PRODUCTION SYSTEMATICS OF RADIONUCLIDES IN THICK EARLY-SOLAR-SYSTEM MATTER

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Introduction: Meteorite studies show that radionuclides (RNs) such as ^{10}Be and ^{26}Al were abundant in the early solar system (ESS). Two sources are usually proposed for them, stellar nucleosynthesis and local particle irradiation by an early active Sun. Many have studied the local particle production of RNs in the ESS [e.g., 1,2]. Major uncertainties have been the lack of knowledge about the energetic particles involved (especially their composition and energy spectra), the nature of the targets, and the cross sections for making these RNs by ^{3}He. Some cross sections for ^{3}He reactions making ^{26}Al, ^{36}Cl, and ^{41}Ca were recently measured [3], and cross sections for proton reactions evaluated [4,5]. As in [3], these results are incorporated, but unlike [3] the slowing down of solar energetic particles (SEPs) is considered.

Model Inputs: Production rates of ^{7}Be, ^{10}Be, ^{26}Al, ^{36}Cl, and ^{41}Ca in matter of solar composition [1] were calculated using codes and procedures for modern SEPs [6]. The incident particles were ^{1}H, ^{3}He, and ^{4}He, individually, with unit flux as only trends for production systematics were studied. Spectral shapes included both power laws in energy, usually used for the ESS [1,2], and exponentials in rigidity, usually used for modern SEPs [6,7]. The shapes of the latter were selected to be similar to those for the power-law exponents (-2.7 to -5) used by [1,2]. The cross sections adopted were the evaluated ones for protons [4,5] and ^{4}He particles [7]. Production of ^{36}Cl by ^{4}He particles was not calculated. For ^{3}He reactions, the new measured cross sections of [3] were used along with some cross sections from [2]. The targets were modeled as a sphere with a radius of 3 g/cm^{2} (about 1 cm) and a thick slab (few SEPs penetrate beyond 1 g/cm^{2}). Results were tabulated for various depths and for layers at various depths.

Calculated Trends: The calculated ^{7}Be/^{10}Be, ^{36}Cl/^{10}Be, and ^{41}Ca/^{26}Al ratios for all three projectiles varied with depth by factors of ~5 or less, except that the depth variation was larger (~40) for ^{3}He reactions making ^{7}Be and ^{10}Be. The ^{41}Ca/^{10}Be and ^{26}Al/^{10}Be ratios varied by factors of ~50-100. The calculated production ratios are consistent with those obtained for ESS matter with no slowing down of particles [3]. The reason is that relative production rates decrease fast as depth increases, especially for ^{3}He and ^{4}He, which have very short ranges. Results for exponentials in rigidity were the same as those for energy power laws.

Discussion: The small spread in many production ratios is caused by the respective cross sections as a function of energy being similar in shape. Thus, changing an irradiation scenario does not change most ratios by much. The rapid drop in production in thick matter means that production will occur mainly in a very thin layer near the source of the irradiating particles. These results show that local irradiation scenarios do not have enough flexibility to reproduce experimental observations.

References: [1] Leya I. et al. 2003. *Astrophys. J.* 594:605-616. [2] Gounelle M. et al. 2006. *Astrophys. J.* 640:1163-1170. [3] Caffee M. W. et al. 2008. Lunar Planet. Sci. 39, #1258. [4] Leya I. and Masarik J. 2009. *Meteorit. Planet. Sci.* 44:1061-1086. [5] Nishiizumi K. et al. 2009. *Geochim. Cosmochim. Acta* 73:2163-2176. [6] Reedy R. C. and Arnold J. R. 1972. *J. Geophys. Res.* 77:537-555. [7] Reedy R. C. 1998. Lunar Planet. Sci. 29, #1701. *Work supported in part by NASA.