Modeling the dose distribution in a human brain structure on the surface of Mars

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1. Motivation and Introduction

One of the most important steps in the near-future space age will be a manned mission to Mars. However, there are various issues that may cause health problems for astronauts in deep space and on the surface of other planets, such as physiological problems[1], Psychological stresses which may arise from isolation [2] and in particular, risks induced by exposure to space radiation[3]. Thus, a better understanding of the radiation environment for a Mars mission and the consequent biological impacts on humans, in particular the human brains, is critical.

2. Model Description

To investigate the impact of cosmic radiation on human brains, we use 134 slices of computed tomography(CT) scans of a real head, which contains the whole brain structures in the GEANT4(GEometry ANd Tracking) , to build a voxelized geometry of human head. The slices taken from the top of the head to the part of the lower jaw, covering the whole brain structure. Then, the 3D-Slicer tool [4] has been used to create a three-dimensional visualization of the human head and segment different parts of the human brain, based on CT images.

3. Objectives

Three different scenarios with different simulation setups has been used in this work: the first two are aimed at model validation and investigation of its potential limitations and uncertainties, while the last scenario is the main outputs of our research. The main purpose and setup for each simulation scenario is listed below:

- ***scenario 1:*** To evaluate the necessity/difference of using a head structure with realistic brain densities in contrast to using a simplified water-equivalent head, we compare simulation results based on a head geometry with different contents (different material and densities).
- ***scenario 2:*** Comparison of the calculated functions using two different physics lists of GEANT4.
- ***scenario 3:*** Calculate the energy and dose functions of incoming protons, neutrons and Helium ions which are the most abundant particles encountered in space and on Mars for different lobes of the brain.

4. Simulation Results

Scenario 1: comparison of three different head structures: The lower panels of Figure.1 shows the differences of the 2D images when comparing cases (a), (b) and (c). A difference as large as 0.6-0.7 µGy, which is more than half of the maximum dose deposited in the brain shown in the upper panels, can be seen at the frontal central part of the head when comparing case (a) and (b) or case (a) and (c).

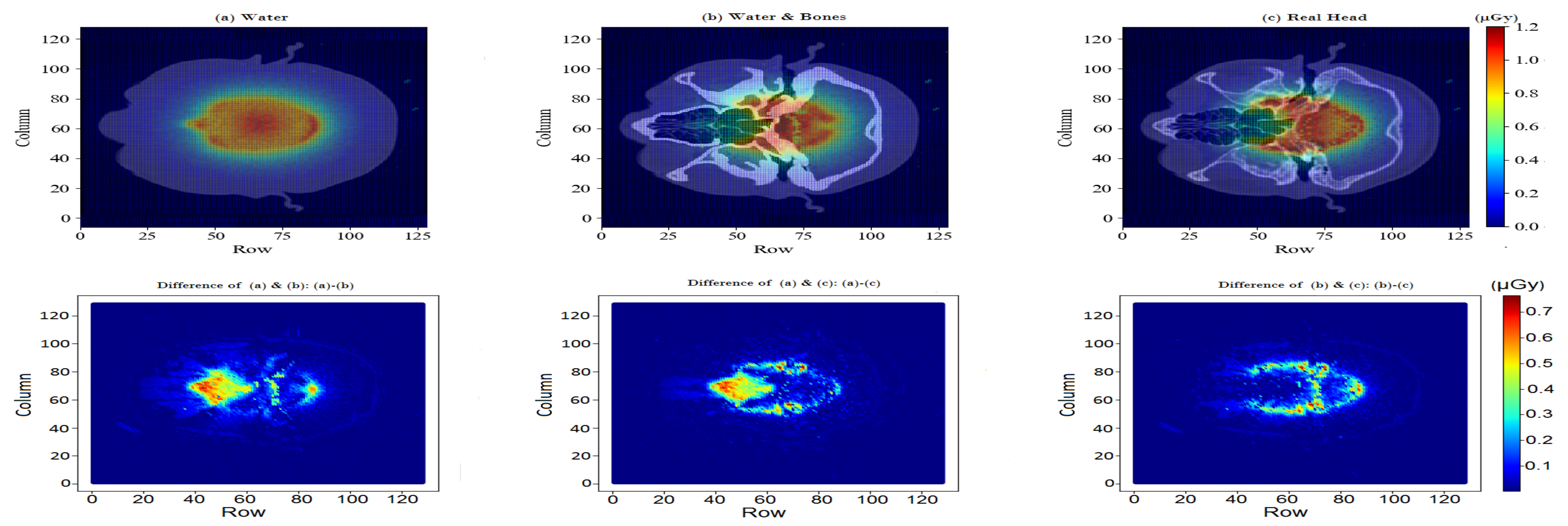

Figure1. Upper panels: Dose distribution of 10^7 protons with initial energy of 100 MeV impinging towards the approximate centre of the brain based on three different structures of a head: (a) filled with water, (b) containing water, bones and (c) with actual densities extracted from the CT scan. Lower panels: Image difference between case (a) and (b), case (a) and (c) as well as case (b) and (c).

Scenario 2: comparison between different physics lists: As it is shown in figure2, the differences between two QGSP-BERT and QGSP-BIC physic lists are within 2.5% , 3.8 % and 6.8 % for protons, neutrons and helium ions respectively, which suggests that the choice between these two lists hardly affects the assessment of the resulting dose deposit for concerned particle energy range and head materials.

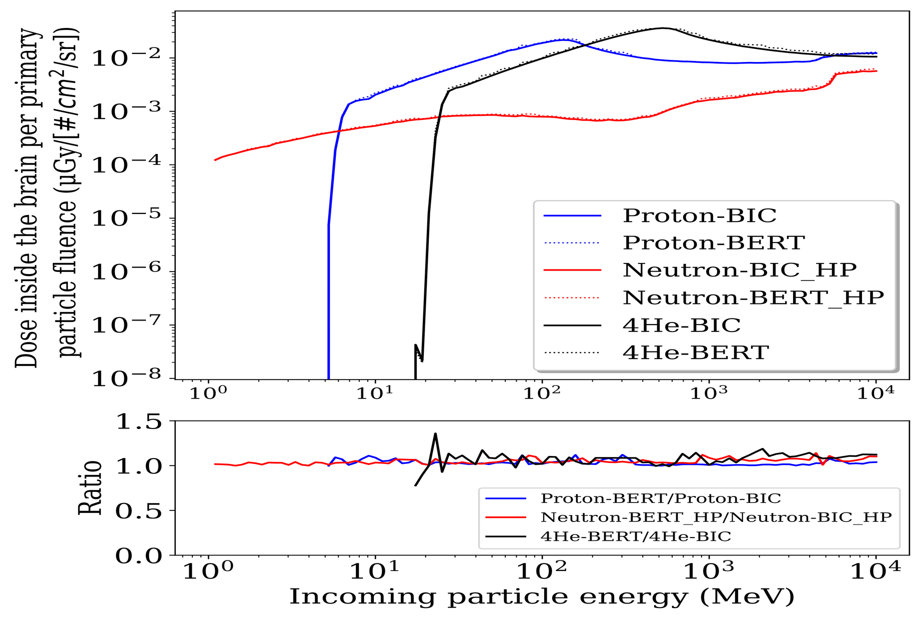

Figure2. Upper panel: Normalized dose functions versus incident particle energy based on simulation results using different physics lists of GEANT4. Lower panel: The ratio of the functions between two physics lists for protons , neutrons and 4He.

Scenario 3: Energy and dose functions for different lobes of the brain: Figs. 3 show the response functions of the deposited energy and dose versus incident particle energy (from 1 MeV to 10 GeV) within each of the 4 major lobes of the brain.

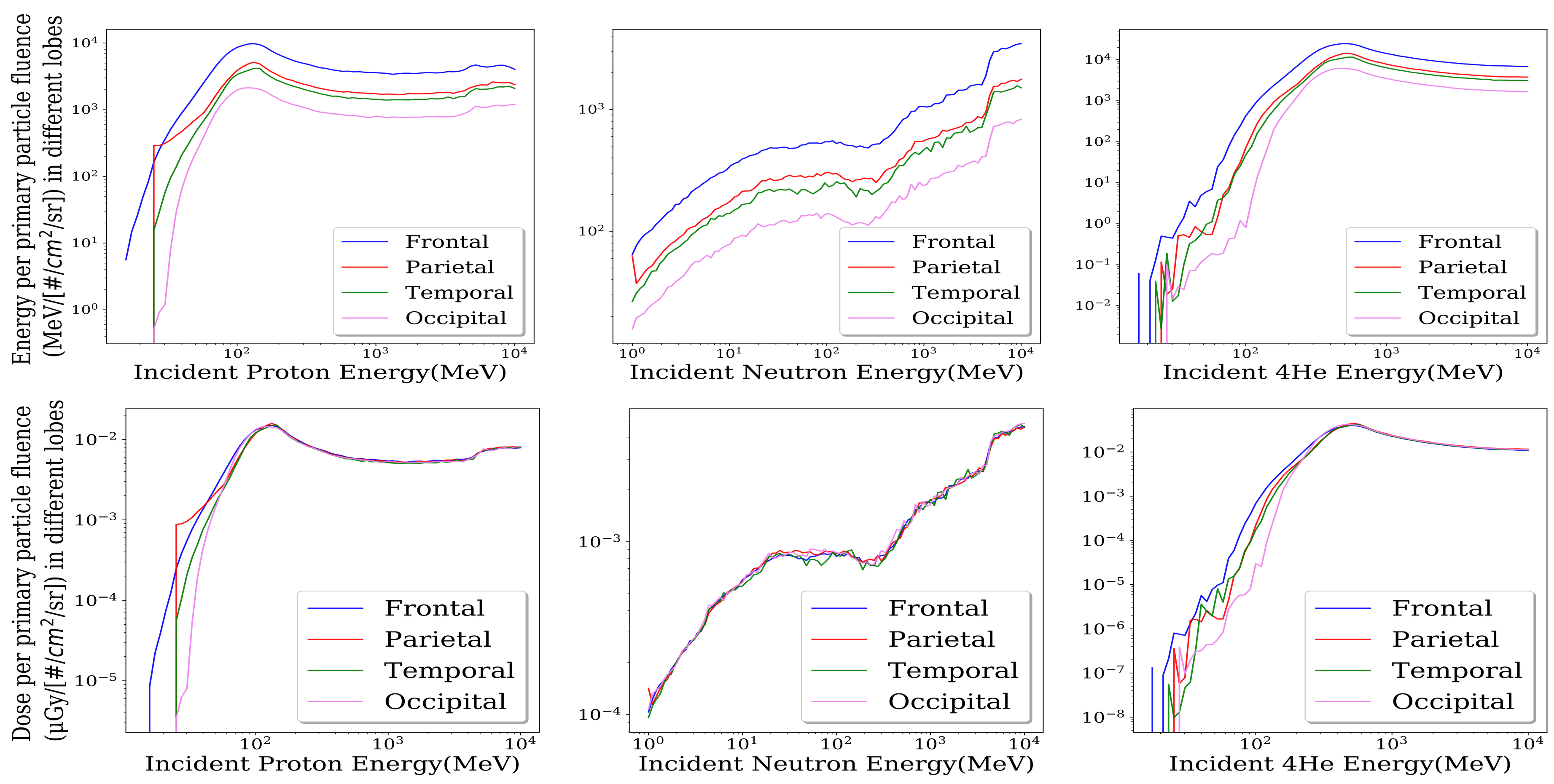

Figure3. Normalized energy (upper panels) and dose (lower panels) functions versus incident particle energy for different lobes of a human brain. The left, middle and right columns show the results from protons, neutrons and Helium ions, respectively. The results are based on isotropic source around human head with different energy bins from 1 MeV to 10 GeV

After folding these functions to the GCR spectrum on the surface of Mars, the summed dose rate of three particle types are between 80 to 280 µGy/day for the solar maximum and minimum conditions.

5. Conclusions

- We found that the using an actual head structure in the model is important especially when considering dose distributions at different parts of the brain.
- Additionally, we have also compared the results from two different physics lists (QGSPBIC and QGSP-BERT) in Geant4 code and found that they are very similar concerning the dose deposition.
- Based on such validated models, we have then calculated and obtained some ready-to-go functions of energy/dose deposit induced by primary particles of protons, helium ions as well as neutrons impinging isotropicaly towards the head.
- These ready functions can be used to quickly convert a certain ambient cosmic ray spectra (e.g., in deep space, on planetary surfaces or within habitats of a spacecraft) into the absorbed energy/dose within the entire head and also at different lobes of the brain.

6. References

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7. Acknowledgements

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