THE "SEP"-COMPONENT IN REGOLITH SAMPLES: CAN WE REALLY DO WITHOUT IT? A. Pedroni[1,2] and U. Ott[2], [1]Grundstrasse 10, CH-8006 Duebendorf, Switzerland (anselmo.pedroni@bluewin.ch), [2]Max-Planck-Institut für Chemie, Abt. Geochemie, Becherweg 27, D-55128 Mainz, Germany (ott@mpch-mainz.mpg.de).

Abstract: In a recent paper, Grimberg et al. [1] present depth-dependent compositional variations of solar Neon implanted in a target of the GENESIS mission. They explore implantation range effects using a model based on the SRIM-code [2], and they challenge the existence of an implanted Solar Energetic Particles ("SEP") noble gas component.

Here we discuss some considerations missing from the Grimberg et al. [1] paper. We argue that Solar Wind (SW) and SEP (while possibly a misnomer) may well be two distinct and detectable components implanted in regolith samples, and suggest that the suprathermal tail of the solar wind ("SUP") may make up the bulk of the detectable "SEP".

Introduction: Depth-dependent compositional variations of solar noble gases implanted in lunar and meteoritic regoliths have been discovered in studies of samples brought back by the Apollo missions (e.g., [3]). The feature has puzzled generations of investigators, leading to various hypotheses on how it may have originated (see [4]; and references therein). Some have invoked *in-situ processes* such as implantation range effects, backscattering, sputtering, diffusive fractionation, and a plethora of mechanisms related to the evolution and maturation of the regolith. Others have invoked *additional radiation sources,* i.e. sources differing in composition and energy spectra from the solar wind (SW), such as solar energetic particles (SEP), galactic pick-up ions (dubbed Heliospheric Energetic Particles, i.e. HEP) and, when it comes to the lunar regolith, a component originating from the ablation of terrestrial atmosphere. At more recent times, in-situ effects have increasingly been perceived as more of an annoyance, and the SEP hypothesis has gained broader acceptance. The situation has changed again with the results from GENESIS (see below).

Recent developments: Targets retrieved from the GENESIS spacecraft are unaffected of intricacies related to the regolith evolution and are free of some of the less tractable in-situ effects. These targets have been irradiated under well monitored conditions thus offering a unique opportunity for critical review of previous interpretations. The depth-dependent isotopic composition of solar neon extracted from a space-irradiated GENESIS target by [1] appears quite comparable to depth profiles of implanted solar noble gases observed in lunar and meteoritic materials, with isotopically heavier neon more deeply sited than the lighter Ne residing closer to the surface. Grimberg et al. [1] explore the effects of variable implantation ranges on the composition of implanted SW and introduce an implantation model based on the SRIM-code [2], which forecasts extreme isotopic fractionation for the most deeply implanted SW-Neon. They and, even more forcefully, Wieler et al. [4] argue that the SEP component is not necessary to explain the more deeply sited and isotopically heavier Neon, and go on to conclude that the "SEP" component does not exist at all.

Discussion: That differences in implantation range lead to adulteration of the composition of an implanted corpuscular radiation is theoretically and experimentally well established. Grimberg et al. [1] clearly have the merit of having triggered broader awareness of this. Their interpretation of implanted Solar Wind (SW) neon being affected by a combination of implantation range effects, recoil losses, and sputtering is not being questioned here. On the other hand, solar energetic particles clearly do exist and have been monitored by instruments aboard spacecrafts such as Ulysses and ACE, and implantation of also these more energetic ions into exposed surfaces is unavoidable. What is lacking in the discussion of [1] is whether SEP implanted in the GENESIS target could be a detectable component. Furthermore, with regolith exposure ages so much longer than the lifetime of the GENESIS mission, it is at least conceivable that contributions from SEP may show up in regolith samples, even if they are below detection limit in the GENESIS targets. Absence of evidence (in GENESIS) is not equivalent to evidence of absence (in regolith samples).

According to [1], by adding the contribution of cosmogenic neon (GCR) their model reproduces almost perfectly the depth-dependent variations of Ne isotope ratios previously observed in regolith samples. To back this up, the authors present a Neon three isotope diagram, $^{20}Ne/^{22}Ne$ vs. $^{21}Ne/^{22}Ne$, and a flat-curved model-line loosely connecting the components SW, SEP and GCR. However, in order to get an eye-appealing overlap of both, the model curve and the analytical data, the relative inventories of solar and cosmogenic neon need to be finely tuned. *This is not a trivial point.* The analytical data stem from lunar samples of differing antiquities, include mineral separates with differing cosmogenic production rates, and also include meteoritic samples with differing cosmic ray exposure ages and solar noble gas concentrations. The solar/cosmogenic inventory ratios in these samples differ by orders of magnitude! When realistic contributions of GCR-Neon are added, the model does not lead to a single line but to an array of curves, some falling above the analytical data and some falling below. In addition, the analytical data, regardless of origin, mineral composition and history, do not fall along a *curved* line, but are aligned along the *straight* GCR-SEP mixing line. This straight mixing line is key evidence suggesting that a detectable "SEP" component may still exist after all.

The calculations of [1] predict extremely low $^{20}Ne/^{22}Ne$ ratios (down to ≈1) for the more deeply implanted SW. (Note: the lowest ratios ever observed are around $^{20}Ne/^{22}Ne \approx 11.2$ and have been regarded as distinctive for the SEP component). The authors argue that neon with the such low $^{20}Ne/^{22}Ne$ is too rare to be detected. However, it is in the very nature of numeric simulations to become increasingly unreliable and systematically biased at the extreme edges of the range that is covered. Only a finite input can be managed, requiring in this case the assumed velocity distributions to be cut off at some more or less arbitrary value. The "where" and the "how" of this cutoff has severe influcence on what is forecast for the deeper sections of the target. For example, if the velocity distribution is truncated at the same *velocity* for all isotopes, the heavier isotopes at the upper edge of the (truncated) velocity distribution have more kinetic energy than the lighter isotopes and end up (on average) somewhat deeper in the target. This leads to a model forecasting very low $^{20}Ne/^{22}Ne$ ratios in the deepest section of the target. If, on the other hand, the same velocity distribution is truncated for all isotopes at the same kinetic *energy*, different isotopes at the upper edge of the velocity distribution end up (on average) closer together, leading to predicted $^{20}Ne/^{22}Ne$ ratios in the deeper sections that are not as extreme. Clearly it is also necessary to properly take into account physically realistic thermal broadening effects.

An alternative scenario, SUP rather than SEP? A long lasting problem with the SEP acronym is that there are dissenting and fuzzy perceptions on what it is supposed to be. To most geochemists (as to the authors of this paper), SEP comprises all components of the solar corpuscular radiation apart from the SW. The solar physics community and a few geochemists tend to associate the acronym SEP to sporadic, localized and spectacular high-energy outbursts from the sun (such as solar flares). The sun emits so much less particles from sporadic sources than through the SW that one can safely assume the highest-energy components not to be detectable as distinct components implanted in the regolith. This is confirmed by the fact that the exotic compositions observed by spacecraft during energetic events have never been detected in regolith samples. Obviously, if there is something like a distinct and detectable implanted "SEP" component, only the *most prolific sources of ions* qualify as a prime source candidates. Most of the analytical data have been obtained by stepped etching in vacuo, a technique that peels mineral grains layer by layer and allows selective extraction of noble gases sited at incremental depths. The fact that neon released later (i.e. more deeply sited) fits the SEP-GCR mixing line is not only the key evidence that something like a SEP component may exist after all, it is also a severe constraint requiring an essentially *depth-independent composition*.

The latter seems to be at odds to implantation range effects as discussed by [1] but, in fact, it is not. Pedroni [5] discussed implantation range effects on the SEP component and showed that a power law velocity distribution will lead to an implanted component with an essentially depth-independent isotope composition. The combined requirements of being a prolific source of ions and having a power law velocity distribution are best fulfilled by suprathermal ions [6]. These show up at approximately twice the solar wind speed as non-maxwellian tails of the SW velocity distribution and extend to energies up to several MeV/nuc. Heliospheric-pick-up ions have their own suprathermal tails as well. It is known that shocks and MHD-turbulence powerfully energize the suprathermal population, but suprathermal ions are ubiquitous and detectable also at quieter times. Suprathermal ions are not generated in the process of SW acceleration, and cannot be linked to any specific solar source. Nevertheless, it appears that at any distance from the sun so far investigated (up to 5.4 AU), there is an exchange of energy and matter between suprathermal ions and the SW plasma, which suggests there is close relationship between their compositions (for deeper insights see [6]). Remarkably, also a strong compositional link between the SW and the SEP components trapped in regolith samples has been shown to exist (see [5] and references therein).

Summary: While not evident in the GENESIS analyses, a more energetic and detectable component may still be present in regolith samples. Key features of suprathermal ions suggest that the suprathermal tail of the SW may correspond to the "SEP" component known from regolith samples: a more proper name for **SEP** might be **SUP** (for **Sup**rathermal).

References: [1] Grimberg A. et al. (2006) *Science,* 314, 1133-1135. [2] Ziegler J.F. (2004) *Nucl. Instrum. Meth. Phys. Res. B,* 1027, 219-220. [3] Wieler R. et al. (1986) *GCA,* 50, 1997-2017. [4]. Wieler R. et al. (2007) *Chem. Geol., 244*, 382-390. [5] Pedroni A. (1994) *LPS XXV,* 1059-1060. [6] Gloeckler. G. (2003) *AIP Conf. Proceedings, 279*, 583-588.