DEPTH PROFILES CALCULATED FOR RADIONUCLIDES MADE IN METEORITES BY ENERGETIC SOLAR PROTONS. R. C. Reedy[1], [1]Planetary Science Institute, 152 Monte Rey Dr., Los Alamos NM 87544 USA <reedy@psi.edu>.

Introduction: Many small meteorites show production of cosmogenic nuclides by energetic particles from the Sun (often called solar cosmic rays, or SCR), including many meteorites from the Moon and Mars plus other special cases like Salem. Rates as a function of depth and pre-atmospheric radius for SCR-produced nuclides in meteorites have been calculated [e.g., 1,2] and used to study their exposure records [e.g., 3].

Recently, cross sections for proton-induced reactions making cosmogenic nuclides have been compiled and evaluated [4,5]. Some of these revised cross sections have been used to study SCR production in lunar rock 64455, and average fluxes of solar energetic protons over the last ~1 and ~0.5 Myr determined [4]. These revised cross sections were used to calculate the rates for SCR-produced radionuclides in meteorites as a function of depth and pre-atmospheric radius.

Calculations of Depth Profiles of SCR-Produced Radionuclides in Meteorites: The calculations were done with the model of [6] for the interactions of solar cosmic rays with matter. The incident fluxes of solar protons had exponential-rigidity spectral shapes [6] of 70, 80, 90, and 100 MV, which covers the spectral-shape ranges determined for SCR-produced nuclides [4]. The integral fluxes of [4] were used. The latest sets of cross sections discussed above were use. The rates for mono-elemental targets were calculated for O, Mg, Al, and Si making 1.37 Myr ^{10}Be; for Mg, Al, and Si making 0.7 Myr ^{26}Al; for K and Ca making 0.3 Myr ^{36}Cl; for K, Ca, and Ti making 0.1 Myr ^{41}Ca; and Fe making 3.7 Myr ^{53}Mn. Other target elements are too low in abundance (e.g., Sc for ^{41}Ca) or too far away in mass from the product nuclide (such as Fe for ^{10}Be). Various depths to the center were used for radii of 1, 5, 10, and 25 g/cm^2 and depths to 25 g/cm^2 used for a slab geometry (a 2π irradiation). Because of the short ranges of solar protons [6], most SCR production occurs in the top few g/cm^2 (~1 cm). Production at greater depths can be important in small objects.

Calculated SCR Depth Profiles of Radionuclides in Meteorites: The calculated profiles as a function of pre-atmospheric depth and radii are reported and discussed below for these 5 long-lived cosmogenic radionuclides. Only profiles for the main targets are shown. Ratios of rates for other targets relative to a major target are given. All of these profiles are flat near the center and steepest at the surface.

SCR-produced ^{10}Be. The major target is O, with minor production from Mg, Al, and Si. The calculated profiles for pure O making ^{10}Be are shown in Fig. 1.

Elemental rates for Mg, Al, and Si relative to O increase slightly with depth and are about 0.2, 0.14, and 0.04, respectively.

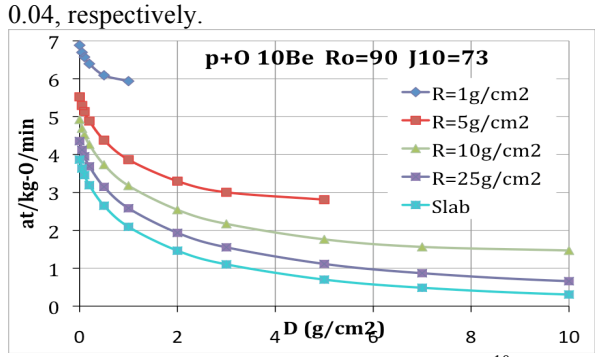

Fig. 1. Calculated depth profiles for making ^{10}Be from mono-elemental O by solar protons in meteorites.

SCR-produced ^{26}Al. The major targets are Al and Si, with minor production from Mg (mainly at the very surface. The calculated profiles for pure Al and Si making ^{26}Al are shown in Figs. 2 and 3, respectively.

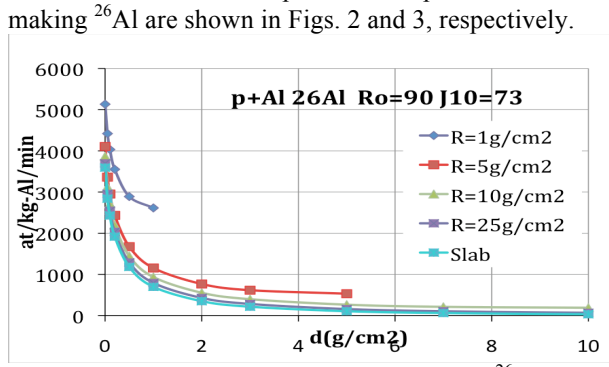

Fig. 2. Calculated depth profiles for making ^{26}Al from mono-elemental Al by solar protons in meteorites.

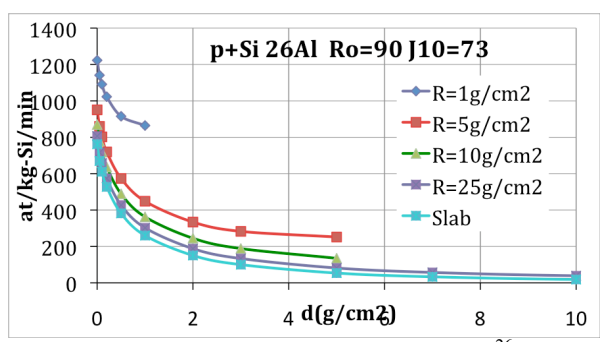

Fig. 3. Calculated depth profiles for making ^{26}Al from mono-elemental Si by solar protons in meteorites.

Elemental rates for Mg relative to Si decrease rapidly with depth, going from about 0.5 at the surface to ~0.05 at 5 g/cm^2.

SCR-produced ^{36}Cl. The major target is Ca, with minor production from K. The calculated profiles for pure Ca making ^{36}Cl are shown in Fig. 4.

Elemental rates for K relative to Ca decrease with depth from about 4 to 2.5.

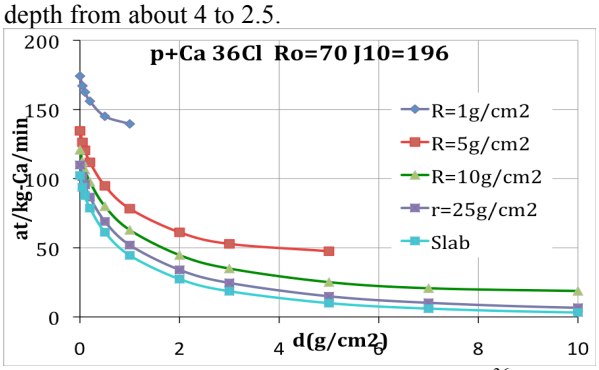

Fig. 4. Calculated depth profiles for making ^{36}Cl from mono-elemental Ca by solar protons in meteorites.

SCR-produced ^{41}Ca. The major targets are K (only ^{41}K) and Ca (mainly ^{42}Ca and ^{44}Ca), with minor production from Ti. The calculated profiles for pure K and Ca making ^{41}Ca are shown in Figs. 5 and 6, respectively.

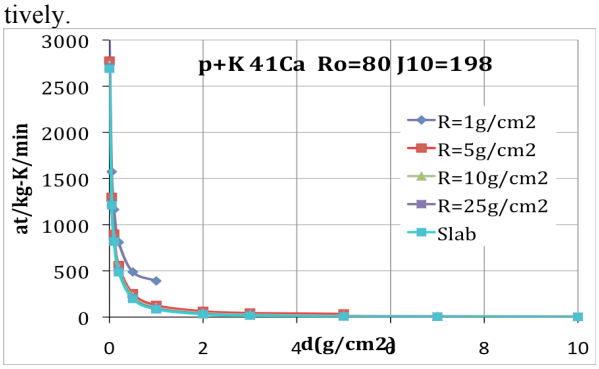

Fig. 2. Calculated depth profiles for making ^{41}Ca from mono-elemental K by solar protons in meteorites.

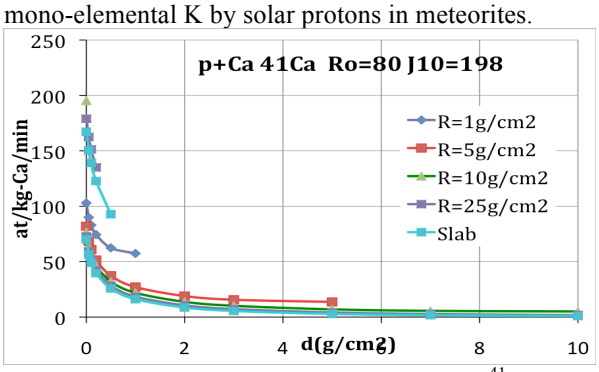

Fig. 3. Calculated depth profiles for making ^{41}Ca from mono-elemental Ca by solar protons in meteorites.

Elemental rates for Ti relative to Ca increases with depth, going from about 2.5 at the surface to ~6 at 5 g/cm^2.

SCR-produced ^{53}Mn. The major target is Fe, with very minor production from other elements. The calculated profiles for pure Fe making ^{53}Mn are shown in Fig. 7.

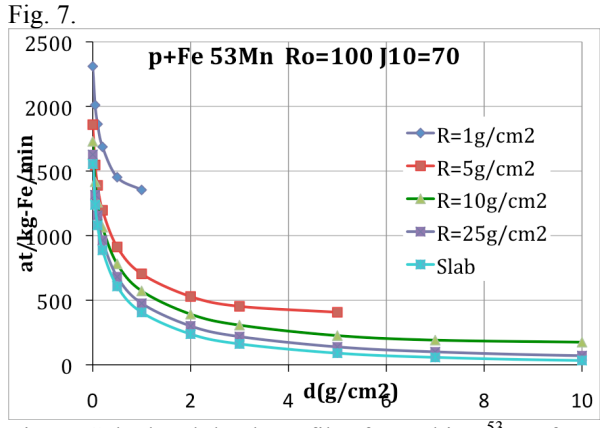

Fig. 7. Calculated depth profiles for making ^{53}Mn from mono-elemental Fe by solar protons in meteorites.

Summary: Profiles for the production of 5 long-lived radionuclides in meteorites as a function of pre-atmospheric depth and radius are given above. Plots are shown for major target elements, and relative ratios given for minor targets.

The mono-elemental rates can be used to help interpret measurements of cosmogenic nuclides in some meteorites, especially lunar and martian meteorites. In some cases of meteorites that were small in space and that had very little ablation of its surface while entering the Earth's atmosphere, SCR production can be a significant fraction of the total production.

Acknowledgments: This work was supported by NASA's Cosmochemistry program.

References: [1] Reedy R. C. (1987) *LPS XVIII*, pp. 822-823. [2] Reedy R. C. (2000) In *Workshop on Extraterrestrial Materials from Cold and Hot Deserts*, LPI Contribution No. 997, pp. 69-71. [3] Nishiizumi K. et al. (1995) LPS XXVI, pp. 1053-1054. [4] Nishiizumi et al. (2009) *GCA, 73*, 2163-2176. [5] Reedy R. C. (2007) *LPS XXXVIII*, #1192. [6] Reedy R. C. and Arnold J. R. (1972) *JGR, 77*, 537-555.