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PRODUCTION RATES OF COSMOGENIC NUCLIDES IN STONY METEORITES*

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ABSTRACT

Monte Carlo calculations of Al^{26} and Mn^{53} production due to spallation induced by cosmogenic protons in model meteorite composition similar to L Chondrite has yielded predictions which are consistent with the observed decay rates in L Chondrite stony meteorites. The calculated Al^{26} production rate (54 dpm/kg) in a 1 m diameter meteorite is within 1/2 S.D. of the mean (49 ± 11 dpm/kg) taken from 100 bulk determinations in L Chondrite samples compiled in Nishiizumi (1987). Similarly calculated average value for Mn^{53} (223 dpm/kg) is consistent with one S.D. off the mean in the widely scattered Mn^{53} data (362 ± 113 dpm/kg) compiled by Nishiizumi (1987).

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INTRODUCTION

In our calculations, use is made of Monte Carlo techniques for identifying nuclear collissions and specific nuclear reactions as well as establishing the transport of the incident nucleon and its generated nucleons. It is thus possible to use an integrated calculational approach in predicting the cosmogenic nuclide production rate and depth dependence. Previous calculational approaches have examined the production of nuclides by separating the collision into spallation, neutron capture or fragmentation processes. The calculations use a transport type mechanism for predicting the depth dependence of the cosmic ray induced nuclides (i.e. cosmogenic nuclides). One of the problems in predicting the production of cosmogenic nuclides, as a function of depth in meteorites, has been the need to determine the numerous nucleon–nuclear cross sections and then the subsequent nuclide excitation rates. In the case of neutron capture induced nuclides these difficulties have led many authors (e.g. Eberhardt et al., 1963, Lingenfelter and Ramaty, 1967, Reedy and Arnold, 1972, Reedy et al., 1979 and Reedy, 1985, Spergel et al., 1986) to utilize the similarity in the shape to the production of H^3 for predicting the production of neutrons. These tritium rates were normalized to neutron production observations either for the Moon or for Chondrite meteorites.

In particular, the High Energy Intranuclear Cascade (INC) and Internuclear Cascade Transport Code, HET (Armstrong et al., 1972) is used to calculate directly the nuclide production rate due to spallation. It is planned to link the neutron source results generated with HETC to the low energy neutron transport code, MORSE. The neutron induced cosmogenic nuclide production will be calculated without the resort to extrapolations of excitation functions.

INC MODEL CALCULATIONS

The isotropic irradiation of a stony asteroid in space is modeled by utilizing the observed cosmic ray proton spectrum up to 200 GeV to select energy and frequency via Monte Carlo techniques. The composition of the bombarded asteroid is taken to be an L Chondrite like composition (Mason, 1979): Oxygen (37%), Iron (22%), Silicon (19%), Magnesium (15%) with lesser amounts of other refractory elements. The HETC code follows the incident particle and its subsequent descendent light particles (A < 5) until they are absorbed, exit the meteorite (presently set at 1 m diameter) or drop below the low energy cut off. The neutrons generated in collisions which are below their 15 MeV cut off, are recorded at their site of production with their kinematic descriptors. These neutrons are stored in a file for subsequent neutron capture studies. The nuclei produced are recorded at their collision sites with their production energy. The abundance and distribution of these nuclei, essentially the spallation induced nuclei, are presently analyzed in 5 shells of equal volume.

The analysis of the history events generated by HETC utilizes 4 outer shells down to a depth of 30 cms and the central sphere to yield the production rate of Al^{26} at 3.1810–2 #/sec/cc which is equivalent to 54 dpm/kg for the decay rate predicted. The predicted Mn^{53} production rate is 2.91–2 #/sec/cc. Here the decay rate is calculated using the accepted Bogou standard: kg(FE +1/3Ni), to give 223 dpm/kg for the Mn^{53} decay rate.

DISCUSSION

Monte Carlo calculations of Al^{26} and Mn^{53} production in model meteorite composition similar to L Chondrite has yielded predictions which are consistent with the observed decay rates in L Chondrite stony meteorites (Nishiizumi, 1987). The calculated Al^{26} production rate (54 dpm/kg) in a 1 m diameter meteorite, is within 1/2 S.D. of the mean (49 $\pm$ 11 dpm/kg) taken from 100 bulk determinations in L Chondrite samples compiled in Nishiizumi (1987). Similarly calculated average value for Mn^{53} (223 dpm/kg) is consistent with one S.D. off the mean in the widely scattered Mn^{53} data (362 $\pm$ 113 dpm/km) compiled by Nishiizumi (1987).

The calculated depth dependence of both Al^{26} and Mn^{53} show an increase with depth through the first 20 cms before demonstrating the expected fall off with depth. This depth dependence maybe due to range–energy effects for the bombarding protons and the cross sectional energy dependence of the "in situ" nuclei. More extensive calculations are needed however to predict statistically meaningful depth–dependent results.

Depth dependent neutron source spectra are calculated for a 1 m diameter meteorite in order to calculate the neutron capture contribution to nuclide production. Spallation and neutron induced production of cosmogenic nuclides will both be examined in detail for frequently measured radiogenic nuclides such as Na^{22}, Cl^{36}, Ni^{59} and Co^{60}. It is usually expected that the spallation contribution will dominate near the surface while neutron induced contributions will dominate deep within the meteorite. Since cosmogenic nuclide ratios are less sensitive to incident flux normalization, selected isotopic ratios are being examined to give insight into inherent properties of the meteorite, such as pre–atmospheric–exposure size.

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