

EFFECTS OF CUTOFFS ON GALACTIC COSMIC-RAY INTERACTIONS IN SOLAR-SYSTEM MATTER. K. J. Kim¹, R. C. Reedy¹, and J. Masarik², ¹Institute of Meteoritics, Dept. of Earth and Planetary Sciences, MSC3-2050, 1 University of New Mexico, Albuquerque, NM 87131-1126 USA (kkim@unm.edu; rreedy@unm.edu), ²Dept. of Nuclear Physics, Komensky University, Mlynska dolina F/1, Sk-84248 Bratislava, Slovakia (masarik@fmph.uniba.sk)

Introduction: The energetic particles in the galactic cosmic rays (GCR) induce many interactions in a variety of solar-system matter. Cosmogenic nuclides are used to study the histories of meteorites and lunar samples [e.g., 1]. Gamma rays and neutrons are used to map the compositions of planetary surfaces, such as Mars [e.g., 2], the Moon, and asteroids. In almost all of these cases, the spectra of incident GCR particles are fairly similar, with only some modulation by the Sun over an 11-year cycle [3].

Strong magnetic fields can seriously affect the energy spectrum of GCR particles hitting the surface of objects inside the magnetic fields. The Earth's geomagnetic field is strong enough that only GCR particles with magnetic rigidities above ~17 GV (a proton energy of ~17 GeV) reach the atmosphere over certain regions near the equator. This effect of removing lower-energy GCR particles is called a cutoff. The jovian magnetic fields are so strong that the fluxes of GCR particles hitting the 4 large Galilean satellites are similarly affected. The cutoff at Europa is estimated to be similar to or a little higher than at the Earth's equator [4].

Terrestrial cosmogenic nuclides made in the Earth's atmosphere have been used for over 50 years [cf., 1], and during the last 20 years nuclides produced in situ in surface rocks are used for many studies [5]. Measurements of cosmogenic nuclides have been proposed to determine the age of surface samples on Europa [4]. We report calculations that study the effects of cutoffs on interactions of GCR particles, both rates and depth profiles.

Calculations: The numerical simulations were done using the MCNPX (Monte Carlo N-Particle eXtended) code to calculate particle fluxes for a range of cutoffs and objects. We used version 2.5.d of the MCNPX code and the CEM (Cascade-Exciton-Model) option for nuclear interactions. This code has been well tested using cosmogenic nuclides in documented samples from the Apollo 15 deep drill core [6] and the L-chondrite Knyahinya [7]. These results agreed well with calculations done with the GEANT code.

For both the Earth and Europa, the spectrum of GCR protons averaged over a solar cycle [e.g., 6,7] was used along with the same spectrum but with all protons below various cutoffs removed. For the Earth,

these cutoffs corresponded to those for various latitudes. For Europa, cutoffs of 17 and 25 GeV [4] were used.

For the Earth's atmosphere, we used the standard composition with an average terrestrial surface chemistry at the atmosphere-surface boundary. The densities and heights were those of the standard atmosphere. The fluxes of thermal (< 0.3 eV) and fast (1-20000 MeV) neutrons were tallied for many layers of the atmosphere.

For Europa, we adopted a composition that was half of the salts expected at Europa [4] with the rest being water (ice). The rates for neutron-capture reactions with Cl making ³⁶Cl were tallied with MCNPX. The fluxes of energetic neutrons and protons were also tallied and used with existing cross sections to calculate rates for producing ³⁸Ar by spallation reactions with K and Ca, see [4] for details.

Results: The rates for making ³⁸Ar and ³⁶Cl in Europa as a function of depth are shown in Figs. 1 and 2 for no and cutoffs of 17 and 25 GeV. The fluxes of fast and thermal neutrons in the Earth's atmosphere as a function of depth are shown in Figs. 3 and 4 for a range of cutoff energies. The results were normalized to the actual flux of GCR particles hitting the surface relative to the cases for no cutoffs.

These fluxes decrease considerable for cutoffs above several GeV. However, the rates or fluxes per incident GCR particle are higher with increasing cutoffs, as these high-energy protons make more secondary particles than lower-energy protons.

Discussion: The peak depths of the highest rates or fluxes vary with the cutoffs, with higher cutoffs having peaks that are deeper. For Europa, where a finer set of layers were run, the peak for ³⁸Ar production moved from about 38 g/cm² for no cutoff to about 90 g/cm² for high cutoffs, and the peak capture rate moved from about 53 to 80-85 g/cm². The slopes of the calculated profiles are less steep for the higher cutoffs. Both effects are caused by the fact that the higher-energy particles are more penetrating. They are not slowed down as fast as lower-energy particles. The secondary particles made by the higher-energy particles have higher energies and are also more penetrating.

These results show that, when the spectrum of GCR particles is cut off at lower energies, the rates and profiles of interaction products are significantly changed. Thus, when cutoffs are present, it is important to know the spectrum of interacting particles. For the Earth, these spectra are fairly-well known. For Europa, the spectrum of GCR particles needs to be known before measurements of cosmogenic products can be interpreted.

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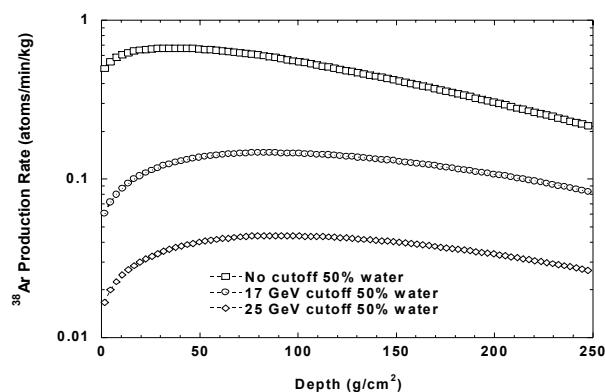


Fig. 1. Calculated production rate profiles of ^{38}Ar made by fast neutrons in the surface of Europa for various GCR cutoff energies.

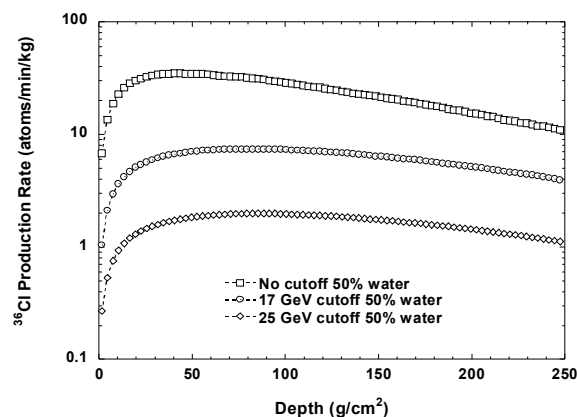


Fig. 2. Calculated production rate profiles of ^{36}Cl made by thermal neutrons in the surface of Europa for various GCR cutoff energies.

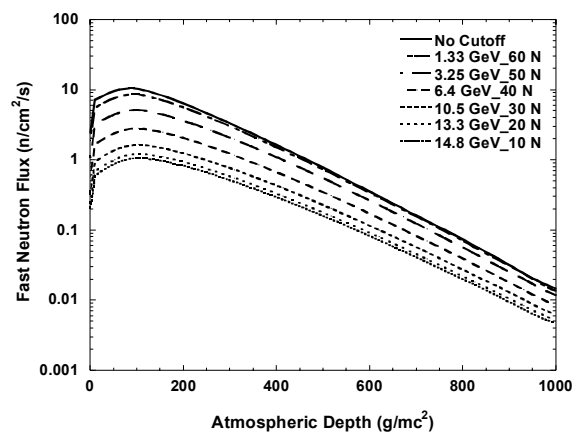


Fig. 3. Calculated fluxes of fast neutrons in the Earth's atmosphere as a function of depth for various GCR cutoff energies.

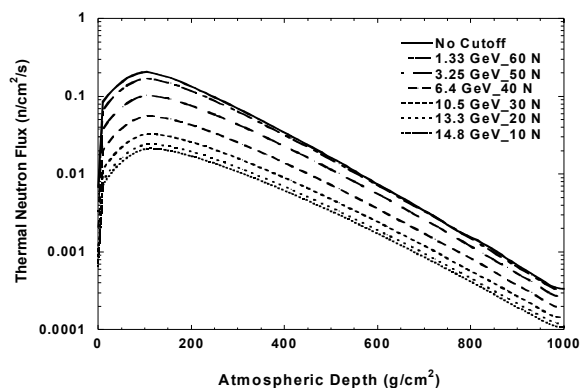


Fig. 4. Calculated fluxes of thermal neutrons in the Earth's atmosphere as a function of depth for various GCR cutoff energies.