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Monte Carlo Simulation of a Tissue Equivalent Proportional Counter for the Low-Earth Orbit

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1. Introduction

Almost all human activities in space is done in the LEO (Low-Earth Orbit). The space radiation environment is one of the most important factors that can pose a direct risk to the health of astronauts in LEO. Space radiation environment also contains various types of radiation including protons, electrons, and neutrons. Since each radiation has different effects on the human body depending on its kind and energy, it is important to accurately measure the each space radiation environment components and to determine RBE (relative biological effectiveness). Therefore, in this study, Monte Carlo simulation was performed to predict which lineal energy spectrum the TEPC (tissue equivalent proportional counter) shows in the space radiation environment of the LEO and to obtain the energy spectrum of the radiation from the lineal energy spectrum. Since the neutron environment model for LEO is not established yet, only the modeling of the proton environment has been performed.

2. Methods and Results

First, the selection of the orbit and the selection of the space radiation environment model were carried out. In this process, integral fluence spectrum of the orbit was obtained. From the integral fluence spectrum, proton source information was determined. Since the trapped particle environment with the largest share of radiation exposure in LEO is highly variable, the mission duration was set to one year.

2.1 Space radiation environment models

Trapped particle environment can be modelled with the AP/AE8 model. The AP/AE9 model was released in 2013, but there was a problem with reliability due to the difference between the model and the measurement result [1], [2]. SPENVIS version 4.6.9 was used to obtain the integral fluence spectrum using the AP/AE8 model. As the orbit, ISS orbit (400 km altitude, 51.64 degree orbital inclination, 105.83 degree RAAN (right ascension of ascending node), 223. 71 degree argument of perigee) is selected. Trapped proton fluence increases in solar minimum phase. Since many missions are performed at the solar minimum phase, AP8MIN model was chosen for the simulation. As a result of the modeling, integral fluence spectrum and differential

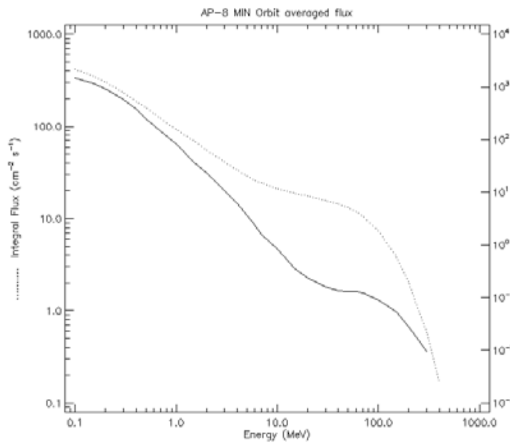

Fig.1. averaged flux for the ISS orbit using AP8-MIN model. The solid line is the integral flux and the dotted line is the differential flux.

fluence spectrum was obtained. Due to the constraints of computing power, the annual fluence spectrum was normalized back to the fluence spectrum per minute.

2.2 Detector geometry

Because the TEPC is a device to be used in space mission, there exist limitations in terms of weight and consuming power. So it is necessary to choose an optimum radius that can be exposed to a measurable degree of radiation flux while minimizing the size. A radius of about 30 mm was chosen as a condition to meet this requirement. More specifically, the geometry of the TEPC is a 4 mm thick, 15 mm radius of the A-150 plastic shell surrounding the propane gas, and a 0.5 mm thick, 26 mm radius Al6061 wrapped around the A-150 plastic shell structure. The pressure of the inner propane gas was adjusted to 177.2 Torr to simulate a cell nucleus of 2 micrometer diameter.

2.3 Monte Carlo simulations

Two different Monte Carlo simulations were done. First, the lineal energy spectrum of each mono-energy proton beam was confirmed. Geant4 10.03.p02 and PHITS 3.02 were used for the Monte Carlo simulation, and the results were compared. For the physics list in Geant4, G4EmPenelopePhysics and QGSP_BIC were selected. 1 micrometer range cut was set for the calculation efficiency. As a result, lineal energy spectrum was obtained. From the lineal energy spectrum,

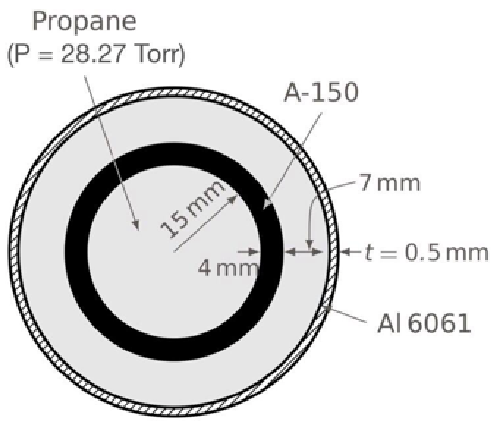

Fig.2. Simulation geometry of TEPC.

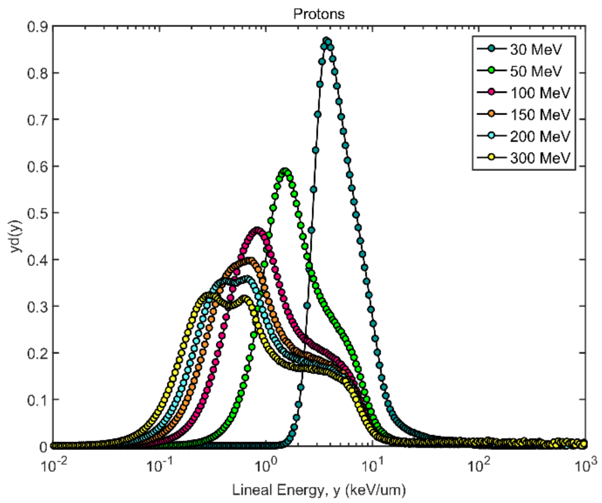

Fig.3. Lineal energy-yd(y) spectrum of mono-energy proton beam.

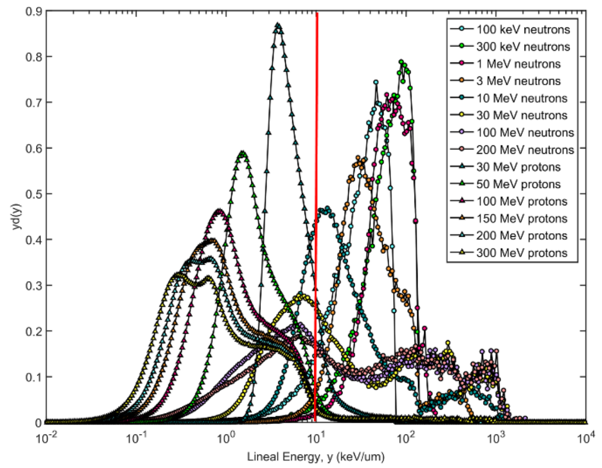

Fig.4. Lineal energy-yd(y) spectrum of mono-energy proton and neutron beam. The proton and neutron spectrum's peak are classified by about 10 keV/μm. But 10~200 MeV neutrons were not able to classify with the proton spectrum.

dose-mean lineal energy can be calculated with the equation:

$$\bar{y}_D = \int_0^\infty y d(y) dy = \frac{1}{\bar{y}_F}\int_0^\infty y^2 \cdot f(y) dy \quad (1).$$

Then the final lineal energy-yd(y) spectrum can be obtained. 30, 50, 10s, 150, 200, 300 MeV protons were simulated with 10^8 histories. As a result, the lineal energy peaks of protons were located between 0.1 and 10 keV/μm. As the proton energy increases, peak of the spectrum moved to the left and broadened. Also, neutron simulations were also done for the comparison with proton spectrum. A rough classification of the proton and neutron spectrum was done, but several energy range were not distinguishable.

The space radiation environment is originally omnidirectional (the fluence is constant regardless of direction of incidence), but the geometry of the current TEPC is spherical and thus simulated as a mono-directional beam. Number of histories was 10^8, as same as the number of histories of mono-energy beam case. Lineal energy-yd(y) spectrum was also generated by the same procedure with mono-energy case. As expected, the lineal energy spectrum was broader than at single energy. Also, in the space radiation environment, since the fraction of the low energy particles is much higher, the number of particles that cannot penetrate the aluminum shell is increased and the detection efficiency is decreased.

3. Conclusions

Monte Carlo simulations using Geant4 and PHITS were done for the TEPC for LEO. As a result, proton lineal energy peak can be observed in the mono-energy case. For the case of the trapped proton environment, it was difficult to separate each specific energy proton's peak. For the acquisition of proton energy-fluence spectrum, further study for the unfolding mechanism would be required.

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