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Lineal energy spectrum of heavy ions in deep space environment: Monte Carlo simulation

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1. Introduction

GCRs (Galactic Cosmic Rays), heavy charged particles incident from the outer space, includes all naturally occurring ions (from hydrogen to uranium). Because of its high energy, GCRs induce single events in the deep space mission, and even penetrates the skin and deposits its energy to human body [1], [2].

Especially, in the solar minimum phase (Korean lunar orbiter is planning to launch in the solar minimum phase), galactic cosmic ray flux increases as solar wind becomes weak. Therefore GCR environment's effect to human body and electronics should be analyzed accurately. Because the energy range of GCR varies from few MeV to GeV scale (different energy range in comparison with on-ground artificial sources), microdosimetric approach is essential to investigate GCR's effect to astronauts.

In this research, we obtained responses of TEPC, a standard detector in microdosimetry [3], to GCR heavy ions by Monte Carlo simulation. It was able to get lineal energy spectrum of high energy heavy ions, and we were able to obtain data that could be a guideline for the space radiation detector.

2. Methods and Results

For the simulation, galactic cosmic ray environment was defined using existing model. KASI's D60 TEPC geometry (in development) was selected as the detector geometry. Angular distribution of the radiation source did not have to be considered because of the detector's spherical geometry, so the source term was generated as mono-directional beam.

2.1 GCR Environment

CREME96 model was used for GCR environment modelling among two dominant GCR models (CREME96, ISO15390) because CREME96 implements anomalous cosmic rays and low-energy components [4]. SPENVIS (Space ENVironment Information System) version 4.6.10, which is a web-based space environment modelling tool, was used to generate an orbit (KPLO orbit) and access CREME96 model data. Elements such as hydrogen, oxygen and carbon were abundant in the environment. Each lines in the Fig. 1 represents the LET-flux spectrum for each situation (solar maximum, solar minimum, worst week, worst day, and worst 5 minutes). Flux at solar minimum phase is slightly higher than that of solar maximum phase. Elements heavier than iron showed very low flux.

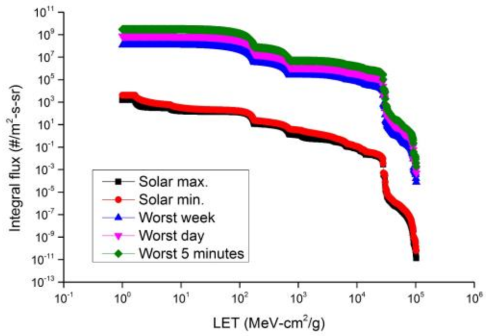

Fig. 1. LET-flux spectra of GCR environment, CREME96 model.

2.2 Detector Geometry

For the simulation efficiency, a simplified geometry of KASI's D60 TEPC is selected as the geometry of the Monte Carlo simulation. Basically it has a spherical shell shape, and the electrode geometry is neglected because of its negligible energy absorption. Gray area in Fig.2 is filled with propane-based TE gas, and its pressure is adjusted to 28.27 Torr to copy the energy deposition in 2 micrometer-sized cell. Inner cavity is covered with A-150 tissue-equivalent plastic of 4 mm thickness. The aluminum housing is cylindrical in real world, but to imitate the omnidirectional condition from the mono-directional beam by biasing the incident angle of the beam, housing is set to spherical shape.

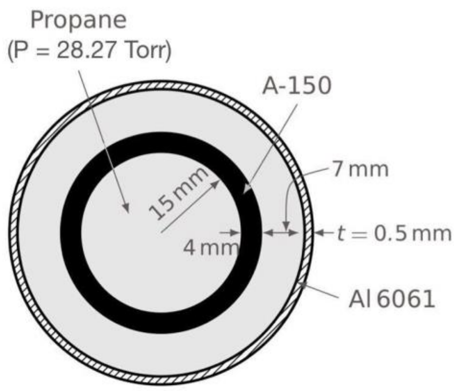

Fig. 2. TEPC geometry

2.3 Monte Carlo simulation

MCNP 6.1 is used for the simulation code. Simulation mode is set to H, and the energy cutoff is set to 0.001 MeV. As a reference source, carbon-12 ion is selected. To compare the simulation with on-ground measurement data [5], particle energy is set to 89~430 MeV/u.

2.4 Output Data Processing

By dividing deposited energy into mean chord length, lineal energy distribution can be calculated. Mean chord length is the mean length of all available traversing chord. Mean chord length of a convex body is 4V/a where V is the volume and a is the surface area. In the case of 2 micrometer-sized sphere, mean chord length is 1.33 micrometer. yf(y) and yd(y) spectrum was compared for each energy where f(y) is lineal energy's frequency distribution function and d(y) is its dose distribution function.

2.5 Simulation Result

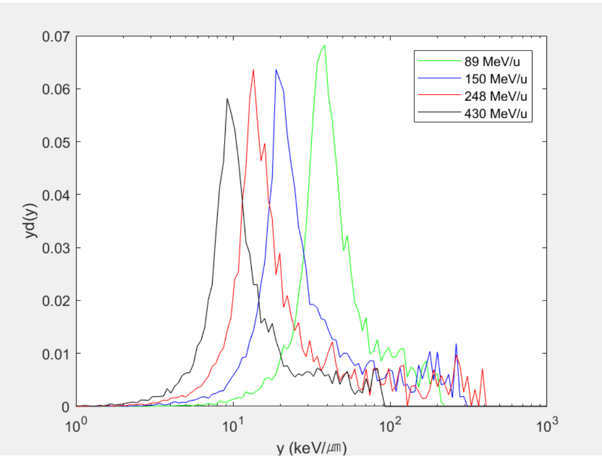

Fig. 3. yd(y) spectrum of carbon-12 ion in 5 mm Perspex phantom. Energy of the ion is changed from 89 MeV/u to 430 MeV/u

As ion energy increases, peak moved to left because the particle can penetrate the gas cavity easier. Also, for all energies simulated, tail was observed right after the peak in the case of MCNP. Same phenomenon occurred in the case of proton beam. In comparison with the measurement data, peaks became sharpened and showed no large difference between each energies. It's also because of the tails observed. Constant numbers of 50~100 keV/μm events are not able to be described in the manner of physics, so it is thought to be an error caused by the physics algorithm itself. Delta rays should have to be set in case of using MCNP. It can be a reason of the produced tails. Further research about the tails will be conducted.

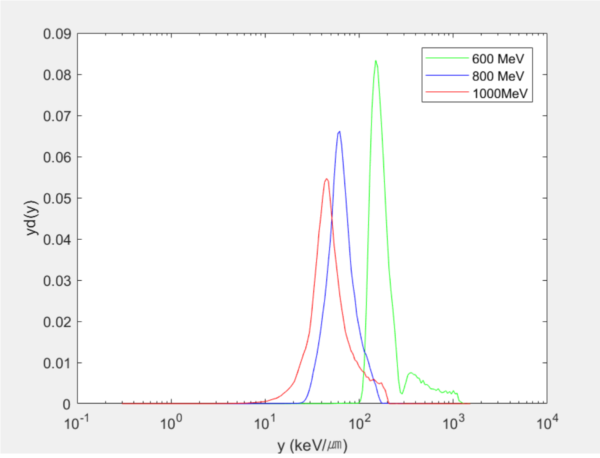

Fig. 4. yd(y) spectrum of carbon-12 ion in 5 mm Perspex phantom. Energy of the ion is changed from 600 MeV/u to 1000 MeV/u

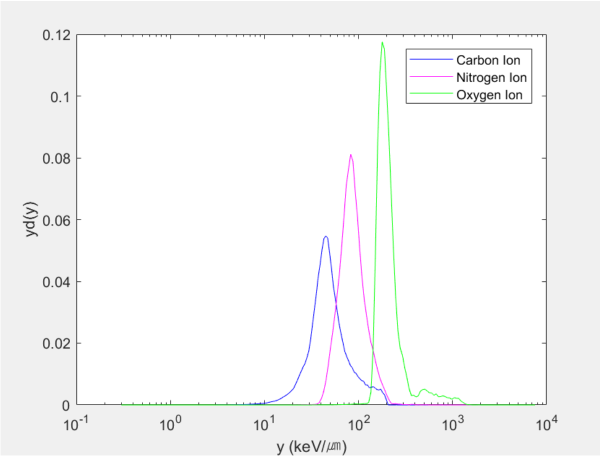

Fig. 5. yd(y) spectrum of carbon, nitrogen, and oxygen ion. Particle energy was set to 1000 MeV/u

1000 MeV carbon, nitrogen, and oxygen ions were also simulated to compare particles of various Z number. As expected, peak goes right as the ion becomes heavier. We also could observe the tail in this simulation.

As the particle gets higher energy, its tissue effect became weaker. And GCR particles less than 10 MeV are hard to penetrate the human skin. So TEPC's detectable energy range (about 50 MeV – 500 MeV/u) can cover charged particles' energy range that largely affects human body.

3. Conclusions

Sort of Monte Carlo simulations were done to investigate the microdosimetric quantities of GCR environment. As the particle energy increases, lineal energy decreased. From the lineal energy spectrum we gained, precise estimation of dose equivalent in GCR environment can be done by conducting research about RBE (Relative Biological Effectiveness)-lineal energy relation [6]. From the fact that higher energy particles are less dangerous to human body because of its low lineal energy, exclusion of GeV particles that are hard to detect by TEPC can be justified. Furthermore the desired detection range (40 – 400 MeV/u) of LEO-DOS, TEPC under development at KASI, may considered to be suitable to measure GCR's effect to the human body.

Further research about tails in MCNP simulation will be conducted to enhance the simulation reliability.

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