Production rates of nuclide in synthetic silica induced by high-energy muon beam at CERN

H. SAKURAI[1], Y. TAKAHASHI[1], N. DOSHITA[1], T. OE[1)], T. SATO[1)], S. KIKUCHI[1], K. HORIUCHI[2], N. SASAKI[2], K. KONDO[1], N. IWATA[3], F. TOKANAI[1], S. GUNJI[1], H. MATSUZAKI[4]

[1] Department of Physics, Yamagata University, 1-4-12 Kojirakawa,Yamagata 990-8560, JAPAN
2 Dept. of Earth and Environmental Science, 3 Bunkyoumachi, Hirosaki, 036-8561, Japan
3 Dept. of Earth and Environmental Science, Yamagata University, 1-4-12 Kojirakawa,Yamagata 990-8560, JAPAN
4 Dept. of Nucl. Engin. And Management, The University of Tokyo, 2-11-16 Yayoi. Bunkyo-ku, Tokyo 113-0032, Japan

sakurail@sci.kj.yamagata-u.ac.jp
DOI: 10.7529/ICRC2011/V11/0981

Abstract: The rocks in deep underground are exposed by high energy muon for long time and record the accumulation of the cosmogenic nuclides of Be-10 and Al-26. We attempted to calibrate the cross-sections of the production rates of Be-10 and Al-26 using the muon beam with the energy of 160 Gev/c at CERN. At the first experiment the total muons of $1.3x10^8$ was exposed to the synthetic SiO2 plates. The cross sections were 7.6±0.2 μ b and 0.111±0.004 mb for Be-10 and Al-26, respectively.

Keywords: high energy muon, Be-10, Al-26, secular variations in cosmic rays, cross sections

1 Introduction

Detection of secular variations in cosmic rays gives a clue to elucidate the origin of cosmic rays and their propagation in the Galaxy. Moreover, the variations presumably indicate a distribution of the density of cosmic rays in the galactic arm, because the solar system is passing through the arm by very long time. Usually, cosmogenic nuclides such as Be-7, Be10, and C-14 are produced in the atmosphere and circulated in the air and ocean. However, these productions are dominated by the relatively low energy components of the Galactic cosmic ray spectrum and hence their variations are mainly influenced by solar modulations. To detect the secular variations in high energy component of cosmic rays, cosmogenic nuclides produced by mu-on are available. It is because high energy mu-on can produce the nuclides of Be-10 an Al-26 by the interactions with SiO_2 in a rock at deep lithosphere as shown Figure 1. Since the half-life of Be-10 and Al-26 are $1.6x10^6$ yr and $7.2x10^5$ yr, respectively, the rocks in deep underground are exposed by high energy muon for long time and record the accumulation of the cosmogenic nuclides produced during the three or four half-life. Therefore, measuring the concentrations of Be-10 and/or Al-26 in the rock provides us information of the variations in high energy cosmic rays during approximately 5000 thousands years.

First of all, we attempted to calibrate the cross-sections of the production rates of Be-10 and Al-26 using the muon beam with the energy of 160 Gev/c at CERN, because the published cross sections are only the results of experiment by Heisinger et al[1]. We used pure SiO_2 plates for the target material considering the ingredient of rocks. The Be-10 and Al-26 in the plates were measured using Accelerator Mass Spectrometry (AMS) at MALT, The Tokyo University. The exposure of muon beam was carried out two times in 2007 and 2010 over approximately 100 days. We describe the exposure experiment and the production rates of the nuclides for the SiO_2 plates.

2 SET-UP of EXPERIMENT

The exposure experiment was carried out using the muon beam line of Compass experiment. The target with a muon monitoring system was placed at downstream region on the beam dump. Several pieces of synthetic SiO_2 plates with 50 mm square in the thickness of 5 mm were set in the target box as shown in Figure 2. The target box was sandwiched with two scintillation counters which consist of 1 mm thick plastic scintillator of 50 mm square as well as the target plate and a photomultiplier (PMT) in the diameter of 2 inches.

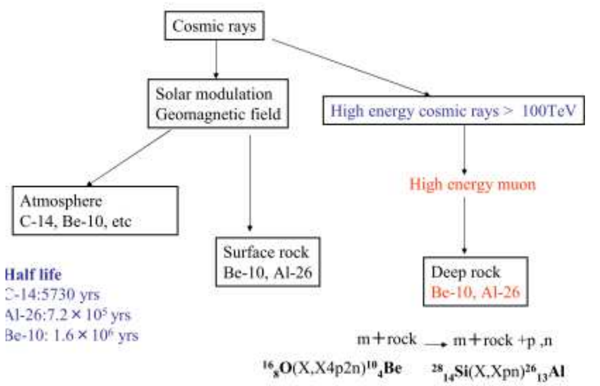

Figure 1. The concept for detection of secular variations for high energy cosmic rays

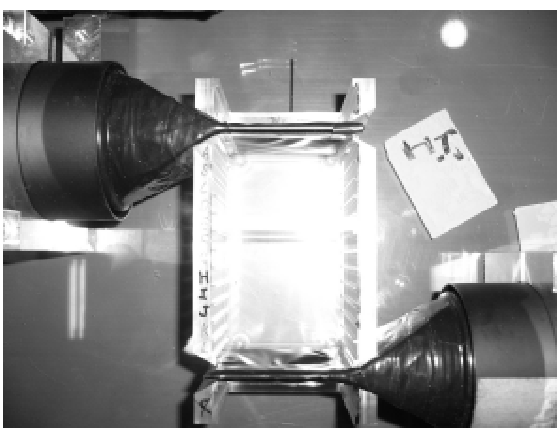

Figure 2. The target box of SiO_2 set between the plastic scintillation counters

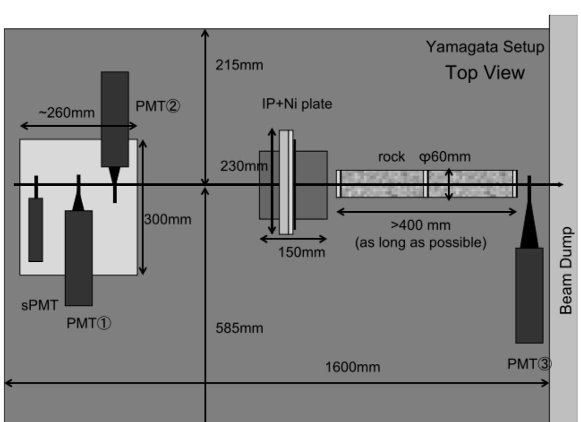

Figure 3. Configirulation of the set-up for the target box, imaging plate, granite rocks, and PMTs

Behind the target box we set an imaging plate with Ni plates to observe the beam profile and approximately 1 m long cylindrical granite in the diameter of 60 mm to investigate the influences of real rocks for the production rates of the Be-10 and Al-26. The total set-up of the target box, the imaging plate, the granite rock, and PMTs are shown in the Figure 3. The sPMT and PMT3 are mounted in front and rear for the muon stream, respectively.

3 EXPOSURE

The first exposure was carried out for approximately 100 days from 17th June to 8th November 2007 and the second exposure was from July to December 2010. The total muon counts accumulated during the first exposure was 1.8×10^{13}, counted by the plastic sincillation counters.
The figure 4 shows an example of the counting rates per second for the 4 plastic scintillation counters. The bunch shows one spill. The counting rates (cps) were 1~1.2 $\times 10^7$ for the second exposure.

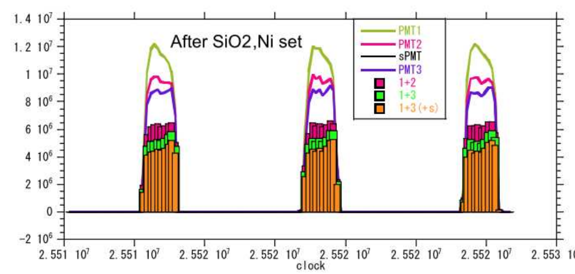

Figure 4. The counting rates of four plastic scintillation counters by cps.

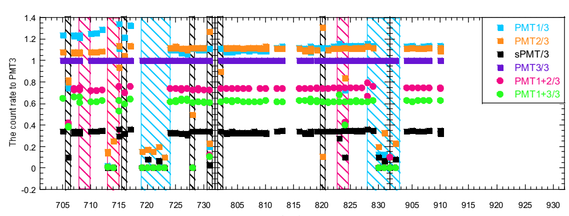

Figure 5. Time profiles of the normalized counting rates for the four plastic scintillation counters.

Figure 5 shows the time profiles of the counting rate for the four scintillation counters normalized to PMT3 for the 2010 experiment. It shows stable exposure for long time.
It is important to know the position distribution of muon beam exposed to the target, because of check of the uniform exposure. However, as the intensity of the muons is strong, it is hard to use conventional position sensitive detectors. Hence, we have employed a Ni plate to look at the beam profile. After the long exposure to the Ni plate, we took images of muons using the radiations emitted

from the nuclides produced in the Ni plate. Figure 6 shows contour map of beam intensity for the position at the second exposure. It indicates most of muon beams are confined to the region of 60 x65 in mm covering the target plates with 50 mm square.

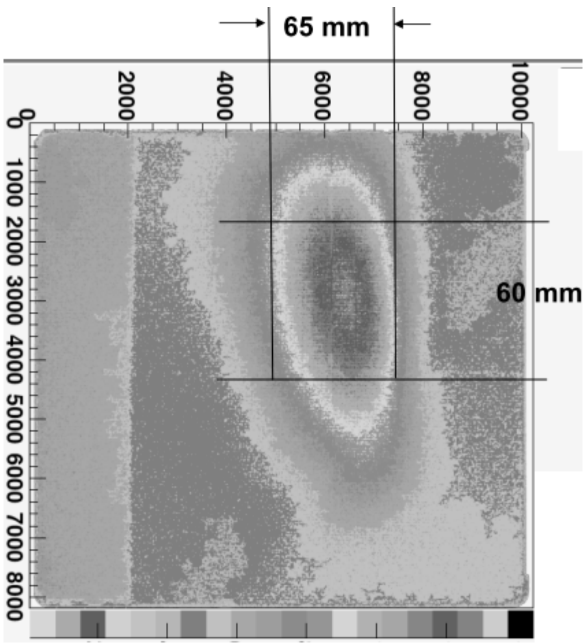

Figure 6. Contour map of the muon beam

4 RESULT and Discussion

The nuclides produced in the SiO_2 target, which are Be-7, Be-10, and Al-26, measured by gamma ray spectroscopy or AMS. Figure 7 shows the produced Be-7 for each SiO_2 plate as a function of the position in the target box for the first exposure. The Be-7s is gradually increasing with the rate of 2% per plate according to the down-stream, implying effects of secondary particles produced in the SiO_2 plates.

In order to measure the Be-10 and Al-26, the AMS samples were prepared as follows: After the SiO_2 plate was crashed, adding the carriers of Be and Al the Be and Al samples were extracted with chemical treatment. Moreover, in this process blank samples of CERN background and laboratory background were prepared with same time. The Table 1 and Table 2 sow the contents of Be-10 and Al-26, respectively. The results are for two SiO_2 plates in the First exposure. As shown in the Tables, the content s of Be-10 for the C16 and C17 show evidently similar. The contents of Al-26 were consistent within the errors for C16 and C17. These results indicate confidence of the exposure experiment and the AMS measurements.

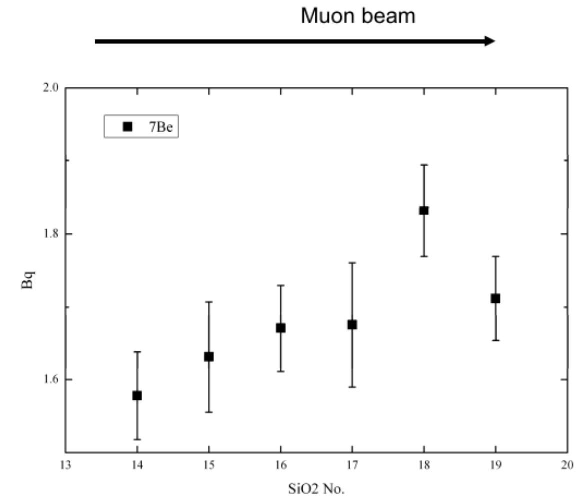

Figure 7. Production of Be-7 for each plate as a function of the target position

Finally, as shown in Table 3, both the cross sections of the Be-10 and Al-26 were approximately one order smaller compared with the Heisinger' s cross sections. However, the ratio of the cross section for Al-26 to that for Be-10 was quite similar to that of Heisinger. Although they used 190 GeV/c muon, the difference of the muon energies does no matter for the cross sections. Since their set-up mounted a 3 m concrete block in front of the targets, the materials presumably affect on their cross sections. We set no materials in front of the pure SiO_2 plates.

5 SUMMARY

The rocks in deep underground are exposed by high energy muon for long time and record the accumulation of the cosmogenic nuclides of Be-10 and Al-26 produced during the three or four half-life. We attempted to calibrate the cross-sections of the production rates of Be-10 and Al-26 using the muon beam with the energy of 160 Gev/c at CERN. The muon exposure during approximately 100 days was carried out two times at 2007 and 2010. At the first experiment the total muons of $1.3x10^8$ was exposed to the synthetic SiO_2 plates. The Be-10 and Al-26 produced in the plate was measured by AMS. The cross sections were 7.6±0.2 μ b and 0.111±0.004 mb for Be-10 and Al-26, respectively. Although they are smaller than that of Heisinger, the ratio of cross sections between Al-26 and Be-10 was quite similar. Their experiment is presumably affected by the concrete materials mounted in front of the targets.

Reference

[1] B. Heisinger et al. EPSL, 200, **200**: 345-355

Sample	Weight (g)	^{9}Be carrier (mg)	^{10}Be/^{9}Be (10^{-13})	^{10}Be content (10^{5} atoms g^{-1})
C16	25.0061	0.1495	2.74 ± 0.07	1.09 ± 0.03
CERN-2-6-BG	24.0945	0.1489	Blank level	Blank level
HRSK	25.6874	0.1498	Blank level	Blank level
C17	26.1084	0.1499	2.94 ± 0.08	1.08 ± 0.03

Table 1 Content of Be-10

Sample	^{27}Al (mg)	^{26}Al/^{27}Al (10^{-12})	^{26}Al content (10^{5} atoms g^{-1})
C16	0.313 ± 0.004	2.87 ± 0.09	8.02 ± 0.26
CERN-2-6-BG	0.307 ± 0.004	0.0013 ± 0.0012	0.004 ± 0.003
HRSK	0.3026	Blank level	Blank level
C17	0.3100	2.80 ± 0.18	7.43 ± 0.47

Table 2 Content of Al-26

	Be-10 (μb)	Al-26 (mb)	Al-26/Be-10
This work	7.6±0.2	0.111±0.004	14.5
Heisinger	94±13	1.41±0.17	15

Table 3 Comparison of cross sections