^{39}Ar PRODUCTION CROSS SECTIONS IN Ti FOR SOLAR-PROTON EFFECTS IN LUNAR SURFACE SAMPLES, F. Steinbrunn and E. L. Fireman, Center for Astrophysics, Harvard College Observatory and Smithsonian Astrophysical Observatory, Cambridge, Mass. 02138

^{39}Ar activities were measured in lunar surface and drill core samples from all Apollo missions.[1-7] The ^{39}Ar activity in near-surface samples is produced by solar- and cosmic-ray-proton spallation of Ti and Fe and, therefore, gives information about the average solar-flare proton intensity over the past ~1000 yr.[8] The ^{39}Ar data indicate an unusually high solar-proton intensity, if cross sections extrapolated to low energies are used.

The ^{39}Ar activity in six titanium foils, irradiated with protons of 15, 30, 45, 319, 433, and 584 MeV, was therefore measured in small gas proportional counters. Many other radioisotopes were measured previously in the same foils by γ-spectrometry by Brodzinski et al.[9] The argon was extracted by dissolving the foils in hot sulfuric acid while helium was bubbled through the solution for 4 to 14 hours. The activities from the 15- and 30-MeV foils were within counter-background fluctuations. These cross sections were smaller than ~0.5 μb. For protons of 45, 319, 433, and 584 MeV, the following ^{39}Ar production cross sections were obtained: 0.37 ± 0.09, 12.4 ± 3.7, 9.1 ± 2.7, and 17.8 ± 6.2 mb. Statistical counting errors (2σ) were below 5% throughout. Errors of 5% and 10% were assigned to the chemical extraction yield and the counter efficiency, respectively. Errors of 5% for the 45-MeV foil, 10% for the 319- and 433-MeV foils, and 15% for the 584-MeV foil were assigned to the proton fluxes.[9,10]

The ^{39}Ar production cross sections agree with Rudstam's CDMD formula[11] for 319-, 433-, and 584-MeV protons, as shown in Fig. 1; however, at 45 MeV, the cross section does not agree with the formula, probably because the formula is derived from data at higher energies.

The fraction of ^{39}Ar from Ti that is produced by protons below energy E can be estimated by drawing a smooth curve through our data. The fractions for two differential proton spectra of the form $\sim E^{-\alpha}$ with $\alpha = 2.5$ and 3 are shown in Fig. 2. Fifty percent of the ^{39}Ar from Ti (in surface samples) is produced by protons below 116 and 142 MeV for $\alpha = 3$ and 2.5, respectively.

References

[1]E. L. Fireman, J. D'Amico, and J. DeFelice (1970) Tritium and argon radioactivities in lunar material. Science, 167, 566-568.

[2]J. D'Amico, J. DeFelice, and E. L. Fireman (1970) The cosmic-ray and solar flare bombardment of the moon. In "Proc. Apollo 11 Lunar Sci. Conf," Geochim. Cosmochim. Acta, Suppl. 1, 2, pp. 1029-1036, Pergamon Press.

[3]J. D'Amico, J. DeFelice, E. L. Fireman, C. Jones, and G. Spannagel (1971) Tritium and argon radioactivities and their depth variations in Apollo 12 samples. In "Proc. Second Lunar Sci. Conf.," Geochim. Cosmochim. Acta, Suppl. 2, 2, pp. 1825-1839, MIT Press.

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Steinbrunn, F., and Fireman, E. L.

[4]E. L. Fireman, J. D'Amico, J. DeFelice, and G. Spannagel (1972) Radioactivities in returned lunar material. In "Proc. Third Lunar Sci. Conf.," Geochim. Cosmochim. Acta, Suppl. 3, 2, pp. 1747-1761, MIT Press.
[5]E. L. Fireman, J. D'Amico, and J. DeFelice (1973) Radioactivities vs. depth in Apollo 16 and 17 soil. In "Proc. Fourth Lunar Sci. Conf.," Geochim. Cosmochim. Acta, Suppl. 4, 2, pp. 2131-2143, Pergamon Press.
[6]R. W. Stoenner, W. J. Lyman, and R. Davis Jr. (1970) Cosmic-ray production of rare-gas radioactivities and tritium in lunar material. In "Proc. Apollo 11 Lunar Sci. Conf.," Geochim. Cosmochim. Acta, Suppl. 1, 2, pp. 1583-1594, Pergamon Press.
[7]R. W. Stoenner, W. J. Lyman, and R. Davis Jr. (1971) Radioactive rare gases and tritium in lunar rocks and in the sample return container. In "Proc. Second Lunar Sci. Conf.," Geochim. Cosmochim. Acta, Suppl. 2, 2, pp. 1813-1823, MIT Press.
[8]E. L. Fireman (1973) Solar flares during the past 1000 years as revealed by lunar studies. In "Proc. First European Astron. Meeting," Athens, Sept. 4-9, 1972, 1, Springer-Verlag.
[9]R. L. Brodzinski, L. A. Rancitelli, J. A. Cooper, and N. A. Wogman (1971) High-energy proton spallation of titanium. Phys. Rev. C, 3rd series, 4, 1250-1257.
[10]R. W. Perkins (1973) Private communication.
[11]G. Rudstam (1966) Systematics of spallation yields. Z. Naturforschg., 21a, 1027-1041.

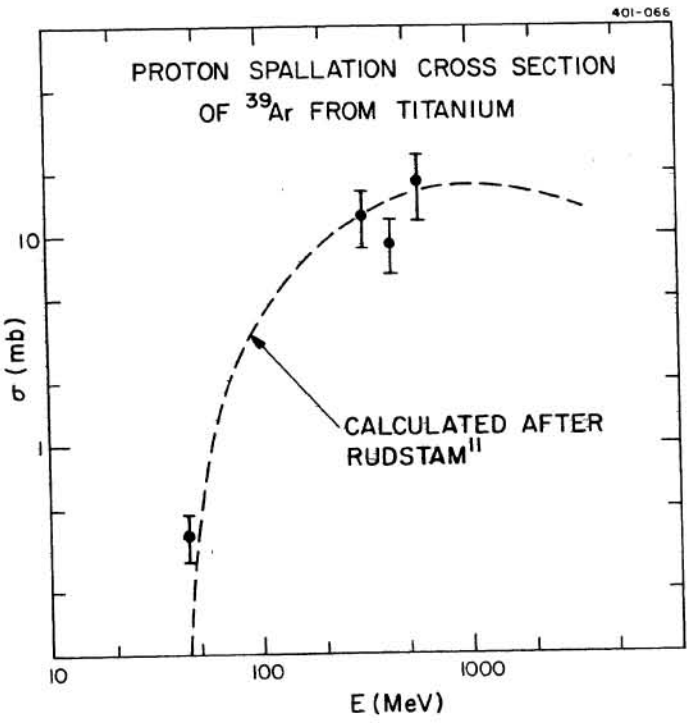

Fig. 1

^{39}Ar FROM Ti AND SOLAR FLARES

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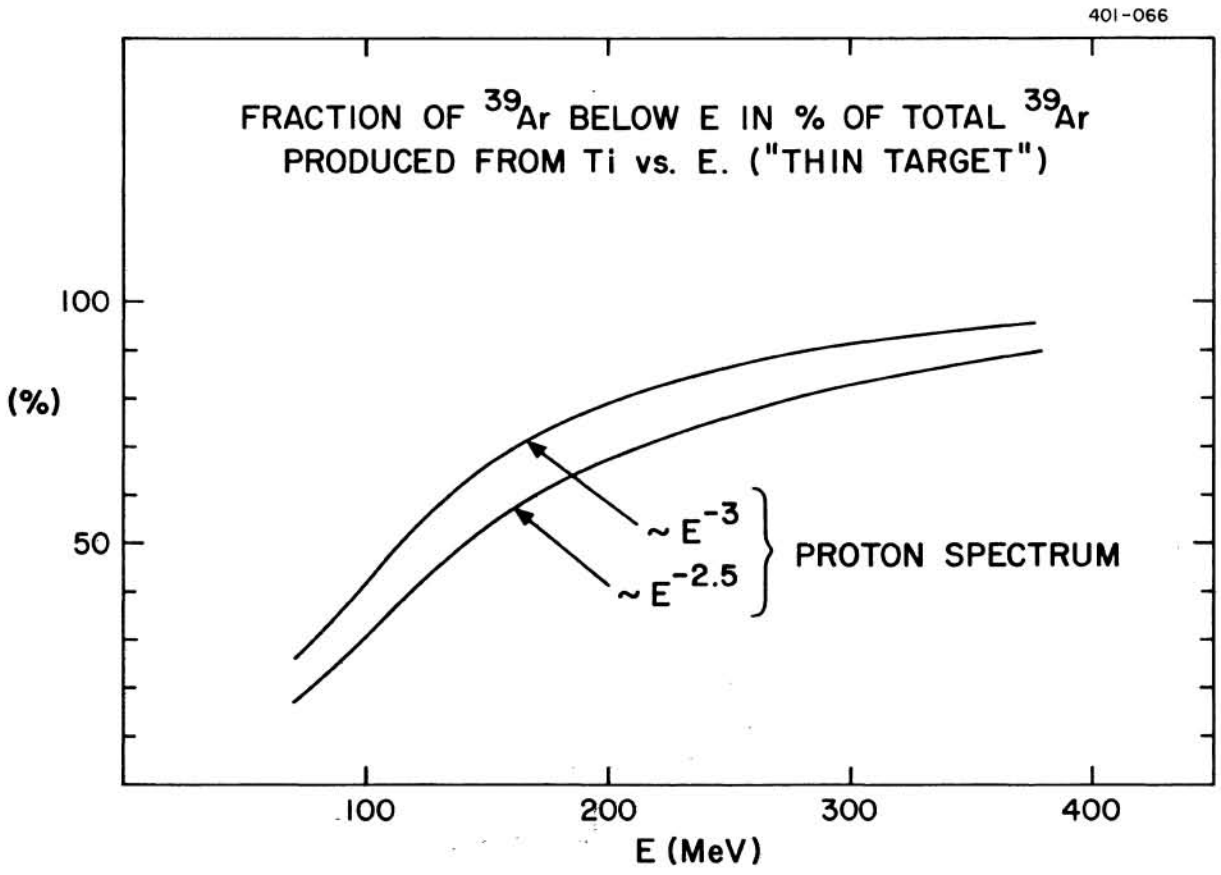

Fig. 2