Proceedings of ICRC 2001: 3073 © Copernicus Gesellschaft 2001

ICRC 2001

The possible use of high altitude lakes as solar neutron detectors

K. Watanabe, Y. Muraki, T. Sako, and T. Takami

Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, 464-8601, Japan

Abstract. The possibility is investigated of installing a huge solar neutron detector in lakes located high mountains. Instead of using conventional neutron monitors, ^{3}He proportional counters are supposed to be placed in the lake water. High energy (>100 MeV) neutrons entering into the water are thermalized and detected by the counters aligned as far apart as possible. The optimal alignment of counters was determined using the Geant3 Monte Carlo simulator. We have found, however, the large cross section for thermal neutrons in water does not allow the installation of the counters at wide separation. With the optimal separation of 15 cm, an extremely large detector cannot be realized. A test experiment has been performed with a ^{3}He proportional counter, which is set in a water tank at Mt. Norikura in Japan.

1 Introduction

The sun is the only robust nearby astrophysical accelerator of ions. The study of solar flares, where high energy particles are generated, is believed to provide us with fruitful information on the problem of cosmic-ray acceleration. On the other hand, due to the interplanetary magnetic field, low energy solar cosmic-rays cannot arrive at the earth straightforwardly. To avoid such propagation effects, observations of neutral particles have been proposed (Ramaty et al., 1983). Neutrons produced by accelerated protons in the solar atmosphere ('solar neutrons' hereafter) are the best probe to investigate the acceleration of protons (or ions).

At ground level, solar neutrons are detected with the traditional neutron monitors spread all over the world and with the special neutron telescopes developed by our group. So far, solar neutrons have been detected in association with a number of major solar flares (Lockwood and Debrunner, 1999; Muraki et al., 1992). Although several interesting candidate events observed during the solar cycle 23 are now under analysis (Tsuchiya et al., 2001; Flueckiger et al., 2001), it is time to develop detectors with a larger sensitivity for the next generation.

The idea presented in this paper is to expand the concept of the traditional neutron monitor. Neutron monitors themselves are difficult to enlarge because they use a massive lead for producing thermal neutrons. We have studied the possibility of substituting water for lead. Because there are usually lakes in the high mountains where the solar neutron telescopes have been placed, huge neutron detectors could be realized if the substitution works effectively. We also propose the use of ^{3}He proportional counters, which have a higher sensitivity to thermal neutrons than BF_3 counters.

In this paper, we first describe the basic properties of the ^{3}He counters in section-2. In section-3, the behavior of thermal neutrons in various materials (water, lead) is discussed with the aid of Monte Carlo calculations using Geant3. In section-4, the optimal alignment, separation of the new detectors and their sensitivity are presented. Some results of test experiments at Mt.Norikura is also presented in section-5. Finally, our conclusions are summarized in section-6.

2 ^{3}He counter

The helium-3 proportional counter used in this study (LND25373 produced by LND, Inc.) is a cylindrical tube with 50 mm diameter and 200 cm length. The tube is filled with 3040 torr of ^{3}He gas. The ionization loss of a passing cosmic ray muon is typically below 10 keV, which is negligible compared with the Q-value which occurs in the nuclear reaction described below.

Thermal neutrons are captured by ^{3}He through the reaction, $^3\mathrm{He} + \mathrm{n} \rightarrow {}^3\mathrm{H} + \mathrm{p}$. The Q-value of the reaction, 765 keV, is shared into the kinetic energies of ^{3}H and p. The cross section of this reaction rapidly increases with decreasing neutron energy: $\sim 10^2$ barns at 100 eV and $\sim 10^4$ barns at 0.01 eV. The cross section is slightly higher (less than factor 2) than that of the BF_3 counters that are used in conventional neutron

---

Correspondence to: Takashi Sako (sako@stelab.nagoya-u.ac.jp)

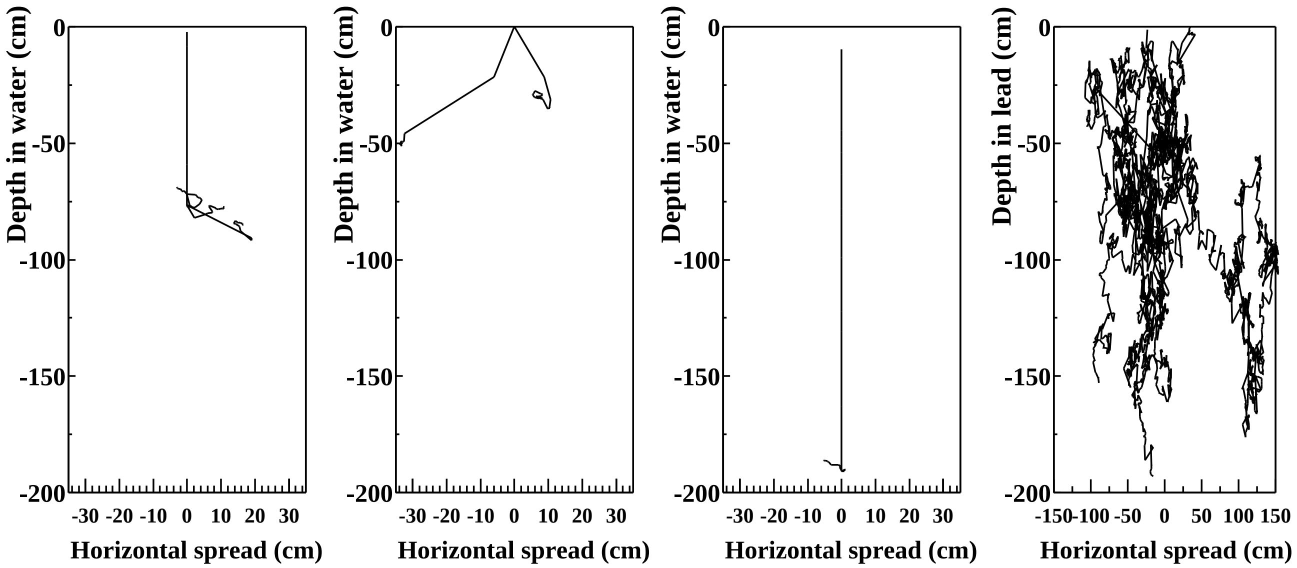

Fig. 1. Typical simulated tracks of neutrons in water and lead. The three left panels show the tracks in water and the right panel shows the tracks in lead. Note that the horizontal scale is different for the two materials. Each panel corresponds to a single incident neutron with an energy of 100 MeV. A neutron is injected at the position (0, 0) into the downward direction.

monitors. However, because a ^{3}He counter can be operated with a high pressure (e.g. 3000 torr), a high detection efficiency can be achieved. In the case of LND25373, more than 50% of neutrons with energy below 0.5 eV are detected when they pass 5 cm (diameter of the counter) in the counter.

3 Thermal neutrons in water and lead

Primary solar neutrons with energies below 100 MeV suffer heavy attenuation in the atmosphere of the earth (Shibata, 1994) as well as decaying during their flight between the sun and the earth. Therefore for ground-based observations, the useful energy range is above 100 MeV. To detect such high energy neutrons through a nuclear capture reaction, thermalization of the neutrons is a crucial process. At the same time, thermalized neutrons must diffuse through the material until they meet one of the counters. Material with a large cross section for higher energy neutrons and small cross section for lower energies is ideal.

Secondary neutron tracks both in water and lead were simulated using Geant3. Some typical tracks for neutrons with an incident energy of 100 MeV are shown in Fig-1. Thermal neutrons were tracked down to an energy of 10^{-3} eV. Apparently, the total diffusion path length is longer in lead. This means that neutrons have a chance to meet a proportional counter with a larger probability. That is the reason why lead is chosen as a producer for neutron monitors (Hatton, 1971). In spite of its disadvantages, a detector using water is capable of enlarging the area up to the size of a lake. To optimize the detection efficiency of the detector, counters must be aligned at intervals of the order of a typical diffusion length. The average distribution of thermal neutrons in water is presented in Fig-2, where the number density of neutrons with energies below 1 keV is plotted. When 100,000 100 MeV neutrons were injected, 6,400 low energy neutrons were found at the maximum contour of Fig-2. Neutrons were counted in every 5 cm × 5 cm × 5 cm cubic volume. From Fig-2, it can be seen that the optimum separation of the counters is about 15 cm at a depth of 30 cm. In further simulations, we fixed the separation at this value. Fig-2 also indicates that neutrons are widely distributed in the vertical direction. It would therefore be effective to install counters aligned in the vertical direction. Of course, such an alignment makes the physical area quite small, but it would achieve a higher detection efficiency. If we define the sensitivity as (physical area)×(efficiency), a higher efficiency may compensate for a smaller area.

4 Properties of the new detector

We have simulated two cases of counter alignment. One is horizontal and the other is vertical as shown in Fig-3. In both cases, the separation was fixed at 15 cm as described in section-3. For the horizontal design, counters were placed at a depth of 30 cm where the number of thermal neutron reaches a maximum. Vertically incident neutrons were uniformly injected into the water within the area shown shaded in Fig-3. In the case of horizontal alignment, six counters were placed in a manner similar to an existing neutron monitor. In the case of vertical alignment, 900 counters (30×30 array) were used. Although the detection efficiency becomes smaller near the edge of the arrays, the effect becomes negligible if we use a large number of counters. This is because the typical diffusion length of thermal neutrons, 15 cm, is

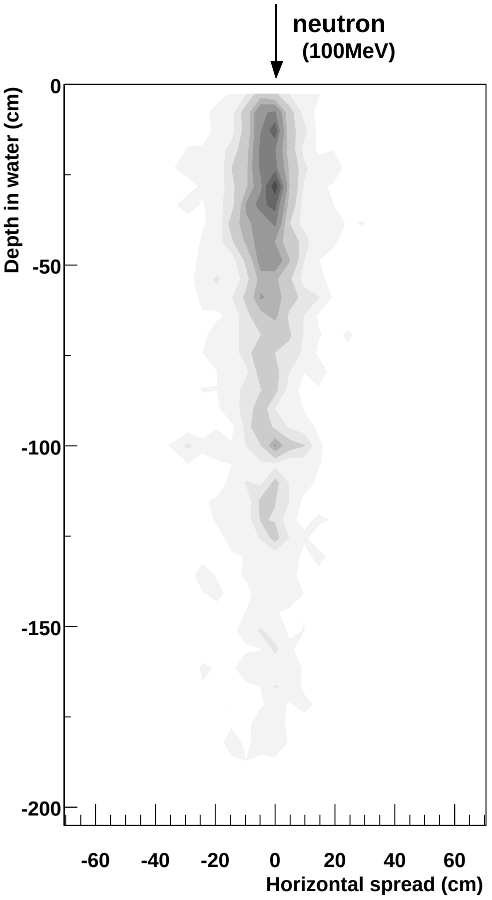

Fig. 2. Number density of low energy neutrons (< 1 keV) in water. 6,400 low energy neutrons were found at the darkest contour when 100,000 neutrons with 100 MeV were injected. The contour level is linearly scaled. The number of neutrons was counted in every 5 cm × 5 cm × 5 cm cubic volume along the x-z plane. (The z-axis is defined as the injection direction and the x-axis is arbitrarily defined in the horizontal direction.)

smaller than the size of arrays we propose. Therefore, we regard the detection efficiencies obtained using simulations as being uniform over the array.

The detection efficiencies are summarized in Fig-4 as a function of the incident neutron energy. As expected from section-3, higher efficiency is obtained with the vertical alignment. If we assume the use of 1000 counters, the physical coverage becomes 300 m^2 and 22.5m^2 for the horizontal and vertical cases respectively. Combined with the detection efficiency, the sensitivity becomes some square meters at 100 MeV, which is comparable with the sensitivity of currently operated neutron monitors. In case of the 6NM64 neutron monitor, the physical area is 6 m^2 and the efficiency is 0.25 at 100 MeV. This results in a sensitivity of 1.5 m^2, same order of our water detectors.

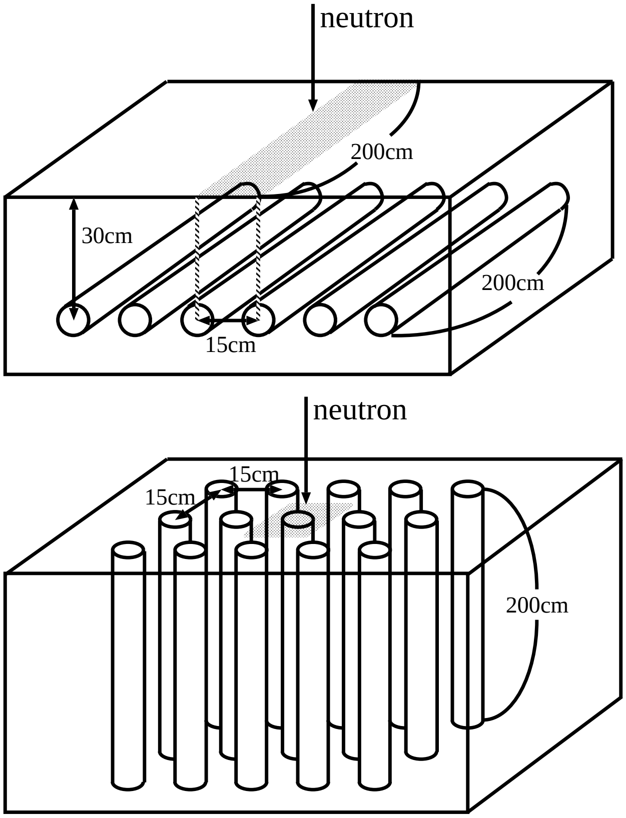

Fig. 3. Simulated set-ups of the ^{3}He counters in water. Top : For the case of ’Horizontal’ alignment. The counters were fixed at 30 cm under the water surface at intervals of 15 cm. Neutrons were uniformly injected in a 200 cm × 15 cm area on the surface as indicated by the shadow in the figure. Bottom : For the case of ’Vertical’ alignment. The counters were again placed at 15 cm intervals. Neutrons were injected in an area 15 cm × 15 cm on the surface.

5 Test experiments

From November 2000, we have continuously operated a ^{3}He counter placed in the water tank at the Mt. Norikura cosmic-ray observatory (137°.5E, 36°.1N, 2770 a.s.l.). The counter is contained in a stainless steel waterproof package with an amplifier and a discriminator circuit (Fig-5). High voltage is generated by a DC-DC converter in the package. Through a half year of winter, the counter has given a stable output even under the severe conditions existing on the high mountain (-25°C minimum temperature).

Because the counter is placed in deep water (200 cm below the surface), the counting rate is small as expected from Fig-2. The absolute counting rate expected from cosmic-rays will be calculated using a simulation to validate the simulation results described above. More detailed tests of the counting rate are planned after the ice in the tank melts.

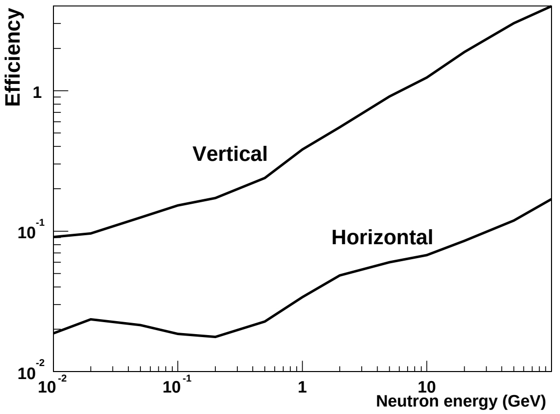

Fig. 4. Detection efficiency of the water neutron detectors as a function of the incident neutron energy. Results for the two alignments are presented. Because the efficiency is defined as (Number of detected thermal neutrons)/ (Number of incident neutrons), it becomes >1.0 when multiplicity is large. This definition is consistent with that used for traditional neutron monitors.

6 Conclusions

A new generation solar neutron detector using a huge volume of lake water has been studied. The water is supposed to work as a producer of thermal neutrons as is the case with lead in traditional neutron monitors. However, a Monte Carlo study showed the thermal neutrons did not spread in the water as effectively as in lead. This is mainly because of the difference of the cross section for thermal neutrons between water and lead. The relatively large cross section in water prevents thermal neutrons from arriving at counters aligned at wide separation. Even when using 1000 ^{3}He counters, the sensitive area of the detector is only same order of that of a 6NM64 neutron monitor.

Although water is not a good producer of thermal neutrons, it would be worth considering the possibility of using natural materials (rocks, for example) to realize an extremely large area neutron detector for the next solar cycle.

Acknowledgements. The authors thank Dr. John Clem, University of Delaware, who kindly made suggestions about the read-out circuit of the ^{3}He counter. We also thank the staff of the Norikura observatory, Institute for Cosmic Ray Research, the University of Tokyo. They helped us to install the ^{3}He counter and the observations have been possible thanks to their maintenance work even in the winter season. The authors thank Prof. Ian Axford for careful reading of the manuscript.

References

Flueckiger, E. O. et al., 27th Intern. Cosmic Ray Conf., Hamburg, these proceedings.

Hatton, C. J., Progress in Elementary Particle and Cosmic Ray Physics, *X*, ed. J. G. Wilson and S. A. Wouthuysen, 1–100, 1971.

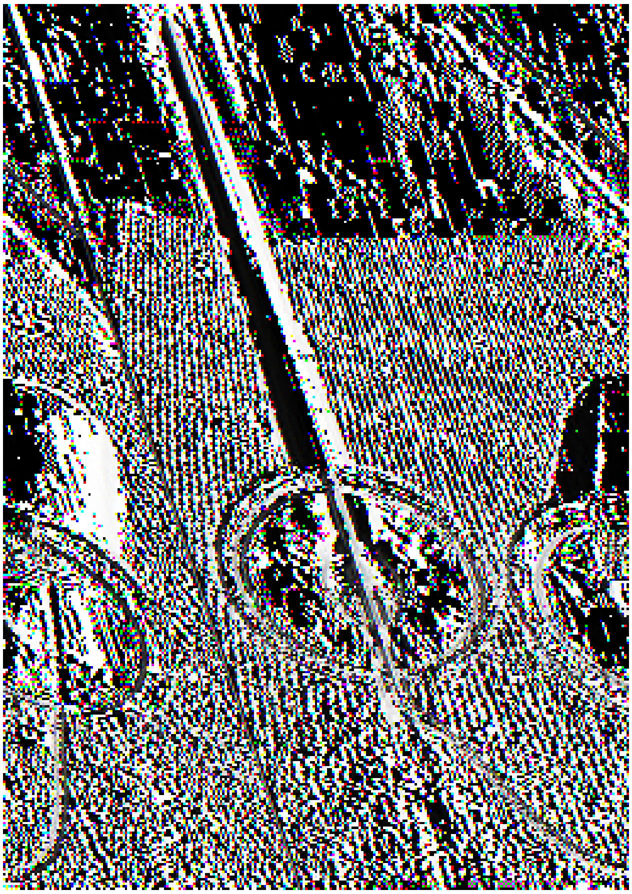

Fig. 5. Photo of the ^{3}He counter with the waterproof package installed in Mt. Norikura. The top hat-like tube in the right side contains an amplifier, a discriminator, and a DC-DC converter to generate a high voltage.

Lockwood, J. A. and Debrunner, H., Space Sci. Rev., *88*, 435–500, 1999.

Muraki, Y. et al., ApJ, *400*, 75–78, 1992.

Ramaty, R., Murphy, R. J., Kozlovsky, B., and Lingenfelter, R. E., ApJ, *273*, L41–L45, 1983.

Shibata, S., J. Geophys. Res., *99*, 6651, 1994.

Tsuchiya, H. et al., 27th Intern. Cosmic Ray Conf., Hamburg, these proceedings.