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Comparison of the evaluation methods for the effectiveness of the active shielding

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1. Introduction

The shielding concept of passive shielding for the radiation facilities on the earth is using the proper massive block to shield the radiation produced from the sources by using the interaction of radiation with matter. The space radiation environment is different from that experienced on the earth. Most of radiations in the space are the energetic charged particles which are the Solar Cosmic-Ray(SCR) from the Solar Particle Event(SPE) and Galactic Cosmic-Ray(GCR). The energetic charged particles up to a few tens of GeV in GCR require very thick shield material, and the reason why passive shielding concept is not enough to design the space craft for deep space missions. Since 1960s, active shielding concept was proposed and studied for deep space mission.[ref1] The active shielding uses the deflection of the charged particle in the magnetic or electro-magnetic field. Over the last several decades, many active shielding design concepts using electrostatic, plasma, and magnetic fields were proposed.

Shielding calculation for active shielding design should also represent the space radiation environment and detailed transport analyses to account for primary charged particles and secondary particle production mechanisms. Analytical method for active shielding analysis divides the shielding calculation to two steps which are analytical solving the charged particle distribution in the magnetic field and transport of the particles in the geometrical model without consideration of magnetic field effect. Recently particle transport codes using Monte Carlo method adopted magnetic field representation in the particle transport simulation.

In this paper, the analytical method and Mote Carlo codes simulation were compared with the GCR model and simplified active shielding model.

2. Methods and Results

2.1GCR Model

The most common models found in the literature are CREME, Matthia and Badhwar-O'Neill (BON) model. These models are in good agreement within 10% of each other, on average, over past 40 years[1]. Although the models are relatively similar, they are continually being updated with available data and differences in the flux profiles do exist. The GCR flux and spectrum evaluated by CREME model and Matthia/BON model are provided by SPENVIS(SPace ENVironment Information System) and OLTALIS(On-Line Tool for the Assessment of Radiation in Space, respectively. In this work, the BON2010 GCR model [ref] was used as a radiation source term with a isotropic distribution.

The BON2010 model has substantially lower flux profiles for both proton and alpha particles in the energy ranges below approximately 10^3 MeV/n. The BO2010 model provides the GCR energy spectrum for 1 to 106 MeV/n for elements with Z = 1 through Z = 94. In this work, it was only takes into account elements with Z = 1 through Z =28, since the resulting dose equivalent for elements with Z greater than 28 provides a negligible contribution to the total dose equivalent. The model output is the differential flux and is assumed to be isotropic. The GCR model output used in this analysis is based on a solar modulation parameter value of 481 MV, corresponding to the 1977 solar minimum. This solar minimum is commonly used to provide a design basis in the literature because it results in the highest radiation exposure during the time period for which GCR data is available.

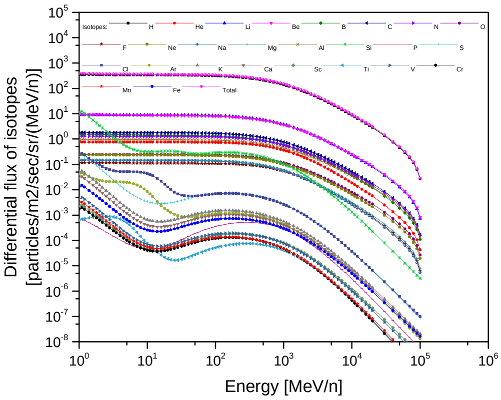

Fig. 1. Differential flux of from Z=1 to Z=26 from BON14 GCR model corresponding to 1977 solar minimum.

2.2 Simplified active shield model

The simplified solenoid magnetic field model of open-ended cylindrical shape shown in Fig. 2 was considered as the active shield model. Inside the magnetic field, the Aluminum shield was added.

2.3 Evaluation methods

The charged particle distribution based on the particles tracking in the magnetic field is required to evaluate active shielding effects.

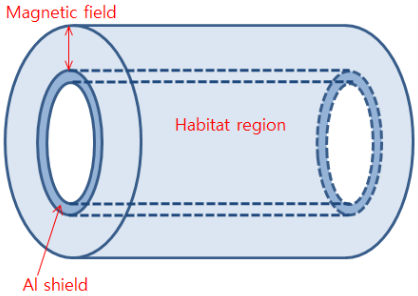

Fig. 2. Open-ended cylindrical calculation model for active shielding.

One of the common techniques assessing the effectiveness of the active shielding is to use Monte Carlo simulation codes. The particle transport codes, MCNP6, PHITS, FLUKA, GEAT4 and MARS, using Monte Carlo method had been adopted the magnetic field options. But much computing time is required to simulate energetic ions interactions. The analytical method has an advantage in the view of economic computing. Analytical methods provide firstly the charged particles distribution in the magnetic field, and the charged particles distribution is applied as a radiation source term in the transport calculation with particle transport codes.

In this work, analytical method proposed by S.A. Washburn in 2014 was used with MCNP6 instead of HZETRAN and MCNP6 with the particle ray tracking option in the magnetic field[2]. In the MCNP simulation the curved surface of the cylindrical magnetic field geometry was described with many meshed cells because the MCNP code provides only the magnetic field description of dipole and quadrupole.

2.4 Comparison of effectiveness of active shielding

To compare the effectiveness of the active shielding, equivalent dose variation along the axial distance from the center of cylindrical magnetic field and the annual exposure inside the habitat region with the magnetic field thickness and strength were estimated.

The equivalent dose inside the active shield does not significantly depend on the radial distance from the central axis of the active shield. The annual exposure inside the habitat region depends on the magnetic field strength and thickness. The relative differences between analytical method and MCNP simulation with COSY map is evaluated less than 42% on average for two calculation of equivalent dose distribution along the axial center and annual exposure with magnetic field strength and thicknesses.

3. Conclusions

The analytical method and Mote Carlo codes simulation with COSY map were compared with the GCR model and simplified active shielding model. The relative differences between analytical method and MCNP simulation with COSY map is evaluated less than 14% on average.

In the view of the computing time, analytical method is useful compared to the Monte Carlo simulation but analytical method to obtain the energetic charged particle distribution has limitations to describe magnetic field shape and variation of field strength because analytical solution is only obtained with the limited condition. The Monte Carlo code simulation has less error due to the active shield design shape than analytical method. But the Monte Carlo code has limitations in the magnetic field simulation, since the current version of MCNP6 code can’t simulate cylindrical and spherical magnetic field.

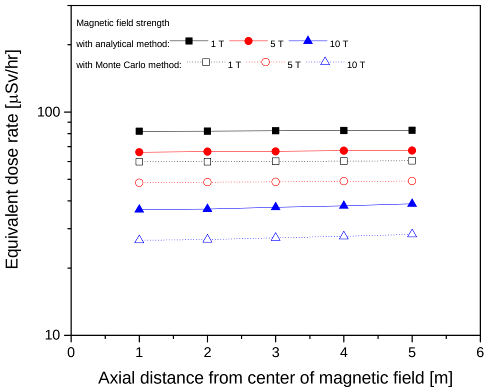

Fig. 3. Equivalent dose rate distribution along the center of magnetic field.

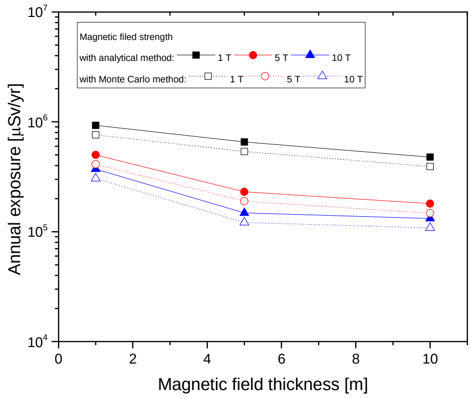

Fig. 4. Annual exposure inside habitat region of the active shielding.

REFERENCES

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