ION TRAJECTORY SIMULATIONS OF THE GENESIS SOLAR WIND CONCENTRATOR PERFORMANCE

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Introduction: The GENESIS mission collected samples of solar wind from November, 2001 to April, 2004 and returned them to Earth for isotopic and elemental analyses, with the purpose of precisely determining the solar photospheric composition and thereby obtaining the average composition of the solar nebula [1]. In addition to > 1 m^2 of passive collectors, GENESIS had one active collection experiment on board, called the Solar-Wind Concentrator. The Concentrator was an ion telescope designed to enhance the fluence of SW ions by an average factor of 20x onto a 6 cm diameter target [2]. The purpose of the active collection was to increase the signal to contamination ratio, particularly for oxygen, which is a ubiquitous elemental contaminant in terrestrial materials, and which was, as isotope ratios, the highest measurement objective of the mission. While the crash-landing of the return capsule resulted in the breakage of a large fraction of the passive collectors, the Concentrator target survived almost completely intact [3]. Consequently, the target has been analyzed successfully to date for He, Ne, Ar [4], O [5], and N [6]. Future analyses are being considered for C, Mg, Al, Si, S, and Li isotopic and elemental compositions.

Because it was impossible to realistically imitate the solar-wind environment for accurate testing of the Concentrator, a program was begun in 1992 to accurately simulate the Concentrator performance using early versions of the ion trajectory program SIMION [7] and variations thereof. The SIMION Concentrator simulations became the primary means for validating the performance of the Concentrator prior to flight [8]. As the inputs required a number of assumptions of various solar-wind parameters, and because simulation capabilities improved over time, the model has been continuously updated since launch. Here we describe the improvements to the Concentrator simulations, compare the results to measurements made on the Concentrator target, and use these to predict the utility of the Concentrator target for analyses of other elements and isotopes mentioned above.

Description of the Concentrator Simulation Model and its Updates: The original model, running in SIMION 7.0, used 23 million grid points to achieve a spatial resolution of 0.67 mm modeling one quarter of the instrument, as the other quadrants were identical by symmetry [8]. Subsequent to the launch of GENESIS, the program was migrated to SIMION 8.0, which permitted increased resolution to 0.40 mm using 110 million grid points. As vertical distances of some optical elements are in the range of 2-6 mm, this increase in resolution allowed a significantly more accurate model, particularly for these components. For both the original and the revised models, files were set up for simulating solar wind velocities of 350, 450, 550, 650, and 750 km/s. The results of these runs were combined based on solar-wind velocity distributions to provide a composite result. Advances in computing facilitated flying more ions in the new model, typically using two million ions per velocity bin rather than half of that or less in pre-launch simulations. Given the radial symmetry of the ion patterns on target, proven by both simulations [3] and by analysis [4], the typical simulation output is the radial position on the target for each ion that is implanted in the target, according to the simulation.

Solar Wind Parameters: Critical SW parameters are velocity, angular distribution, and charge state distribution. All of these were modified relative to pre-launch assumptions. However, the first two were changed quite significantly and have substantial impacts on the focusing capabilities of the Concentrator.

Angular distribution by necessity includes wobble, precession, and nutation of the spacecraft as well as mis-alignment of the instrument to the spacecraft pointing vector [3]. The pre-launch Concentrator simulation model used worst-case assumptions for these parameters. Actual flight conditions were significantly better, leading to a more tightly focused beam at the target resulting in higher Concentration at the center relative to the edges. In addition, angular distributions are narrower for alpha particles than for protons. Under the assumption that heavier ions follow the alphas, we have begun using alpha angular distributions.

Velocity distribution was somewhat higher than pre-launch projections due to the high fraction of coronal hole material emitted in the ecliptic shortly after the solar maximum. In addition, pre-launch projections used proton velocities, while heavy ions tend to have 4-7% higher velocities at Earth due to the influence of Alfven waves [9]. Post-launch simulations have taken this into account by launching at slightly higher energies the ions used for each run at a given voltage level (corresponding to 368, 475, 580, 686, and 790 km/s for the respective voltage settings corresponding to the velocity bins given in the previous section). Another feature that is being incorporated into final simulations is a Gaussian distribution around the above mean velocities.

Results and Discussion: The pre-launch simulations [8] predicted an isotope fractionation pattern that varied relatively slowly as a function of target radius with a minimum mid-way to the edge and an overall range of <12‰/amu for oxygen. It also predicted an oxygen concentration factor of > 55 near the center, dropping to < 5 at the perimeter. Predictions for Ne and N were qualitatively similar.

Ne, N, O Results: Recent simulations incorporating the changes noted above result in steeper isotopic fractionation patterns (>20‰/amu range; Fig. 1) and similar overall concentration factors.

Post-flight measurements of neon [4] showed an isotopic fractionation pattern of continuously diminishing ^{22}Ne/^{20}Ne from center to perimeter extending ~30‰/amu and a concentration factor of ~20% lower than predicted near the center, but close to prediction at the edge. Oxygen measurements [5] concur with the Ne measurements in terms of the overall patterns.

The main differences between simulations and measurements are slightly higher concentration factors in the simulations and a departure from a monotonically decreasing fractionation trend with radial distance near the perimeter in the simulations. As nearly 100% of the ions at r > 25 mm enter the Concentrator near the edges, it is likely that an edge effect that is not easy to simulate in SIMION causes this difference. One possibility is that the domed grid stretched slightly and assumed a more parabolic shape than in the computer model. The crash landing made it impossible to verify the post-flight grid conditions.

He, Ar Results: Both of these elements are outside the m/q range (2.0-4.3) for which the Concentrator was designed so they represent novel tests for the instrument performance and for the ion simulations. In the case of He, $(m/q)_{3He} = 1.5$, so ions reflect at a higher locus of points above the mirror electrode and closer to the domed grid than was designed for O. The domed grid is an imperfectly-shaped parabolic grid surface. The fact that ^{3}He reflects closer to this relatively poorly-shaped surface results in greater aberration, i.e., a strong mass fractionation gradient, as seen in Fig. 1. The actual He measurements [4] show a fractionation gradient from +80 to -40‰, but without the subsequent rise at r > 25 mm. ^{3}He is also slightly susceptible to loss by the proton rejection grid, but this loss will not be evident in the simulations, and based on the measured data [4] seems not to have affected the He.

Argon has the opposite problem: With high m/q the low charge-state ions are destroyed by impact with the mirror. A worst-case charge state distribution was used from polar coronal holes [10] which have lower freeze-in temperatures (and lower charge state distributions) than the bulk solar wind. The results are shown in Fig. 1, and indeed, there is clear mass fractionation from loss of ^{38}Ar at the mirror (there is essentially no ^{40}Ar in the Sun). The measured Ar profile also showed loss of ^{38}Ar, but less, as expected based on the worst-case nature of the simulation, between -25 and -35‰/amu [4].

Colleagues may wish to use the Concentrator target for analysis of elements between Ne and Ar in mass. Careful study of the charge state distribution of these elements and additional modeling should indicate the feasibility of such analyses.

The results presented here are preliminary. More complete treatment is expected at the meeting and in a forthcoming paper.

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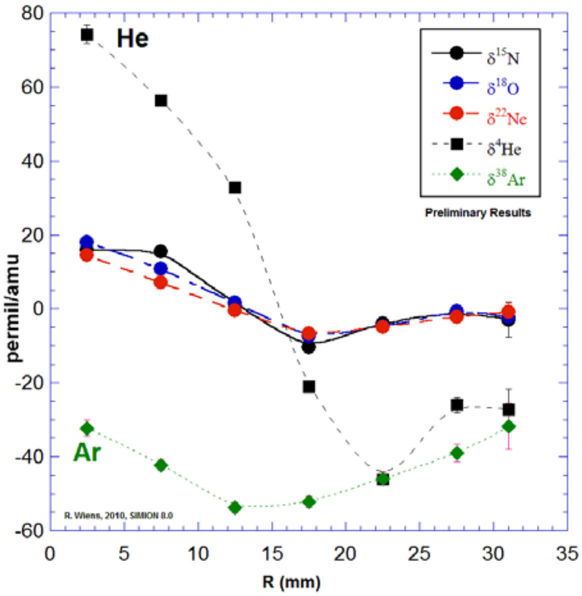

Fig. 1. Isotopic fractionation pattern on the GENESIS Concentrator target as a function of radius, based on modeling simulations.