
Cosmic-ray-produced nuclides measured in samples taken from known locations on a big slab of the large (R~45 cm) I-L chondrite Knyahinya [1] provide good depth-v-s.-concentration profiles to develop and test models for the production of cosmogenic nuclides in meteorites [e.g., 2,3,4]. We report new profiles for 10Be, 26Al, 36Cl in metallic and non-magnetic phases of 8 documented samples from Knyahinya and for 14C in bulk samples from 7 Knyahinya samples. These new measured profiles are very similar to profiles calculated with particle fluxes from the LAHET Monte Carlo production and transport code system and with cross sections for major reactions.

Samples and Measurements. Our samples are from 8 locations on the same big slab of Knyahinya used by [1] for their measurements. The chlorine content of one sample was determined by M. Honda and M. Ebihara [priv. comm.] to be 50 parts-per-million by weight. One set of 8 samples was separated into metallic and non-magnetic phases, and major target elements in each phase were measured by atomic absorption spectrometry. The metallic phases contained ~0.2% silicates. Be, Al, and Cl were chemically separated, and 10Be, 26Al, and 36Cl were measured at Livermore by accelerator mass spectrometry (AMS). Measured concentrations as a function of depth from the pre-atmospheric surface determined by [1] are shown in Figs. 1–3, except for 26Al in the metallic phase, which is being measured. The 10Be and 26Al in our non-magnetic samples agree well with the same radionuclides measured by [1] in bulk samples. A set of 7 samples was analyzed at Tucson for their 14C contents using AMS, and results are shown in Fig. 4.

The profile for 10Be in the metallic phase decreases slightly from the surface to the center. The profile for 36Cl in the metallic phase is fairly flat, similar to that measured for 36Cl in metallic phases from other chondrites, and the measured concentrations are the same as those in most other chondritic metal [e.g., 5]. The other profiles show a decrease in concentration with decreasing depth for depths <20 cm and a flat profile nearer the center.

Model and Calculated Production Rates. Our calculations are based on Los Alamos LAHET Code System (LCS) [6], which is a system of coupled Monte Carlo computer codes that treats the relevant physical processes of particle production and transport. This code system is discussed in [7,8] and is very similar to that used by [4]. An isotropic GCR irradiation by 4.8 protons/cm²/s, corresponding to the GCR primary particle spectrum averaged over a typical solar cycle, of a sphere with a radius of 45 cm (160 g/cm²) and Knyahinya’s bulk composition was simulated, and neutron and proton fluxes were calculated for concentric shells with 2.5-cm thickness. Production rates for spallogenic nuclides were calculated with these particle fluxes and cross sections for neutron- and proton-induced reactions on major target elements. The proton-induced cross sections are mainly experimental ones used to model nuclide production by solar protons. The cross sections for energetic neutrons are ones used previously at Los Alamos for GCR production in the Moon and meteorites and usually have been adjusted to fit measured data, such as done for 36Cl [5]. Rates for the 35Cl(n,γ)36Cl neutron-capture reaction were calculated directly by LCS. Statistical errors in the calculated particle fluxes were less than 5%.

The production rates calculated with LCS are shown as the lines in Figs. 1–4, with production by secondary energetic neutrons and by primary and secondary protons shown as well as the total rate. For 36Cl in the non-magnetic samples, an additional line shows production by the 35Cl(n,γ)36Cl reaction for 50-ppm chlorine. For 10Be and 26Al, the total production rates calculated for bulk samples also are shown. Our calculated production rates for 26Al in bulk Knyahinya samples are similar to those calculated by [4]. In metal, 26Al is calculated to be ~3 dpm/kg.

Comparison of Measured and Calculated Activities. For 14C in bulk samples, there is good agreement (~10%) of the calculated production rates with the measured activities, with energetic-neutron production dominant. For 10Be and 26Al, the calculated production rates agree within about ±10% of the measured concentrations, except for an unusually low value for 10Be in one metallic sample. For bulk and non-magnetic samples, production by energetic neutrons dominates for 10Be and 26Al, whereas high-energy particles, mainly protons, dominate their production in metal. The production rates in bulk samples are slightly lower than for non-magnetic samples.
because of the lower rates for the metal in the bulk samples.

For $^{36}$Cl in the metallic phase, the calculated production rates in deeper samples are less than the measured activities. The difference in measured to calculated activities parallels the calculated rates by energetic neutrons, suggesting that the cross sections estimated by [5] for $^{36}$Cl made from Fe and Ni by high-energy neutrons are too low at lower energies. Our calculations for $^{36}$Cl in metal from St. Severin are also similarly low. Production of $^{36}$Cl by high-energy particles is very important in metallic samples. In non-magnetic samples, the calculated and measured $^{36}$Cl activities and profiles agree well, within ~10%. The calculations indicate that pure spallogenic $^{36}$Cl in the non-magnetic phase would have a fairly flat profile and that it is production of $^{38}$Cl by the capture of thermal neutrons that causes most of the observed increase in activity near the center relative to that near the pre-atmospheric surface.


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Figs. 1-4. Measured and calculated activities of $^{10}$Be, $^{26}$Al, $^{36}$Cl, and $^{14}$C in samples from Knyahinya are shown as functions of depths from the pre-atmospheric surface. The $^{14}$C is from bulk samples, as are results by [1] shown for $^{10}$Be and $^{26}$Al. Other activities were for separated metallic or non-magnetic phases. If not shown, experimental errors are smaller than the symbol. Calculated rates are shown as lines for production by energetic neutrons and protons as well as total rates in the phases measured. Calculations for the neutron-capture production of $^{36}$Cl in non-magnetic samples and for total production of $^{10}$Be and $^{26}$Al in bulk samples are also shown.

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