Beryllium-7 production from oxygen by atmospheric cosmic rays

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Abstract—The production rates of ^7Be from ^{16}O by cosmic rays were measured at three locations of different latitudes and altitudes. From the altitude dependence of the production rates, the attenuation length of $L = 165 \pm 30 \text{ g/cm}^2$ was obtained. This value falls in the range of the reported values obtained by physical methods for the atmospheric neutrons.

The experimental value at the sea level of the geomagnetic latitude, $\lambda = 25^\circ\text{N}$, was in good agreement with the value calculated from the generally accepted atmospheric neutron spectrum and the best estimated excitation function. The latitude effect on the production rate is also discussed.

INTRODUCTION

Since the experiment by LAL *et al.* (1960), several measurements of the radio-nuclides produced in laboratory chemicals by the atmospheric cosmic rays have been reported for various combinations of targets and nuclear reactions. (LAL *et al.*, 1960; RAMA and HONDA, 1961a; HUSAIN and KURODA, 1968; TAKAGI and TANAKA, 1969; BHANDARI *et al.*, 1969; MABUCHI *et al.*, 1971)

MABUCHI *et al.* (1971) reported the ^{32}P production from sulfur, and noted that the production rate at $\lambda = 25^\circ\text{N}$ is much lower than that observed at $\lambda = 44^\circ\text{N}$ by RAMA and HONDA (1961a), even if the difference of the latitudes is taken into account. In order to confirm this discrepancy, we have chosen another nuclear reaction, that is, production of ^7Be from oxygen. This reaction has a higher threshold value than the (n, p) reaction and was once investigated at $\lambda = 51^\circ\text{N}$ by LAL *et al.* (1960). Further experiment at different latitudes and altitudes will serve to confirm their result. The ^7Be production is important in connection with the production rate of ^{10}Be in the atmosphere.

In this paper we report the result of the experiment carried out at three locations; Tokyo (sea level, $\lambda = 25^\circ\text{N}$, 1970), Mt. Fuji (2345 m above sea level, $\lambda = 25.5^\circ\text{N}$, 1970), and Gif-sur-Yvette (sea level, $\lambda = 50^\circ\text{N}$, 1971) in France.

EXPERIMENTAL

Target exposure and chemical procedure: Tap water was purified by a cation-exchange resin. Be^{2+} carrier was added and the final pH was adjusted to ~ 2 with HNO_3 . The water target thus prepared was put into a number of polyethylene bottles ($30\text{cm} \times 30\text{cm} \times 25\text{cm}$) and exposed to atmospheric cosmic rays.

After the exposure, beryllium was separated from a large quantity of water by a cation-exchange resin column (Diaion SK-1A, 50–100 mesh, $10\text{cm}\phi \times 45\text{cm}$). Beryllium was eluted by 4N HCl and then purified by precipitation of the hydroxide in the presence of EDTA. Finally, the hydroxide was ignited into BeO which was subjected to the measurement of radioactivity.

Counting of beryllium-7: The 477 keV γ -ray of ^7Be (10.3% γ) was measured with the use of a NaI (Tl) spectrometer 7.6 cm in diameter and 7.6 cm long, which was specially designed for low-level counting (TANAKA *et al.*, 1967). The background counting rate was 5.0 cpm for the 477 keV photopeak, and the counting efficiency was $14.6 \pm 0.6\%$. The sample and the background counting runs were alternated after a period of about 1000 minutes. The decay of ^7Be was confirmed by remeasuring each sample 60 days after the first counting.

RESULT AND DISCUSSION

Our result is tabulated in Table 1 together with the data obtained by LAL *et al.* (1960). In Fig. 1, the production rates of ^7Be are plotted as a function of atmospheric depth. In the high energy region ($\geq 1\text{GeV}$) of the atmospheric cosmic rays, the ratio of protons to neutrons is nearly unity, while below 100 MeV it is less than 0.03 (LAL and PETERS, 1967). Because the threshold values of the ^7Be producing reactions from ^{16}O are in the range of 25–90 MeV, the observed ^7Be at sea level is produced mostly by neutrons.

The atmospheric neutron spectra were studied by HESS *et al.* (1959), YAMASHITA *et al.* (1966), TAJIMA *et al.* (1967) and others. Except those given by HESS *et al.* (1959), almost all spectra are for the low energy region, $\leq 10\text{MeV}$. The production rate of ^7Be from oxygen target at the sea level, $\lambda = 25^\circ\text{N}$, was calculated by means of the neutron flux and the excitation function given by BERNAS *et al.* (1967). In our calculation, the shape of the neutron spectrum reported by HESS *et al.* (1959) was used by normalizing the neutron flux at 10 MeV to that of TAJIMA *et al.* (1967). The excitation function by BERNAS *et al.* (1967) measured for $^{16}\text{O}(\text{p}, \text{sp.})^7\text{Be}$ was assumed to be valid for $^{16}\text{O}(\text{n}, \text{sp.})^7\text{Be}$ in high energy region. The calculated value is shown in Table 1. It is in good agreement with our experimental value.

The flux of the atmospheric neutrons at depths deeper than $200\text{g}/\text{cm}^2$ (equilibrium region) decreases exponentially with the atmospheric depth, but the shape of spectrum remains unchanged. The production rates of ^7Be , therefore, must decrease exponentially

Table 1. Production rate of cosmic-ray induced ^7Be from Oxygen

Sample	Location	Weight of target (H ₂ O, kg)	Exposure interval (days)	Chemical yield (%)	Net dpm at t=0 after exposure $\times 10^4$	Production rate (experimental) atoms/(g target 0) sec $\times 10^{-6}$	Production rate (calculated) atoms/(g target 0) sec $\times 10^{-6}$
I	5th station of Mt. Fuji 25.5°N 772g/cm ²	390	99	91.2	3.02 $\pm$ 0.51	2.40 $\pm$ 0.40	
II	Tokyo 25°N Sea level	1127	153	86.8	1.47 $\pm$ 0.19	1.47 $\pm$ 0.07	0.48
III	Gif-sur-Yvette 50°N 1030g/cm ²	660	127	97.8	2.78 $\pm$ 0.50	1.0 $\pm$ 0.2	
	Echo Lake 51°N 685g/cm ²	395	85	—	—	9.0 $\pm$ 1.0*	9.8**

* LAL *et al.* (1960).

The branching ratio 11.0% was adopted for gamma-ray of ^7Be .

Therefore, this value must be corrected to $(9.6 \pm 1.0) \times 10^{-6}$ atoms/(g target 0) sec.

** LAL *et al.* (1958).

Fig.1. Production rates of ^7Be from oxygen as a function of atmospheric depth. The upper line corresponds to the production rates at 50°N and the lower one to those at 25°N.

with increasing atmospheric depth. Thus, the attenuation length L can be calculated from our data and those of LAL *et al.* (1960).

$$\begin{array}{lll} L = 165 \pm 30 & \text{g/cm}^2 & \text{for } \lambda = 25^\circ \text{N} \\ \text{and} & & \\ L = 158 \pm 30 & \text{g/cm}^2 & \text{for } \lambda = 50^\circ \text{N} \end{array}$$

Both values agree with each other and also with the presently accepted value, $L = 160$ (MABUCHI *et al.*, 1971) as the attenuation length of the atmospheric neutron.

The variation of the production rates as a function of latitude should reflect that of atmospheric neutron flux. From the comparison of the two results at sea level, Tokyo and Gif-sur-Yvette, the latitude effect of neutrons can be obtained.

$$\frac{\phi n(25^\circ \text{N})}{\phi n(50^\circ \text{N})} = 0.42 \pm 0.15$$

This value is smaller than that of 0.76 given by ROSE *et al.* (1956) who measured it with a physical method. Similar discrepancy was mentioned earlier on the production of ^{32}P from sulfur by MABUCHI *et al.* (1971).

RAMA and HONDA (1961b) measured ^7Be activities in the stratosphere and found that the measured values are only about 60 percent of the values calculated for static stratosphere. Their calculation is based on the production rate, 0.9×10^{-5} atoms (g target O) $^{-1}\text{sec}^{-1}$ obtained by the exposure experiment at the Echo lake ($\lambda = 51^\circ \text{N}$, 685g/cm^2) by LAL *et al.* (1960). They ascribed this discrepancy to errors in the calculations and in the experiment. The value of 0.9×10^{-5} atoms (g target O) $^{-1}\text{sec}^{-1}$ at $\lambda = 51^\circ \text{N}$ by LAL *et al.* (1960), however, occupies a reasonable position in the production rate-altitude diagram in Fig.1.

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