THE NEXT GENERATION OF MODEL CALCULATIONS FOR COSMOGENIC PRODUCTION RATES IN PLANETARY OBJECTS.

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Introduction: Production rates of cosmogenic nuclides in planetary bodies are of major importance for studies of cosmic ray exposure histories of meteorites, e.g., simple or complex exposure histories, cosmic ray exposure ages, and pre-atmospheric geometries. They are also used to study processes affecting the surfaces of asteroids and moons, like, e.g., gardening of the regolith and surface exposure dating. In addition, comogenic nuclides are valuable tools for a variety of terrestrial applications, including geology, archeology, and climate studies. In another important application cosmogenic nuclides enable to understand and quantify temporal and spatial variations of the cosmic ray fluence over long timescales. For all those applications, the production rates of cosmogenic nuclides and their dependence on the geometry of the object, its chemical composition, and also their dependence on the galactic cosmic ray particle spectra must be known. A variety of models exist, e.g., [1,2,3,4,5], but so far, a consistent model aiming to reliable describe cosmogenic nuclide production in all types of planetary bodies, i.e., from micrometeorites to planetary atmospheres, is not available. Within this project we aim for such a reliable and consistent model, which we plan to finally extend to the study of exoplanetary atmospheres.

Model and Improvements: The new model version is based essentially on the same ingredients as the earlier approaches [1,2|, i.e., the differential spectra for primary and secondary particles and the cross sections for all relevant nuclear reactions. This new version of model calculations, however, differ in some very important points from our earlier approaches. *First*, the particle spectra are no longer calculated using the LAHET code system but the GEANT4 toolkit. Thereby, the INCL code within GEANT4 used by us for modeling the intranuclear cascade, has been significantly improved. It now includes the emission of light charged particles and light charged particle induced reactions. In addition, strange particles are now fully considered, which was necessary for extending the approach to higher energies in the range 20 GeV. *Second*, we are for the first time able to include primary and secondary galactic α-particles and, *third*, there was a need to adjust some of the relevant cross sections due to a change in the accepted half-life (e.g., ^{10}Be) and/or due to a change in some of the AMS standards (e.g., ^{10}Be, ^{26}Al). For more details see [6].

First Results: In a first approach we calculated the differential particle spectra for a L-chondrite with a pre-atmospheric radius of 45 cm and we varied the solar modulation function from Φ = 100 MeV to Φ = 1000 MeV in steps of 50 MeV, i.e., we calculated 19 spectra. For each spectrum we calculated the ^{10}Be and ^{26}Al depth profiles and compared the results to experimental data from Knyahinya. We found a good agreement between modeled and measured depth profiles for Φ = 600 MeV. In a next step, we calculated the particle spectra for the lunar surface for Φ = 456, 620, 660, and 700 MeV assuming a density and chemical composition comparable to the Apollo 15 drill core. By comparing again measured and modeled ^{10}Be and ^{26}Al depth profiles we found the best agreement for a solar modulation potential Φ = 660 MeV. From this finding we conclude that the long term average gradient in the galactic flux is $\Delta\Phi \sim 30$ MeV/au, which corresponds to a gradient in the particle density of ~5%/au. Note that such a gradient is well understood in terms of galactic cosmic ray transport theory but is very often ignored in cosmogenic nuclide studies [7,8].

Outlook and Conclusions: We are currently extending the new model calculations to H-, L-, and LL-chondrites with radii between 4 cm and 500 cm with the aim to cover the entire group of ordinary chondrites. In the next step we will extend the model to carbonaceous chondrites and iron meteorites and finally we will perform model calculations for achondrites, a group of meteorites not included before. In addition, we already started using the new version of model calculations to study micrometeorites, this time by fully considering the gradient in the galactic cosmic ray particle spectrum. Furthermore, we already started to study the interactions of primary galactic cosmic ray particles with planetary magnetic fields and (re-)discovered a new effect, the focusing and dispersion of galactic cosmic rays in planetary magnetic fields. This so-called funnel effect has the ability to change the particle spectra inside planetary atmospheres by a factor of a few, i.e., it is indeed very relevant. Finally, with the new model we will tackle the long standing question why so far two different approaches are needed for neutron capture and spallation reactions.

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