

## Energy spectrum measurement and dose rate estimation of natural neutrons in Tibet region (Postprint)

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### Abstract

In this work, natural neutron spectra at nine sites in Tibet region were measured using a multi-sphere neutron spectrometer. The altitude-dependence of the spectra total fluence rate and ambient dose equivalent rate were analyzed. From the normalized natural neutron spectra at different altitudes, the spectrum fractions for neutrons of greater than 0.1 MeV do not differ obviously, while those of the thermal neutrons differ greatly from each other. The total fluence rate, effective dose rate and the ambient dose equivalent rate varied with the altitude according to an exponential law.

### Full Text

### Preamble

#### Energy Spectrum Measurement and Dose Rate Estimation of Natural Neutrons in Tibet Region

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**Abstract:** In this work, natural neutron spectra at nine sites in the Tibet region were measured using a multi-sphere neutron spectrometer. The altitude dependence of the spectra, total fluence rate, and ambient dose equivalent rate were analyzed. From the normalized natural neutron spectra at different altitudes, the spectrum fractions for neutrons above 0.1 MeV do not differ significantly, while those for thermal neutrons vary greatly. The total fluence rate, effective

dose rate, and ambient dose equivalent rate varied with altitude according to an exponential law.

**Keywords:** Natural neutron, Spectrum, Effective dose rate, Tibet

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## Introduction

The health effects of natural radiation have long been a focus of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), with natural neutrons representing an important component of this issue [?]. Natural neutrons near the ground surface are produced through several mechanisms, including interactions of cosmic ray particles with the atmosphere and surface media, capture of cosmic ray particles by the Earth, and terrestrial natural radiation [?]. The energy spectrum spans over ten orders of magnitude, ranging from thermal neutrons to high-energy neutrons of hundreds of MeV [?, ?]. Measurement of natural neutron energy spectra is an active area of international research, with laboratories in the USA, Japan, and other countries conducting such measurements for over half a century [?]. In particular, Japan has completed a nationwide survey of natural neutron radiation levels [?]. Although numerous studies on natural neutron dose have been conducted in China, there remains a need for comprehensive measurement of the national natural neutron spectrum [?, ?]. Due to Tibet's high altitude and elevated cosmic ray radiation levels, the natural radiation dose in this region is higher than in low-altitude areas. In this work, measurements using a multi-sphere neutron spectrometer were performed to characterize natural neutron spectra across various altitudes in Tibet. The altitude-dependent variations in the spectrum, total fluence rate, and ambient dose equivalent rate were analyzed. The results provide technical support and baseline data for radiation surveys and hazard assessments of natural neutrons in Tibet.

## II. Experimental

### Instrument

The multi-sphere neutron spectrometer used in this work is shown schematically in Fig. 1 [Figure 1: see original paper]. A  $\Phi 5.08$  cm  $^3\text{He}$  spherical proportional counter (LND-27036) served as the thermal neutron detector. The moderator consisted of high-density polyethylene ( $0.94 \text{ g/cm}^3$ ) spheres with diameters of 8 cm, 11 cm, 15 cm, and 23 cm, plus a bare detector configuration. The moderator balls and detector configuration are illustrated in Fig. 2 [Figure 2: see original paper]. The response functions of the multi-sphere neutron spectrometer were calculated using the MCNPX code following the method in Ref. [?], with results shown in Fig. 3 [Figure 3: see original paper]. Prior to the field survey, the neutron spectrometer was tested to verify its performance. Energy resolutions of the detector with different moderator balls were measured to be approximately 7% at 765 keV for the  $^3\text{He}(n,p)\text{T}$  reaction, while detection efficiencies were

about 10% as calibrated with  $^{252}\text{Cf}$  and  $^{241}\text{Am-Be}$  neutron sources. These experimental results agreed well with simulation predictions.

### Measurement

Natural neutron spectra were measured at various altitudes across Tibet using the neutron detector with different moderator balls. The spectrometer system configuration remained unchanged for all measurements, with each spectrum recorded over two hours to ensure each moderator ball accumulated more than 300 counts. A Global Positioning System was used to obtain the coordinates and altitudes of each measurement location. The measurement sites and their corresponding altitudes, longitudes, and latitudes are listed in Table 1 .

## III. Results and Analyses

### Neutron Energy Spectra

The natural neutron spectra obtained using a least-squares unfolding program are shown in Fig. 4(a) [Figure 4: see original paper]. It is evident that neutron fluence rates across all energy ranges increase with altitude, consistent with the increase in cosmic-ray intensity. Figure 4(b) [Figure 4: see original paper] displays the neutron spectra normalized to the total fluence rate. The spectrum fractions for neutrons above 0.1 MeV show no significant differences across altitudes, whereas the thermal neutron fractions vary considerably. This variation is likely due to differences in ground media and vegetation at the measurement sites, which affect the moderation and absorption of natural neutrons differently at various altitudes.

### Neutron Fluence Rate and Estimated Neutron Dose Rate

Total fluence rate, effective dose rate, and ambient dose equivalent rate were calculated from the measured spectra at each altitude, as presented in Table 2 . In these calculations, the effective dose per unit fluence for monoenergetic neutrons in isotropic geometries incident on adult male and female reference phantoms—calculated using PHITS [?]-were employed, and the conversion coefficients for ambient dose equivalent rate were adopted from GBZ/T 202-2007 [?]. By fitting the data in Table 2, the altitude variations of neutron fluence rate and dose rate were obtained, as shown in Fig. 5 [Figure 5: see original paper]. The total neutron fluence rate, effective dose rate, and ambient dose equivalent rate all increase exponentially with measurement site altitude, as noted in Refs. [?, ?].

The variations in total neutron fluence rate  $\Phi$ , effective dose rate  $E$ , and ambient dose equivalent rate  $H^*(10)$  can be fitted by the exponential function  $R \cdot e^{\alpha \cdot h}$ , where  $h$  is the altitude of the measurement sites and  $R$  and  $\alpha$  are fitting parameters. The fitted functions are given by Eqs. (1), (2), and (3):

$$\phi = 0.0073e^{0.000625h},$$

$$E = 8.61e^{0.000642h},$$

$$H^*(10) = 12.5e^{0.000641h},$$

where  $\phi$  is in  $\text{cm}^{-2} \text{s}^{-1}$ ,  $h$  is in meters, and  $E$  and  $H(10)$  are in  $\text{nSv/h}$ . Standard deviations of the  $\alpha$ -values are provided in Table 3. The  $\alpha$ -values for  $\phi$ ,  $E$ , and  $H(10)$  are nearly identical, indicating that the natural neutron spectra changed only slightly with altitude, so all  $\alpha$ -values derived from the spectra varied in a similar manner.

Table 4 compares  $\alpha$ -values obtained at various geomagnetic latitudes by different research groups. Both the  $\alpha$ -value ( $0.625 \times 10^{-3} \text{ m}^{-1}$ ) and the geomagnetic latitudes ( $18^\circ$ - $21^\circ$ ) from the present work are the smallest reported. This confirms that  $\alpha$ -values increase with geomagnetic latitude and that the attenuation magnitude of natural neutrons is influenced by geomagnetic intensity [?]. Consequently, to assess natural neutron dose in Tibet more accurately, the local  $\alpha$ -value should be applied.

#### IV. Conclusion

Natural neutron spectra were measured at nine locations across different altitudes (1946-4544 m) in the Tibet region. Effective dose and ambient dose equivalent rates were calculated, yielding the following conclusions: In the normalized natural neutron spectra at different altitudes, the spectrum fractions for neutrons above 0.1 MeV do not differ significantly, while those for thermal neutrons vary considerably. The natural neutron fluence rate of each energy range increases with altitude according to  $\phi = 0.0073e^{0.000625h} \text{ cm}^{-2} \text{ s}^{-1}$ . The effective dose rate of natural neutrons varies with altitude according to  $E = 8.61e^{0.000642h} \text{ nSv/h}$ , and the ambient dose equivalent rate follows  $H^*(10) = 12.5e^{0.000641h} \text{ nSv/h}$ .

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