^{10}Be and ^{26}Al production from Mg, Al, Si, and O by 600-MeV protons in granodiorite spheres.

S. Theis and P. Englert, Inst. Kernchemie, Univ. Köln, Köln, Fed. Rep. Germany, R. Michel, Inst. F. Strahlenschutz, Univ. Hannover, D3000, Fed. Rep. Germany, D. Aylmer and G. F. Herzog, Dept. of Chem., Rutgers Univ. New Brunswick, NJ, 08903, T.H. Kruse, Dept. of Phys., Rutgers Univ., New Brunswick, NJ 08903, R. K. Moniot, Div. Sci. Math., Fordham U., New York, NY 10023, C. Tunis, Ist. Fisica Nucleare, Univ. Studi, Trieste, Italy, A. Jermakian, Dept. Phys., N.J. Inst. Tech., Newark, NJ 07100, J. Klein and R. Middleton, Dept. Phys., Univ. Penna., Philadelphia, PA 19104.

INTRODUCTION The reconstruction of a meteorite's exposure history depends on an understanding of how the production rates of cosmogenic nuclides are influenced by the meteorite's size and composition, and by the sample's location. These factors in turn can be determined if one knows the relative contributions of primary cosmic rays and secondaries to the production of nuclide x from target element y. Over the past three years a series of modeling experiments has been carried out, in which granodiorite spheres 10 cm, 30 cm, and 50 cm in diameter were isotropically exposed to 600 MeV proton beams in order to simulate the 4π-irradiation of meteoroids. Short-lived and long-lived radioisotopes as well as stable nuclides have been measured in cosmochemically significant target elements at various locations within the spheres. The goal of these experiments is to obtain absolute cross sections, and depth profiles, and to determine the relative contributions of primary and secondary cosmic rays. Englert *et al.*[1] and Michel *et al.*[2] provide a detailed description of the experimental methods. Middleton and Klein[3] describe the technique used for ^{26}Al analysis. Here we summarize some recent work that includes over 40 new analyses of ^{10}Be and 20 of ^{26}Al.

EXPERIMENTAL METHODS The spheres were irradiated at CERN. A controlled combination of rotational and translational motion mimicked the effects of isotropic irradiation[2]. Estimates of the flux come from counting ^{22}Na and ^{24}Na produced in monitor foils placed in front of the spheres and from geometric considerations. Englert *et al.*[1] describe the chemical methods used to isolate ^{10}Be and ^{26}Al which we analyzed by accelerator mass spectrometry. The ^{10}Be contents were determined both at Rutgers Univ. and the Univ. of Penna. The ^{26}Al measurements were made at the Univ. of Penna. To obtain production rates for oxygen, we subtracted measured values for Si from those for quartz with the appropriate stoichiometric correction.

RESULTS AND DISCUSSION Cross sections measured for the production of ^{10}Be in thin targets that were positioned near the surface of the 30 cm sphere agree well with literature values (table 1), and particularly with those of ref. (4). As expected, production of ^{10}Be from oxygen is largest and from Si smallest. The uncertainties include counting statistics, errors of flux assessment and an additional 5% for chemical preparation.

In table 2 we present the average ^{10}Be and ^{26}Al production rates in targets irradiated within the spheres. These production rates differ from the thin target results for two reasons. First, as the incident beam penetrates the sphere it loses energy. Published cross sections[4] indicate that direct ^{10}Be production will fall accordingly. Second, the primary proton beam creates secondary particles that contribute significantly to the observed production rates.

On the other hand, the results of table 2 may approximate, albeit roughly, the ^{10}Be and ^{26}Al production in meteoroids by cosmic rays. With one exception, $P_{10}(O)$ in the 10cm sphere, the trends for P_{10} are the same for all four elements in all three spheres: comparable values in the 10 and 30cm spheres and 33% lower values in the 50cm sphere. Accordingly, the ratios $P_{10}(X)/P_{10}(Mg)$ [X= O, Al, or Si] are virtually identical, with the one exception noted above. This observation helps to justify the use of production rate formulas for ^{10}Be in which the elemental coefficients stand in fixed ratios. The decrease in P_{10} in the largest sphere suggests that the development of the secondary cascade no longer compensates for decreasing production due to primaries.

The ^{26}Al production rate from Si behaves differently, increasing steadily from the smallest to the largest sphere, a trend that parallels that calculated for meteorites[5]. The difference between P_{10} and P_{26} may reflect the lower Q values for the reactions $^{28}Si(n \text{ or } p,X)^{26}Al$.

Mg has received attention as a possibly significant target for ^{26}Al production in extraterrestrial materials. Our results indicate that Mg contributes less than 2% of the total in the model system.

One of the surprising results is the large secondary contribution to ^{10}Be production. We have used our results for the 10cm sphere and a nuclear-transport calculation to estimate the contributions of primary and of secondary particles to ^{10}Be production (see table 3). The last column shows that secondary particles give rise to 18-35% of the total. The fraction of ^{10}Be production due to secondaries decreases with increasing target mass.

REFERENCES 1. P. Englert *et al.* (1984), Nucl. Inst. Meth. **B5** ,415-419. 2. R. Michel *et al.* (1986), Nucl. Inst. Meth. (in press). 3. R. Middleton *et al.* (1983), Nucl. Inst. Meth. **218**, 430-438. 4. G. Raisbeck & F. Yiou (1977) Proc. of 15th Int. Cosmic Ray Conf. **2** Plovdiv Bulg. 203-207. 5. R.C. Reedy (1985), J. Geophys. Res. **90**, suppl. C722-C728. 6. L. Dedieu (1979), Ph.D. Dissertation, Univ. Bordeaux. 7. B.S. Amin *et al.* (1972), Nucl. Phys. **A195**, 311-320.

Table 1. ^{10}Be Production Cross-Sections

Target Element	Proton Beam Energy	This Experiment	Previously Measured Values
O	600 MeV	1.52 ± 0.12mb	1.94 ± 0.36mb*
	550 MeV		1.72 ± 0.10mb†
Mg	600 MeV	1.03 ± 0.07mb	1.27 ± 0.33mb*
Al	600 MeV	1.16 ± 0.07mb	
Si	600 MeV	0.63 ± 0.046mb	0.82 ± 0.15mb*
	1000 MeV		1.00 ± 0.20mb‡

*Raisbeck & Yiou[4] †Dedieu[6] ‡Amin, *et al.*[7]

Table 3. ^{10}Be Production Rate in Center of 10cm Sphere

Target	Production from Primaries (calculated)	Total Production (measured)	Production from Secondaries (% contribution)
O	48.5 ± 3.0	74.4 ± 13.4	35%
Mg	21.8 ± 2.0	31.5 ± 8.6	31%
Al	21.9 ± 0.8	30.3 ± 3.8	28%
Si	11.5 ± 0.6	14. ± 2.0	18%

All rates have units: 10^{-6} atoms g^{-1} s^{-1} with flux of 1 proton cm^{-2} s^{-1}.

Table 2. Average ^{10}Be and ^{26}Al Production Rates

Sphere Dia (cm)	Nuclide	Target Mg	Al	Si	SiO_2	O
10	^{10}Be	30.3± 1.0	28.7± 0.8	13.6± 1.5	41.4± 4.1	65.9± 4.9
	^{26}Al	< 6		433± 22		
30	^{10}Be	26.9± 2.6	32.3± 1.3	14.5± 0.6	61.7± 2.6	102.6± 4.9
	^{26}Al			445± 21.5		
50	^{10}Be	19.1± 2.2	18.5± 1.4	9.8± 1.6	41.3± 1.5	68.8± 3.2
	^{26}Al			552± 22		

All production rates have units: 10^{-6} atoms g^{-1} s^{-1} with flux of 1 proton cm^{-2} s^{-1}.
Values in this table are averages over the entire diameter and therefore differ slightly from those in table 2 (for 10cm sphere) which are for center only.