IN-SITU MEASUREMENTS OF COSMOGENIC RADIONUCLIDES ON THE SURFACE OF MARS.
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Introduction: Cosmogenic nuclides are produced by cosmic-ray nuclear interactions with target nuclei in rocks, soils, ice, and the atmosphere. Cosmogenic nuclides have been widely used for investigation of solar system matter for several decades [1]. Stable nuclides, such as 3He, 21Ne, and 38Ar, are built up over time as the surface is exposed to cosmic rays. The concentrations of cosmogenic radionuclides, such as 10Be (half-life=1.5 Myr), 26Al (0.705 Myr), and 14C (5,730 yr) also build up with exposure time but reach saturation values after several half-lives.

Especially after development of accelerator mass spectrometry (AMS), cosmogenic nuclides in terrestrial samples are routinely used for geomorphic studies such as glaciation, surface erosion, and tectonics, and studies of atmospheric and ocean circulation [2]. Cosmogenic nuclides on Mars will be able to answer questions of exposure ages, erosion rates, tectonic events, and deposition rates of sediments and/or volatiles. The concentrations of cosmogenic stable nuclides gives the integrated exposure time of the rock/mineral, and the activities of radionuclides give recent records for times back as long as a few half-lives.

Cosmogenic Nuclides on Mars: Unlike on the Earth, the cosmic rays readily reach the Martian surface because of its thin (~15 g/cm2) atmosphere and very weak magnetic fields. The cosmogenic nuclide production rate and profiles in the Martian surface are similar to those on the Moon, even after taking into account the average Martian atmospheric depth of 15 g/cm2 [3]. The production rates of various cosmogenic nuclides on Mars can be calculated using LAHET Code System that has been well tested using a database of cosmogenic-nuclide observations in lunar, meteoritic, and terrestrial samples. Because the production rates on Mars are 3 orders of magnitude higher than those on the Earth’s surface, at levels like those in meteorites and lunar samples, many cosmogenic nuclides can be measured in Martian surface features.

Although production rates of nuclides on the Martian surface are similar to those in extraterrestrial materials, the application of cosmogenic nuclides are somewhat similar to terrestrial applications [4]. The terrestrial applications of cosmogenic nuclides have included erosion and exposure histories (by glaciation, floods, landslides, faults), ages of impact craters, deposition or ablation of soils and icecaps, and ages of young volcanic eruptions. Steady state erosion of bedrock surfaces may give information on long-term erosion rates of the Martian surface. The histories of aeolian dust and layered terrains near the poles can also be studied. The use of multiple cosmogenic nuclides is required to constrain exposure histories of Martian surface samples.

The promising nuclides for up to 106-107 years of histories on Mars (14C, 36Cl, 26Al, 10Be, 53Mn, 3He, and 21Ne) are those often used to study other extraterrestrial materials. The 9Be-26Al-21Ne combination is very good for solving complex histories of terrestrial surface morphologies as well as histories of meteorites. However, all of these cosmogenic nuclides can be measured only in returned samples at the present detection methods.

The radionuclide 14C made in the Martian atmosphere has been proposed to study the nature of atmosphere-regolith interactions [5]. However, the Martian atmosphere is so thin that production of 14C in soil nitrogen could be a serious complication [6]. Some cosmogenic radionuclides made in the Martian atmosphere could be deposited on the surface, as is the case for terrestrial cosmogenic nuclides.

The global surface chemical composition of Mars can be mapped by orbital gamma-ray measurements [7], and a Ge gamma-ray spectrometer is scheduled to fly on the Mars 2001 orbiter. However, the gamma-ray flux is dominated by prompt gamma rays, with decay gamma rays generally having much weaker fluxes.

Detection of Cosmogenic Radionuclides on the Surface of Mars: Because the production rates of cosmogenic nuclides on Mars are high, the activities of some cosmogenic radionuclides can be detectable on the surface of Mars. An excellent candidate is 26Al, but other nuclides, such as 22Na (half-life=2.61 yr), 53Mn (312 d), 60Co (5.27 yr), as well as 40K and the U-Th decay chains can be measured.

However, the high cosmic-ray intensity increases detector background levels. This requires massive shielding for detectors or coincidence and/or anti-coincidence counting systems. However, massive shielding is not practical on the surface of Mars except by putting detector systems into deep cores or tunnels.

The γ-γ coincidence method is a good technique for the detection of several important radionuclides.
The coincidence can be obtained with two gamma-ray detectors in order to reduce background level. For $^{26}$Al measurements, using the 0.511 MeV-1.809 MeV coincidence eliminates the interference of $^{26}$Mg* prompt $\gamma$ rays of 1.809 MeV in addition to the reduction of background. For $^{22}$Na measurements, the 0.511 MeV-1.275 MeV coincidence can be used.

$^{22}$Na-$^{26}$Al pair: Both nuclides are produced similar nuclear reactions. The ratio and activities of two nuclides will tell us recent geometry and histories. $^{22}$Na can give the sample’s geometry during the last 5 years and the prediction of the $^{26}$Al production rate at that location. $^{26}$Al can be used to determine the exposure time at the location or average shielding depth or gardening rate of regolith samples. Further more, combining of $^{22}$Na-$^{26}$Al and proposed in-situ noble gas measurement ($^{21}$Ne) in the same sample would provide both erosion rate and exposure age.

The gamma-ray spectrometer used to measure cosmogenic nuclides could simultaneously be used to determine the surface’s elemental composition. Unlike an orbital gamma-ray spectrometer, which detects individual gamma rays [7], our surface system would use gamma rays in coincidence. Gamma-ray pairs (energies in MeV) that could be used to measure elements include: 2.741-6.129 for O, 1.369-2.754 for Mg, 4.934-3.539 for Si, any two of the 5.421-2.380-0.841 cascade for S, any two of the 6.111-0.517-1.951 cascade for Cl, 6.419-1.943 for Ca, 6.760-1.382 for Ti, and 5.920-1.725 for Fe.

The $\gamma$-ray detector system can be also used for in-situ instrumental neutron activation analysis using a $^{252}$Cf or other removable intense source of low-energy neutrons.

There are some technical problems in using germanium gamma-ray detectors. The Ge detectors would have to be cooled to ~100 K when they are used. A passive radiator, like that proposed for a Ge gamma-ray spectrometer on a Rosetta comet lander [8], could be used at night. Operation of Ge detectors would be easier in winter or near the Martian poles. Radiation damage is a problem with Ge detectors, and the ability to anneal the Ge detectors might be needed. The weight and power for a Ge gamma-ray detector system might be fairly high.

Another good detector system for Martian surface gamma-ray measurements could be made using CdZnTe room-temperature solid-state detectors [9]. While the energy resolution is not as good as Ge, it is good enough (about 2%) for use in a coincidence system and would be lighter and more compact.

**Conclusion:** The measurement of multiple cosmogenic nuclides is required to understand surficial histories of Mars. The high cosmogenic nuclide production rates on Mars allow us to use multiple nuclides as in studies of terrestrial samples, meteorites, and lunar samples. Although sample return is extremely important for such studies, we feel that in-situ gamma-ray measurements of cosmogenic nuclides on Mars during future missions can provide valuable information about the history of the Martian surface.

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**References:**