RADON-222 AND POLONIUM-210 IN THE MARTIAN ATMOSPHERE: A NEW INSIGHT INTO THE EXCHANGE OF VOLATILES AND THE DUST CYCLE.

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Introduction: Radon-222 and polonium-210, two radioactive isotopes from the uranium-238 series, have been measured at the surface of the Moon for decades, from Explorer 35 [1] to Lunar Prospector [2], in an attempt to trace today's lunar outgassing activity. On Mars, however, these isotopes (alpha emitters) had never been measured up to now, probably owing to the short range of alpha particles in the martian atmosphere (a few meters), while these particles can be detected from orbit on the Moon, and the radon-222 mapped accordingly.

Sabroux et al. [3, 4] have stressed the relevance of measuring radon-222 at the surface of Mars, in particular to estimate the water abundance of the first meters of the subsurface, the emanation of radon being a steep function of the water content in the 0-10wt% range, a likely range in the mid-latitudes regions of Mars according to neutron data [5]. Other issues of interest that can be addressed by measuring radon and its progeny (the short-lived ^{218}Po, ^{214}Po and the long-lived ^{210}Po) include the exchange of volatiles between the regolith and the atmosphere, the dynamics of the planetary boundary layer, the detection of active "hot spots", the atmospheric aerosol cycle and the estimation of the ^{238}U/^{232}Th ratio, provided radon-220 and its progeny are also measured, as summarized in [6].

An unanticipated by-product of the MER mission was to provide the first evidence of polonium-210 at the surface of Mars [7], proving in the same time that radon-222 is present in the martian atmosphere (which was of course expected, but never assessed). This discovery was made possible by the alpha detector of Opportunity's Alpha Particles X-rays Spectrometer (APXS), whose primary goal was to measure the chemical composition of rocks, soil and dust particles by Rutherford backscattering of alpha particles emitted by a ^{244}Cm source [8]. In the next section, we briefly describe the main steps leading to this detection. We then discuss what the inferred activity level could imply in terms of radon flux on a global scale. We finally compare these results with lunar and terrestrial figures, and draw some preliminary conclusions.

Detection of polonium-210 by Opportunity's APXS: The range of alpha particles useful for the determination of the chemical composition of rocks (i.e., backscattered alpha particles) is restricted to energies lower than about 4.5 MeV. Over the 4.5 - 6 MeV energy range, alpha spectra are primarily affected by the radiative environment prevailing at the martian surface (mainly protons penetrating through the thin atmosphere), and possibly by the presence of radioactive sources around the detectors. But this energy range also encompasses emission lines from several natural alpha-emitting radionuclides, namely radon-222 (below 5.5 MeV) and polonium-210 (at 5.3 MeV). Polonium-210 is a decay product of radon-222, which has the property to stick to aerosols or available surfaces and to stay attached until it disintegrates. In the martian atmosphere, it is thus expected to be transported by dust particles and to be deposited with them onto the ground. Alpha spectra acquired on targets exposed to the atmosphere were therefore analyzed and compared to spectra obtained on unexposed targets (abraded rocks and trenches), which provided the background noise. A statistically significant difference was found at 5.3 MeV (energy precisely localized on alpha spectra by a prior energy calibration). However, owing to the low dust cover index at the landing site, the strongest signal was found on the dust Capture Magnet. The corresponding activity level was determined by numerical calculation of the detection's efficiency using the Monte-Carlo code MCNPX. An activity of $(4.6\pm2.4)\times10^{-3}$ Bq.cm^{-2} was found, integrated over a depth of 1.5 to 3 μm. The detection of radon-222 is more challenging, because it constitutes a volume source, and its signature is thus spread over a larger energy range and is therefore more ambiguous. Furthermore, it is mixed through the whole boundary layer, whereas polonium-210 is concentrated in a thin dust layer deposited on the surface. But most of all, given the low signal-to-noise ratio and the small detector's surface area, the integration time with the instrument pointing towards the atmosphere was not long enough to detect any radon signal. Analysis of Spirit's alpha spectra is currently under way.

Polonium-210 and the dust cycle: As previously stated, ^{210}Po basically follows the dust cycle, while ^{222}Rn is probably intimately connected to the water cycle. ^{210}Po has a half-life of 138 days but the time delay between ^{222}Rn exhalation and ^{210}Po disintegration is constrained by the 22.3 years half-life of ^{210}Pb

(Figure 1). This means that dust particles accumulate ^{210}Pb during their atmospheric transport, and once buried, keep the memory of this atmospheric journey for a few decades. The unsupported [210]Po-induced radioactivity, integrated over the dust reservoir that has been exchanged with the atmosphere for the last decades, is therefore in secular equilibrium with atmospheric [222]Rn (assuming that the radon exhalation rate was constant over this time scale). The existence of frequent and global dust mobilization processes such as dust devils, regional and global storms has most likely homogenized the dust particles with respect to their [210]Po content throughout the planet, and to a first order approximation, one can assume that spatial variations should be quite small (besides dust cover differences). If such variations exist, they would reveal a peculiar dust exchange history (such as net deflation, or confined atmospheric transport in a region of anomalous radon exhalation rate). Assuming that the [210]Po activity of the dust surface layer stirred up by winds is homogeneously distributed, and that the load of this dust reservoir is given by the opacity of the atmosphere measured during periods of dust storms (we referred to the values derived by [9]), a global average radon exhalation flux of 5 to 10×10^{-3} atom.cm^{-2}.s^{-1} was inferred.

Mars: an intermediate case between a dry Moon and a wet Earth?

This figure is two order of magnitudes lower than the average Earth continental flux (~0.7 atom.cm^{-2}.s^{-1} [10, 11]), but greater than the upper limit of radon-222 flux derived by Apollo 15's alpha particles spectrometers of ~1×10^{-3} atom.cm^{-2}.s^{-1} [12].

For a simple 1D isothermal diffusion model, the radon exhalation rate is given by:

$$\Phi = \varepsilon . E . C_{Ra} \sqrt{\frac{D_{eff}}{R.\lambda}}$$

where ε is the porosity, E the emanation coefficient, C_{Ra} the radium content, D_{eff} the effective diffusion coefficient, λ the half-life of [222]Rn and R a parameter depending on the adsorption coefficient of [222]Rn on the solid matrix [13]. From that expression, one can see that four parameters (besides the mechanical properties of the subsoil) will mainly control the exhalation rate and thus explain the observed differences: 1) the uranium (and thus, radium) content of the subsurface; 2) the water content, which strongly affects the emanation coefficient in the 0-10wt% range, but also blocks diffusion if the soil is saturated; 3) the pressure, which controls the diffusion mode in unsaturated media (Knudsen diffusion on the Moon and generally on

Mars, molecular diffusion on Earth) and thus D_{eff}; 4) the temperature, which governs the adsorption and reduces the radon diffusion length $(D_{eff}/R\lambda)^{1/2}$ as it decreases. Compared to the Moon, Mars seems to have a somewhat lower thorium (hence, most likely, uranium) content [14] and a lower average surface temperature. The presence of water in the first meters of the subsurface, as well as co-adsorption of water and CO_2 on the solid matrix could thus be responsible for the observed difference. Further laboratory studies and modeling efforts are needed to fully characterize these competing effects.
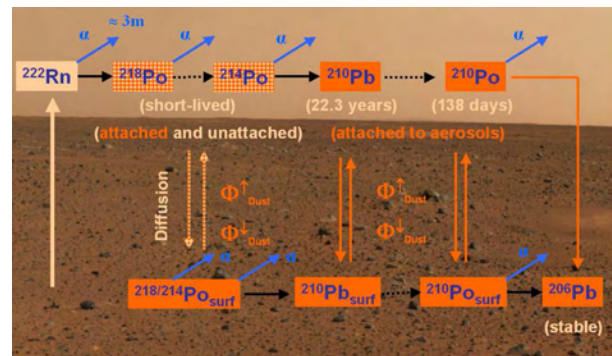

Figure 1. Box model relating radon-222 and its progeny (attached and unattached) in the martian atmosphere, with their half-lives. [222]Rn has a half-life of 3.8 days. Blue arrows indicate alpha emitters. [214]Pb, [214]Bi and [210]Bi were omitted (dashed arrows).

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