COSMOGENIC ^{36}Cl PRODUCTION ON THE LUNAR SURFACE ; K. Nishiizumi[1], J. R. Arnold[1], P. Sharma[2], P. W. Kubik[2] and R. C. Reedy[3] ; (1) Dept. of Chemistry, Univ. of Calif., San Diego, CA 92093-0317, (2) Nuclear Structure Res. Lab., Univ. of Rochester, Rochester, NY 14627, (3) Group SST-8, Los Alamos National Lab, Los Alamos, NM 87545

Cosmogenic nuclide concentrations in lunar surface materials have been used for studies of SCR (solar cosmic rays) and GCR (galactic cosmic rays) histories and of lunar surface dynamics [1]. The radionuclide ^{36}Cl (half-life=3.01×10^5 years) is produced by both SCR and GCR bombardment [2, 3]. We report here ^{36}Cl results in lunar surface rock 74275 and in lunar soils with a range of chemical compositions. The ^{36}Cl results were determined by the University of Rochester tandem accelerator [4].

74275: The cosmogenic nuclides ^{10}Be, ^{26}Al, and ^{41}Ca were measured in lunar rock 74275 (5x12x15 cm) [5, 6]. We received aliquots of this material for ^{36}Cl and ^{53}Mn determination. The rock has experienced a two stage GCR bombardment as determined by Eugster [7]. The second stage exposure at the surface of the moon was estimated to have lasted 2.8 My based on cosmic ray tracks [8]. A surface exposure of this duration insures the saturation of ^{36}Cl in the rock. ^{36}Cl was measured in 11 samples from the surface to 50 mm (15.8 g/cm^2) depth. Since the samples were sawed rather than ground, the depth intervals are not as precise as those obtained in the 68815 studies [9]. Figure 1 shows ^{36}Cl activities in the 11 bulk samples from 74275 along with calculated GCR ^{36}Cl production rates using the Reedy-Arnold model [2] and cross section data which has been modified to fit lunar cores and meteorites [3].

SCR: The observed excess of ^{36}Cl in the top several g/cm^2 was produced by SCR. SCR production of ^{36}Cl can be calculated by subtracting theoretical GCR production of the nuclide (Figure 1) [2, 3] from observed activities and is shown in Figure 2. The profile for rock 74275 is very similar to ^{36}Cl in the undisturbed core 15008 [3]. About 85 % of the SCR produced ^{36}Cl in 74275 is produced via the Ca(p,x)^{36}Cl reaction. The remainder of the ^{36}Cl is produced from Ti, K, and Fe. Figure 2 also shows the Reedy-Arnold theoretical profile [2] calculated using SCR parameters, R_0=85 MV and J(>10 MeV)=110 protons/cm^2 s 4π. These parameters were obtained from measurements of other SCR produced cosmogenic nuclide concentrations in 68815 [10] and have been verified by measurements of ^{26}Al and ^{41}Ca in 74275 [5, 6]. This calculated profile falls below the measured SCR ^{36}Cl activities. A theoretical calculation with 2 times the SCR flux (J=220 protons/cm^2 s 4π) gives a better fit to the observations. However such a high SCR flux does not fit other cosmogenic nuclides. To properly interpret the SCR profile of ^{36}Cl, low energy cross sections for the Ca(p,x)^{36}Cl reaction must be measured.

GCR: The GCR production rate of ^{36}Cl in the moon is relatively constant at depths between 20 and 100 g/cm^2. To obtain elemental production rates empirically, we measured ^{36}Cl in 6 different lunar cores (12028, 15008/7, 15006-5, 60010/9, 74002/1, and 76001) at depths of about 25, 50, and 75 g/cm^2. The target element compositions are widely different in the six cores (K:0.05-0.3 %, Ca:5.3-12.4 %, Ti:0.37-5.3 %, and Fe:2.3-18.1 %). The ^{36}Cl results are shown in Figure 3. The experimental errors (1σ) are nearly the same size as the data points. The scatter in this graph is due to the different chemical compositions. Assuming a constant production rate over this depth interval, elemental production ratios can be calculated. The production ratios for K:Ca:Ti:Fe are 5:1:1/4:1/12. The Reedy-Arnold model predicts production ratios of 3:1:1/6:1/15 at similar depths [2, 3]. The ^{36}Cl production ratio, 12, for Ca/Fe is higher than the value of about 8 which was obtained from meteorites [11]. Since the majority (~90 %) of the ^{36}Cl in lunar samples is produced from Ca by GCR, the regression coefficient for the Ca production rate can be obtained within a few %. On the other hand, the coefficients for K and Ti contain large errors, ±30-50 % due to the smaller contributions from these elements. The error for Fe is about 10-15 %. Since the Reedy-Arnold calculation fits well for ^{36}Cl from Fe in meteorites [3], the model must slightly overestimate the Ca(n,x)^{36}Cl cross section. Reduction of the Ca(n,x)^{36}Cl cross section lowers the calculated production profile. With this change in cross section the Reedy-Arnold calculation would be about 1-2 atoms/kg min lower than the

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observed profiles at the depth 20-100 g/cm^2. This deficit can be explained by adding a ^{35}Cl(n,γ)^{36}Cl contribution which the Reedy-Arnold model doesn't consider. Figure 4 shows the ^{36}Cl activities normalized to the Apollo 15 drill core chemical composition using the production ratios K:Ca:Ti:Fe = 5:1:1/4:1/12. The normalized profiles show less scatter but a slight increase in the activity near 50 g/cm^2. This is the expected profile of the secondary neutrons that induce the dominant Ca(n,x)^{36}Cl reactions in the cores.

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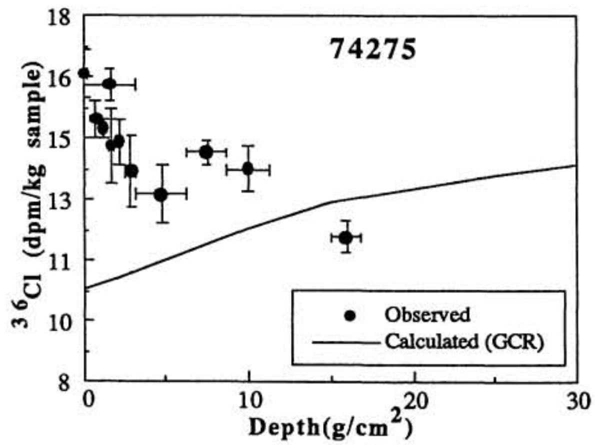

Fig. 1. ^{36}Cl depth profile in 74275

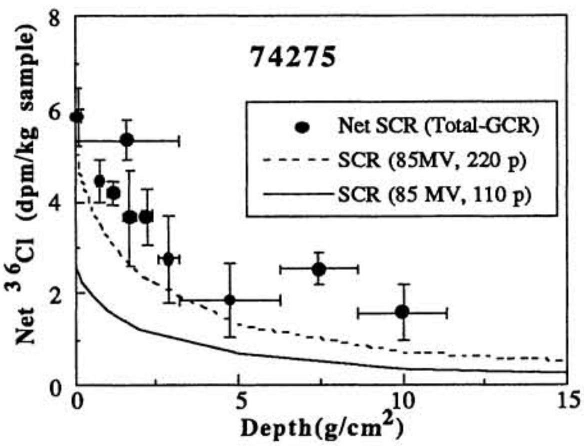

Fig.2. SCR produced ^{36}Cl in 74275

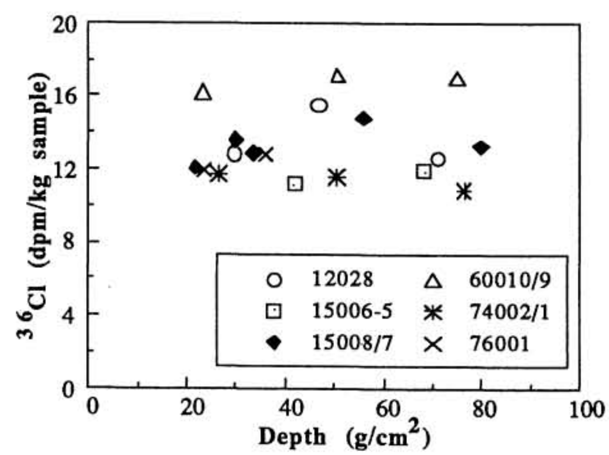

Fig. 3. ^{36}Cl depth profile in 6 lunar cores

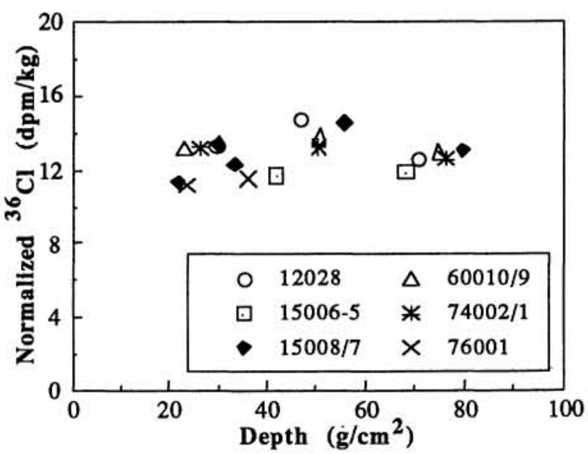

Fig. 4. Normalized ^{36}Cl depth profile

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