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Modeling of the Calibration Neutron Monitor

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Abstract

Neutron monitor is an instrument which measures neutron amounts in the air for studying the propagation of the cosmic ray from space to the Earth's atmosphere. Recently, neutron monitors were set on around the world, the objective of which is to study the energetic particle amounts coming into the Earth from the various locations and the influence of the environment that affect the neutron measurement such as instrument design, surrounding environment, cutoff rigidity of the Earth's magnetic field, and altitude of the sea level. The standard instrument calibration is necessary for data study from neutron monitor. Princess Sirindhorn Neutron Monitor at Chiang Mai, Thailand is one of the neutron monitors which can detect the highest energy neutron on the Earth because its geomagnetic cutoff rigidity is 16.8 GV. This neutron monitor was set in the pool with its diameter of 270 cm and the water level was changed from 0, 25, 50, and 65 cm, respectively. We found that the amounts of neutrons decrease as the increase of water high level. We simulated the standard calibration of neutron monitor by FLUKA program with the technique of Monte Carlo to study the process of particle interaction and important factors to the neutron measurement to control the standard of neutron monitor calibration.

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1. Introduction

Cosmic rays are the energetic particles or gamma rays coming from galaxy which the velocity of these particles can move nearby speed of light. When the primary cosmic rays enter the atmosphere of the earth, they collide with molecules in the atmosphere then produce the secondary cosmic rays with lower energy than primary cosmic rays as known as cosmic ray shower. These particles can be detected by neutron monitor, which the numbers of detected particles at various positions on the earth are different. The highest energy particles will be recorded less than the lower energy particles. The amount of cosmic rays will be changed, which depends on the activity on the Sun such as, solar flare or the effects from the other galaxy. The solar flare is a suddenly explosive on the Sun and releases the high energy ion from the outer most part of the Sun into the interplanetary.

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Some solar flare may be observed the shock waves in space after its explosion. These are the reports of the effects of the solar flare at the earth, which are reports caused the damage the pernicious electric currents, the communications systems, aircraft and the satellites for the world. Consequently, it is necessary to know the intensity of these particles at the earth to analyze and report the early warning to the relevant agencies for the promptly solvable plan so that it can reduce the damage caused.

1.1 Neutron monitor

A neutron monitor is a ground-based measurement of the number of neutrons from cosmic rays outer space. It was been developed by J.A. Simpson [6] who found that the earth's magnetic field can act as a cosmic energy filter. In general, the geomagnetic field can determine the energy of the particles move into the neutron monitor, which is called cutoff rigidity [5]. At least, the energy of the particles is not lower than the cutoff rigidities of the earth's magnetic field at the various locations. The cutoff rigidity; P_c was defined by

$$P_c = \frac{Pc}{q} \tag{1}$$

where P_c is the cutoff rigidity (GV), P is the momentum (GeV/c), c is the velocity of light and q is the particle charge

Currently, the neutron monitors were set up in the worldwide network about 50 stations [2]. The locations of neutron monitor stations will be different in the vertical geomagnetic cutoff rigidity. So, the neutron energies come into the neutron monitors for each stations are different. In Thailand, the Princess Sirindhon Neutron Monitor (PSNM) [3] was set at Doi Inthanon, Chiang Mai province, of which location is at highest magnetic cutoff rigidity (P_c = 16.8 GV) on the Earth. The altitude of the sea level of PSNM is 2,560 meters. Thus, the energetic particle data from PSNM are higher energy than 16.8 GV.

The relation between the counting rate [2], N, of neutron monitor and intensity, $j(P,t)$ of the primary cosmic rays at the top of the atmosphere as following the equation *(2)* and *(3)*

$$N(P > P_c) = \int_{\infty}^{P_c} S(P,x)\, j(P,t)\, dp \tag{2}$$

$$-\frac{dN}{dP_c} = S(P,x)\, j(P,t) \tag{3}$$

where dN/dP is the differential response function, $S(P,x)$ is the neutron monitor yield function of the secondary cosmic rays at atmospheric depth (x) [2].

In order to the deriving spectra from neutron monitor count rates of the various stationary neutron monitors, we can calculated the response function from the counting rates of individual neutron monitors as

$$\frac{dN}{dP} \approx \frac{N(P_{c2}) - N(P_{c1})}{P_{c2} - P_{c1}} \tag{4}$$

where P_{c1} and P_{c2} are the cutoff rigidity at the different stationary neutron monitors and $N(P_{c1})$ and $N(P_{c2})$ are the counting rates at the different stationary neutron monitors [2].

In this research, we simulated the neutron monitor calibration of PSNM at Doi Inthanon with the data of latitude 18.59 ^{o}N, longitude 98.49 ^{o}E, and altitude 2,560 meters.

1.2 The calibration neutron monitor

The neutron monitor calibration used neutron monitor with the length of 753 mm, which its length is about 1/3 of the standard NM64 neutron monitor. Its mass is 201.3 kg, mass of the cradle is 21.5 kg and the total mass is 222.8 kg [4]. The calibration neutron monitor has the small size, so it was easy remove to other places. Thus the standard calibration of the world's stationary neutron monitors need to be use the exact inter-calibrated neutron monitor for the identical standard.

The standard calibrator consists of the four main components:

1) a proportional counter is filled with ^{3}He 97% and CO_2 3% type LND25373
2) a moderator of polyethylene
3) a producer has seven lead rings
4) a reflector of polyethylene

These components are shown separately in Fig. 1

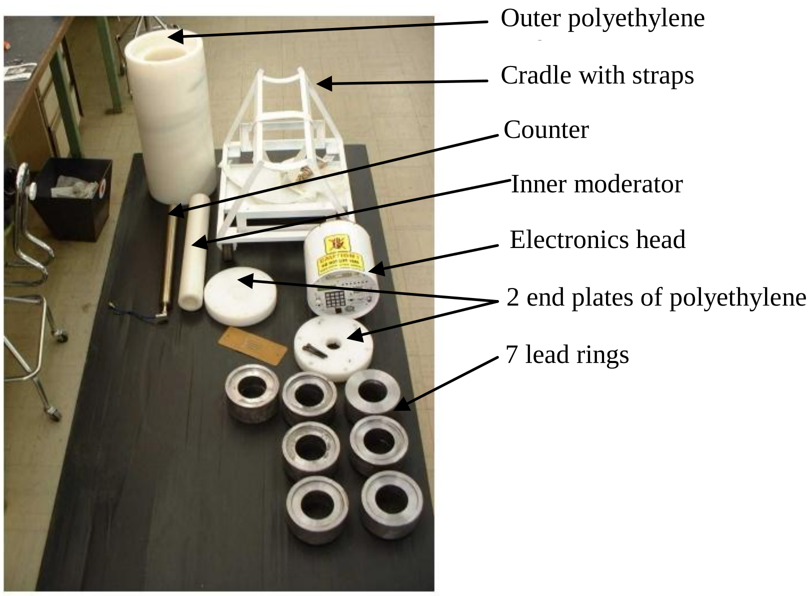

Fig. 1. The separate components of a calibration neutron monitor (by H. Kruger, 2006)

2. Methodology

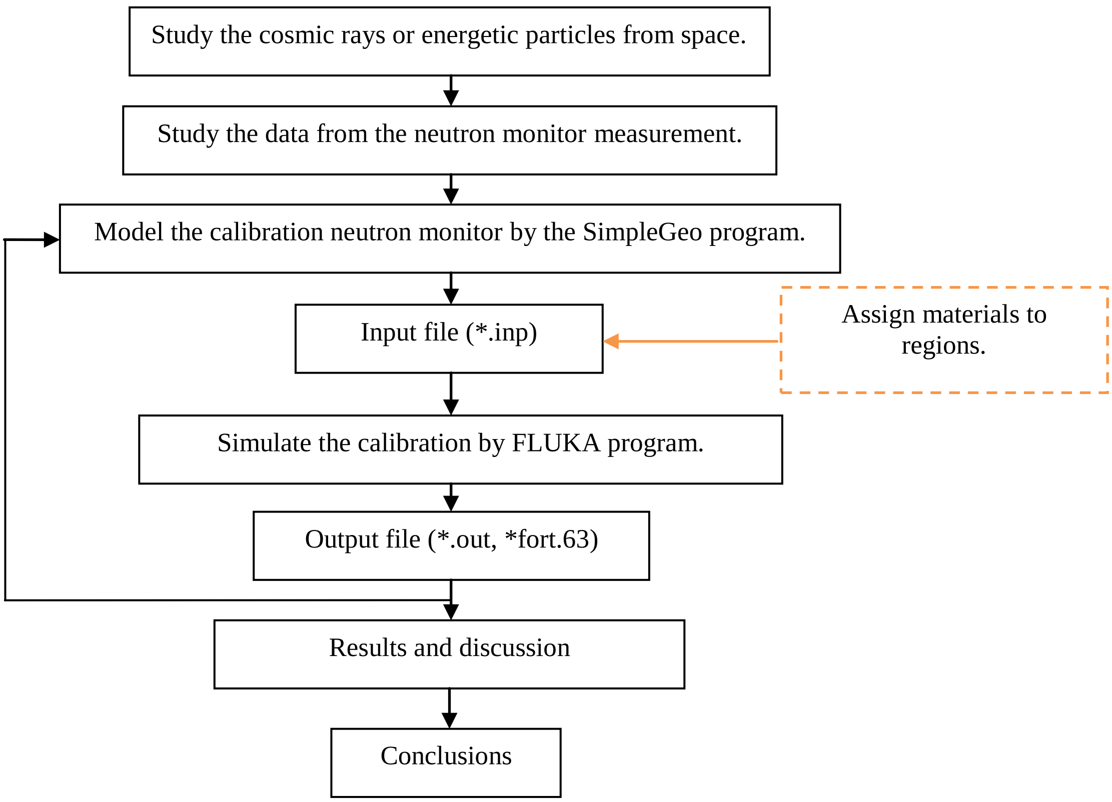

Fig. 2. The flow chart of the methodology

In this research, we created the modelling of the calibration neutron monitor which it was similar to the standard neutron monitor. We used SimpleGeo program for designing the pattern of the calibration neutron monitor as in the constructive solid geometry. An efficiency of the SimpleGeo program is it can build the 3D geometry instructor. This program can assign the materials for the exported FLUKA file as the input file (*.inp), that it was simulated by FLUKA program. The FLUKA program uses the technique of Monte Carlo simulation [1] for the interaction and transport of the particles determining in other regions in the instrument. In the FLUKA simulations, we can set the types of the particles, the energy and the sources of the particles as you want, then the program will generate a random number and start the interaction and transport of the particles simulation, finally the output file (*.out and *fort.63) reported the types of the secondary particles, the type of interactions, the energy and the position vector of the particles.

In the created calibrator, we assign this calibrator is set in the pool with its diameter of 270 cm, which it is on the top of the outside concrete bunker of any buildings or structures. The height of the bunker is 220 cm from the ground. The calibrator is set at 140 cm above the surface, while the levels of water in the pool are 0, 25, 50 and 65 cm respectively.

3. Results and discussion

This research, we design a geometrical structure similar to the calibration of PSNM station which consists of concrete bunker, wooden roof, wooden pool and a calibration neutron monitor. The inside structure of a calibration neutron monitor consists of polyethylene reflector, lead producer, polyethylene moderator and proportional counter which is filled ^{3}He 97% and CO_2 3% gas. When neutrons collide with ^{3}He gas then the ^{3}He nucleus produces charged particles that they were detected by proportional counter.

In Fig. 3 and 4, show the various components and the installation of the calibration neutron monitor by using the SimpleGeo.

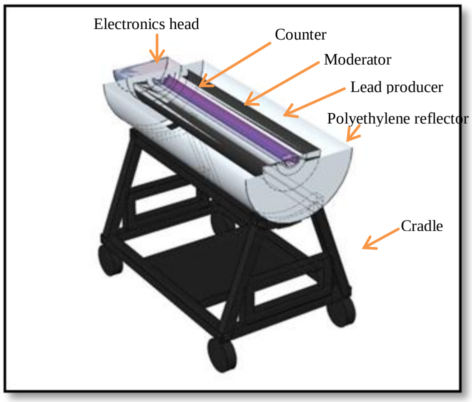

Fig. 3. The sketch of the calibration neutron monitor

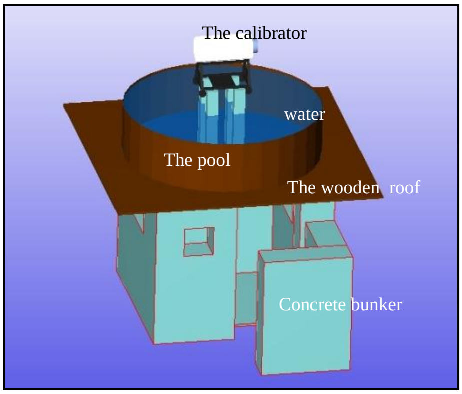

Fig. 4. The sketch of calibrator installation

According to the output file,*fort.63, consists of the column of particle numbers, secondary neutron interaction, particle interaction position in xyz coordinates and time as shown in Fig.5

```
1364 300 0 4 246  1.0561548 -44.4197643  1.75928835  7.52492636E-05
1708 300 0 4 238 -1.94024766 -34.9980257 -0.364164208  3.72840562E-06
2271 300 0 4 246 -0.706537126 -52.2145292  0.84670844  7.77609861E-05
2271 300 0 4 244 -0.22576855 -28.690626 -1.03064484  0.000540125899
2271 300 0 4 247  2.10378674 -32.756927 -0.887557281  0.000178329646
2271 300 0 4 244  0.250717887 -48.1741474  2.24908251  4.72256137E-05
4441 300 0 4 245  2.00644123 -26.7643645 -0.738719151  0.000118818494
4443 300 0 4 244  0.203660264 -53.4876426 -1.68987611  0.000535618958
4443 300 0 4 243  1.95859153 -57.5294466 -0.818675074  4.88121845E-05
4443 300 0 4 246 -0.205443209 -34.0604302  2.23774954  7.3616544E-05
4946 300 0 4 243  0.215616589 -43.8444907  0.0788239241  1.56552273E-05
5870 300 0 4 222  1.15636125 -24.7901163  0.552819322  1.93878593E-06
6378 300 0 4 245  2.45281373 -30.210444 -0.0874823243  1.978788E-05
6510 300 0 4 245 -0.756355667 -51.0483437  1.76199527  0.000458381183
6510 300 0 4 250  1.15273285 -51.2484669  2.14576257  6.64959634E-05
6538 300 0 4 244 -1.21375051 -5.76173466  0.106362072  0.00022136836
7837 300 0 4 245 -2.31472644 -17.5843955  0.0545180097  6.2618645E-05
7837 300 0 4 243  0.307864905 -36.4347362  1.73173799  0.000121628644
8950 300 0 4 244 -1.07311384 -17.6503625  0.827844013  4.53729628E-05
9277 300 0 4 244 -1.65819331 -44.5725808  1.36908411  6.88060121E-05
9657 300 0 4 215  0.76657051 -52.372332  2.08647488  3.6996329E-07
```

Fig. 5. The output file of *fort.63 file

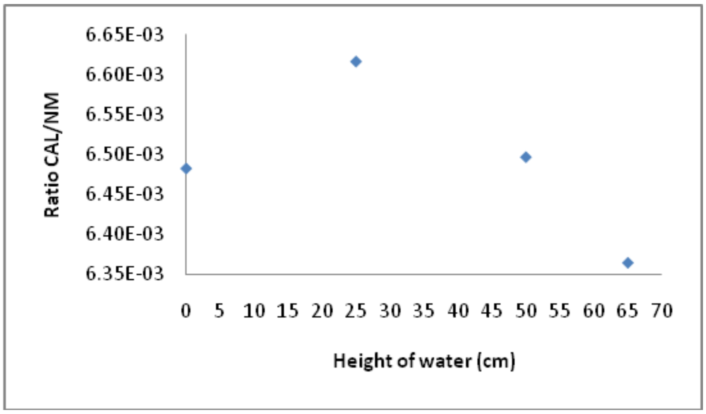

Fig. 6. The ratio of the count rates of the simulated calibrator and the neutron monitor at Doi Inthanon with the varying heights of water

In this model, we try to simulate the occurred secondary neutrons which the value of the energy is 100 MeV, at the height above the calibrator is 500 cm of the incident area is 400 x 400 cm^2 by FLUKA program with Monte Carlo method. Therefore, we calculate the ratio of the calibrator count rates per neutron monitor at Doi Inthanon by changing the height of water as 0, 25, 50 and 65 cm. The Figure 6 shows decreasing of the count rates when the water height increases. It can explain that the properties of the water height will affect the interaction of absorbed and reflected particles. As a result shown the count rate is small when the water level less than 25 cm because the chemical structure of the wooden pool consists of cellulose ($C_6H_{10}O_5$) 50%, hemicelluloses ($C_5H_{12}O_5$) 25% and lignin ($C_9H_{10}O_2$) 25%. The mostly detected particles are hydrogen, so when neutrons collide with the wood molecules, they will be absorbed more than water and there is some reflected particles, so the result of the count rates at the water level less than 25 cm is small.

4. Conclusions

In this research we model the calibration neutron monitor by FLUKA program and SimpleGeo for study the process of the particle interaction inside the neutron monitor and the relationship between the particle count rate and the water level in the pool of the calibration neutron monitor. We found that the increased heights of water affect to the count rates of neutrons which they are reduced. This simulation of FLUKA uses Monte Carlo method to random simulation in each interaction. Therefore, the simulation should be replicated several times to reduce the standard error for the accurate results.

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