RADON EXHALATION AS A POSSIBLE EXPLANATION TO THE LOW TH/U RATIO MEASURED BY MESSENGER GRS ON MERCURY. P.-Y. Meslin[1] and G. Deprez[1], [1]Institut de Recherche en Astrophysique et Planétologie (IRAP), 9 avenue Colonel Roche, BP 44346, 31028 Toulouse, France ; pmeslin@irap.omp.eu; +33 (0)5-61-55-75-53

Introduction: In 2011, the Gamma-Ray Spectrometer (GRS) onboard MESSENGER started to measure the average abundance of radioactive elements on Mercury's surface and particularly of uranium and thorium [1], after having performed some preliminary measurements during its three flybys of the planet [2]. According to the usual formation model of the Solar system, the bulk Th/U ratio in terrestrial planets is expected to be close to its chondritic value, whose estimates vary from 3.53 ± 0.10 [3] to 3.9 ± 0.2 [4], or slightly larger as uranium can behave as a moderately volatile element [3]. It is also reasonable to assume that the average crustal value of terrestrial planets is close to this value (e.g., Th/U~3.9 in the Earth's crust, ~3.7 in lunar rocks [5], ~3.75 to 4.4 in SNC meteorites [6,7]), unless a large scale process has led to a global fractionation of these two lithophile, incompatible elements. One such large scale process proposed for Mercury is the depletion of the relatively more volatile UO_3 species upon formation and evolution of this planet at high temperatures [4]. Preferential incorporation of U in the core is another possibility. These processes would lead to an increase of the Th/U ratio compared to its chondritic value. However, the Th/U ratio measured on Mercury by the MESSENGER GRS is 2.5 ± 0.9 [1], well below the chondritic value. If this ratio is confirmed after statistical uncertainties have been reduced, it would be very puzzling and a yet unknown fractionation process should be proposed to account for it. Another mechanism can, however, be invoked to explain this trend, namely the exhalation of radon from the regolith.

Exhalation of radon as a possible explanation: A possible explanation for the low Th/U ratio observed is an increase of the concentration in the topmost centimeters of the regolith of the decay products of uranium which are used to measure it by gamma spectroscopy, namely ^{214}Bi and ^{214}Pb. Both radionuclides are produced after the decay of radon-222, a gas whose half-life (3.8 days) is sufficient to allow its transport by diffusion through several meters of regolith in the warm regions of Mercury, where adsorption is strongly reduced. Concentration gradients at the regolith-exosphere interface (and possibly sporadic venting with other gases) will indeed bring this gas, and thus ^{214}Bi and ^{214}Pb, to the surface if it is present in the pore space. In this case, instead of quantifying the abundance of uranium contained in the first centimeters of the subsurface, the gamma ray lines will also include an extra contribution from these unsupported radionuclides (very much like the topmost centimeters of terrestrial soils or sediments are enriched in unsupported ^{210}Pb due to radon transport) (Fig. 1). The very same process was proposed to explain the abnormally low Th/U ratio measured on Mars by *Mars Odyssey* GRS [8], and was recently confirmed by a refined analysis of uranium lines at several energies [9].

Of course, there are differences with the Martian case, in particular regarding the fate of ^{222}Rn after it has been released from the subsurface. We may argue that once radon reached the surface of Mercury, it will travel through the exosphere, thus reducing its concentration on the surface, but its kinetic energy due to thermal agitation (~0,05 eV) is not large enough for it to escape Mercury's gravity, and it will merely "bounce off" the surface of the planet by ballistic jumps, and thus spread until it decays into polonium-218, just like in the lunar environment [10]. In contrast to Mars, the system is not closed on Mercury, as 50% of ^{218}Po nuclei and a somewhat lower fraction of ^{214}Pb nuclei can escape to space by recoil. This escape requires the exhalation flux of radon to be several times the one necessary to explain the Th/U shift if the system was closed.

The phenomenon described here may also apply to the thorium decay chain, since radon-220 (thoron) is part of it and the decay products used to track thorium are daughters of this isotope. Nevertheless, its half-life of only 55 seconds prevents it from diffusing significantly through the regolith. Therefore, only the denominator of the Th/U ratio may be significantly biased by this process.

Hypothesis testing: Our hypothesis could be tested by different means, other than a mere shift of the global average Th/U ratio: by looking at time and space variations of the ^{214}Bi or ^{214}Pb signals, which are expected to be correlated with surface temperature, and by looking at the intensity of the signal measured at different energies [8]. As a matter of fact, the values published by Peplowski et al. [1] possibly support already our hypothesis. Indeed, an energy dependence of the intensity of the peaks used to characterize uranium can be observed in the fitted gamma-ray spectra, namely a decrease of the apparent uranium concentration with energy (U_{app} = 0.099 ± 0.041 at 352 keV and U_{app} = 0.081 ± 0.024 ppm at 609 keV), although these results are still subject to large statistical uncertainties. This energy dependence, if real, is consistent with the presence of a vertically non-uniform radioactive distribution, increasing toward the surface, since high energy gamma rays emitted by a source in the subsurface are less attenuated than smaller energy ones [8].

To test our hypothesis, we also developed a global transport model of radon in the subsurface of Mercury and were able to constrain the source term (in fact, the product emanation × diffusion length) necessary to account for a shift from Th/U=3.8 to 2.5 by this process. Realistic values of these parameters can lead to the observed decrease.

A possible objection to this theory is that it should also be observed at the surface of the Moon where the regolith characteristics are basically the same, while analyses of Kaguya-Selene GRS data performed so far have not reveal any such trend yet [11], but it is without taking into account the effect of temperature on the emanation of radon from the regolith, and on its transport properties. Indeed the mean and maximum surface temperature is far greater on Mercury (respectively 440K and 700K) than on the Moon (220K and 390K) and these high temperatures could lead to a larger emanation factor of radon from the regolith (already s observed on some fibrous basalt sorbents [12]) and a greater mobility of this gas within it, and therefore to the biased results that we can observe in MESSENGER GRS data. We are currently measuring the dependence of radon emanation factor of a hermean-like regolith (Lunar JSC-1AF) on temperature (from 300K to 700K) in order to quantify this emanation parameter which is used in our model and to corroborate this temperature effect.

Perspectives: The possibility to extract uranium lines in MESSENGER GRS spectra may provide a unique opportunity to investigate the transport of radon in the subsurface and exosphere of Mercury. This would provide an innovative insight into the current degassing activity of Mercury and subsequent transport of volatiles from hot regions to cold ones. Conversely, our transport model (although still in need for some experimental data to feed it) show that realistic emanation factors or diffusion lengths can easily explain a decrease of the apparent Th/U ratio, so that a precise determination of the U concentration of the surface of Mercury cannot be obtained if the problem raised by the mobility of radon is overlooked.

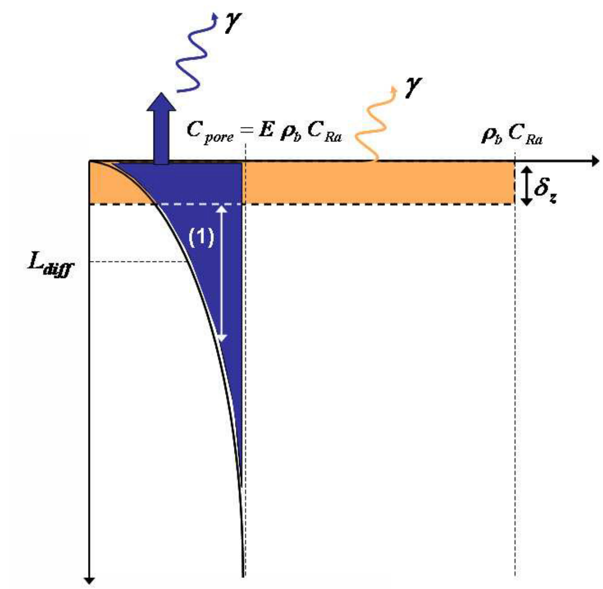

Figure 1: Sketch of the influence of radon transport on the gamma ray signal measured by orbital remote sensing. L_{diff} is the diffusion length of radon (probably a few meters on Mercury), E its emanation factor (i.e., its escape to production ratio in the solid matrix), still unknown, but possibly increasing with temperature, C_{Ra} the soil radium concentration, ρ_b the soil bulk density, and δ_z the attenuation depth of gamma rays, which depends on their energy, and which represents the depth over which the U signal is integrated. The exponential profile represents the radon volume activity in the soil pore space. The area (1) represents the amount of radon that will diffuse up to the atmosphere and contribute to the signal in excess of the uranium contained in the yellow box.

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