33RD INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013
THE ASTROPARTICLE PHYSICS CONFERENCE

Derivation of Neutron Ambient Dose Using Neutron Monitor in Daejeon

YUN HO KIM[1], JEONGSOO KANG[1], JAE BUM SON[1], DOH-YUN JANG[1], SUNG JOONG KIM[1], YONG-KYUN KIM[1,2]

[1] *Department of Nuclear Engineering, Hanyang University, Seoul 133-791, Korea*
[2] *Institute for Basic Science, Daejeon 305-811, Korea*

ykkim4@hanyang.ac.kr

Abstract: The Basic Atomic Energy Research Institute (BAERI) of Hanyang University in Korea constructed a cosmic ray detection system, which is being operated currently. In this study, neutron ambient dose equivalent rate variation from cosmic ray were analyzed under various environmental conditions using the Excel-based Program for calculating Atmospheric Cosmic-ray Spectrum (EXPACS) applying PHITS (Particle and Heavy Ion Transport code System) based Analytical Radiation Model in the Atmosphere (PARMA). Obtained results were compared with previous other studies and confirmed reliable. Measurement from the detection system was used for evaluation of neutron ambient dose equivalent rate at various environmental conditions in Daejeon. Finally, a conversion coefficient defined as the ratio of counts from the neutron monitor to the neutron ambient dose equivalent was obtained considering atmospheric depth, which have a impact on the conversion coefficient derived. The derived formula was polynomial form with r-square adjusted value of 0.9998. This confirms satisfactory accuracy and reliability of the formula and thereby the legitimate methodology introduced for neutron ambient dose equivalent evaluation using neutron monitor in Daejeon.

Keywords: Cosmic ray, Neutron monitor, NM64, Dose conversion coefficient

1 Introduction

In recent times, research on cosmic rays has been actively performed because of increasing concern for the origins of cosmic rays, exposure doses from cosmic rays, and changes in the environment of Earth because of changes in space weather [1]. Above all, over the past 10 years, exposure of public and aircraft crew to atmospheric cosmic radiation has been become as a significant concern. The exposure from cosmic radiation is accounted for about 7.5 percents of the exposure from environmental radiation. However the solar and interplanetary events cause variation of intensity and dose from cosmic ray, ultimately, the environmental dose can be affected by change of cosmic rays due to the space events.

The Basic Energy Research Institute (BAERI) of Hanyang University in Korea operates a cosmic ray detection system to analyze the effect of cosmic rays on the climate, monitor solar activity, and estimate the exposure dose from cosmic rays through measurement and analysis [2]. First purpose of this study is to analyze changes of neutron ambient dose equivalent rate due to various environmental conditions. Final goal is to obtain the relation between neutron ambient dose equivalent and estimated count rate from BAERI's neutron monitor at various conditions. Dose conversion coefficient, as ratio of neutron ambient dose rate to count rate, can be used to evaluate dose from cosmic neutron in Daejeon, Korea. To analyze environmental effect on neutron ambient dose equivalent rate, the "Excel-based Program for calculating Atmospheric Cosmic-ray Spectrum (EXPACS)" applying PHITS (Particle and Heavy Ion Transport code System) based Analytical Radiation Model in the Atmosphere (PARMA) was used.

2 Environmental Effect on the Ambient Dose Equivalent Rate

The cosmic neutron ambient dose equivalent rate, dH*(10)/dt can be affected by the various environmental condition such as humidity, heliocentric potential, cutoff rigidity, and atmospheric depth. Factors mentioned above are important factors for variation of cosmic ray intensity on ground or representation of space weather such as solar activity and interplanetary events. In order to analyze changes of dH*(10)/dt due to environmental factors, available data from other experiments and program results was compared with obtained results in various cases from EXPACS.

2.1 Heliocentric Potential and Cutoff rigidity

Heliocentric potential and cutoff rigidity are well-known factors that affect intensity change of cosmic ray significantly. Heliocentric potential is characteristic which indicates level of solar activity. As a solar activity becomes roaring, heliocentric potential becomes higher. The period is repeated every 11years and heliocentric potentials at maximum and minimum period are about 1000 MV and 400 MV [3]. Cutoff rigidity is geological factor that represents a intensity of Earth's magnetic field and its value is based on geological location as altitude, longitude, and latitude. High cutoff rigidity means strong magnetic field of Earth, fewer incident particle reaches on ground. It becomes higher at low-latitude region and lower at high-latitude region, substantially.

Considering heliocentric potential and cutoff rigidity, total ambient dose equivalent rate with various cutoff rigidity at potentials were obtained as 610 and 470 MV and they were compared with EPCARD data reported the DOSMAX consortium as shown if Fig. 1 [4]. In analysis of data from EXPACS, relative humidity was assumed as 0 and atmospheric depth was applied as about 11,127 m for

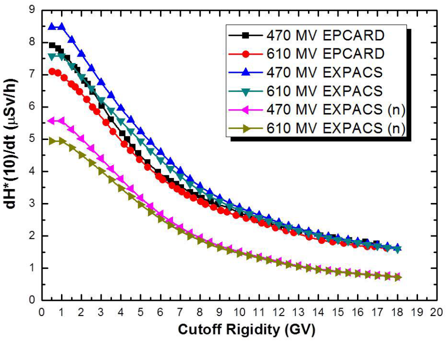

Figure 1: Appearance of ambient dose equivalent changes due to cutoff rigidity and heliocentric potential with 2 stages of heliocentric potential from data analyzed using EXPACS and EPCARD results reported by the DOSMAX consortium: at 11,127 m altitude

comparison. Although an intensity may be linearly proportional to dose, intensity variation due to cutoff rigidity or heliocentric potential induce change of ambient dose equivalent rate. Then we confirmed that obtained result is higher than result from EPCARD. Difference with result of EPCARD at 11.2 GV are about 10% in cases of both 470 MV and 610 MV. Because the gap tends to decrease as cutoff rigidity increases and the purpose is to confirm qualitative relation between ambient dose equivalent rate and rigidity with heliocentric potential, the difference ca be judged acceptable.

2.2 Atmospheric Depth and Relative Humidity

Besides above factors, the atmospheric depth is another factor to cause variation of cosmic ray intensity and dose from cosmic ray. As reported in many studies, neutron ambient dose equivalent rate varies in log-scale at below about 15,000 m altitude (above 120 g/cm^2 atmospheric depth) [5]. Also considering intensity variation due to atmospheric depth, appearance of neutron ambient dose equivalent is deserved features. In data analysis, cutoff rigidity and heliocentric potential were assumed as 11.2 GV and 525 MV approximately year-averaged value in 2012. Then relative humidity was assumed 0. Variation of dH*(10)/dt from EXPACS due to altitude or atmospheric depth change is shown in Fig. 2(a). From 984 to 1034 g/cm2, same as from ground to about 400 m altitude, a correlation between dH*(10)/dt and atmospheric depth can be fitted linearly as shown in Fig. 2(b). For reliability, R^2 was 0.9975, and therefore analysis can be considered successful.

The fact that a high humidity reduces intensity of cosmic ray is well-known and its feature is shown in of Fig 3(a) [6]. It is well seen that as cosmic ray intensity decreases, therefore ambient dose equivalent rate from cosmic neutron also decreases. dH*(10)/dt from the cosmic neutron under various humidity conditions was obtained at heliocentric potential of 525 MV, 200 m altitude, and R_c of 11.2 GV. As shown in Fig. 3(b), dH*(10)/dt decreases as relative humidity increases. Obtained dH*(10)/dt decreases as a function of log-scale similar to Fig. 6(b), which suggests that acquired data follows the trend qualitatively well.

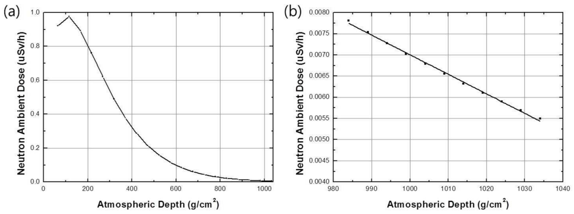

Figure 2: Variation of neutron ambient dose equivalent rate due to atmospheric depth from EXPACS: (a) obtained value between 54 and 1034 g/cm^2, (b) fitted line from 984 to 1034 g/cm^2.

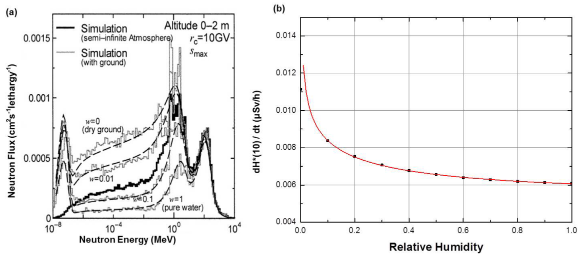

Figure 3: Appearance of cosmic neutron ambient dose equivalent rate due to relative humidity: (a)Calculated neutron spectra at the ground level in cases of various relative humidity and cutoff rigidity of 10 GV and (b) Analyzed data at 200 m altitude, heliocentric potential 525 MV and cutoff rigidity of 11.2 GV from EXPACS

3 Derivation of Neutron Ambient Dose Equivalent Rate

In order to evaluate neutron ambient dose equivalent rate in Daejeon using neutron monitor, a ratio of neutron ambient dose equivalent rate to count rate measured by neutron monitor was calculated. Object is dose evaluation in Daejeon, therefore cut off rigidity among aforementioned factors was fixed as 11.2 GV. Count rate of neutron monitor was calculated using neutron energy spectra and neutron dose equivalent rate from EXPACS and well-known response function of NM64 type neutron monitor. Calculation of count rate was performed using following equation.R(E), w(E), and I(E) are a response (a ratio of count to beam luminosity) from response function of 6-NM64, an energy width, and a flux of cosmic neutron from EXPACS, respectively.

$$N(E) = \sum_{i=1}^{n} R_i(E) I_i(E) w_i(E) [Cnts/s] \qquad (1)$$

Environmental factor	Input parameter
Atmosphere depth [g/cm^2]	1024
Cutoff rigidity [GV]	11.2
Heliocentric potential [MV]	525
Local effect parameter [water fraction]	0.5

Table 1: Input conditions in EXPACS used for calculation of neutron monitor.

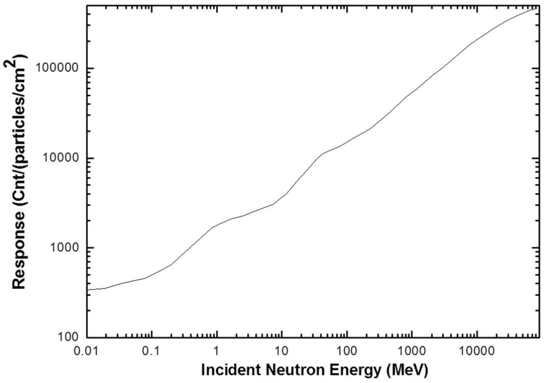

Figure 4: Response function of 6NM-64 neutron monitor using ^{10}BF$_3$ for vertical incident neutrons [7].

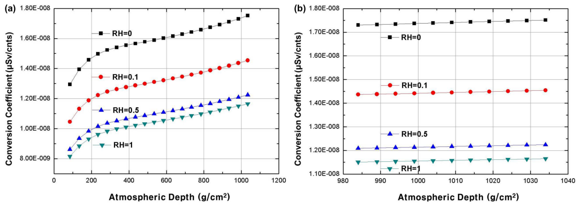

Figure 5: Conversion coefficients variation due to atmospheric depth for 4 RH values: (a) from 84 to 1034 g/cm^2 (b) from 984 to 1034 g/cm^2

Energy spectra was obtained at condition shown above table. Calculated count rate was about 483,000 cph from 18-tube NM64 neutron monitor. From January to November in 2012, measured averaged count rate were about 501,800 cph. 3.95 % difference can be acceptable, however correction of this gap should be applied to derivation of ambient dose equivalent rate.

Firstly, conversion coefficient as a ratio of neutron ambient dose to count was confirmed at various heliocentric potential. Other factors, relative humidity and atmospheric depth were fixed equal to 0 and 1034 g/cm^2. From 100 to 2500 MV, it is observed that conversion coefficients have almost same value. Therefore it is unnecessary to include effect of heliocentric potential for evaluation of dose. At various values of relative humidity and atmospheric depth, the conversion coefficient changes were analyzed. Variation of conversion coefficients with respect to the atmospheric depths for four cases of humidity (RH=0, 0.1, 0.5, 1.0) is shown in Fig. 5. All calculation was performed under conditions of 11.2 GV (R_c) and 525 MV (heliocentric potential).

The conversion coefficients are increased as an atmospheric depth goes higher. Then for relative humidity, low coefficient value at large humidity. To obtain more precise neutron ambient dose equivalent rate, relative humidity and atmospheric depth should be included for empirical formula. However humidity sensing system is not installed at BAERI monitoring system. Finally, relative humidity of 0.6, year-averaged value, was fixed and conversion coefficients as function of atmospheric depth (atmosphere measured at station) were obtained. The formula obtained from fitting result shown in Fig. 6(a) is shown below. Using polynomial model, fitted formula has adj.R-square value of 0.9998. Therefore obtained formula can be judged well-matched.

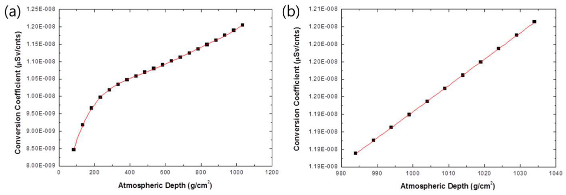

Figure 6: Conversion coefficient variation due to atmospheric depth: (a) from 84 to 1034 g/cm^2 (b) from 984 to 1034 g/cm^2

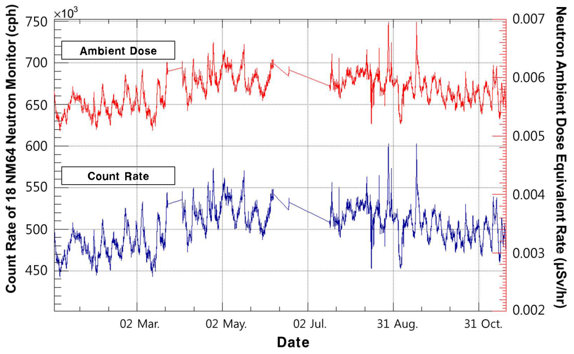

Figure 7: Result of measured count rate and evaluated neutron ambient dose equivalent rate from January to November in 2012.

$$\frac{dH*(10)/dt}{dN/dt} = 6.657\times10^{-9} + 2.8\times10^{-11}d_a$$
$$-8.566\times10^{-16}{d_a}^2 + 1.36\times10^{-16}{d_a}^3$$
$$-1.041\times10^{-19}{d_a}^4 + 3.096\times10^{-23}{d_a}^5 \qquad (2)$$

Calculated value is conversion coefficient included theoretical count rate using EXPACS and response function. Therefore correction for gap between calculate count rate and measured one should be performed. The correction factor of 0.9545 was used for evaluation. Final result is shown in Fig. 7.

4 Conclusions

Through this study, neutron ambient dose equivalent rate in Daejeon of Korea was evaluated and formula of conversion coefficient using neutron monitor was derived. To confirm effect of environmental factors on the neutron ambient dose equivalent rate as dH*(10)/dt, the variation of dH*(10)/dt was confirmed at various conditions through qualitative comparison with the other studies. Ultimately, a conversion ratio, a ratio of neutron ambient dose equivalent rate to the expected count rate of neutron monitor, was analyzed at various geological and meteorological factors and derived as a formula of atmospheric depth. Through the analysis of tendency we confirmed derived formula represents a precise fitted model with R^2 of 0.9998. Therefore derived formula could be determined reliable to evaluate neutron ambient dose equivalent rate in Daejeon, Korea. Through analysis and derivation of neutron ambient dose equivalent rate, we confirmed the feasibility more precise dose evaluation from cosmic ray using NM64 neutron monitor. Additional study for Monte-Carlo simulation of detector and installation of various sensors for environmental factors will lead to development of precise dose evaluation.

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