Annual Effective Dose of Cosmic Rays Exposure in Myanmar

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Abstract

Radiation is exposed in various forms every time. In the report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000), the global average cosmic rays' exposure contributes to about 16% of the annual effective dose from natural radiation sources. Cosmic rays exposure relies upon three factors, elevation, geographic locations, and solar activity. Among them, elevation (altitude) mainly affects cosmic ray dose rates. The annual effective dose due to cosmic rays was evaluated for different locations in Myanmar using EXPACS program (EXcel-based Program for calculating Atmospheric Cosmic-ray Spectrum). The annual effective dose due to cosmic ray exposure in Myanmar was estimated from 0.25mSv to 0.52mSv.

Keywords: Cosmic radiation, Annual effective dose, EXPACS

Introduction

Natural ionization radiations are always with us everywhere all the time. And ionization radiation can harm to all pieces of the DNA of the body. The significant health effect that has been connected ionization radiation is cancer. People are exposed due to various sources of natural ionization radiation in the environment. Among natural ionization sources, cosmic radiation is one of the major natural ionization sources. Cosmic rays mainly contain protons and alpha particles and other particles which are high energy and travel nearly the speed of light and they originate from outer space. At the point when they bombard the earth, they cooperate with molecules or atoms of the upper layers of the earth's atmosphere. After interacting with them, secondary or cascade particles (extensive air shower) come out. These secondary particles are neutrons muons, pions, electrons, positrons, photons, and protons. The particle flux striking on the ground changes with altitudes.

At higher elevations, cosmic rays exposure is more than the low ones. So, the dose from cosmic radiation is more predominant on aircrews in flight than at ground level. But, studying cosmic ray exposure at ground level is of interest to more understand cosmic radiation exposure and its related risk. The world-population weighted annual effective dose due to cosmic ray exposure is 0.38mSv, with a range from 0.3 to 2 mSv [1,2]. The purpose of this work is to calculate the annual effective dose due to cosmic rays' exposure for Myanmar people living in different locations, namely, Tedim, Hakha, Pin laung, Pyin Oo lwin, Kyung tong, Mandalay and Sittwe, by applying EXPACS [3].

Theoretical framework

In the mentioned above, doses from cosmic rays exposure depends on altitude, geomagnetic effect (geographic locations), solar activity. The vast magnetic field encloses around the earth. Thus, cosmic ray needs to penetrate the magnetic field in order to enter the top of the atmosphere. The ability to penetrate cosmic rays to this magnetic field is called the magnetic rigidity. Each location on the earth

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has rigidity. If cosmic rays' rigidity is lower than the location's rigidity on the earth, they will not reach the top of the atmosphere. This rigidity is defined as the geomagnetic cut off rigidity. The value of the cut off rigidity depends on geographic coordinates (latitude and longitude). The sun releases the stream of particles and plasmas as a solar wind into space. The solar wind's intensity varies during eleven years of solar activity. When cosmic particles meet the solar wind, they are swept away. When solar activity is at its highest, the solar wind is stronger and the cosmic particles flux on the earth is less. When solar activity is minimum, the solar wind is weak and the cosmic particles flux on the earth increases.

Thus, solar activity influences cosmic particles flux on the earth. Nowadays, several computer codes are developed for cosmic ray dose calculation, such as CARI-6, EPCARD, SIEVERT and PCAIRE. These models are proposed to calculate the dose for air travelers at the flight altitudes. PARMA model [4,5] based on the Monte Carlo simulations was accessed to estimate doses due to cosmic rays exposure at ground level and its implementation called EXPACS program (EXcel-based Program for calculating Atmospheric Cosmic-ray Spectrum) [3]. It is based on the analytical model PHITS-based Analytical Radiation Model in the Atmosphere; PARMA developed by the Japan Atomic Energy Agency.

On that model involves a few theoretical or empirical functions with free parameters whose numerical values were resolved from the least square (LSq) fitting of EAS (extensive air shower) data. By applying that model, the fluxes of neutrons, muons, pions, electrons, positrons, photons, and ions with charge up to 28(Ni) can be determined over an energy range from 10 keV to 1 TeV (per nucleon for He ions). But neutron flux can be determined down to 0.01 eV.

In order to calculate the primary ion flux, the energy loss and nuclear interaction in the atmosphere are considered. The primary ion flux can be expressed as

$$\emptyset_{i,pri}(E,d,W) = \emptyset_{i,1AU}(E + S_i(E)d, W)(4\pi - \Omega_E) \times$$

$$\{b_{1,i}(d)exp(-b_{2,i}d) + [1 - b_{1,i}(d)]exp(-b_{3,i}d)\}$$

where E is energy, the solar modulation index is W, d is the atmospheric depth. $S_{i,E}$ is the stopping power of particle i with energy in the atmosphere, Ω_E is the solid angle of the earth and $b_{1,i}$ to $b_{3,i}$ are free parameters.$\emptyset_{i,1AU}$ can be calculated from Matthia model.

Although electrons, positrons, photons have in space, they were not recognized as primary particles in EAS simulation. So, their flux can be calculated as the secondary ion fluxes as followed by,

$$\emptyset_i\ (E, d, r_c, W) = \Phi_i\ (d, r_c, W)\ \varphi_i\ (E, d) \text{ for i= electron, positron, photon}$$

where $\Phi_i\ (d, r_c, W)$ and $\varphi_i\ (E, d)$ are the normalization flux in $cm^{-2}s^{-1}$ and the normalized energy spectrum in MeV^{-1} respectively. The normalization flux can be calculated by the following

$$\Phi_{(i)}^{(W\mp)}(d, r_c) = c_{1,i}^{(W\mp)}(r_c)\ \left\{exp\left[-c_{2,i}^{(W\mp)}(r_c)d\right]\right\} - c_{3,i}^{(W\mp)}\left\{exp\left[-c_{4,i}^{(W\mp)}(r_c)d\right]\right\}$$

where $c_{1,i}^{(W\mp)}$ to $c_{4,i}^{(W\mp)}$ are free parameters dependence on cut-off rigidity.

The normalized energy spectrum for electron and positron can be expressed as followed by;

$$\varphi_{e(\mp)}(E,d) = \frac{h_{1,e(\mp)}(d)\, E^{h_{2,e(\mp)}(d)}}{\left[1+h_{3,e(\mp)}(d)\, E^{h_{4,e(\mp)}(d)}\right]\left[1+h_{5,e(\mp)}(d)\, E^{h_{6,e(\mp)}(d)}\right]}$$

where $h_{1,e(\mp)}(d)$ to $h_{8,e(\mp)}(d)$ are free parameters depending on atmosphere depth, d. The normalized energy spectrum for photon can be expressed as followed by;

$$\varphi_{\gamma}(E,d) = \frac{h_{1,\gamma}(d)\, E^{h_{2,\gamma}(d)}\left[1 + h_{3,\gamma}(d)\, E^{h_{4,\gamma}(d)}\right]}{\left[1 + h_{5,\gamma}(d)\, E^{h_{6,\gamma}(d)}\right]}\left\{1 + exp\left[-h_{7,\gamma}(d)(ln(E) + h_{8,\gamma}(d)\right]\right\} + h_{9,\gamma}(d)\delta(E_a)$$

Where δ is Dirac's delta function and E_a is energy of the annihilation γ-rays which is equal to the rest mass of the electron. The numerical values of h parameters were resolved by LSq fitting with the normalized spectra.

In the atmosphere, all the neutrons are secondary particles. The neutron flux can be expressed by the secondary flux function as followed by;

$$\emptyset_{\mathrm{n}}\,(\mathrm{E,d,r_c,W}) = \Phi_{\mathrm{n}}\,(\mathrm{d,r_b}\,(\mathrm{r_c,d}),\mathrm{W})\ \varphi_{\mathrm{n}}\,(\mathrm{E,d,r_c}\,)\ \mathrm{C_n}\,(\mathrm{E,d,r_c,W})$$

where $\mathrm{r_b}$ is the best-fit rigidity and $\mathrm{C_n}$ is the Correction factor of the spectrum. The normalized energy spectrum of neutron can be expressed by the following;

$$\varphi_{\mathrm{n}}\,(\mathrm{E,d,r_c}\,) = p_1(E/p_2)^{p_3} exp(-E/p_2) + p_4(d,r_c) exp\left\{\frac{-[log_{10}(E) - log_{10}(p_5)]^2}{2[log_{10}(p_6)]^2}\right\} +$$

$$p_7 log_{10}(E/p_8)\{1 + tanh[p_9 log_{10}(E/p_{10})]\}\{1 - tanh[p_{11} log_{10}(E/p_{12}(d,r_c)]\}$$

where p_1 to p_{12} are free parameters.

In that model, it is suggested that muon fluxes over 10 GeV do not depend on r_c and W. Thus, muon flux can be determined by the same function as the secondary ion flux as followed by;

$$\emptyset_{(\mu\mp)}\,(\mathrm{E,d,r_c,W}) = \Phi_{(\mu\mp)}(\mathrm{d})\ \varphi_{(\mu\mp)}\,(\mathrm{E,d,}r_c,W)$$

where $\emptyset_{(\mu\mp)}(\mathrm{d})$ and $\emptyset_{(\mu\mp)}\,(\mathrm{E,d,}r_c,W)$ are the normalization flux in $cm^{-2}s^{-1}$ and the normalized energy spectrum in MeV^{-1} respectively. The normalized energy spectra can be expressed as followed by;

$$\varphi_{(\mu\mp)}^{(W\mp)}(E,d,r_c) = \left[E + \frac{t_{1,(\mu\mp)}^{(W\mp)}(d,r_c) + t_{2,(\mu\mp)}^{(W\mp)}(d) log_{10}(E)}{\beta^{t_{3,(\mu\mp)}^{(W\mp)}(d,r_c)}}\right]^{t_{4,(\mu\mp)}(d)} \times$$

$$\left\{1 + exp\left[-t_{5,(\mu\mp)}^{(W\mp)}(d,r_c)(ln(E) + t_{6,(\mu\mp)}^{(W\mp)}(d,r_c))\right]\right\}$$

where β is the speed of muon relative to light and $t_{1,(\mu\mp)}^{(W\mp)}(d)$ to $t_{8,(\mu\mp)}^{(W\mp)}(d)$ are free parameters depending on d and r_c.

The total flux can be calculated by combining primary ion flux and secondary ion flux as followed by;

$$\emptyset_i(E,d,r_c,W) = \emptyset_{i,pri}(E,d,W)\left\{tanh\left\{o_{1,i}\left[E/E_{s1,i}(r_c,d) - 1\right] + 1\right\}\right\}/2 +$$

$$\emptyset_{i,sec}(E,d,r_c,W)\left\{tanh\left\{o_{2,i}\left[1 - E/E_{s2,i}(r_c,d) - 1\right] + 1\right\}\right\}/2$$

where $E_{s1,i}$ and $E_{s2,i}$ are switching energies between the primary and secondary ion fluxes and

$o_{1,i}$ and $o_{2,i}$ are free parameters that influence the smoothness of the spectra switching. In general, $E_{s1,i}$ is equal to $E_{s2,i}$ and they can be expressed as;

$$E_{s,i}(r_c,d) = o_{3,i}\left[E_{c,i}(r_c) - o_{4,i}\mathrm{d}\right]$$

where $o_{3,i}$ and $o_{4,i}$ are constant parameters and $E_{c,i}$ are cut-off energy of the particle i at the top of the atmosphere.

In this model, solar activity effect is determined on the count rates of several ground-level neutron monitors around the world. In calculation, the neutron spectra at ground level, the facts on the water density in the soil are added to this model because the albedo-neutron spectra from the soil depend on water density [6].

In this work, the weight fraction of water was set 0.15. For performing the cosmic ray exposure, isotropic geometry is used in this model. Based on that model, EXPACS gives the cosmic rays flux for one day per hour. This given flux is converted to the effective dose by using calculation of fluence to dose conversion coefficients. In order to calculate the annual effective dose, the dose for each day is calculated for twelve months. The annual effective dose for three major regions, i.e., high, middle, and low above sea-level in Myanmar will be calculated and discussed.

Results and Discussion

In this study, the annual effective doses due to cosmic rays exposure are calculated for three categories having different elevations above sea-level. They are listed in Table 1. In order to calculate the annual effective doses, altitude and geographic information are necessary inputs. We collect the required information from Google Earth and perform the calculations using EXPACS program.

Table 1 List of towns in this study.

High above sea-level (above 1500m)	Middle above sea-level (below 1000m)	Near sea-level (sea-level to 100m)
Tedim, Hakha, Pin laung	Pyin Oo lwin, Kyung tong	Mandalay, Sittwe

The annual effective doses due to cosmic rays exposure for Myanmar people in 2019 are tabulated in Table 2. The annual effective dose in Hakha is twice higher than in Sittwe. Thus, people from Hakha are more exposed to cosmic rays than from Sittwe. And those from Mandalay are less exposed to cosmic rays than from Pyin Oo Lwin. From Table 2, it is found that the neutron and muon doses are higher than those of electrons, photons and positrons. Moreover, more muon dose can be found on the ground level. As represented in Fig.1, the annual effective dose increases with increasing altitude. Most of the towns in Myanmar have nearly the same latitudes and longitudes. Therefore, dose due to cosmic rays weakly depends on the effect of geographic locations.

Table 2 Annual effective dose due to cosmic rays exposure for Myanmar in 2019

Towns	Altitude (m)	Neutron dose dose	Proton dose	Electron dose	Photon dose	Muon dose	Dose (mSv)
Hakha	1867	0.1257	0.0361	0.0270	0.0521	0.2472	0.513
Tedim	1680	0.1210	0.0313	0.0251	0.0470	0.2392	0.488
Pin Laung	1510	0.1025	0.0264	0.0229	0.0427	0.2291	0.455
Pyin Oo lwin	1070	0.0678	0.0186	0.0187	0.0343	0.2142	0.371
Kyung Tong	798	0.0596	0.0142	0.0163	0.0297	0.2040	0.339
Mandalay	80	0.0324	0.0074	0.0105	0.0189	0.1811	0.260
Sittwe	6	0.0274	0.0068	0.0098	0.0175	0.1797	0.250

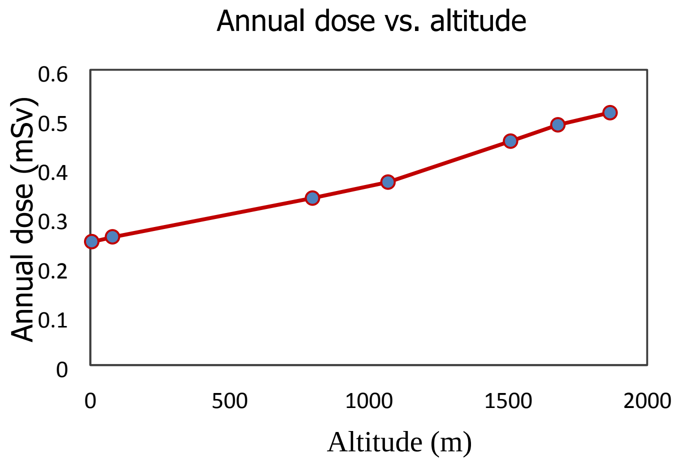

Fig. 1 Annual effective dose for seven selected locations in Myanmar as a function of altitude

Conclusion

In summary, the annual effective dose for Myanmar people living in different locations to cosmic rays exposure is calculated by applying EXPACS. At different elevations, the annual effective dose of Myanmar people in 2019 is from 0.25 mSv to 0.52 mSv. This study can be supported information for national databank of background radiation, environmental physics, and geoscience.

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