us consider the neutron flux by detector A under the snow surface. The ratio of this count to that of detector B should vary with thickness of snow cover over detector A, characterizing by a definite attenuation equation in snow. When a snow cover exists not only over the detector but also below it, the attenuation of neutrons in snow seems equivalent to that measured by a detector placed in water. KODAMA (1979) gave the following attenuation equations based on water pool experiments and snow observations:

$$N_w = N_0 \exp[-a\{1-\exp(-bW)\}], \quad \text{for } W \leq d \tag{1}$$

and

$$N_w = N_d \exp[-c(W-d)], \quad \text{for } W > d \tag{2}$$

where N_w is the neturon count measured under snow cover having a water equivalent of W cm. N_0 and N_d are neutron counts at $W=0$ and $W=d$, respectively. Four parameters a, b, c and d are given for the different boundary conditions at snow-soil and water-water interfaces. If eqs. (1) and (2) are also applicable to the snow-snow interface on Mizuho Plateau, the count ratio A/B of 0.48 to 0.42 between detectors A and B gives an estimated water equivalent depth of snow of 12 to 18 cm, or 33 to 60 cm, corresponding to the water-water or snow-soil interface. On the other hand, the observed snow depth over detector A was about 70 cm during December 1982 to January 1983 when detector A operated normally, as seen in Fig. 2. This gives a snow density near the surface of either 0.2 to 0.3 or 0.5 to 0.9. The snow density actually measured was about 0.4, which is between the above two estimated density groups. It is, therefore, concluded that the attenuation of neutrons at the snow-snow interface is between that at an ordinary snow-soil interface and an idealized water-water interface. This does not contradict the spatial distributions of neutron fluxes in Table 1, but quantitative conclusions need further experiments, particularly at different depths under the snow surface.

4. Conclusions

Fluxes of atmospheric neutrons with energies of less than 1 MeV on a snow field having an effectively infinite depth on Mizuho Plateau, East Antarctica, are found to be between the fluxes on soil and water. The attenuation of neutrons in snow cover on snow is between those in snow cover on soil and in water. These suggest that the atmospheric neutron technique for estimating snow water equivalents is applicable to a snow cover accumulated on an ice field or glacier, if the correct attenuation curve of neutrons is determined experimentally.

The instruments used in this work were provided by courtesy of the Institute of Physical and Chemical Research. In particular we thank Mr. K. NAKAI for his efforts in preparation of the detectors. Also thanks are due to Mrs. K. IMAI for data supply for the Tokyo NM-64 cosmic ray neutron monitor.

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(*Received May 7, 1984; Revised manuscript received August 20, 1984*)