Measurement of Cosmic Ray Neutron Spectra in the Energy Region of 20-200 MeV at the Summit of Mauna Kea and Several Different Altitudes

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Abstract: In order to get accurate soft error rate of computer system, we measured cosmic ray neutron spectra at the summit of Mauna Kea and several different altitudes.

Introduction

Nowadays, the information on the flux of cosmic ray neutrons has become quite important for the computer technology. Since the reduction of LSI (large scale integrated circuit) scaling proceeds, the effect of cosmic ray neutrons predicted to become significant. Neutrons hit the LSI of the computer and make pseudo-signals and false data [1, 2]. This phenomenon is known as soft error of the computer. The soft error is defined as a single event upset (data error) in a memory cell that can be correctly rewritten. The error is "soft" because the circuit itself is not permanently damaged and behaves normally after the data state has been restored [3].
The soft error may cause incorrect operation of the computer system, and in the worst case, the computer system will be stopped. Therefore, the soft error may cause severe situation especially in mission critical application. Many efforts have been made to reduce soft error rate. The cause of soft error is α-particle, thermal neutron, and high-energy neutron. In the latest semiconductor technologies, influence of α-particle and thermal neutron is fairly reduced by using material technology. However, the influence of high-energy neutron still remains. Therefore we focus on high-energy neutron.

For evaluating the reliability of computer systems, the accurate estimation of the soft error rate has become essential. In this purpose, the accurate observation of the cosmic ray neutron spectrum in the energy range up to several hundreds of MeV has been anticipated.
In this study, we report the energy spectra of neutron in the energy range of *ca* .20 MeV – 200 MeV at various altitudes including the summit (Subaru Telescope, 4200 m) and foot (Hilo City, ~100 m) of Mauna Kea (Hawaii) and New York City (100 m). Reason for measuring at Mauna Kea is wide elevation span. There are many factors that determine the neutron flux (altitude, geomagnetic ridgidity etc.), but we can extract the effect of elevation by measuring at the summit (4200 m) and foot (~100 m) of Mauna Kea. The spectrum measured at sea level of New York City is also important because it is used as a *de facto* standard of the neutron spectrum in the field of computer technology.

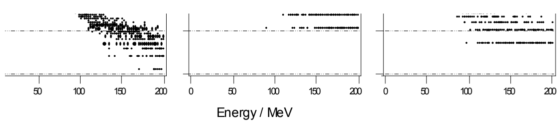
Experimental

Neutron Spectrometer

The neutron spectrometer used in this study consists of two apparatus; Bonner multi-sphere spectrometer and scintillation counter. The Bonner multi-sphere spectrometer is for low-energy region (≤ 20 MeV), and the scintillation counter is for higher energy region (40 – 200 MeV).

Figure 1: Experimental apparatus for measurement of cosmic ray neutron spectra. (Left) Bonner multi-sphere spectrometer (right) scintillation counter.

Figure 1 shows the spectrometer set in the building of Subaru Telescope.
The Bonner multi-sphere spectrometer is constructed based on a spectrometer firstly introduced by Bonner *et al.* [4]. In this study, we use four 2-inch ^{3}He proportional counters enclosed by a polyethylene moderator balls with various thickness up to 200 mm.
The scintillation counter uses 10 cm-thick plastic scintillator as a main detector. The 10 cm scintillator is surrounded by 1 cm-thick plastic scintillators used as veto. All scintillators are enclosed in lead box. Scintillation light is detected by photomultiplier. Detection signals are accumulated on multi-channel analyzer after amplification. The neutron is detected by taking anti-coincidence with veto signal.



The plastic scintillator with 2 cm-thick is also used as main detector for 8 – 40 MeV range.

Results and Discussion

Spectral change

In figure 2, neutron spectra measured with 10 cm-thick scintillator are shown. The energy range is 40 – 200 MeV. The vertical axis is normalized by observation time.
The shapes of the three spectra are fairly similar. This observation is consistent with the formerly reported spectra [2]

Altitude Dependence of the Flux

In Figure 3, neutron spectra of 8 – 40 MeV range measured at inside and outside of Subaru Telescope building are shown. Because shapes of the spectra are quite similar, shielding efficiency of the building seems to be nearly constant versus energy in this range. The total flux ratio [inside]/[outside] is 0.47. In Table 1, measured neutron flux are summarized.
To consider the altitude effect, a correction equation is proposed.

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Figure 2: Neutron spectra measured at (a) New York City, altitude ~100 m (b) Mauna Kea summit (in the Building of Subaru Telescope), altitude 4200 m (c) Hilo (foot of Mauna Kea, altitude ~ 100 m)

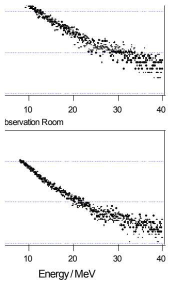

Figure 3: Neutron spectra measured by 2 cm scintillator. (8 – 40 MeV) (a) measured at outside of Subaru Telescope building (b) measured at inside of the building

$$\gamma = \frac{\Phi_n}{\Phi_0} = \exp\left[-\frac{A - A_0}{L}\right] \qquad (1)$$

where, γ is correction factor, Φ_n, and Φ_0 are neutron flux at the altitude of interest and reference altitude, respectively. A and A_0 are air pressure at relevant altitudes (g/cm^2). L is flux attenuation factor (L = 148 g/cm^2 for neutron)

For calculating A and A_0, NASA-Langley formulation is proposed [3];

$$A = 1033\exp[-0.03813 \times (a/300) - 0.00014 \times (a/300)^2 + 6.4 \times 10^{-7} \times (a/300)^3] \qquad (2)$$

where, a is altitude in meters from the sea level.

According to (1) and (2), the flux ratio [Mauna Kea Summit (open air)]/[Foot of Mauna Kea (open air)] is calculated as 18.1. On the other hand, from the data of Table 1, flux ratio [Mauna Kea Summit (open air)]/[Foot of Mauna Kea (open air)] is calculated as 8.06. The reason for discrepancy is not clear at present stage.

Neutron flux at New York City is higher than that at foot of Mauna Kea. This observation is consistent with the fact that the geomagnetic rigidity at New York (5 GV) is lower than that of Hawaii (13 GV).

Time Dependent Change

Figure 4 shows time dependence of neutron flux measured at Mauna Kea Summit. Standard deviations of the neutron flux in the range of 40 – 200 MeV (figure 4b) and 20 MeV (figure 4c) are 2.8 % and 5.6 % of average value, respectively. The flux seems to be nearly constant both in 40 – 200 MeV and 20 MeV range in the time span of *ca*. 4 months.

Location	Altitude (m)	Geomagnetic rigidity (GV)	Neutron flux (relative)
New York City (open air)	100	5	1.00
Mauna Kea Summit (open air)	4200	13	6.77
Mauna Kea Summit (building)	4200	13	3.18
Foot of Mauna Kea (open air)	100	13	0.84

Table 1: Neutron flux in energy range of 40 – 200 MeV measured in this study. The neutron flux is normalized at New York value.

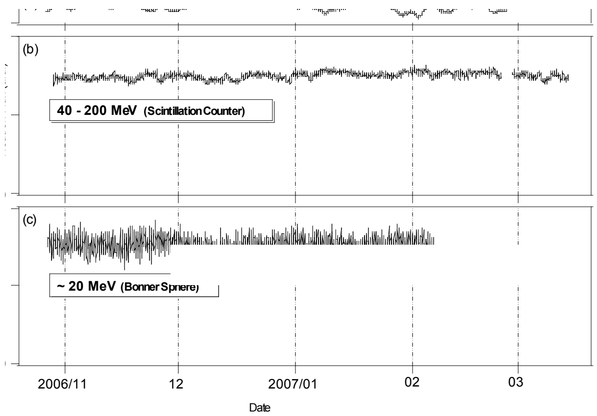

Figure 4: Time dependence of neutron flux measured at Mauna Kea Summit. (a) atmospheric pressure measured at Subaru Telescope building (b) neutron flux in 40 – 200 MeV range measured by scintillation counter (c) neutron flux at around 20 MeV measured by Bonner sphere detector.

Small humps and depressions are seen simultaneously in both in 40 – 200 MeV and 20 MeV curves. In figure 4a, the atmospheric pressure measured at Subaru Telescope is also plotted as a function of time. Weak relationship between the neutron flux and atmospheric pressure is observed; high atmospheric pressure lowers the neutron flux. This indicates that the atmosphere near ground level act as a neutron shield.

Summary

In order to get accurate value of soft error in computer system, we measured cosmic ray neutron spectra at Mauna Kea summit and several different altitudes. Measurement of absolute neutron spectra at various locations is now undergoing.

Acknowledgement

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