MEASUREMENT AND SIGNIFICANCE OF COSMOGENIC NUCLIDES FOR RETURNED SAMPLES.,

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Introduction: Sample return missions enable the use of state-of-the-art scientific instrumentation and techniques in labs on terra firma to investigate extraterrestrial samples. In addition to lunar samples, the Genesis, Stardust, and Hayabusa missions are excellent examples of the scientific yield made possible by sample return. The availability of even a small amount of sample allows multiple complementary techniques to be applied to the same sample.

Cosmogenic nuclides (CNs) are produced by cosmic-ray nuclear interactions with target nuclei in rocks, soils, ice, and the atmosphere. They are widely used for the investigation of solar system processes. Concentrations of stable nuclides, such as ^{3}He, ^{21}Ne, and ^{38}Ar, grow monotonically over time as the target material is exposed to cosmic rays. The concentrations of cosmogenic radionuclides, such as ^{10}Be, ^{26}Al, and ^{14}C also build up with exposure time but reach saturation values after several half-lives.

Cosmogenic Nuclide Production on Asteroids: Asteroids, which have neither atmospheres nor magnetic fields, do not impede incoming cosmic rays. Cosmogenic nuclide production rates and depth profiles should resemble those observed in surface samples and cores from the Moon and in large meteorites. Both the Moon and an asteroid present what is essentially an infinite plane (2π geometry) to cosmic-ray bombardment. Some near-surface differences between asteroidal and lunar production of CNs may arise as a result of differences in orbital parameters. These differences are important and can be interpreted in terms of the nature of the irradiation. Cosmic rays come from two distinguishable sources. Galactic cosmic rays (GCR), which do *not* normally contribute to the orbital sensitivity of production rates, originate outside the solar system and have relatively high energies. Their flux appears to have varied by less than ~20% over the last 10 Myr and their spatial gradient in the ecliptic plane does not exceed +2%/AU, where distance is measured going away from the sun. Today, with the aid of advanced computer programs such as the Los Alamos MCNPX (Monte Carlo N Particle eXtended) code, we can model GCR production rates for CNs in an asteroid with an accuracy of about 10%. The Sun is also a source of cosmic rays. Temporally sporadic and considerably lower in average energy than the GCR, the flux of solar cosmic rays (SCRs) is angularly and radially anisotropic. SCRs mainly produce CNs in the outer ~1 cm of an object [1].

Cosmogenic Nuclides on Planetary Surfaces: The CN production rates and depth profiles on planetary surfaces are similar to those on the Moon. The production rates of various CNs have been calculated using MCNPX, which has been well tested using a database of CN observations in lunar, meteoritic, and terrestrial samples. These results show that the production rates of CNs on planetary surfaces are 3 orders of magnitude higher than those on the Earth's surface. The case CN analyses of Martian return samples has been previously detailed [2].

Issues Addressed by Cosmogenic Nuclides Measurements: The measurement of cosmogenic nuclides in returned samples will elucidate the dynamic processes that sculpt the surface of the object. Cosmogenic nuclides directly address regolith gardening rates, exposure ages of surface materials and craters, erosion rates, and orbital histories for asteroids or dust.

Sample Requirements: The masses needed for measurement of CNs shown in Table 1 vary. Recent instrumental advances allow for analysis of masses as small as ~ μg for noble gas mass spectrometry and ~10μg for accelerator mass spectrometry.

Table 1. Selected cosmogenic nuclides.

Nuclide	Half-life (yr)	Major targets
^{54}Mn	0.855	Fe
^{22}Na	2.61	Mg, Si
^{60}Co	5.27	Co
^{14}C	5,730	O
^{41}Ca	1.04×10^{5}	Fe, Ca
^{81}Kr	2.3×10^{5}	Sr, Y, Zr
^{36}Cl	3.01×10^{5}	Cl, K, Ca, Fe
^{26}Al	7.05×10^{5}	Mg, Al, Si
^{10}Be	1.36×10^{6}	C, O, Mg, Si
^{53}Mn	3.7×10^{6}	Fe
^{129}I	1.57×10^{7}	Te, Ba, REE
^{3}He	Stable	O, Mg, Si, Fe
^{21}Ne	Stable	Mg, Si
$^{36, 38}$Ar	Stable	Ca, Fe
^{150}Sm	Stable	^{149}Sm
^{158}Gd	Stable	^{157}Gd

References:

[1] Reedy R. C. and Arnold J. R. JGR 77, 537-555 (1972) [2] Nishiizumi K. et al. LPI Contribution 1401, 75-76 (2008).