COSMOGENIC ^{36}Cl PRODUCTION RATES IN METEORITES AND THE LUNAR SURFACE: K. Nishiizumi[1], P. W. Kubik[2], D. Elmore[2,3], R. C. Reedy[4], and J. R. Arnold[1]; (1) Dept. of Chemistry, B-017, Univ. of Calif., San Diego, La Jolla, CA 92093, (2) Nuclear Structure Research Lab, Univ. of Rochester, Rochester, NY 14627, (3) Center for Environmental Res., Argonne Nat'l Lab, Algonne, IL 60439 (4) Earth & Space Sciences Div., Los Alamos Nat'l Lab, Los Alamos, NM 87545

Cosmic rays produce rare radioactive and stable nuclides in target elements by several different reaction mechanisms. The solar cosmic rays (SCR) fall in a lower energy range (10-100 MeV) than galactic cosmic rays (GCR) and hence penetrate much less deeply into solid bodies. To understand and exploit these effects, it is useful to study a nuclide produced by all the major processes, and ^{36}Cl (half-life 3.0×10^5 years) is probably the best example.

^{36}Cl is produced by high energy (e.g., $Fe(p,x)^{36}Cl$) and low energy (e.g., $^{40}Ca(n,\alpha p)^{36}Cl$) nuclear spallation reactions on a variety of target elements and also by neutron capture on ^{35}Cl. In this study, we used samples of a lunar core and two meteorites to better understand ^{36}Cl production rates. The ^{36}Cl measurements were carried out using the MP tandem Van de Graaff accelerator at the University of Rochester [1].

15008: The upper portion (0-35 g/cm^2) of the double drive tube 15008/7 was chosen for this study because the core has a unique undisturbed surface based on ^{26}Al measurements [2]. Fig. 1 shows ^{36}Cl activities in ten bulk samples from the 15008 core. The observed excess of ^{36}Cl in the top 5 g/cm^2 of 15008 clearly shows SCR effects. This excess is consistent with the theoretical Reedy-Arnold model [3]. The model predicts a surface production of 2-3 dpm/kg ^{36}Cl due to SCR bombardment of Ca and K target elements. Since the low energy excitation function for ^{36}Cl production from Ca, K, Ti, and Fe have large uncertainties, the theoretical calculations with different SCR parameters such as R_0 = 100 MV, J(E>10 MeV) = 70 p/cm^2 s or R_0 = 75 MV, J(E>10 MEV) = 150 p/cm^2 s fit the data equally well. This result is in agreement with our previous study of ^{10}Be in 68815 [4], where we predicted that SCR produced ^{36}Cl would be less sensitive than ^{10}Be for determining unique SCR parameters. ^{36}Cl below 10 g/cm^2 is essentially all produced by GCR. The flat and slightly increasing profile with increasing depth was also seen for the Apollo 15 deep core [5]. ^{36}Cl production in lunar samples is a complex process. The model predicts that in lunar samples about 80% of ^{36}Cl is produced from Ca and the remaining amount is produced from K, Ti, and Fe. This is in contrast to production in ordinary chondrites because of the higher concentration of Ca (7-12 %) and sometimes Ti in lunar soil. The observed ^{36}Cl profiles of cores 15008 and 15006-1 are slightly higher and flatter than predicted by the Reedy-Arnold model. This small discrepancy is probably due to the uncertainty of low energy excitation functions of ^{36}Cl production from different target elements and to some undetermined contribution from the $^{35}Cl(n,\gamma)^{36}Cl$ reaction.

St. Séverin: Fig. 2 shows the ^{36}Cl depth profile measured for the A-III and CB-2 cores in the St. Séverin meteorite. In this case ^{36}Cl was measured in the metal phase. ^{36}Cl in metal is produced from Fe and Ni by high energy spallation reactions. The data are somewhat scattered but show a flat depth profile. This profile is in contrast to the ^{53}Mn and ^{10}Be depth profiles in this meteorite, which increase with increasing depth [6, 7, 8]. The average ^{36}Cl activity of 21.1 ± 1.2 dpm/kg in the St. Séverin core is about 8% lower than the average in metal phases from ordinary chondrites (22.8 ± 3.1 dpm/kg). The metal phase of LL chondrite St. Séverin contains a very high Ni concentration (about 66% of Fe, 1% of Co, and 33% of Ni). The model [8, 9] predicts that the production rate of ^{36}Cl from Ni is about 25-30 % lower than that from Fe. If we take into account this difference between Ni and Fe, the above discrepancy can be explained. The theoretical calculation also predicts a flat or slightly decreasing production profile [9]. However, the absolute production rate predicted is about 25% lower than the observed profile. One explanation for this difference is that the neutron cross sections for making ^{36}Cl from Fe and Ni may be higher than the proton ones. In the case of ^{10}Be the neutron cross sections are known to be higher than the proton cross sections for production from oxygen [8].

Jilin: ^{36}Cl was also measured in two cores from the Jilin meteorite. Core A and B were taken respectively perpendicular and parallel to the surface of the 2π first stage irradiation that the object experienced in space [10]. Fig. 3 shows ^{36}Cl activities in the metal phase of core B. The horizontal axis shows the length of core B. The ^{36}Cl activity decreases toward the center of the meteorite. The low ^{36}Cl activity is due to the large size of the Jilin meteorite and the short 2nd stage exposure time (0.4 My) [11]. More than 80% of the ^{36}Cl in core B was produced during this 2nd stage irradiation. The theoretical production rate [9] agrees with the measured values for near surface samples, but calculations predict a steeper decrease with increasing depth than is observed in the data, which is the same trend as for measured and calculated ^{22}Na in this core [9, 11, 12].

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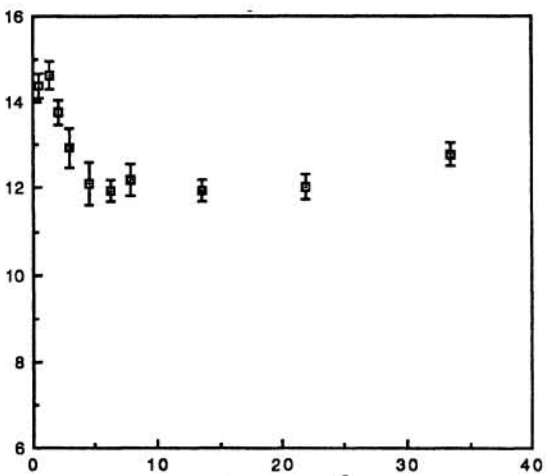

Fig. 1

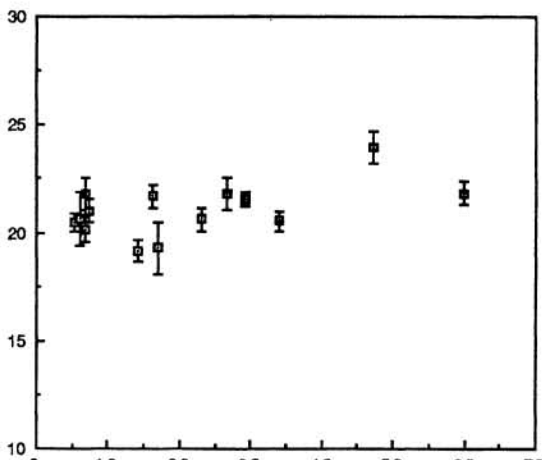

Fig. 2

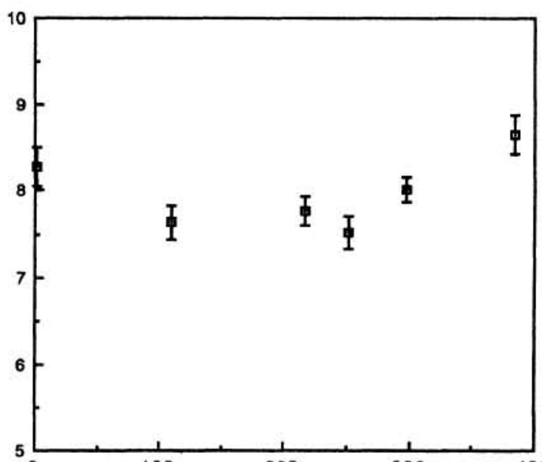

Fig. 3