INTERPRETING MEASURED SOLAR WIND IMPLANT PROFILES THROUGH SIMULATION. C. T.
Olinger[1] and R.C. Wiens[2], [1]Neutron Science and Technology, Los Alamos National Laboratory (MS H803, Los
Alamos, NM 87544; colinger@lanl.gov), [2] Space Science & Applications, Los Alamos National Laboratory.

Introduction: Simulations of ion implantation using the open source code SRIM [1] have enabled corrections to measured isotopic and elemental ratios in Genesis collection materials for backscattering of incident solar ions [2,3]. Simulated depth profiles have also been used to correct for surface contamination that gets gardened into collection surfaces during secondary ion mass spectrometry measurements [4]. Simulations of solar wind ion implantation have also improved interpretation of deeply implanted solar Ne, which had been interpreted as Ne from solar-energetic particles, but is now understood to represent implant-fractionated solar wind, favoring heavier ^{22}Ne at depth [5].

However, these single-episode, static-surface implantation simulations do not adequately reflect long-term lunar soil exposure to solar wind. One of the surprises from closed system stepped etching (CSSE) and stepped pyrolysis of Genesis samples was the level of isotopic fractionation at the very surface of the sample, i.e., ^{20}Ne/^{22}Ne ratios in excess of 15.0 [6], which is generally not seen in lunar grains . Here we show that this is not due to anomalously low-speed particles captured by Genesis, but rather the difference from lunar grains is due to the lack of weathering erosion of the Genesis samples.

Background: SRIM simulations are performed for solar wind compositions of all noble gases, using the velocity distribution as measured by the Genesis Ion Monitor (GIM) and the Advanced Composition Explorer (ACE) [6]. He and Ne velocity distributions were directly measured by ACE; the heavy noble gas distributions used in this study are interpolated from the ACE data using first ionization potential as the interpolation parameter. SRIM input files are developed from these distributions with a Monte Carlo routine. These input files are run through SRIM, with the simplifying assumption that ions have normal incidence to the surface with an ilmenite (FeTiO$_3$) target composition. SRIM output files are then post processed to obtain backscatter and implant depth distributions for each isotope, and implant isotopic ratios as a function of depth are then generated from these individual files.

After developing the incident depth profile (blue symbols in figure 1), an implant-erosion equilibrium profile is developed by integrating each depth in this distribution from that depth to the bottom of the implant profile (magenta symbols in figure 1). This rep-

resents a constant erosion process, where each depth element has spent an equal period of time from that depth to every depth below it, essentially mechanically integrating the exposure from the original depth to the current depth of that element.
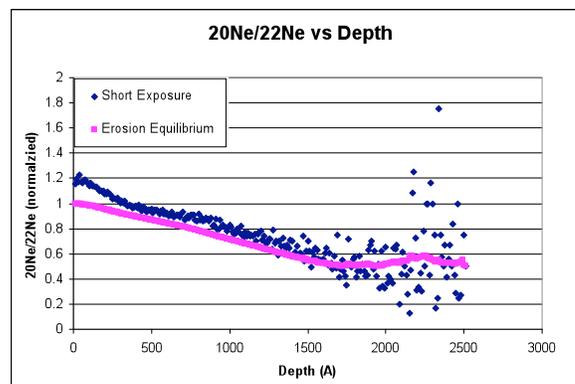

Figure 1: Simulated ^{20}Ne/^{22}Ne depth profiles, normalized to the incident flux ratio assuming short-duration exposure (blue diamonds) such as the Genesis experiment and very long exposure (magenta squares) where there is equilibrium between incident ions and loss due to surface erosion.

Literature Data: Noble gas studies of lunar ilmenites by CSSE placed constraints on noble gas isotopic and elemental compositions for two distinct epochs. One soil, 71501 exposed ~100Ma and a second 79035 acquiring its implanted solar gas ~1Ga [8]. The CSSE procedure has the intrinsic advantage over pyrolysis of 1) low temperature extraction, significantly reducing diffusion from the extraction process and 2) the potential to correlate release profiles with depth.

Comparison of Simulations with Literature: The magenta profile in figure 1 represents the model assumptions of steady state erosion as well as equilibrium between solar wind accumulation through implantation with loss of solar wind from surface erosion. Ideally CSSE extraction removes a uniform layer from all soil grains in the sample system. This results in a mechanical integration of gas released from the depth liberated by the etching. Thus, simulated equilibrium profiles were similarly re-integrated from each new CSSE-exposed depth to the next to reflect the cumulative Ar fraction released from each CSSE measurement step from soil sample 71501 soil sample #4 [8] to al-

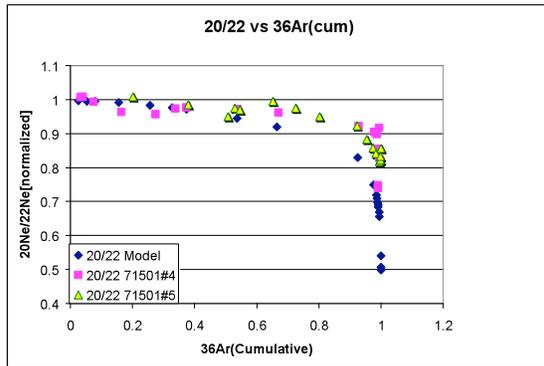low meaningful comparison between model and experiment (figure 2).

Figure 2: $^{20}Ne/^{22}Ne$ ratios(normalized to the indent flux ratio) vs. Cumulative ^{36}Ar released for the erosion-equilibrium model simulation (blue diamonds) and two sets of CSSE analyses on ilmenites from lunar soil 71501(yellow triangles and magenta squares) [8].

Discussion: This relatively simple model (blue diamonds in Fig. 2) does not precisely reproduce the data, but the vertical scatter is on the order of the variation in two different ilmenite separates from the same soil. The model exaggerates the significant dip of the $^{20}Ne/^{22}Ne$ ratio near the end of the range, where straggling effects are important, but this mismatch is likely at least in part due to 1) diffusion in the actual soil samples 2) imperfect depth profiling by CSSE, both of which will tend to wash out the amplitude of this valley in the experimental data; and 3) the simplification in SRIM modeling that assumed normal ion incidence, which would exaggerate the valley in the model results.

The general consistency between model and experiment in this case suggests that these simulations can now be used to infer average depths sampled by each CSSE step. Simulated *elemental* profiles show larger differences with the measurements. Generally, the measured light gases are depleted relative to the heavy gases near the surface as compared to implant simulations, strongly suggestive of diffusive loss. Thus, information added through the simulation will enable us to place constraints on diffusion models for these exposed materials.

This model further validates the assumption in Benkert et al [8] that for soils exposed over millions of years the first extraction step is the most accurate reflection of solar wind *isotopic* compositions incident on the soil (barring significant fractionation due to diffusion and small biases introduced from preferential backscattering of lighter isotopes during implantation). This is fundamentally different from Genesis meas-

urements, where the most accurate reflection of the incident solar wind requires an integration of the entire measured profile.

Conclusions: We have shown that erosion accounts for differences between isotopic compositions in the topmost nanometers of Genesis samples and those of lunar grains, without the need to invoke Genesis surface contamination or low-energy particles. Successful SRIM simulation of measured depth profiles demonstrates that the SRIM code provides reliable results even for high Z incident ions into planetary materials. Models of isotopic ratios enables estimates to be made on average depth sampled in CSSE, which can then be used to parameterize diffusion. Also, this model assuming equilibrium between ion implantation and erosion (whether that is due to ion erosion or other mechanisms) provides a new tool for estimating erosion rates.

References: [1] Ziegler J. F. (2004) *Nucl. Inst. Meth. Phys. Res 219/220 1027-1036.* [2] Heber V.S., Wiens R.C., Bochsler P., Wieler R., and Burnett D.S. (2009) Fractionation processes in the solar wind revealed by noble gases collected by Genesis regime targets. Abstract 2503. *Lunar Planet. Sci. LX.* [3] Meshik A., Mabry J., Hohenberg C., Marrocchi Y., Pravdivtseva O., Burnett D., Olinger C., Wiens R., Reisenfeld D., Alton J., McNamara K., Stansbery E., and Jurewicz, A.J.G. (2007) Constraints on neon and argon isotopic fractionation in solar wind. *Science* 318, 433. [4] McKeegan et al. (2009) *LPSC XXXIII,* Abstract #1402. [5] Wieler R., Grimberg A., Heber V.S. (2007) Consequences of the non-existence of the "SEP" component for noble gas geo- and cosmochemistry. *Chem. Geol. 244*, 382.. [6] Reisenfeld D.B., Burnett D.S., Becker R.H., Grimberg A.G., Heber V.S., Hohenberg C.M., Jurewicz A.J.G., Meshik A., Pepin R.O., Raines J.M., Schlutter D.J., Wieler R., Wiens R.C. Zurbuchen T.H. (2007) Elemental abundances of the bulk solar wind: Analyses from Genesis and ACE. *Spa. Sci. Rev.* 130, 79 [7] Grimberg A., Baur H., Bochsler P., Buehler F., Burnett D.S., Hays C.C., Heber V.s., Jurewicz A.J.G., Wieler R. (2006) Solar wind neon from Genesis: Implications for the lunar noble gas record. *Science 314*, 1133. [8] Benkert J.-P., Baur H., Signer P., and Wieler R. (1993) He, Ne, and Ar from the solar wind and solar energetic particles in lunar ilmenites and pyroxenes. *J. Gelphys. Res. 98,* 13147.