REFINING FLUENCES FOR GENESIS BULK SOLAR WIND 23Na AND 39K, AND REGIME 12C USING MORE PRECISE SRIM MODELS, AND ANALYTICAL ARTIFACT DELETION, RESPECTIVELY.

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Introduction: Solar wind (SW) was returned to Earth for analysis by the Genesis spacecraft so that matter taken directly from the Sun could be used to model the solar nebula and the formation of solar system objects, including chondritic meteorites [1]. However, SW is fractionated [e.g., 2, 3] (factor $F_{(sw\text{-}phot)}$) relative to the solar photosphere. To derive accurate solar data, measurements from Genesis collectors must be corrected for $F_{(sw\text{-}phot)}$.

SW measurements from spacecraft indicate that $F_{(sw\text{-}phot)}$ is related to each element's first ionization potential (FIP), but secondary factors (e.g., an ion's atomic mass and velocity) also affect fractionation [3]. Laming et al. [4] proposed models (constrained by Genesis-derived data) of SW formation. These models incorporate both the ponderomotive force in the chromosphere, and conservation of the first adiabatic invariant in the low corona to predict solar wind element and isotope fractionation. These models successfully model the FIP correlation of $F_{(sw\text{-}phot)}$ observed for most elements [5].

Our goals are to test the models of [4] by providing additional elemental data related to FIP and mass dependence. Task (1) is to make accurate and precise measurements of ^{23}Na and ^{39}K in bulk SW to test model predictions [4] at low FIP. Task (2) focuses on ^{12}C, ^{14}N, and ^{16}O in both bulk SW and the three SW regimes Genesis measured (high speed, low speed, and coronal mass ejections) as defined in [6]) and will look for mass dependence in $F_{(sw\text{-}phot)}$.

Background Specific to These Analyses:

Task (1). Rieck et al. [7, 8] measured bulk solar wind samples of ^{23}Na and ^{39}K in Genesis silicon (Si) and diamond-like carbon (DLC) collectors by secondary ion mass spectrometry (SIMS). The novel analytical approach (internally-standardized back side depth profiling) should have given accurate and precise results; but, the results had large uncertainties. In particular, front- and back-side Na measurements in DLC did not agree, and Na measurements in DLC did not agree with measurements in Si. The data from the front side DLC measurement were closest to measurements in Si.

Task (2). Rieck et al. [9] measured ^{12}C and ^{16}O fluences in bulk SW samples as well as the three SW regimes. Again, a novel approach was used: ion imaging depth profiling [10] by SIMS, which allows measurement of solar material only nanometers from the collection surfaces. However, preliminary C measurements were less than half the abundances predicted based on bulk C measurements, despite obtaining what appeared to be complete H and L profiles.

Methods Employed to Refine Previous Results:

Task (1). A data reduction method implemented for SW H [11] and SW Mg isotopes [12] was applied to SW Na and SW K. Specifically, model SW depth profiles (SW given velocity distribution of [13] into a carbon matrix) were created using SRIM software (available from *https://www.srim.org*), and fit to the SW Na and K data by adjusting density, intensity, and background. To eliminate error from extrapolation, SRIM ion depths were binned directly to the depths of the SIMS duty cycles. Integration of SW counts used the models when it was necessary to remove contamination; otherwise, profiles were integrated, as usual.

Task (2). Ion imaging allows pixel-by-pixel depth correction and elimination of pixels that are contaminated by terrestrial particulates and analytical artifacts. To improve the data reduction by rapidly and accurately identifying anomalies, MP4 movies were made in which each frame was a cycle of 2D ion intensity data. The videos allow identification of artifacts (glitches in the digitization electronics and software that appear in one cycle in one or more ion channels) and contaminants (signals from Utah dirt or other terrestrial contamination that affect the SW profile). The MP4 movies were reviewed frame by frame using open source VirtualDub2 software. Cycles that contain artifacts were removed from the data set. Individual pixels that appeared to contain contaminants were also removed. After removal of contaminants and artifacts, the data were analyzed as described in Rieck et al. [9]. The optimization routine to calculate the SW fluence could robustly tolerate missing cycle data. We found that contaminants affected the calculated SW fluence significantly, so we were aggressive in removing contaminated pixels (at the expense of statistical precision).

Results with Discussion: Task (1) reprocessed data from DLC bulk SW fragments 60867, 60407, and 61090, all of which were implanted with reference ions having a calibrated fluence to provide an internal standard. Collectors 60867 and 60407 were back side depth profiled (reference ions in the back surface); 61090 was front side depth profiled (reference ions implanted through SW at the collection surface). Experimental details are in [7, 8]. SW results using the new data-reduction technique are in Table 1. The discrepancy between the front-side and back-side Na results from DLC has been resolved.

An interesting quirk was that, when the matrix ion (C^+) was not used to normalize the SW data during reprocessing, the results were significantly different and the SRIM models did not fit as well, even when beam current seemed stable. It may be that the current drifted during the run, but returned to starting conditions near the end of the profile. Possibly, the C normalization corrects for minor heterogeneity in the film.

Na results from Si are still higher than from DLC. Because (i) Na is known to diffuse in Si [14, 15] and (ii) back side depth profiles of SW Na exhibit "early breakthrough" before a close approach to the surface (e.g., SW Mg vs. SW Na in Figs. 6 and 7 of [16]), we suspect there is near-surface gain of non-SW Na in Si.

For Task (2) we reprocessed C data from Genesis collectors 61409 (H array) and 61386 (L array), both float zone (FZ) Si. Both collectors were thinned for back side depth profiling by SIMS, and implanted with reference ions to create internal standards. Experimental details are available in [9]. The preliminary result of removing anomalous cycles from two profiles resulted in ~3% change in the resulting fluences. This change was much smaller than our uncertainty (20%, 2-sigma). If removal of analytical artifacts from the remaining analyses similarly results in <<20% change in reported SW fluences, then our results are robust against these types of analytical artifacts.

Summary with Conclusions: Genesis measurements are a special case of SIMS analyses because the signal-to-noise is so low. How data are collected with SIMS, and the assumptions for reducing the raw data, have an enhanced effect on the reported fluences. Therefore, it is worthwhile to reevaluate standard procedures to assess the robustness of the techniques.

Task (1). Using a data reduction method implemented for SW H [11] and SW Mg isotopes [12], the discrepancy between the front side and back side ^{23}Na results from DLC have been resolved and are described herein. For Si, because Na is known to diffuse in Si and back side depth profiles of SW Na are not traceable close to the surface (e.g., SW Mg vs. SW Na in Figs. 6 & 7 of [16]), we suspect a near-surface gain of Na in Si collectors. ^{39}K measurements in DLC and Si have always been consistent, but precision improved.

Future work might entail adding a Si component to our SRIM DLC models instead of simply adjusting the target density. The tail of the data would be fitted more accurately, and might give more accurate results when the SW and internal standards overlap. For engineering uses, the model DLC density would be more realistic. Note also that a back side implantation of reference ions of the isotope of interest avoids error due to instrumental mass fractionation, which can be (~3-5%).

Task (2). The removal of contamination and analytical artifacts from ion probe data is critical for calculating precise and, especially, accurate SW fluences. It is not easy to remove artifacts or contaminants in "spot" data, but it is possible with imaging data using the video technique described here. The change made by removing artifacts from two of our profiles is 3%, which is within the uncertainty of ~20%. Although precision was not improved for the C fluences we reported last year, our measurements reported in [9] remain robust.

Table 1. Results of Reprocessing SW ^{23}Na and ^{39}K data from Genesis DLC collectors.

Sample	Run	Isotope	Profiling from front (F) or back (B)	Model ρ (g/cm^3)	Sputter rate for std. (Å/s)	Sputter rate for SW (Å/s)	Bkg. intensity (cts/s)	Std. fluence used (atoms/cm^2)	IMF used	Fluence (atoms/cm^2)
60867	6,7	23Na	B	2.85	1.43	1.43	16	1.95E+12	0	6.73E+10
61090	1	23Na	F	2.65	2.17	2.17	27.1	1.95E+12	0	8.84E+10
				2.68	2.17	2.17	8	1.95E+12	0	8.83E+10
				2.76	2.1	2.1	8	1.95E+12	0	9.09E+10
				2.76	2.1	2.1	8	1.95E+12	0	8.01E+10
				2.81	2.17	2.17	6	1.95E+12	0	8.02E+10
								Average B & F:		7.37E+10
60407	1,2	39K	B	2.8	3.42	3.42	64	1.72E+12	10%	3.58E+09
				2.8	3.42	3.34	64.6	1.72E+12	10%	3.30E+09
				2.8	3.42	3.34	64.6	1.72E+12	0	3.63E+09
61090	1	39K	F	2.85	2.17	2.17	6.05	4.66E+09	0	1.36E+09
				2.8	2.17	2.17	6.05	4.66E+09	0	3.34E+09
								Average B & F:		3.42E+09

= Indicates no C normalization. Models were fit to raw data. Results were not included in the averages.

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