THE GENESIS SOLAR-WIND COLLECTOR MATERIALS

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Abstract. Genesis (NASA Discovery Mission #5) is a sample return mission. Collectors comprised of ultra-high purity materials will be exposed to the solar wind and then returned to Earth for laboratory analysis. There is a suite of fifteen types of ultra-pure materials distributed among several locations. Most of the materials are mounted on deployable panels ("collector arrays"), with some as targets in the focal spot of an electrostatic mirror (the "concentrator"). Other materials are strategically placed on the spacecraft as additional targets of opportunity to maximize the area for solar-wind collection.

Most of the collection area consists of hexagonal collectors in the arrays; approximately half are silicon, the rest are for solar-wind components not retained and/or not easily measured in silicon. There are a variety of materials both in collector arrays and elsewhere targeted for the analyses of specific solar-wind components.

Engineering and science factors drove the selection process. Engineering required testing of physical properties such as the ability to withstand shaking on launch and thermal cycling during deployment. Science constraints included bulk purity, surface and interface cleanliness, retentiveness with respect to individual solar-wind components, and availability.

A detailed report of material parameters planned as a resource for choosing materials for study will be published on a Genesis website, and will be updated as additional information is obtained. Some material is already linked to the Genesis plasma data website (genesis.lanl.gov). Genesis should provide a reservoir of materials for allocation to the scientific community throughout the 21st Century.

1. Introduction

The concept behind Genesis, the solar-wind sample-return Discovery Mission, is simply to expose materials to the solar wind and to bring them back to Earth for laboratory analysis. Accordingly, the heart of Genesis is the suite of ultra-pure materials used as collectors.

Fifteen high-purity materials were chosen using criteria that will eventually allow for high-precision laboratory analyses of specific solar-wind elements or isotopes in each collector. The most important selection criteria were: bulk purity, surface cleanliness, and the retentiveness of solar-wind components under mission conditions. Further, these flight-qualified materials can physically withstand the environment the spacecraft sees during launch, cruise, and landing phases. Finally, there was an effort to insure that the collector-material designated for a given element (or isotope) was compatible with the technique(s) most likely to be used for the eventual, high-precision laboratory analysis.

Conveniently, the semiconductor industry has pioneered manufacturing and handling techniques for many ultra-pure materials. In fact, most of the materials used in Genesis were commercially available (eg., silicon, germanium, and sapphire). A few collector materials were not commercially available but have commercial counterparts. These flight-materials were especially tailored for the Genesis mission (e.g., ^{13}C-diamond, diamond-like carbon, bulk metallic glass). The rest were thin-film coatings produced under the auspices of the Genesis science team. Control samples of the flight materials will be curated at the Johnson Space Center (JSC) and allocated for testing purposes. Similarly, all relevant portions of the spacecraft will be archived for additional solar wind, micrometeorite, and other future studies.

The Genesis collector materials are deployed in several locations: the concentrator; the five collector arrays; the two side collectors; the top of the array-deployment mechanism, and the sample-return capsule lid-foil collector. All materials are passive collectors in the sense that when the materials are exposed to the solar wind, the ions will implant themselves into the materials. However, in the concentrator, solar wind is reduced in hydrogen and helium, and an applied voltage concentrates the solar-wind ions in the 4 to 28 amu range before they implant themselves into the collector materials. The concentrator increases the fluence on the target collector materials by a factor of 20, thus facilitating the isotopic analysis of light elements (Nordholt et al., 2002; Wiens et al., 2002). The locations where collector materials are deployed are given in Figures 1, 2, and 3. Note that, except for the lid-foils, all of the collectors are contained in a cylindrical "canister". The canister fits inside a sample-return capsule, the exposed portion of which is lined by lid-foil collectors. Both the canister and the sample-return capsule must be open for solar-wind collection (Burnett et al, 2002 and Figure 3). Most materials will be exposed to the solar wind throughout the mission, and so will bring back bulk solar-wind samples. However, three collector arrays will be deployed (ie, exposed to the solar wind) independently when specific types ("regimes") of solar wind are present, thereby providing independent samples of solar wind from different regimes (Burnett et al, 2002). Between exposures, the deployable collector arrays will be shaded by the uppermost, bulk-solar-wind collection array. Note that the deployable arrays can be seen in Figure 2 (a side view of the stack of collector arrays) and Figure 3 (the deployed arrays on the spacecraft) but not in Figure 1 (a top view with the deployable-arrays stowed).

The fifteen materials selected for solar wind collection and their positions are listed in Table 1, and an overview for each material is given in section 3. A discussion of how they were selected is given below.

2. The Material Selection Process

The process of choosing the materials was complex, as the criteria used in the selection were influenced by a variety of factors, some of which are not necessarily intuitive. For example, different techniques for manufacturing otherwise equivalent, ultra-pure materials incorporate different trace impurities. So, manufacturing technique entered into consideration (cf., float-zone silicon vs. Czochralski-pulled silicon vs. vapor-deposited silicon; Wiens and Burnett, 1999). Similarly, solar-thermal properties such as emissivity and solar absorbance were important because the diffusive-loss during collection will depend upon the collector's ambient temperature (ie., solar-heating). Bulk purity, surface and interface cleanliness, diffusion coefficients (retentiveness) and analyzability had to be weighted with respect to specific elements that the material was a candidate to collect.

Fortunately, data for many of the selection parameters are in the semiconductor industry literature and could be used as a baseline. However, the final selection was based on our own testing whenever time allowed. In other cases (eg., diffusion coefficients for specific elements and/or specialty collector materials) there was no choice but to determine parameters through *in house* experiments by members of the Genesis science team. Prior to assembly, the science team focused on those materials that carried out the highest-priority measurement objectives required by the Genesis Science Requirements (Burnett et al., 2002). Now, after launch, the science team is still working, determining the usefulness of specific collectors for elements in addition to the highest-priority goals. Before the actual sample return, these details will be published on a Genesis website as a report available to the planetary materials community-at-large. The website is envisioned as a document that can be updated as new information is obtained, and as a resource for future researchers. This concept is already being tested by the Genesis plasma data website (*genesis.lanl.gov*), which currently has a link to the older Genesis material's selection and feasibility information, www.gps.caltech.edu/genesis, (Wiens and Burnett, 1999) and will eventually have a link to the most current information on the Genesis collector materials (both collector arrays and concentrator targets). Prior to the completion links to updated materials, it is suggested that researchers requiring specific details on Genesis materials contact the second author (D. S. Burnett).

The Genesis materials-selection criteria are discussed below, along with examples of how they were applied.

2.1. ULTRA-PURE MATERIALS AS COLLECTORS

Purity was the prime science requirement for the Genesis collectors because, in an ultra-pure material, an analytical measurement should give a large signal-to-noise ratio (necessary for high analytical precision) for even small additions of specific solar-wind components.

For elements and isotopes, Genesis Mission purity requirement was determined by error analysis. The requirement was that the background-impurity concentration for a given element be 10% or less than the expected contribution from the solar wind during ~2 years of exposure (Burnett et al., 2002, Table 2). Where practicable, our goal was to have impurity levels at 1% or less of the solar wind. Therefore, for each solar-wind element, determining whether or not the potential collector material was pure enough required: (a) analyzing that element in the bulk material, and then (b) comparing the measured value with a solar-wind concentration calculated from the estimated fluence implanted by the solar wind during the collector's ~2 year exposure[1]. To convert fluence to concentration, it was assumed that the solar-wind fluence was distributed over the outer 1000 Angstroms of the collector.

Potential collector materials were sent to academic and commercial laboratories around the country for trace-element analysis. Often, measured concentrations were at or below the detection limit of the technique. However, in many cases these detection limits implied upper limits to element concentrations that were lower than the 10% solar wind science requirement. Therefore, these materials were still of acceptable purity. Future measurements with improved instrumentation will yield background values below our current baseline.

A summary of the laboratory results for elemental purity: at launch, we knew that (1) we had materials pure enough to collect and measure 44 elements; (2) our analytical sensitivity was insufficient to test purity for the remaining 37 elements; and, (3) there is no element for which we know that there is no collector material of adequate purity. The distribution of elements with undocumented purity with respect to their location on the periodic table is given in Figure 4.

2.2. ANALYZABILITY OF COLLECTORS

Although purity was a prime requirement for materials selection, there is an obvious risk in using even an infinitely pure material for which there is no potential scheme for analysis. Therefore, if a given technique for analyzing a given element or isotope was known to have an especially high analytical precision and sensitivity, then materials easily analyzed by that technique were given preference. Analyzability was not a firm pass/fail criteria, however, since the Genesis mission mandates the future development of high-precision analytical instrumentation.

In the selection of materials for isotopic analyses, analyzability played a major role, especially for oxygen. The literature suggested that float-zone silicon was sufficiently pure that oxygen isotopes could be measured after a simple, two-year exposure to the solar wind. However, high-precision analysis would require a large collection area; moreover, silicon forms a native oxide layer that would interfere with analyses unless removed or otherwise avoided. To avoid these practical problems, the "concentrator" was developed. This instrument is an electrostatic mirror with materials collecting solar wind for isotopic analysis placed at the focal point. It concentrates elements in the 4 to 28 amu range, increasing the 2-year fluence of these isotopes by an average factor of ~20x (Nordholt et al., 2002; Wiens et al., 2002).

Even with the design and development of the solar-wind concentrator, there was still some concern about quantitatively analyzing the relatively scarce ^{17}O isotope. The science team decided to make at least one concentrator-target either diamond or diamond-like carbon so that CO mass spectrometry could be used (Butterworth et al., 2000). A problem was that, normally, CO mass spectrometry for the 3-isotopes of oxygen (^{16}O, ^{17}O, ^{18}O) uses m/z 28:29:30. But, diamond and diamond-like carbon almost invariably contain at least some terrestrial nitrogen impurities. Therefore, to calculate for ^{17}O we have to correct for background at m/z 28and 29 (^{14}N^{14}N, ^{12}C^{16}O and ^{15}N^{14}N, ^{13}C^{16}O, plus some cracking from organics). By using ^{13}C in place of normal ^{12}C in the target material, we shift the 3-isotope spectrum up 1amu to m/z 29:30:31. Accordingly, there are two main advantages: the shift separates measured solar wind atoms from terrestrial nitrogen contamination, and strips away almost all isobaric interference (e.g. ^{13}C^{16}O interference with ^{12}C^{17}O) from the ^{17}O/^{18}O measurement. These improvements lead to at least a 5-fold improvement in signal-to-background, extremely important given the sensitivity requirements for Genesis.

A more mundane way of making solar-wind elements more analyzable in the collectors array was to decrease the volume of collector material used to catch the 2-year solar-wind fluence. That is, consider an ideal collector that consists only of a clean, high purity, extremely thin membrane: then, the number of implanted solar-wind ions may be large relative to contaminants in the collector simply because there is so little mass in the collector itself. This

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[1] Anticipated solar-wind fluences (atoms/cm2) were based on the solar abundance estimates of Anders and Grevesse (1989), and an average solar-wind proton flux of ~3x10^{+8} cm^{-2}s^{-1} (Burnett et al, 2002).

ideal scenario is equivalent to a layered collector in which a thin layer of collector material is deposited on a clean, inert substrate that provides structural support only. On Genesis, this concept is represented by using high-purity, thin-films deposited on sapphire. Thin metallic films on sapphire can be analyzed separately from the sapphire itself through either laser ablation or differential dissolution.

2.3. THE ROLE OF SURFACE AND INTERFACE CLEANLINESS

Because the solar wind will be implanted near the surface ($\leq$~1000 Å, depending on the material), being able to differentiate between surface contamination and the implanted solar wind is a significant science issue. The limits for terrestrially-derived surface contaminants are stipulated in the Genesis Mission science requirements. Specifically, at the time of analysis, the surface concentrations of C, N, and O must be $<10^{15}$ atoms/cm^2; for the other elements, the terrestrial contamination must be lower than the estimated solar-wind fluence of the element of interest. These limits were based on the experience of the science team that, in practice, surface cleaning could decontaminate surfaces by no more than a factor of 10-100. Thus, if the contaminant atom/cm^2 were both equal to the solar-wind fluence and could be cleaned by at least a factor of 10, then the minimum purity requirements could be met at the time of analysis. Additional signal-to-background enhancement could then be achieved if analytical techniques with good depth resolution are employed.

For solar wind measurements, analytical techniques are required that are depth sensitive. That is, the techniques need to independently analyze the implanted zone, distinguishing it from both the bulk of the collector material (deeper than the implantation zone) and from any residual surface contamination layer. For example, surface-sensitive techniques such as Secondary Ion Mass Spectroscopy (SIMS) will be able to distinguish between the implanted solar wind and surface contamination. The requirements are still necessary, however, because during SIMS analysis with a high impact-energy primary ion beam (e.g. 20 keV Cs), some fraction of the surface-contaminant atoms (~1%) can be driven to depths where they would interfere with the analysis of implanted solar-wind ($\leq$~1000 Å) by atomic knock-on effects. Therefore, if there were no requirements on the surface contamination, a component of terrestrial surface contamination at or above the solar-wind fluence could be the limiting factor on the analytical precision during SIMS analysis of a collector. Defining surface-cleanliness standards for Genesis, it was conservatively assumed that stray elemental counts from the surface are ~1 – 10% of the contamination.

In order to meet the stringent cleanliness requirements, we concluded that it was not possible to defer cleaning until after recovery. Rather, it was necessary to install clean materials in the canister and to keep them clean throughout the duration of the mission. Consequently, all collectors were installed under the cleanest possible conditions (cf., Fig. 2) and then enclosed inside the Genesis canister while still in the Genesis Class 10 curatorial cleanrooms at JSC in order to keep them as clean as possible. The exceptions are the foils that line the lid of the sample-return capsule: these were installed in the high bay at Lockheed-Martin Astronautics. These “lid-foil” collectors (Figures 1 and 3) are designated for collecting radioactive nuclei, and were a special case because the potential for external contamination by radioactive nuclei was considered negligible.

The required levels of surface cleanliness can sometimes be obtained by cleaning procedures and maintained through handling techniques (e.g., Stansbery et. al, 2001). Semiconductor industry standards are very high and many materials, e.g. silicon for the collector-arrays, were used as received. For other materials, optical inspection, optical microscopy and/or surface-analysis techniques (e.g., X-ray Photo-electron Spectrometry, XPS) were performed prior to installation in the payload canister. For the concentrator target material, semiconductor cleaning techniques were used to remove particles and/or surface films. Similarly, the specialty laminated materials gold on sapphire and aluminum on sapphire were fabricated using a hot-stage under vacuum, so that volatile adsorbed species could be desorbed before coating. In many cases, witness coupons (e.g., fragments of silicon, gold-on-sapphire, or other material of known surface cleanliness) followed collector materials though the fabrication and installation process, so that surface contamination could be evaluated after the fact by analysis of the coupon.

There is still the possibility of removing some contaminants at the time of analysis, if necessary. For example, adsorbed volatiles might be removed through heating prior to analysis. Moreover, both our experience and that of colleagues in the semiconductor industry suggest that there are cleaning procedures developed for semiconductors that will not remove a significant fraction of the implanted solar wind in our collectors (i.e., that will remove less than the outer ~50 Å of the collector), such as low-energy ion milling and low-density plasma etching.

2.4.TESTING OF PHYSICAL PROPERTIES

Because Genesis uses passive collectors, the only physical/structural criterion was that the materials used for collection would withstand the launch, flight and re-entry environments. To qualify for flight, individual materials had to undergo a series of environmental tests. Random samples of candidate hexagonal wafers for the collector arrays underwent 3-axis vibration in groups of three wafers; concentrator-target candidates also underwent a 3-axis vibration test in flight-like fixtures. Laminated wafers intended for collector arrays underwent thermal cycling (six-cycles at 20 °C to –170 °C). In addition, gold on sapphire (AuOS) and aluminum on sapphire (AlOS) went through both tape-testing – pealing strips of tape from the surface of the laminate -- to check the adhesion of the specialty films as well as additional months of thermal-fatigue testing (daily thermal cycling between room temperature and 0 °C). Inside an engineering-model of the canister, all materials underwent both another 3-axis vibration test simulating launch, and a subsequent thermal-vacuum test to simulate the environment expected in space. Following assembly, the Genesis spacecraft itself underwent vibration and thermal-vacuum testing.

After each of these tests, the wafers were inspected for signs of catastrophic failure such as cracking and chipping. In terms of influencing the selection, the impact was generally to modify the specifications for the collectors, rather than the choice of material itself. For example, the tape testing of AuOS and AlOS indicated that sapphire wafers needed to be cleaned in an O_2 plasma after etching in order to obtain the maximum adherence between the film and the substrate. Similarly, the thickness of all of the collectors in the canister-cover collector array was changed from 500μ to 700 μ, because 500 μ silicon collectors had cracked during 3-wafer vibration tests, and because cracks or chips were observed in other 500 μ collectors, including silicon and silicon-on sapphire, after the vibration test of the engineering-model canister.

2.5. SOLAR-THERMAL PROPERTIES OF COLLECTOR MATERIALS

The ability of a material to retain solar wind is clearly an important factor in the selection. Each collector material will retain some solar-wind components better than others because of differences in chemical and structural properties. The optical properties of materials determine their ambient temperature during exposure to the sun; therefore, in general, the optical properties of individual collector materials had to be determined to calculate the ambient temperature and its influence on the diffusion rates of solar-wind components. However, because the concentrator target materials are inverted (facing the focal point of the electrostatic mirror) their exposure temperature is fixed by the optical properties of their holder.

Genesis engineers modeled the temperatures to be expected during solar-wind collection using emissivity and solar absorbance values measured at the Jet Propulsion Laboratory/California Institute of Technology (JPL). Emissivity measurements were performed using a Gier Dunkle Infrared Reflectometer (Model DB100). Solar absorbance measurements were performed using a Gier Dunkle Reflectometer (Model MS251). In addition, during thermal-vacuum testing, the engineering-model canister was wired with thermocouples in order to measure collector temperatures directly. Table 2 gives representative collector material temperatures measured inside of the canister during the solar-thermal vacuum test of the engineering model. We believe that these measured temperatures will closely approximate the ambient temperatures that individual collectors will experience during the mission.

We note that in most cases the ambient temperatures of the collectors are relatively low and will not dramatically enhance diffusive loss of implanted solar-wind components. There are also advantages to having the collectors warm, but not hot. For example, contaminants that outgas from the warm spacecraft will condense at cold points rather than sticking to the warm collectors (Wiens and Burnett, 1999). In metallic collector materials, heating may mitigate radiation damage caused by the solar wind through the annealing and stabilization of defects.

2.6. ELEMENTAL DIFFUSION OF SOLAR-WIND IN COLLECTOR MATERIALS

The potential for the steady-state diffusive-loss of solar-wind elements from the material during collection was a major criterion in selecting collector materials. Estimating this loss required knowledge of two components: the ambient temperature that the collector would reach during exposure to the sun, and the diffusion coefficient for that element in the collector at that ambient temperature. When both were known, diffusion rates for solar-wind elements in candidate collector materials could be estimated.

For materials selection and testing, we allowed for ambient temperatures up to 200 °C, which was a conservatively high estimate from what was measured during testing (cf., Table 2, and section 2.5). In some cases, diffusion coefficients could be gleaned from the literature; however, if no appropriate literature value was available, diffusion rates were bounded *in house* using actual diffusion experiments performed on implanted candidate materials (e.g., Wiens and Burnett, 1999; Jurewicz et al., 2000).

The variety of materials on the collector arrays is a good example of how retention factored into the selection of collector materials. The semiconductor literature indicated that alkali elements (at least Li, Na, and K) and Fe will diffuse over large distances in silicon, and similar results were determined *in house* for Ne in silicon (Wiens and Burnett, 1999). Accordingly, other collector materials (e.g., sapphire, gold on sapphire) were added to cover these elements.

In the cases of the specialty materials used on Genesis, clearly no literature values were available. Accordingly, diffusion rates were bounded using actual diffusion experiments performed on implanted samples of these candidate materials (eg., Meshik et al., 2000).

Researchers requiring diffusion information can currently find tabulated results from the original Genesis feasibility study and proposal in Wiens and Burnett (1999) electronically, through a link on the Genesis plasma data website (*genesis.lanl.gov*). Details of the retentivity of solar-wind components in collector materials are still being compiled. Data will eventually be available in final reports; meanwhile pressing questions on information not currently on the web can be discussed with the second author (D. S. Burnett).

3. Flight Solar-wind Collection Materials

The Genesis spacecraft is flying fifteen individual materials designated for solar-wind collection. Again, these collector materials are distributed among (1) the target of the concentrator (Nordholt et al., 2002; Wiens et. al. 2002), (2) the collector arrays and (3) the supplemental collectors, e.g., two side collectors, the cap on the array-deployment mechanism, and the sample-return capsule lid foil (Fig. 1, 2 and 3; cf. Table 1). A discussion of the individual materials organized by position on the spacecraft is given below.

3.1. CONCENTRATOR TARGET MATERIALS

At the focal point of the solar-wind concentrator is a target that is approximately 6 cm in diameter, giving a collection area of ~25 cm^2 of material (Nordholt et al., 2002; Wiens et al., 2002). The target holder is divided into four quadrants each containing a material tailored to collect light elements whose isotopes are of fundamental scientific interest. Of the four quadrants: one is an amorphous diamond-like carbon, one is ^{13}C-diamond, and two are silicon carbide. Because the concentrator separates positive ions from electrons, these collector materials have an additional selection criteria in that they must have a surface resistivity of less than ~10^{11} ohm-cm. The amorphous carbon and the silicon carbide had sufficient conductivity; but, the diamond had to be coated to meet this criterion. At JPL, the flight quadrants were cleaned and an XPS analysis of each quadrant was performed just prior to the final particulate-removal process to insure surface cleanliness. Installation was performed at Los Alamos National Laboratory (LANL).

Detailed chemical properties used in the materials selection will be given in the Genesis concentrator-target materials final report (D. S. Burnett, in preparation). Meanwhile, a summary of how well these materials meet the purity and surface contamination for the top two Genesis Mission science priorities (measurement of O and N isotopes) is given in Table 3, and a general overview of the materials themselves is given below.

3.1.1. *Diamond-like carbon on silicon*

This specialty material is targeting nitrogen and its isotopes, because N_2 can be readily extracted for gas-source mass spectrometry using stepwise oxidation of the carbon. Although potentially useful for oxygen, the background levels are significantly higher than for either the ^{13}C diamond or the silicon carbide targets.

The diamond-like carbon is a thick (1.5 µ – 3 µ), semi-ordered, film on a silicon substrate that was made for Genesis by Sandia National Laboratories (Friedmann et al., 1994, Alam et al., 2001). Using pulsed laser deposition, carbon was sputtered from a target onto a silicon substrate under vacuum. To prevent delamination within the finished, thick film, *in situ* annealing steps were performed after each (thin) deposition to relieve that layer's internal stresses. Because of equilibration with the chamber atmosphere during these annealing steps, there is an internal, layered distribution of terrestrial contaminants (O, F, lesser amounts of N) every 1000 – 1500 Å throughout the standard material. For Genesis, in order to avoid internal contamination in the zone destined to collect solar wind, the second to last annealing step was skipped; accordingly, the upper 2000-3000 Å of the quadrant is not layered with these terrestrial contaminants, but the surface contamination is relatively high (Table 3).

This material was also chosen for the collector arrays and will be deployed as full hexagons (3 each on the bulk solar-wind collector arrays, 4 on each of the three other arrays). However, the special annealing cycle described above for the concentrator was not used. In addition, a 50 Å,^{13}C version of this material was used as a conductive coating on the ^{13}C diamond concentrator target.

3.1.2. *^{13}C Diamond*

Thick, freestanding crystalline-diamond films are produced commercially by several vendors, many of whom use proprietary processes. Example of non-proprietary processes are given by US Patents #5,273,731 and # 5,110,579 assigned to General Electric Corp in 1993 and 1989, respectively (Anthony and Fleischer, 1993, Anthony and Fleischer, 1992). Genesis required a specialty diamond product in which the collection surface was a diamond composed of the isotope ^{13}C, so that mass spectrometric analysis of oxygen isotopes through conversion of oxygen-implanted diamond to CO would have minimal interferences for the $C^{17}O$ species even in the presence of minor amounts of terrestrial nitrogen impurities (e.g. $^{13}C^{17}O$ is not affected by interference with $^{13}C^{16}O$ or $^{14}N^{15}N$ as $^{12}C^{17}O$ would be, and $^{12}C^{18}O$ interference will be negligible with a ^{13}C substrate; c.f. section 2.2, Analyzability of collectors). Fluorine and nitrogen should also be analyzable, so it can be used for other than oxygen if enough material is available.

Raytheon was the vendor chosen to make this material both because of the purity of their standard diamond films and their willingness to develop process techniques for manufacturing the specialty material. Because of the high cost of isotopically-enriched methane, only the top 50 µ or so is the specialty diamond; the rest of the 570 µ thick wafer is the standard commercial material. Wafers were laser cut to shape, mechanically ground, and polished. Between the final cleaning at JPL and installation at LANL, the quadrant was sent to Sandia National Laboratory, where a 50Å ^{13}C diamond-like carbon layer (Alam et al., 2001) was deposited on the surface, in order meet the conductivity requirement. The diamond-like carbon film may need to be removed before laboratory analysis because it is higher in terrestrial atmospheric components than the underlying diamond.

3.1.3. *Silicon carbide*

This commercial material (purchased from CREE, Inc.) comprises 2 quadrants of the 4 concentrator targets, ~ 12 cm^2 of collection material. The collection surface is an ultra-high-purity SiC layer (~2 microns thick) grown epitaxially on a nitrogen-doped, polished silicon-carbide wafer. ("Epitaxial" indicates that the coating shares a crystal-lattice plane with the substrate, and is single-crystal). CREE, Inc.'s fabrication technique is proprietary; however, their website, *www.cree.com*, currently lists a number of references for the epitaxial growth of silicon-carbide films, many of which are variations of either molecular-beam epitaxy or chemical vapor deposition (e.g., Fissel et al, 1995; Powell et al., 1991). After the epitaxy, CREE then laser-cut the resultant wafer to shape. The SiC is sufficiently conductive that no coating was necessary. To meet the structural criteria for flight, a second vendor (RhioTech) mechanically ground and shaped the edges. It is probable that oxygen, nitrogen, fluorine, lithium, beryllium, and boron will be analyzable in this material.

3.2. COLLECTOR-ARRAY MATERIALS

The bulk of the material for collecting solar wind is found in the Genesis collector arrays. Each array holds 54 (55 in the canister-cover array) four-inch diameter hexagonal collectors and 6 collectors shaped as half-hexagons. The distribution of the materials within each array is given in Figure 5. Detailed chemical properties used in their selection will eventually be given on a Genesis website as a Collector-Array Materials Final Report (D. S. Burnett, in preparation). Meanwhile, some older information is available in Wiens and Burnett (1999). In all cases, flight-like materials have been archived at JSC as control samples. For tracing impurities in collectors cut from silicon boules (large, crystollographically-oriented, synthetic single crystals, such as made by Czochralski- and Float-zone growth processes), the terminations of the boules were cut and archived, and the approximate location along the length of the crystal from which the individual collector was cut was recorded. An overview of each collector material is given below.

3.2.1. *Silicon*

Because we have certification of high-purity and a plethora of information from the semiconductor literature on other selection criteria, commercial silicon constitutes more than half of the hexagons in the arrays. There are three individual types of silicon made using three significantly different fabrication techniques: Czochralski-grown silicon, float-zone silicon, and silicon on sapphire (O'Mara et al, 1990 for details; overview below). The three manufacturing techniques result in different trace impurities. The Czochralski-grown wafers and the float-zone wafers are solid silicon; silicon-on-sapphire wafers consist of ~3000 Å of silicon grown epitaxially on a hexagonal sapphire substrate.

3.2.1.1. *Czochralski-grown silicon*. Czochralski growth is where a small seed crystal is slowly pulled from a melt to produce a large, single-crystal boule. For silicon made by this process, there is some potential for the melt to leach contaminants from the crucible holding the silicon melt, and then incorporate them into the boule. However, manufacturing procedures (as well as the large volumes manufactured) insure fabrication of high purity silicon.

For Genesis, the silicon boules to be cut into collectors were a commercial semi-conductor product purchased from MEMC Electronics (MEMC). All of the Czochralski wafers were cut from two single-crystal boules grown for Genesis, and were tracked with respect to both the crystal, as well as the section of the crystal, from which the collector was cut. Each small group of wafers was given a serial number. As quality control, cores were bored from slabs cut from the terminations of the crystals and were sent out for analysis to determine minimum bulk purity.

These round, commercial wafers were then cut into hexagons using laser cutting (Directed Light), mechanically edge-ground to remove flaws and increase their physical strength (RioTech), and then returned to MEMC for cleaning. In order to be flight-quality, these collectors had to have stringent cleanliness and quality control; eg., 5 or fewer particles <0.5μ, and no scratches, stains or solution-spots on the collection surface.

3.2.1.2. *Float-zone grown silicon*. Float-zone growth is where a high-purity but multi-granular rod is melted and recrystallizes to a single crystal when passed through an RF-heating coil. The melt never touches a crucible; moreover, as the rod melts *in situ*, the impurities in the already pure rod are zone-refined (tend to stay in the melt, not the crystal) and are effectively eliminated from the newly-grown bulk crystal. Accordingly, float-zone grown materials have a reputation for ultra-high purity.

Single-crystal semiconductor-grade silicon made by this method is a standard commercial product. The single-metal crystals are grown under an argon atmosphere to prevent oxidation. This method of fabrication produces material of higher purity than the Czochralski-pulling technique, including a lower C, N, and O content.

In the semiconductor industry impurities imply conduction via defects; therefore, the resistivity of a wafer is used as a general indicator of overall purity. Float-zone silicon wafers grown from normal stock typically have impurity levels of ~2000 ohm cm; those produced from ultra-high purity poly-silicon average ~18,000 ohm cm. We have obtained material with over 50,000 ohm cm.

In a procedure similar to that used for the Czochralski-grown collectors, round commercial wafers were purchased from the vendor (Unisil), laser-cut into hexagons (Directed Light), edge-ground to meet flight-specifications (RhioTech), and then cleaned to flight specifications (MEMC).

3.2.1.3. *Silicon on sapphire*. This laminate was produced by Kyocera Industrial Ceramics Corporation (Kyocera), and is nonstandard only in it's hexagonal geometry. A 3000 Å silicon layer is epitaxially grown on a pre-formed, polished, high-quality single-crystal sapphire substrate using a proprietary process. This finished collector was then shipped directly to JSC for a fit-check and installation into the collector arrays, so there was no intermediate handling. The material is clean under XPS analysis, but no other data exist at present on surface contamination levels. Unfortunately, since procurement of collectors for the Genesis mission, Kyocera has discontinued its silicon-on-sapphire product line. Flight-like wafers are, however, archived at JSC for future analysis.

In this case, the thin silicon layer is the solar-wind collector and the sapphire is merely a support. Sapphire is desirable as a substrate because it is transparent to many laser wavelengths and is relatively inert chemically. Therefore, this material was originally included to aid analytical techniques using laser-ablation and/or differential dissolution. However, because the silicon is epitaxial and shares a crystallographic orientation with the substrate, the silicon is also single crystal. Because of this crystallographic coherence between the silicon and the sapphire, it proved to be tougher than either silicon or sapphire alone for engineering purposes. As a solar-wind collector, recent work is proving that the silicon layer has adequate purity for a number of elements (Humayan et al, 2001).

3.2.2. *Sapphire*

Throughout the commercial sector, high-purity, single-crystal Al_2O_3 is known as "sapphire"; this is in contrast to the jargon of the geological community, who would refer to this material mineralogically as high-purity corundum. The sapphire used by Genesis is a commercial product purchased from Kyocera. For electronics, sapphire is usually used as an insulating substrate; for Genesis, as a collector it is used to collect and retain alkalis in the solar wind, as diffusion rates in silicon are known to be relatively high (Treiman, 1993).

The sapphire is single-crystal grown by the edge-defined film-fed growth method. A general description of this technique can be found on the Kyocera website and literature (c.f. www.kyocera.com/KICC/industrial/products/crystal.htm); a more technical overview can be found in Scott et al. (1995). This crystal-growth technique allows Kyocera to make wafers in unusual geometries without the need for excessive cutting and grinding. Potential manufacturing defects include bubbles or other inhomogenieties near the edge of the wafer; however, inspection did not reveal any defects in the Genesis collectors.

Preliminary SIMS analyses by science team members showed that the sapphire easily met bulk purity criteria for Na, K and Si. The fact that the sapphire is insulating required that it be coated before both SIMS analysis and successful ion-implantation performed for laboratory experiments. However, charging is not an issue for the collector array materials because the solar wind is a plasma, and the amount of surface charging during collection has been calculated to be on the order of 10 V.

3.2.3. *Germanium*

These collectors of semiconductor-grade material were brokered through International Wafer Service. Boules of single-crystal germanium were cut, shaped and polished by their subcontractors. Although they are physically more fragile than silicon, no breakage of collectors was observed during the spacecraft's vibration test.

Germanium was chosen for the arrays primarily because (1) the high mass of germanium eliminates low-mass molecular interferences in trace-element analysis techniques that are based upon mass-spectroscopy, and (2) semiconductor germanium is reputed to be of extremely high bulk purity. However, *in-house* verification of the purity was difficult, and we have little data confirming purity for this material. Accordingly, only ~6% of the wafers in the collector arrays are germanium.

3.2.4. *Specialty laminate materials*

Approximately a quarter of the collectors in the arrays are specialty laminate materials prepared either at Sandia National Laboratory (diamond-like carbon on silicon) or in conjunction with JPL (gold on sapphire; aluminum on sapphire; carbon on cobalt on gold on sapphire). In all cases, the silicon or sapphire substrate is simply there to support the films so that a thick, strong hexagonal wafer can be bolted into the collector arrays; only the film actually collects the solar wind.

Because these materials were made specifically for the Genesis Mission, the Genesis archives contains smaller control samples as well as flight-like wafers. For the diamond-like carbon on silicon, 2 inch diameter control wafers were produced after approximately every third hexagon. For the laminates made under the auspices of JPL, small (~2 cm x 2 cm) witness coupons were included in each of the flight (and flight-like) depositions. These control wafers and witness coupons are archived for future use.

For the aluminum- or gold- on sapphire collectors, there is, at present, effectively no data on surface contamination. However, it was determined by science team members that the interface between the aluminum and sapphire in the (AlOS) is too high for a complete noble gas analysis, as will be discussed later.

3.2.4.1. Diamond-like carbon on silicon. This material is essentially the same as the concentrator target material discussed previously (Section 3.1.1 and Table 3). The only differences are the full-hexagon shape and the fact that all of the annealing steps were performed between layers. Accordingly, there will be some atmospheric contamination in the top 2000 Å.

This material has been added to the collector arrays because it should be retentive and is sufficiently conductive for SIMS analyses even without a coating. The nitrogen contamination from the surface to the outer 1000 Å is about 20% of unconcentrated solar wind. However, if the background is sufficiently uniform, analysis of elemental and isotopic analyses of nitrogen may still be feasible on this material. Development of stepped-combustion extraction techniques would permit noble-gas analyses on this material.

3.2.4.2. *Gold on sapphire*. Gold is a good substrate for SIMS in that molecular ion interferences are negligible. However, gold has the significant disadvantage of backscattering losses during collection, with a resultant isotopic fractionation. The backscatter correction is sufficiently accurate for elemental analysis. But, at present, it is unclear if accuracy of the correction is sufficient for isotopic analysis. For other types of analysis, the gold can be mechanically or chemically removed from the sapphire.

A 2000 Å layer of the highest-purity gold (99.9999%) purchased from ESPI (www.espi-metals.com) was e-beam deposited onto sapphire substrates (Kyocera). Prior to deposition, the substrates were cleaned with solvents, etched in HF, cleaned in an RF-generated O_2-plasma, and placed in the e-beam evaporator within an hour of the O_2-plasma cleaning step. During the pump-down of the e-beam evaporator, the chamber was flushed with argon; then, a heat lamp was turned on to keep the wafers hot overnight. After deposition, the wafers were cooled under vacuum; the chamber was again flushed with argon prior to exposure to air. The chamber used for gold deposition had a better vacuum (~10^{-8} torr) and had been previously used for the evaporation of a more restricted set of elements than that used for aluminum deposition (below).

3.2.4.3. *Aluminum on sapphire*. The intent for making this specialty laminate was to have a thin film of aluminum on a substrate transparent to lasers, to enable laser extraction of noble gases. This material can be used for neon (Meshik et al., 2000) and argon analysis; however, the aluminum-sapphire interface contamination levels appear to be too high for krypton and xenon. we note that silicon on sapphire appears to be an adequate alternate for krypton and xenon, even though the silicon is not sufficiently retentive for neon.

Beyond noble gases, we have no direct measurements of the purity of this material. However, the material was made in the JPL Microdevices Laboratory with bulk purity in mind. The Kyocera substrates were prepared using standard semi-conductor techniques, including cleaning with solvents, etching in HF, final cleaning in an RF-generated O_2-plasma, and then placing the wafers in an e-beam evaporator within an hour of the final cleaning. Then, the vacuum chamber of the e-beam was flushed twice with nitrogen, and the fixture holding the wafers were heated to greater than 220°C overnight and achieved a base pressure of $\sim\leq 5 \times 10^{-7}$. "Gettering" (selective removal of reactive gases, in this case oxygen and nitrogen) with chrome and/or titanium further reduced the base pressure ($<2 \times 10^{-7}$) before the aluminum deposition. 3000 Å of the highest-purity aluminum (99.9999%; Goodfellow) was deposited onto the hot substrates; the e-beam chamber was flushed with nitrogen before removal of the completed collectors in order to mitigate any subsequent oxidation.

3.2.4.4. *Carbon-cobalt-gold on sapphire*. This laminate is part of an attempt to provide suitable material for measuring He and Ne particles with greater than solar-wind energy (SEP). The concept was to have a disposable low-density layer (3500Å carbon) that would stop the main solar wind, and a thick (1µ), dense layer (gold) to collect the solar energetic particles. The 2500 Å cobalt layer was added in order to mark the interface so that we could insure that all of the carbon had been removed. Surface contamination was considered a secondary issue for this material, because the cobalt layer and/or the carbon layer will be removed before analysis in order to separate the SEP's from normal solar wind. There is only one full-hexagon and two half-hexagons (~126 cm^2 of exposed area) on the spacecraft; all are on the B-array (cf., Figure 5), which collects bulk solar wind.

The fabrication process for the gold-on-sapphire portion of the laminate was similar to the fabrication of the gold-on-sapphire collector, except that: (1) the gold used was 99.999% purity, and (2) the gold film was ~1 µ thick. The wafers were then transported (in Fluoroware®, under air) from Pasadena, CA to Buellton, CA where cobalt and carbon were sputter-coated under argon by Thin Film Technology, Inc.

3.2.5. Materials for other collectors

The focus of the Genesis science implementation is on the materials in the concentrator and the collector arrays, because those are the instruments initially designed to attain the highest-priority science objectives. However, there are targets of opportunity for additional collection area (cf., Figures 1 and 2). The top of the array-deployment assembly is exposed to the bulk solar wind whenever the canister is opened. Whenever the collector arrays are deployed, two more areas become exposed to the solar wind. These areas contain a "canister closeout radiator" that prevents direct sunlight from hitting the bottom of the canister; the top of each radiator contains a "side collector". Similarly, the inside of the lid of the sample-return capsule is exposed to the solar wind continuously during collection, so it too is lined with a collector material. The four additional collector materials are: a metallic glass (the array-deployment-assembly cover), gold foil (a side collector riveted to a canister closeout radiator) and a polished aluminum alloy (a side collector comprising the entire top surface of a canister closeout radiator), and molybdenum on platinum (the sample-return canister-lid collectors).

3.2.5.1. *Bulk metallic glass*. This collector material is an amorphous metal. That is, it is from a new class of multi-component metallic compositions in which the nucleation rate of crystalline metal is greatly suppressed when the liquid is quenched rapidly. These compositions have sluggish crystallization kinetics, enabling them to form "bulk metallic glasses" (thick pieces of vitreous alloys) at cooling rates comparable to those used for traditional glass formers, such as the sodium-borosilicates that comprise normal window glass. As such, the ability to make vitreous alloys in a variety of compositions has recently triggered a tremendous amount of research into the properties of these unique materials, with the hope of using them in fields ranging from aero-structures to magnetism.

Bulk metallic glasses exhibit properties advantageous for solar-wind collection (Heber, 2002). First, because there is no crystal lattice, fractionation and loss of solar wind due to diffusion along preferred paths on crystal planes is absent. Similarly, there are no grain boundaries to provide high-diffusion paths. Therefore, the glass retains noble gases well, especially He and Ne. Moreover, it etches very uniformly and is, therefore, excellent for analyses that include high-resolution depth profiling (eg., acid etching ; Heber, 2002). This material was included especially to look at the solar energetic particle (SEP) component in the solar wind.

The Genesis Mission wanted a specialty vitreous-alloy composition in order to minimize the potential for contamination in the worst-case scenario in which a micrometeorite impacted the multi-component metallic-glass collector and "splashed" nearby collectors. The final composition was chosen after researching the retentivity and analyzability of glasses in two composition manifolds: Ti-Zr-Cu-Ni, vitreous alloy 101, and Zr-Nb-Cu-Ni-Al, vitreous alloy 106 (Heber, 2002). The Genesis bulk metallic glass is (in atomic %) is: $Zr_{58.5}Nb_{2.8}Cu_{15.6}Ni_{12.8}Al_{10.3}$.

This new bulk metallic glass was custom-made at the California Institute of Technology. It has been the subject of recent NASA sponsored research via electrostatic levitation processing techniques implemented at the Marshall Space Flight Center (Hays et al., 2001). These measurements, on research grade specimens, have shown that the critical cooling rate required to vitrify the liquid on cooling from the liquid state is 1.75 K/sec. This composition exhibits an excellent thermal stability with respect to crystallization. The difference between the crystallization temperature, T_x , and the glass transition temperature T_g , is $\Delta T=T_x-T_g=100$ K.

3.2.5.2. *Gold foil*. High-purity gold foil provided by the University of Minnesota was attached to one of the side collectors. The foil is of sufficient purity that nitrogen can be measured in the outer 1000 Å of this material. No other purity or cleanliness data exist at present.

3.2.5.3. *Aluminum metal alloy (polished)*. The entire top surface of this radiator is polished to make a collection surface. Thus, the collector is a standard commercial aluminum structural alloy (#6061), is part of a structural unit, and will only be useful if a surface analysis technique is employed. The collection surface was hand-polished by JSC curatorial personnel. Nothing is known at present about the purity or surface cleanliness of this collector; again, it is a structural spacecraft component, not originally intended to be a solar-wind collector. However, it is thought that this "collector of opportunity" should be adequate for noble gas analysis.

3.2.5.4. *Molybdenum on Platinum*. This specialty suite of solar-wind collectors is part of an experiment to measure radionuclides (eg., ^{10}Be (Nishiizumi and Caffee, 2001)) produced in the sun. All of the collectors are (~3000 Å) molybdenum on a platinum substrate. Combined, the collectors fill an area of ~13000 cm^2. As with the laminates in the collector arrays, it is actually the molybdenum film that is collecting solar wind, the platinum is merely a chemically-inert structural support.

The collectors were made under the supervision of the science team in the following way. The platinum-foil substrates (purchased from Goodfellow) were first etched by aqua regia to slightly texture the surface in order to modify their optical properties, so that the expected temperature of the foils (when exposed directly to the sun) would be within the spacecraft's engineering tolerance. Then, the foils were coated at a commercial vendor (Thin Film Technology, Inc) during a single deposition by e-beam evaporating molybdenum. These pieces were hand-cut to shape, sewn onto the multi-layered insulation (MLI blanketing) that was mounted over the parachute deck (inside the lid of the spacecraft's sample-return capsule) at Lockheed Martin Astronautics (LMA). Again, molybdenum was chosen in part for engineering reasons: it's solar-thermal properties indicated it would not overheat the parachute deck. It was also chosen because screening tests showed that it should retain ^{10}Be at the high collection temperatures (over 250 °C) for the two years of collection. Most importantly, solar-flare particles produce negligible amounts of ^{10}Be and ^{14}C in molybdenum, so that the analytical (^{10}Be and ^{14}C) background will not increase with exposure time. Unfortunately, because molybdenum makes a thermodynamically-stable carbide, during the e-beam evaporation it tended to "getter" carbon from the atmosphere of the large vacuum chamber, thus incorporating it into the molybdenum film. The Genesis science team is currently checking to see if the ^{14}C background is low enough to also measure that isotope.

4. Curation, Allocation and Early Science Return from Genesis Solar-wind Collection Materials.

A major goal of Genesis is to provide a reservoir of materials for the scientific community during the 21st Century. Accordingly, the majority of the materials used to collect solar wind on Genesis will be archived at the curatorial facility of the Johnson Space Center. Samples will be allocated to researchers based on recommendations from a Sample Allocation Committee, as per the deep heritage going back to returned Apollo samples. It is planned that the opportunity to analyze these samples will be opened to the international planetary materials community within four months of recovery. No special privileges are reserved for the principal investigator or co-investigators, except for the Early Science Return portion of the mission.

The Early Science Return includes a set of four experiments to be performed by members of the Genesis science team upon retrieval of the sample return capsule: N-isotopes, noble-gas isotopes in bulk solar wind, bulk C-isotopes, and the search for radioactive nuclei. The results of these studies are scheduled for publication in the open literature within 1.5 years of recovery of the Genesis materials. However, these studies will not include any material from the concentrator and will use a small amount of the material from the collector arrays.

Accordingly, all the materials in the concentrator and the vast majority of the wafers from the collector arrays will be available to the planetary materials community at large. Further details will be given in the Genesis Mission overview in this issue (Burnett et al., 2002).

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Figure Captions

Figure 1. Genesis sample-return capsule during thermal-vacuum testing. In this case, only the bulk solar wind collectors are deployed; arrays for collecting low-speed, high-speed, and coronal mass ejection (CME) solar wind are stowed below the bulk solar wind collection array. Symbols: (a) stack of deployable collector arrays -- only the top of the stack, a bulk solar wind collector, is visible; (b) concentrator target holder – actual target is located just below the sunshade; (c) canister-cover collector array; (d) metallic glass collector covering the top of the array-deployment mechanism; (e) gold foil mounted on a side collector; (f) polished aluminum side collector; (g) molybdenum-coated foils in the lid of the sample-return capsule.

Figure 2. Genesis sample-return capsule, opened during testing after final assembly in the Class 10 clean room in the Johnson Space Center Curatorial Facility. The stack of collector arrays can be seen in side-view in Figure 2. Collector-array materials are installed separately as individual hexagonal (or half-hexagon) wafers. Quality-assurance personnel shown for scale. Symbols: as in Figure 1.

Figure 3. Cartoon of the Genesis spacecraft in collection configuration. Symbols: as in Figure 1.

Figure 4. Periodic table of the elements giving an integrated purity overview. We have not yet found an element that is not potentially analyzable in at least one of the materials. White lettering on gray background: elements known to have collector materials of bulk purity sufficient for elemental analysis at the time of the Genesis launch. Black lettering on white background: it is not yet known what collector material(s), if any, will be used for that element.

Figure 5. Distribution of collector materials located in the Genesis collector arrays, in percent. Notice that each array contains between ~50% and 60% silicon. Materials designations: (CZ) Czochralski-grown silicon; (FZ) Float-zone silicon; (SOS) silicon on sapphire; (Ge) germanium; (DOSi) diamond-like carbon on silicon; (SAP) sapphire; (AlOS) aluminum on sapphire; (AuOS) gold on sapphire; (CCoAuOS) carbon on cobalt on gold on sapphire. Collector array designations (Bold Capital letters): (B+C) the two collector arrays that capture the bulk solar wind, where B is the top of the stack of collector arrays and C is the inside of the canister cover; (E) collector array capturing the solar wind from coronal mass ejections; (L) low-speed solar wind collector array; (H) high-speed solar wind collector array.

Table 1. Suite of materials chosen to be solar-wind collectors, their position in the Genesis sample-return canister, and their intended use. Designated collector materials may eventually be useful for other elements. Moreover, all relevant portions of the sample return capsule will be archived for future solar-wind, micrometeorite, and other studies, as per the Apollo tradition. Position (symbol): collector arrays (CA); concentrator target (CT); array-deployment cover (ADC); side-collector (SC); sample-return capsule lid (SRCL). A summary of the suite of materials in each array (in percent) is given in Fig. 5.

Collector Material	Wafer/collector type	Position	Target elements/Intended use
^{13}C Diamond*	Thick film: isotopically enriched diamond grown on commercial product	CT	O, N, F .
Silicon carbide	Undoped ("intrinsic") commercial product	CT	O,N, Li, Be, B, F
Diamond-like carbon*	Thick film: Diamond-like carbon on silicon*	CA, CT	N, noble gas isotopes
Aluminum	Laminate: aluminum on sapphire**	CA	Noble gases
Silicon	Czochralski-grown silicon	CA	Same as FZ, except for C and O. CZ is used because it can be obtained with very clean surfaces.
	Float-zone silicon	CA	FZ silicon is exceptionally pure. As far as we know, all elements except those which diffuse rapidly (Fe, alkalis) could be analyzed.
	Silicon on sapphire	CA	C; epitaxial-silicon layer potentially simplifies extraction.
Germanium		CA	No detectable impurities. Ge complements Si for SIMS analysis because of greatly reduced molecular interferences.
Gold**	Laminate: Gold on sapphire**	CA	N, Fe, alkalis.
Sapphire		CA	We are unable to detect any impurities. Potentially useful for alkalis
Carbon+Cobalt+gold on sapphire**	Laminate separating ions of differing energies	CA	Layered film; SEP-particles
Bulk metallic glass*		ADC	Noble gases; SEP-particles
Aluminum alloy	polished Al6061	SC	Bulk solar wind
Gold	Gold foil	SC	N, bulk solar wind
Molybdenum**	Laminate: Molybdenum on Platinum**	SRCL	Radionuclides (e.g., ^{10}Be, ^{14}C)

* indicates a specialty (bulk) material;

** indicates a specialty thin film(s) on a commercial product; unmarked indicates materials commercially available, although the shape was a special order.

Table 2. Ambient collector temperatures for representative materials under solar-exposure conditions. These temperatures were measured during the thermal-vacuum test on the engineering-model and depend on the optical properties of the material. Since the concentrator-target materials face away from the sun, their ambient temperature is determined by the optical properties of the fixture.

Concentrator Target Materials		Temperature (°C)
	Silicon carbide	140
	^{13}C diamond	140
	Diamond-like carbon on silicon	140
Collector array materials		
	Float-zone silicon	141
	Czochralski-grown silicon	156
	Sapphire	56
	Aluminum on sapphire	130
	Gold on sapphire	140
	Germanium	162
Sample-return capsule Lid foil	Molybdenum on platinum	$\leq$ 250

Table 3. A comparison of the purity and surface-contamination of concentrator target materials with respect to the Genesis science requirements for the top two Genesis mission priorities: measurement of oxygen and nitrogen isotopes.

Material	Purity (% of expected solar wind)		Surface Contamination (atoms/cm^2)	
	O	N	O	N
Silicon carbide	0.1	0.5	8e14	<5e14
^{13}C diamond	<1	8	3e15	<5e14
Sandia diamond-like carbon	2	1	3e15	<5e14
Science requirement*	10	10	1e15	1e15

*the requirement for surface contamination is defined at the time of analysis and, therefore, allows for post-flight cleaning if necessary.

Figure 1.

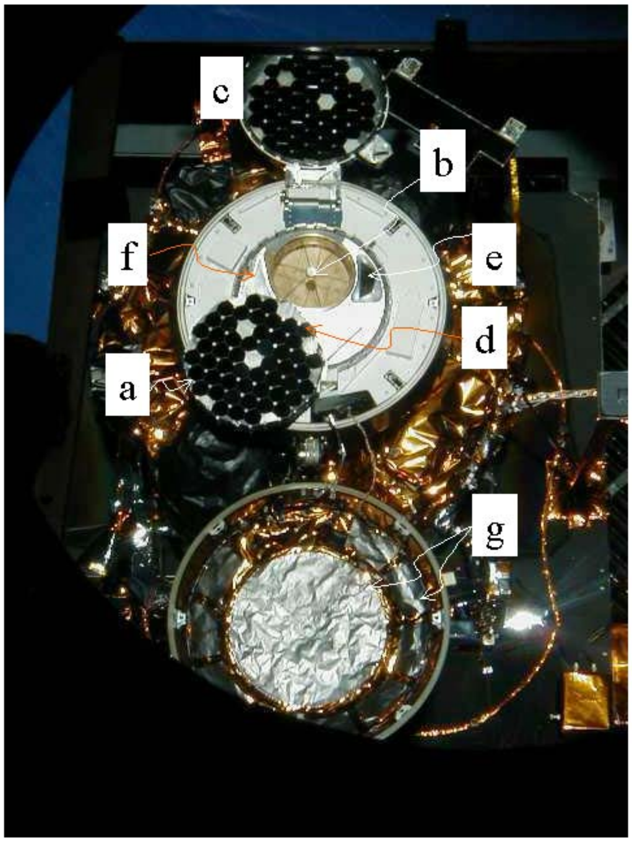


Figure 2

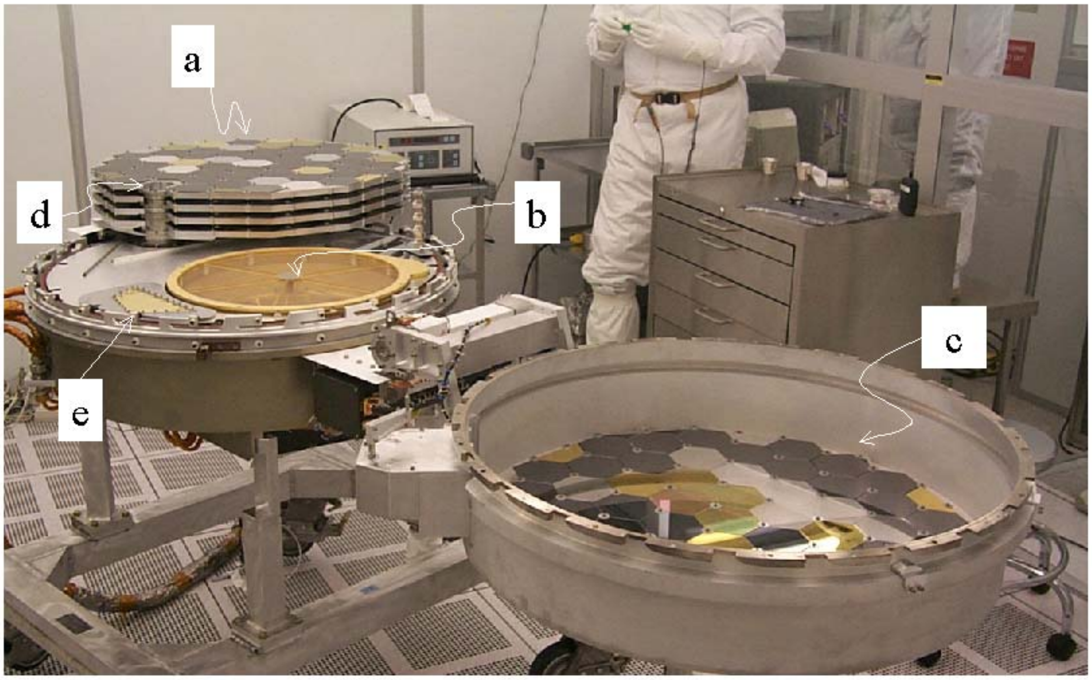
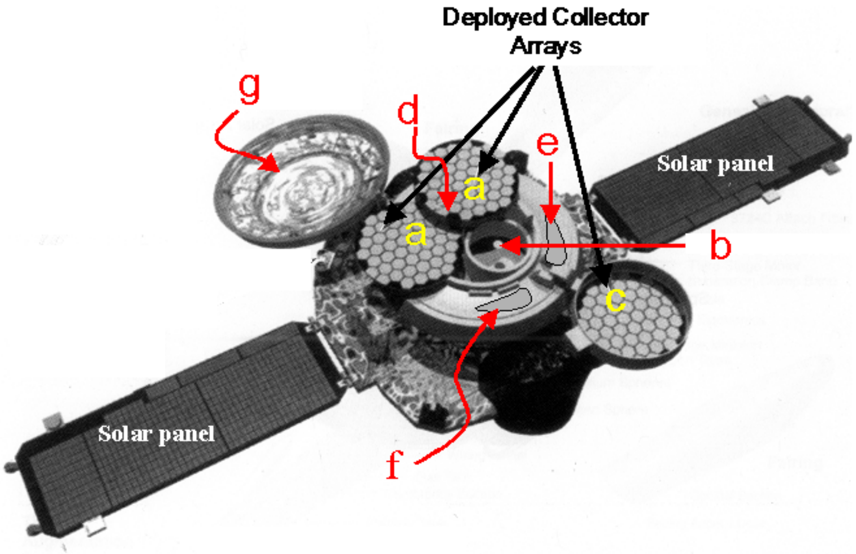
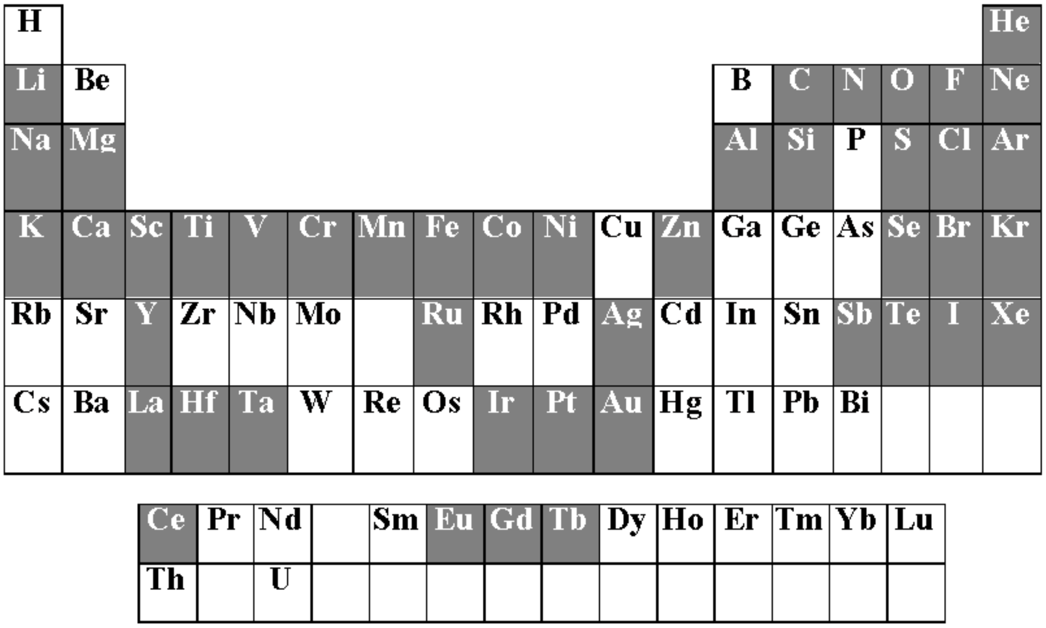


Figure 3



Deployed Collector Arrays
g
d
e
a
a
b
c
f
Solar panel
Solar panel

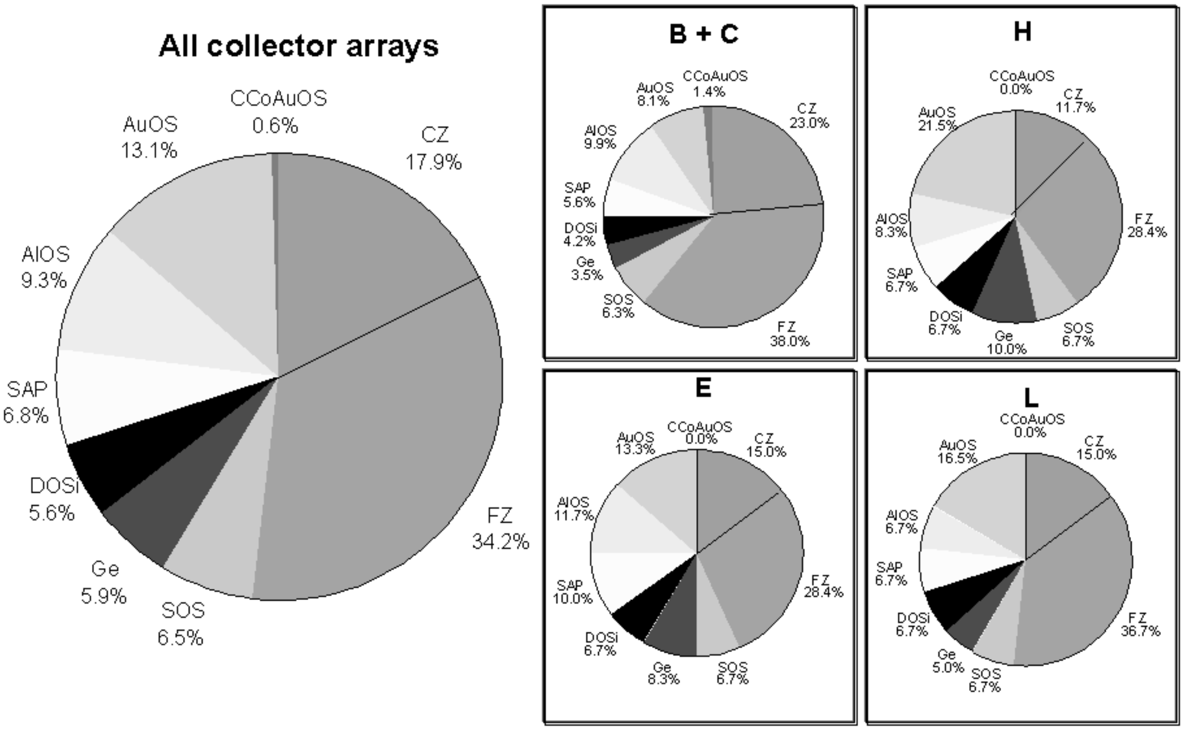
Figure 4



H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo		Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi			

Ce	Pr	Nd		Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th		U											

Figure 5.


All collector arrays
CCoAuOS 0.6%
CZ 17.9%
FZ 34.2%
SOS 6.5%
Ge 5.9%
DOSi 5.6%
SAP 6.8%
AlOS 9.3%
AuOS 13.1%
B + C
CCoAuOS 1.4%
CZ 23.0%
FZ 38.0%
SOS 6.3%
Ge 3.5%
DOSi 4.2%
SAP 5.6%
AlOS 9.9%
AuOS 8.1%
H
CCoAuOS 0.0%
CZ 11.7%
FZ 28.4%
SOS 6.7%
Ge 10.0%
DOSi 6.7%
SAP 6.7%
AlOS 8.3%
AuOS 21.5%
E
CCoAuOS 0.0%
CZ 15.0%
FZ 28.4%
SOS 6.7%
Ge 8.3%
DOSi 6.7%
SAP 10.0%
AlOS 11.7%
AuOS 13.3%
L
CCoAuOS 0.0%
CZ 15.0%
FZ 36.7%
SOS 6.7%
Ge 5.0%
DOSi 6.7%
SAP 6.7%
AlOS 6.7%
AuOS 16.5%