ESTIMATE OF SOLAR WIND HYDROGEN FLUENCE FROM THE GENESIS COLLECTORS.

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Introduction: Although measuring the hydrogen fluence was not originally an objective of the Genesis Mission, as we worked with the collector materials, it became clear that 1) measuring the hydrogen fluence in the collectors should be relatively straightforward using SIMS, and 2) an accurate and precise measurement of the hydrogen accompanying the other elements in the Genesis collectors would provide a good test of models of elemental fractionation during acceleration of the solar wind and could potentially provide an independent measurement of solar elemental ratios and the metallicity of the Sun.

Experimental Methods: We chose diamond-on-silicon (DOS) collectors because DOS should be less subject to diffusive loss of hydrogen. There is a relatively high hydrogen background in the collectors, but it constitutes only a few percent of the solar-wind hydrogen present. We requested collector chips more than 5 mm across to avoid edge effects, as discussed in more detail below. We also requested samples of all four solar wind regimes [1] in order to see if element/hydrogen ratios vary with the nature of the acceleration off of the Sun. We were allocated four chips: B/C array (bulk solar wind) #60628, H array (coronal hole wind) #60631, L array (low speed interstream wind) #60413, and E array (coronal mass ejection wind) #60625.

We carried out a number of developmental measurements on implant standards. We learned that the H/C ratio is a relatively strong function of beam current, so the final measurements used the same beam current for samples and standards. We learned that H/C and CH/C_2 behave differently as a function of position, beam current, crater shape and other parameters. Mapping of H/C and CH/C_2 as a function of position across a sample mounted behind a mask with a 5×5 mm^2 hole showed that, in the central ~3×3 mm^2 region, the two ratios have stable values, but as the primary beam approaches the edges of the exposed sample, the C/H ratio goes down and the CH/C_2 ratio goes up somewhat more rapidly. We continued to measure H/C and CH/C_2 in later work to monitor shifts in relative yields.

Standardization turned out to be quite difficult. Implant standards are spatially homogeneous, but the actual amount of implanted hydrogen is typically not known to sufficient precision. To address this problem, we prepared several materials for implantation with a standard dose of hydrogen in a single irradiation. These materials included a "blank" DOS chip, two Si chips, our flight samples of the B/C and H arrays, and two apatite grains with well determined hydrogen concentrations similar to the expected level of the solar wind (Crystal Lode and Lake Baikal apatites with water contents measured by [2]). We implanted these materials at Kroko, Inc., with a nominal hydrogen fluence of 6×10^{15} atoms per cm^2 and an energy of 30 keV, significantly higher than the ~1 keV energy of the solar wind, so that, in the flight samples, the standard implant would be below and separated from the solar wind.

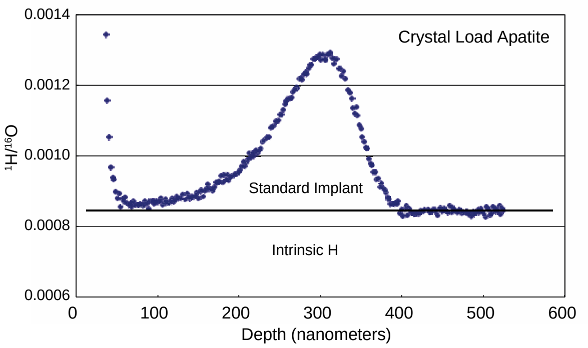

Fig. 1: Depth profile for Crystal Lode Apatite Standard containing 0.37 wt% water. The horizontal line represents intrinsic hydrogen. The implant signal is distinct.

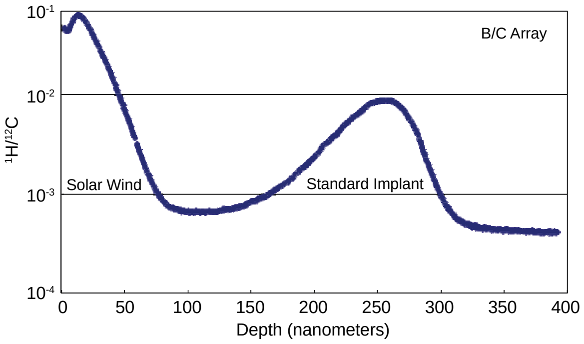

Fig. 2: Depth profile for B/C array sample containing the same hydrogen implant as in Fig. 1. Solar wind and standard implants are clearly separated.

We measured the standards and samples as depth profiles using the UH Cameca ims 1280 ion microprobe. Depth profiles were obtained on the apatite grains (Fig. 1), the DOS standard material, and the Genesis B/C (Fig. 2) and H arrays. The apatite standards provided an independent calibration of the standard implant fluence. The intrinsic hydrogen in the apatite gives a constant signal that can be well measured below the implant. After subtracting the signal from the intrinsic hydrogen, the number of hydrogen atoms in the implant peak can be compared to the number of hydrogen atoms intrinsic to the apatite, calibrating the implant. We found that the implant fluence was ~5.4×10^{15}, about 10% lower than the nominal fluence.

Once the implant was calibrated, depth profiles in the irradiated B/C and H arrays permitted us to compare the solar wind peak directly with the calibrated standard peak to get the fluence of the solar wind.

We also measured the Genesis L- and E-array collectors, although they had not been irradiated. Fluence values come from comparing the integrated solar wind profiles from these collectors with the integrated profiles of the standard implant (calibrated by the apatite crystals) in the blank DOS.

Results: Preliminary estimates of the solar wind hydrogen fluence are presented in Table 1. We currently assign an uncertainty of about 12% to these values. The uncertainty comes primarily from variability of the measurements of standard apatites and is a systematic uncertainty. The solar wind depth profiles were consistent to better than 2%. We should be able to reduce the systematic uncertainties with further work. Fluences reported here for the L and E arrays come from a previous set of measurements, as we have not had time to reduce the newest data. The results for the B/C and H arrays for this older data set are within 10% of the current measurements.

Table 1: Comparison of H flluence estimates (H/cm^2)

Regime	Solar Wind Collectors	Genesis Ion Monitor	Ratio
Bulk SW	1.44×10^{16}	2.06×10^{16}	0.699
Interstream	6.57×10^{15}	9.15×10^{15}	0.718
Coronal Hole	4.82×10^{15}	6.40×10^{15}	0.753
CME	3.88×10^{15}	4.73×10^{15}	0.820

Discussion: Table 1 also compares our results with those from the Genesis Ion Monitor [3]. Our values are 18-30% lower than those of the Ion Monitor. Because measurements made at several different times with different techniques agree to better than 10%, we do not believe that our measurements are in error. So the question becomes, why are the values different? One possibility is that the DOS collectors are not as retentive for hydrogen as we assumed. The ratios of our measured hydrogen fluences to those from the Ion Monitor generally increase with the speed of the captured solar wind. Hydrogen implanted more deeply might be less subject to diffusive loss. The data are generally consistent with this expectation, except that the bulk solar wind was implanted with a higher average speed than the L array and should have been held more tightly. But the implant dose on the B/C array was a factor of 2.2 higher than that on the L array, potentially causing more damage to the collector and facilitating diffusive loss. Overall, one might have expected larger differences between the regimes if diffusive loss was involved, however.

There are things we can do to test the hypothesis that the DOS collectors have lost hydrogen. For example, the Genesis Mission carried out a series of experiments with diamond-like carbon materials in which they were implanted with hydrogen, oxygen, and nitrogen, and then subjected to high temperatures for months to years. These studies demonstrated that oxygen and nitrogen did not move, but not much attention was paid to hydrogen. These materials have been retained and we can examine them for hydrogen retentively. We can also examine the details of the implant profiles to look for distortions due to diffusive hydrogen loss.

Although our hydrogen fluences are lower than anticipated, the diffusion-loss hypothesis has not been confirmed as of yet.

References: [1] Burnett D. S. (2013) *Meteoritics & Planet. Sci.* **48**, 2351-2370. [2] McCubbin F. M., Hauri E., Elardo S. M., Vander Kaaden K. E., Wang J. and Shearer C. K., Jr. (2012) *Geology* **40**, 683-686. [3] Reisenfeld D. B., Wiens R. C., Barraclough B. L., Steinberg J. T., Neugebauer M., Raines J., and Zurbuchen T. H. (2013) *Space Sci. Rev.* **175**, 125-164.

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