Cleaning Genesis Sample Return Canister for Flight: Lessons for Planetary Sample Return

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SECTION 1: INTRODUCTION

1.1 Lessons Learned Summary

Sample return missions require chemical contamination to be minimized and potential sources of contamination to be documented and preserved for future use. Genesis focused on and successfully accomplished the following:

- Early involvement provided input to mission design:
  a) cleanable materials and cleanable design
  b) mission operation parameters to minimize contamination during flight
- Established contamination control authority at a high level and developed knowledge and respect for contamination control across all institutions at the working level.
- Provided state-of-the-art spacecraft assembly cleanroom facilities for science canister assembly and function testing. Both particulate and airborne molecular contamination was minimized.
- Using ultrapure water, cleaned spacecraft components to a very high level. Stainless steel components were cleaned to carbon monolayer levels (10^{15} carbon atoms/cm^2)
- Established long-term curation facility

Lessons learned and areas for improvement, include:

- Bare aluminum is not a cleanable surface and should not be used for components requiring extreme levels of cleanliness. The problem is formation of oxides during rigorous cleaning.
- Representative coupons of relevant spacecraft components (cut from the same block at the same time with identical surface finish and cleaning history) should be acquired, documented and preserved. Genesis experience suggests that creation of these coupons would be facilitated by specification on the engineering component drawings.
- Component handling history is critical for interpretation of analytical results on returned samples. This set of relevant documents is not the same as typical documentation for one-way missions and does include data from several institutions, which need to be unified. Dedicated resources need to br provided for acquiring and archiving appropriate documents in one location with easy access for decades.
- Dedicated, knowledgeable contamination control oversight should be provided at sites of fabrication and integration. Numerous excellent Genesis chemists and analytical facilities participated in the contamination oversight; however, additional oversight at fabrication sites would have been helpful.

1.2 Background

Curation of extraterrestrial samples for planetary science encompasses 6 important elements: keeping samples pure, preserving accurate information about samples, examining and classifying samples, sharing information on new samples, and preparing and distributing samples for research and education. At Johnson Space Center, much experience has been gained during curation of Moon rocks, Antarctic meteorites, and interplanetary dust collected from the stratosphere. Building on this curation expertise, new laboratories were built to prepare the Genesis Mission payload for launch in keeping with curation responsibilities, which begin in the early planning stages of any sample return mission.

Genesis will be the first NASA mission to return extraterrestrial samples to earth since Apollo crews brought back Moon rocks and soils. The goal of this mission is to place solar wind collectors of various materials at the earth-sun L1 position for two years to capture solar wind nuclei by implantation. Then, the spacecraft will return the collectors to Earth for laboratory analysis. Johnson Space Center (JSC) responsibilities were three-fold: a) contamination control; b) payload cleaning and integration; and, c) solar wind sample curation. The cleaning effort of the payload (the canister containing the collector surfaces) is addressed in this report (Fig. 1-1). The Genesis spacecraft also carried some molybdenum-coated platinum foils for the collection of radionuclides. These are installed outside of the clean canister and are not addressed herein.

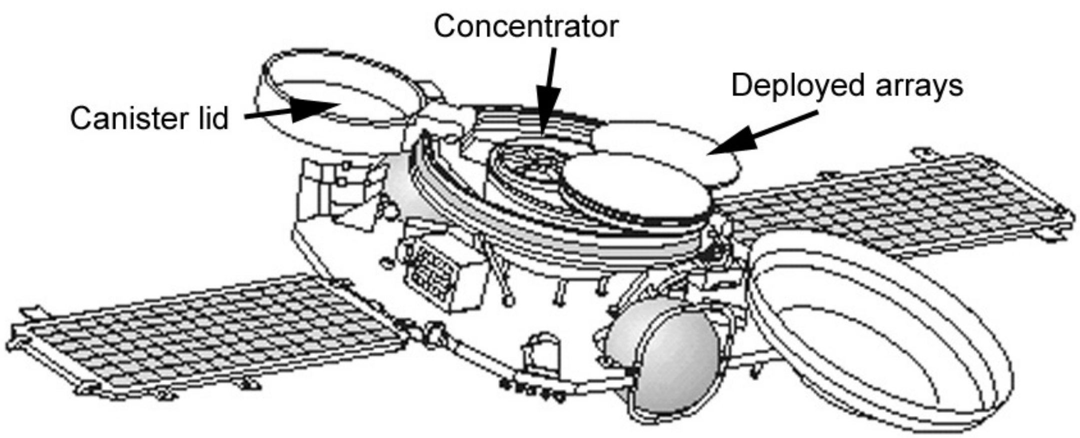


Fig. 1-1. *The payload canister, lid open showing arrays and concentrator, spacecraft aeroshell.*

The payload canister, a 16x30 inch "tuna can" shape, is constructed of aluminum and opens like a clam shell. The canister contents are relatively simple chemically and designed for cleanability (Fig. 1-2, 1-3). Inside are 5 arrays onto which various materials cut into hexagonal shapes are attached. A mechanism to deploy the arrays around a pivot point is sealed such that no parts of the motor are exposed to the interior of the canister.

An electrostatic focusing grid is used to concentrate solar wind low mass nuclei. Two canister interior engineering thermal shields were modified to also serve as solar wind collectors.

The goal of the mission is to sample solar wind for the entire periodic table[1], and, while

[1] Genesis Discovery Mission Implementation Plan: Science, Materials and Analysis (1998)

protons and certain low atomic number elements are abundant, others are scarce. Even extremely low levels of terrestrial contaminants could obscure the solar measurements. Therefore, contamination control is critical for Genesis, resulting in development of new cleaning and verification techniques and payload assembly in Class 10 environment.

Fig. 1-2. *Genesis canister opening*.

The collector surface cleanliness requirements vary by element as a portion of the expected solar wind flux and the requirements range from contaminant atoms less than a ppm to less than 10^{-9} ppm. Specific limits of contamination on the collector surface at the time of analysis by carbon, oxygen and nitrogen are set at less than 10^{15} atoms/cm^2 (roughly one monolayer, as measured under vacuum at 200°C). The surfaces of the canister interior need to be clean with respect to elements easily mobilized, for those atoms could be transferred to collector surfaces as gas or plasma. Micrometeorite impacts play a role in mobilizing material.

Because of these stringent contamination control requirements, many lessons learned in the preparation of the Genesis payload for flight are applicable to future planetary samples return missions, particularly those focused on clean sample handling.

1.3 Rationale and Scope

The Genesis Mission contamination control strategy[2,3] (CCP) can be summarized as "start clean, keep it clean". In detail, the 4 components are:

1. Start with clean collectors, mount into clean canister
2. Minimize surface contamination until sample is received for analysis:
   a) Purge clean canister with pure nitrogen
   b) Keep canister sealed after leaving cleanroom until on station at L1, seal for return to Earth (the "seal" is not hermetic, but closure under positive pressure nitrogen purge prior to launch and after recovery, plus pressure equalization through a filter/sorbant for cruise and re-entry).
   c) On-station thrusters and canister design to eliminate line-of-sight exposure of collectors to unacceptable materials
3. Clean surface prior to analysis, if necessary
4. Use analytical tools that provide depth resolution

[2] Stansbery, E. K. (1998) Genesis Mission Contamination Control Plan. JSC-28272, Johnson Space Center, Houston, TX
[3] Genesis Spacecraft Program Contamination Control Implementation Plan (1999) GN-52400-100

The lessons learned from Genesis applied to other planetary sample return missions should be summarized as "get it clean, keep it clean", for cleaning process development was also a big part of Genesis preparation. Much was learned, not only of technology but also interactions among curators, science team, design engineers and mission planners.

The main portion of this document is dedicated to a technical description of the processes for cleaning hardware, verification of cleanliness and establishing clean assembly environments. However, achievement of the cleanliness goals depended greatly on teamwork among various disciplines.

Fig. 1-3. *Fully open canister revealing deployed arrays and concentrator (in center).*

SECTION 2: OVERVIEW OF CLEAN MISSION DESIGN, CLEANABLE HARDWARE AND MATERIALS

Genesis' extreme cleanliness requirement, as with any future Mars sample return mission looking for evidence of life, is driven by science at the analytical detection limits. Therefore cleanliness was addressed early in the mission planning and shaped both the mission flight profile and the hardware design. The approach presented in the Genesis Discovery Mission Contamination Control Plan (1998):

> *"The strategy to maintaining adequate contamination control to meet science requirements is to start with clean collector materials before launch and keep them clean throughout the mission. Ultra-clean collectors will be sealed inside a clean science canister at JSC. This canister will not be opened until the spacecraft arrives on-station at L1 to begin collecting solar material; thus, no additional cleaning requirements are placed on the assembly and integration of the spacecraft and Sample Reentry Capsule (SRC). The science canister will be purged with clean, dry nitrogen after sealing at JSC until Launch Vehicle fairing closeout. The selection of materials and spacecraft design, as well as flight operations, are designed to minimize contamination of the collectors during the flight portion of the mission."*

The importance of integrating contamination control requirements into the sample acquisition hardware design is highly applicable to sample return missions, and Genesis did this well. From the very beginning, detailed attention was paid to clean sample handling of returned specimens and long-term curation; thus, setting an example for future sample returns.

2.1 Mission Design and Flight Operations

Four primary sources of potential collector surface contamination were identified early: earth-bound handling of collectors and canister, outgassing from spacecraft components during flight, micrometeoroid impacts, and propellant from station-keeping thrusters (Fig. 2-1). Although this document mainly addresses contamination control for ground handling operations, significant restrictions were placed on spacecraft design and flight operations.

The mission was designed to minimize spacecraft outgassing contamination by enclosing collectors in a clean canister and keeping the canister sealed until the collectors were on-station at L1. The rationale was to allow the spacecraft components to outgas in the vacuum of space for 2 months before the canister was opened.

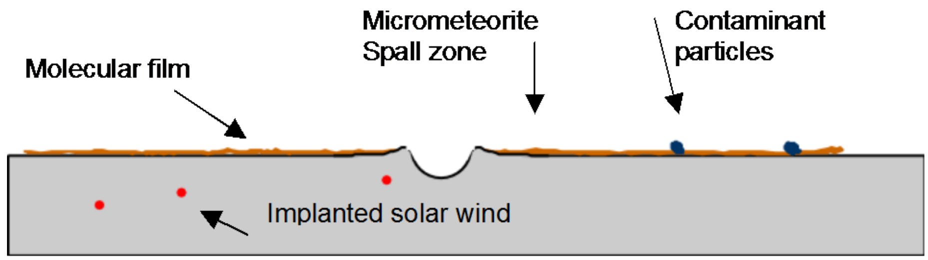


Fig. 2-1. *Types of potential surface contamination acquired during flight include particles and molecular films which can be mobilized by micrometeorite impacts. Implanted solar wind nuclei are expected to be up to 100 nm in the subsurface.*

A SPACE II contamination model was used to assess the return flux self-scattering contamination, which demonstrated that contamination was constrained to depths of <1 Å. Micrometeoroid flux modeling followed by experimental impact studies resulted in design criteria that there would be no line-of-sight between spacecraft components and the solar wind collection surfaces. This was to minimize contamination from mobilization of material by micrometeorite impacts. The station-keeping thrusters were configured to comply with the no line-of-sight rule and modeling of propellant plume distribution verified that contamination from this hydrazine was acceptable.

2.2 Start with Clean Collectors

At the high levels of cleanliness Genesis required, direct measurement of collector surfaces would degrade the cleanliness, so the production process for cleaning the silicon collectors was verified (Fig. 2-2).

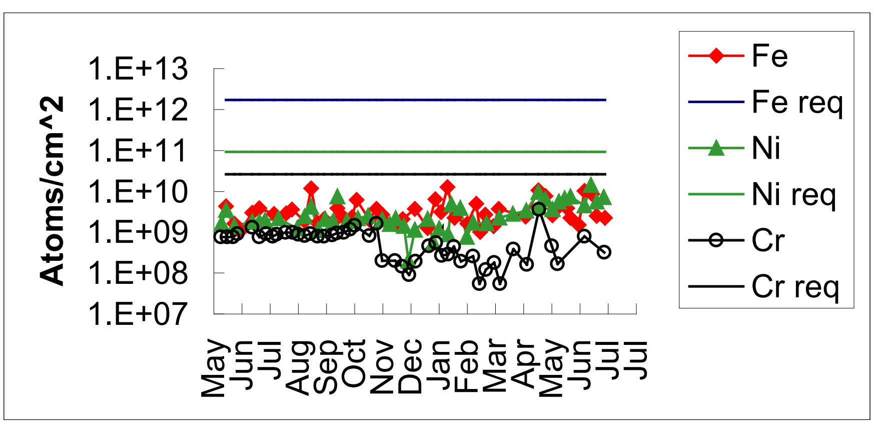


Fig. 2-2. *Example of process cleanliness verification for surface of silicon collectors showing that iron, nickel and chromium are well below the limits of 10^{11} to 10^{12} atoms per cm^2.*

2.3 Keep Collectors Clean Inside of a Sealed Canister

The clean collectors were mounted inside of a clean canister which was "sealed" inside of a Class 10 cleanroom. Since a vacuum seal was not practical, the implementation of "sealed" was accomplished by means of a particulate filter/molecular sieve pressure equalizer and a high purity nitrogen purge to maintain positive pressure (ΔP = 0.1 psi) within the canister. The purge was maintained throughout these activities:

a) the transport from Houston to Denver
b) integration into the spacecraft in Denver
c) functional testing of the spacecraft in Denver
d) transport to KSC
e) launch preparation in Payload Hazardous Processing Facility
f) on the launch pad until launch vehicle fairing close-out

Brief interruptions of purge were allowed for specified payload transitions during spacecraft processing. One impact of the "stay sealed" requirement was that the payload function tests (completed fully in the Class 10 cleanroom environment at Johnson Space Center) could not be repeated after integration into the spacecraft in the Class 100,000 integration facility by opening the canister. Therefore, the payload design incorporated a function testing subset that could be verified without opening the canister.

2.3.1 Particulate Filter/Molecular Sieve

The capacities for the particulate filter/molecular sieve were based on ability to prevent contamination from re-entry ablation and from environmental air pressure changes during the year-long period of integration with the spacecraft and the Delta rocket.

2.3.1 High Purity Nitrogen Purge

Table 2-1. Nitrogen Purity (achieved by point-of-use filtration/purification).

Contaminant	*Genesis Requirement*
Oxygen	<10 ppb
Total hydrocarbons	>5 ppb
Carbon monoxide	<10 ppb
Carbon dioxide	<10 ppb
Water	<10 ppb
Hydrogen	<10 ppb
Particles ≥0.02 µm diameter	<20

2.4 Canister Cleanable Design Features

2.4.1 Mechanisms- Mechanisms produce particles and require lubricants to function; therefore, moving parts are minimized in any clean environment. The Genesis canister had only two moving functions inside the canister: the array deployment and the array latch. The array deployment mechanism was external to the canister, with only the pivot rod extending into the canister through a special low offgassing axial seal. The array latch mechanism was external to the canister with linear motion effected through a metal bellows. The canister lid hinge and locking ring were entirely external to the canister.

2.4.2 Machined Shapes- Blind holes, threaded holes and sharp corners are harder to clean; therefore, these were minimized where possible. However, because of the large number of individual collectors to be mounted, several hundred screws were installed into blind holes. Cleaning these blind, threaded holes required major rework of the array frames (see section 4.6.2).

2.5 Cleanable materials

Special material restrictions for Genesis were due to chemical species being incompatible with science objectives, and these restrictions were levied upon the basic aerospace engineering guidelines for lower mass materials, corrosion resistant materials and stress corrosion cracking resistant materials for use in space. The requirements for materials that could be cleaned to high levels were not well defined during the design phase of Genesis. Low particle generation by abrasion, smooth surfaces and low offgassing qualities were recognized as desirable for cleanability; however, compatibility with the chosen cleaning solvent, ultrapure water, was not fully appreciated.

2.5.1 Volatiles - For science reasons, volatile materials were not permitted inside the canister. Elastomers, plastics, lubricants, and staking compounds for fasteners are typically outgassing compounds and are affected by this restriction. As a practical matter not all of the compounds can be eliminated entirely. The strategy followed was: eliminate use where possible, identify and use only low outgassing species, use smallest amount possible. Fluorine-containing compounds are particularly incompatible with science requirements. The non-metal materials used in the Genesis canister are listed in the Appendix.

2.5.2 Metals - The structural material of the canister and array frames is aluminum, an aerospace staple for structures. However, not wishing to add contaminants from anodizing or other finishing processes, the aluminum parts were not finished after machining. Two significant problems resulted from this decision, which are addressed in Section 4 Cleaning Efficacy. One problem was the reactivity of the native oxide aluminum with ultrapure water and the other concerned the residue from the electric discharge machining (EDM) process. Fasteners were typically stainless steel, the cleaning of which was straightforward and successful. The metal materials used in Genesis canister are listed in the Appendix.

SECTION 3: MAINTAINING A CLEAN ENVIRONMENT

Early in the mission planning a decision was made to clean and assemble the payload canister under Class 10 cleanroom conditions at Johnson Space Center. The cleaning process and the payload assembly would take place under exposure to particle-free room air, as opposed to within a glovebox nitrogen environment (which was deemed impractical for canister assembly and collector installation and which is difficult to keep particle-free).

3.1 Airborne Particle Control

Two connected cleanrooms were built to prepare the payload. One 10 ft x 20 ft room was used for cleaning the hardware with ultrapure water (UPW) and another 15 ft x 15 ft room was reserved only for assembly and curation of solar wind samples (Fig. 3-1).

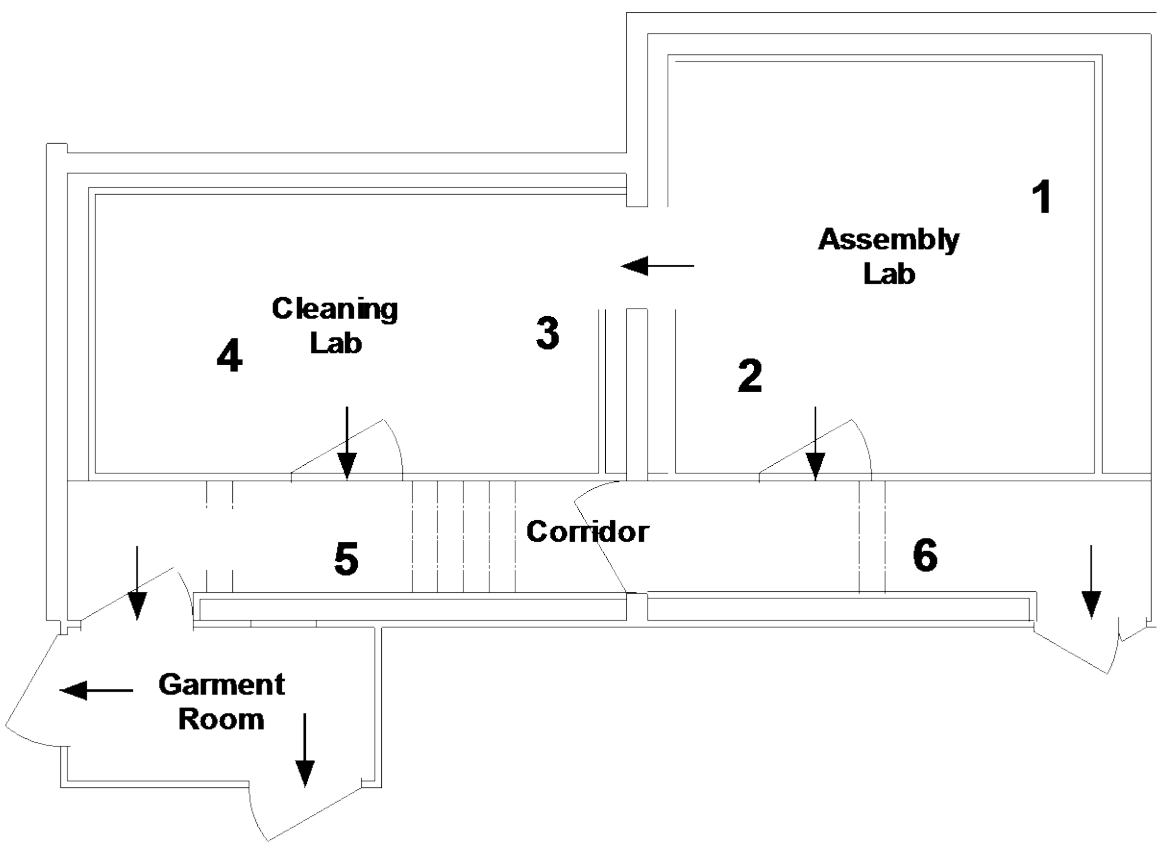
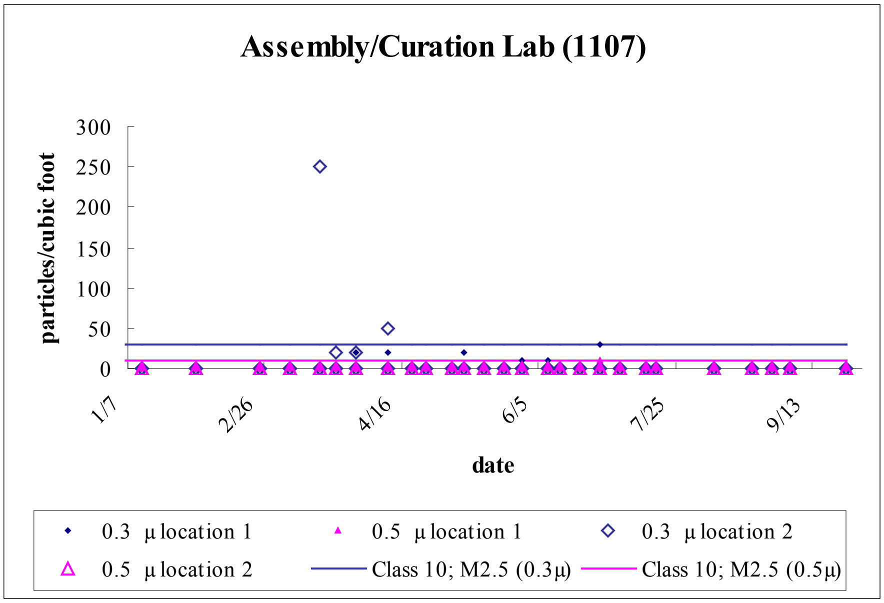


Fig. 3-1. *Genesis Class 10 Cleaning Lab and Assembly Lab. Air pressure gradients are shown with arrows. Particle monitoring stations are numbered. The as-built certification in February 2000 for the Cleaning Lab and the Assembly Lab was Class 1 and for the corridor Class 100.*



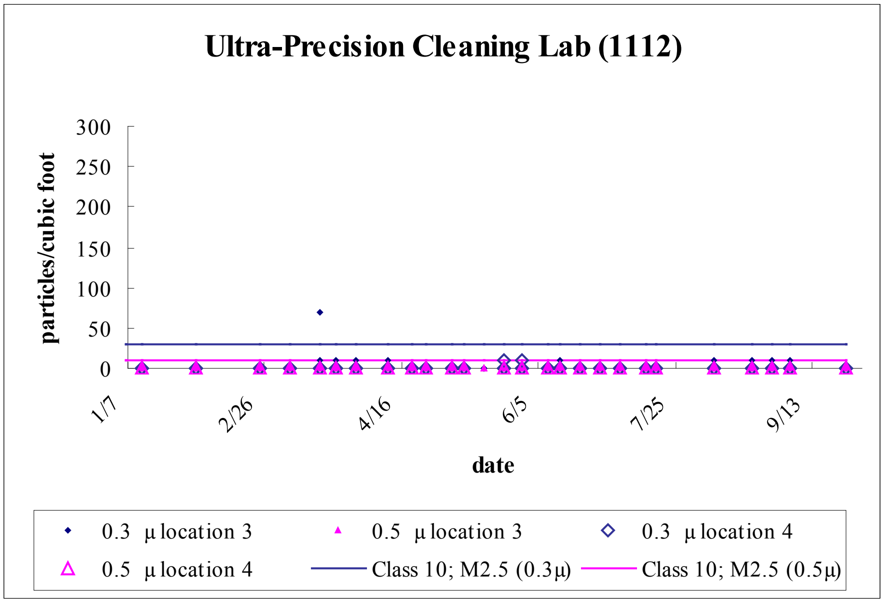


Fig. 3-2. *Weekly "at-rest" air particle monitoring at stations depicted in Fig. 3-1 during year 2000 cleaning and assembly operations. The Assembly/Curation Lab room had two, unexplained, single-point excursions above Class 10, while the Ultra-Precision Cleaning Lab had one.*

Fig. 3-3. *View of Cleaning Lab from corridor.*

The cleanrooms, built to IES standards (Institute for Environmental Sciences), function by sweeping the room ceiling to floor with laminar flow (100 fpm) of ULPA filtered air. The ceiling has total coverage with ULPA filters and the floor is 100% perforated flooring. These environments are good at maintaining a low particulate environment, when operated properly by trained personnel. Proper operation requires vigilance concerning the materials that are allowed into the cleanroom. The JSC curation team has extensive experience in operation of laminar flow cleanrooms, thus, maintaining a low airborne particle environment for Genesis cleaning and assembly was accomplished. Figure 3-2 shows the "at rest" weekly particle monitoring for Assembly/Curation Lab and the Ultra-Precision Cleaning Lab. Airborne particulates are a function of number of people and activity in the cleanroom. During assembly of the canister, airborne particles were counted continually by a sensor which was placed below the assembly activity (Fig. 3.4). Figure 3-5 shows daily averages for sampling by this sensor taken during periods of activity. Particle counts directly related to specific assembly activities are discussed in Section 5, clean assembly.

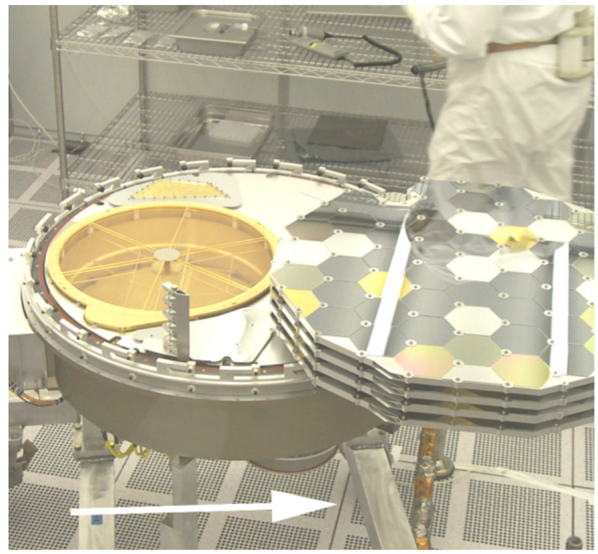


Fig. 3-4. *Particles were monitored continuously during re-assembly of canister. The sensor was located beneath the assembly workstation.*

3.2 Airborne Molecular Contamination Assessment and Control

Historically, airborne molecular contamination has not been assessed in typical aerospace cleanrooms. However, knowing that monolayer organic contamination was a concern for Genesis, attention was paid, during construction of the Genesis cleanroom suite, to choosing the lowest off-gassing paints and sealants practicable and to using minimal amounts of these materials. In addition, carbon sorbant filtration was added to the air handler. Cleanroom air was sampled in three different ways: Sorbant tube, witness wafer, and canister. These techniques each provide different, but complementary insight into the nature of the airborne molecular contamination (AMC) within the room.

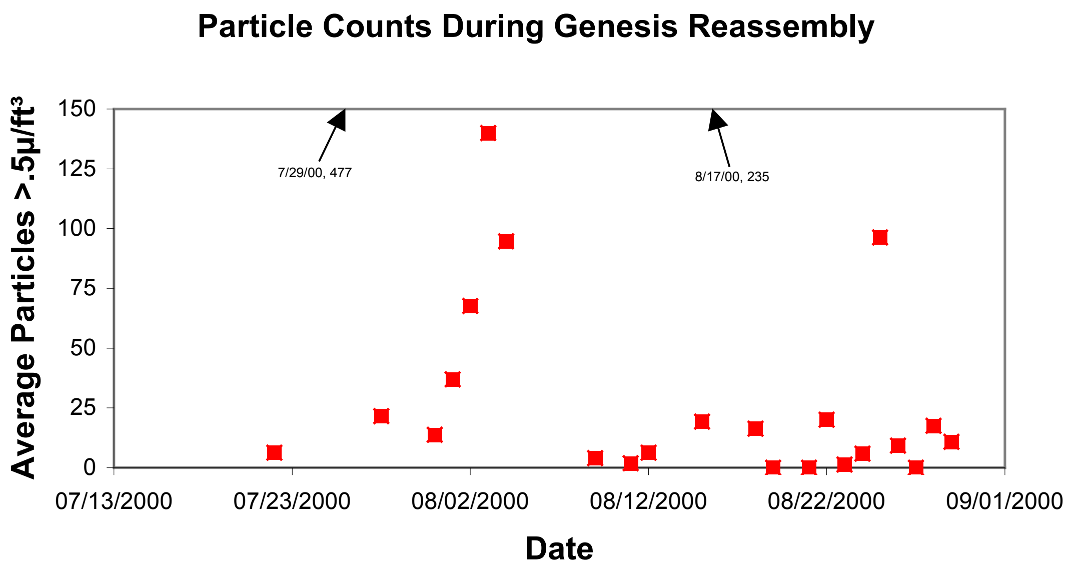


Fig. 3-5. ***Daily average particle counts during active assembly operations from sensor located directly downstream from canister (location shown in Fig. 3-4).***

3.2.1 Sorbant Tube Sampling

The sorbant tube sampling technique is a dynamic method that uses a pump to pull a very large volume of air through a tube containing a sorbant material like Tenax® or Carbosieve®. In theory, this technique has the advantage of having an almost unlimited detection capability for species C6 (hydrocarbon molecules possessing at least six carbon atoms) and larger, realized by sampling for longer times. In reality there are problems that prevent this, most notably the preferential displacement of larger species for smaller species when the number of bound active sites nears its saturation limit. A NASA document exists on this type of sampling in cleanroom environments[1].

[1] Sheldon, L.S.; Keever, J. "Collection and Analysis of NASA Clean Room Air Samples" NASA CR-3947 (1985)

3.2.2 Witness Wafer Sampling

This is a passive sampling technique that involves placing an ultra-clean silicon wafer in the room for some pre-determined amount of time. Volatile condensable material (VCM) accumulates on the surface over a period of time. This technique is good for determining what the build-up of VCM contamination on surfaces is like over a period of time, but it assumes that the silicon is representative of all critical surfaces in the cleanroom and that the affinity of all surfaces for the contamination is uniform. This technique is primarily effective only for looking at high-boiling, "condensable" molecules and obtaining a qualitative determination of the VCM flux on surfaces.

3.2.3 Canister Sampling

The canister sampling technique involves collection of air in an evacuated SUMMA canister of known volume[2]. SUMMA canisters are special stainless steel canisters that have been electropolished or coated on their interior. This type of sampling permits a "live" collection of airborne molecular contaminates C1 and larger. While this sampling technique is, in theory, the most quantitative and representative of the room air, it is generally to difficult to observe any of the medium to high boiling contamination, which tend to be lower in concentration.

3.2.4 Analysis

Analysis of samples was carried out by a technique known as gas chromatography-mass spectrometry (GC/MS). This technique permits a mixture of compounds to be separated (via chromatography) and identified by their corresponding mass peaks (via mass spectrometry). For both the sorbant tube samples and the witness wafer samples the additional step of thermal desorption is needed to introduce species into the GC/MS.

3.2.5 Assessment of Airborne Molecular Contamination Load

Contaminants fell into 5 broad categories: 1) siloxanes, 2) plasticizers, 3) solvent vapors, 4) human metabolic products, and 5) personal hygiene products[3]. With the exception of the cyclic siloxanes, almost all of the AMC collected via the witness wafer and sorbant tube techniques was off-gassed plasticizer or plasticizer derivatives. The cyclic siloxanes are off-gassed from silicones as decomposition products and the primary source of these are HEPA filters.

The active silicon witness wafer was a good measure of the species likely to adhere to room-exposed surfaces, especially for Genesis since many solar wind collectors are silicon wafers.[4]

Six months after completion of the cleanrooms, the molecular organic load measured on silicon wafers was 20 ng/cm^2 per 24-hour period. This baseline remained constant throughout Genesis canister assembly, although the contribution from siloxanes became proportionately less. The bulk of the load is from plasticizers with a siloxane/plasticizer ratio decreasing from 0.4 to less than 0.04 during the 9 months of Genesis canister cleaning and assembly. Human metabolic products and cleaning solvents (isopropanol, ethanol) were best measured by direct air sampling[5] and vary on short time scales.

Typical molecular species found in the Genesis laboratory are shown in Table 3-1. IPA was the standard Genesis organic solvent for cleaning.

In addition to HEPA filters, sources for these trace organic species include adhesives, PVC tubing and piping, plastic containers, laminate flooring, electronics, cleaning solvents (IPA), personal hygiene products ("soaps", moisturizers, deodorants), and metabolic products. In preparation for return of Genesis samples, an ongoing effort to further reduce the organic airborne load is underway and has

[2] Hsu, J.P.; Miller, G.; Moran, Victor, III "Analytical Method for Determination of Trace Organics in Gas Samples Collected by Canister" *J. Chromatographic Sci.*, **29**, 83-88 (1991)
[3] Erickson D. and Pacheco K. (2001) Organic Outgassing in NASA's JSC Genesis Clean Rooms. Report to K. McNamara, Worcester Polytechnic Institute, Worcester, MA 01609.
[4] Analyses by Balazs Analytical Services, Fremont, CA
[5] Mickelson E. (2001) Molecular Contamination Control: Strategies for a Facility to Receive Returned Martian Samples, Report to Mars Returned Sample Handling project, JPL.

already reduced the total load measured by silicon wafer to 10 ng/cm^2. For example, the laminate flooring is being replaced with metal flooring. More rigorous containment of the humans inside the laboratory is being required.

Table 3-1 Typical Airborne Molecular Species

Direct air sampling (low ppb)	Sampling on sorbant (<<10 ng/L)	Sampling on silicon witness wafer (<1 ng/cm^2)
Isopropanol (IPA) (120 ppb)	Toluene	TXIB (Texanol Isobutyrate)
Ethanol (25 ppb)	Benzaldehyde	Butoxyethoxy ethanol
Methanol (20 ppb)	Ethyl hexanol	p-Acetyl acetophenone
Acetaldehyde	Naphthalene	Diethyl phthalate
Acetone	Methyl naphthalene	Dibutyl phthalate
Pentane		Dioctyl phthalate
Toluene		Isopropyl myristate
Hexamethylcyclotrisiloxane		Cyclo $(Me_2SiO)_{10}$
Octametylcyclotetrasiloxane		Isopropenyl benzene
Decamtheylcyclopentasiloxane		Isopropenyl acetophenone
		Cyclo$(Me_2SiO)_8$

SECTION 4: EFFICACY OF CLEANING PROCESS AND VERIFICATION

The cleaning procedures applied to the Genesis canister hardware derive their history from use in cleaning the tools and containers for curation of Apollo lunar samples and Antarctic meteorites. The materials from which these tools and containers are made is limited to 300 series stainless steels, aluminum 6061 and Teflon film and Teflon structural solids. No lubricants are applied to these materials or used within the sample handling environment, except xylan, a solid form of Teflon in an organic binder applied sparingly to some threaded surfaces. The cleaning fluid used is ultrapure water (UPW).

4.1 Ultrapure Water

UPW water (electronic grade E-1, ASTM D5127-90), with cation/anion concentrations in the low parts per trillion, was chosen as the cleaning fluid for Genesis hardware because it was thought to leave very low residue. This ultrapure water, prepared by continuous filtration (at 0.04 µm particle size), irradiation with UV, and ion exchange, is characterized by a resistivity of 18 MΩ and a total oxidizable carbon (TOC) concentration of <10 ppb. This compares with a resistivity of about 14 MΩ for laboratory deionized water. The Genesis ultrapure water system supplies 10 gal/min. Table 4-1 details the chemistry of the UPW used for cleaning Genesis hardware. The UPW is monitored continually for TOC content and particles down to 0.05µm in size (can detect single cells). Figures 4-1 and 4-2 shows the in-line monitoring results. Water of this high cleanliness level is "hungry" and "reactive" (having elevated levels of both H+ and OH), hence, the usefulness as a cleaning solvent.

Table 4-1. UPW chemical analyses.[1] All species are below detection limits except boron.

PARAMETER	CONC PPT	PARAMETER	CONC PPT	PARAMETER	CONC PPT
Dissolved silica	<100	**Low Level Analyses**		**Low Level Analyses**	
		Aluminum (Al)	<2	Copper (Cu)	<2
Anions by IC		Antimony (Sb)	<2	Gallium (Ga)	<0.5
Fluoride (F-)	<100	Arsenic (As)	<3	Germanium (Ge)	<3
Chloride (Cl-)	<200	Barium (Ba)	<0.5	Iron (Fe)	<10
Nitrite (NO2-)	<20	Beryllium (Be)	<1	Lead (Pb)	<1
Bromide (Br-)	<20	Bismuth (Bi)	<1	Lithium (Li)	<1
Nitrate (NO3-)	<20	Boron (B)	2100	Magnesium (Mg)	<2
Phosphate (HPO4=)	<20	Cadium (Cd)	<3	Manganese (Mn)	<2
Sulfate (SO4=)	<50	Calcium (Ca)	<20	Molybdenum (Mo)	<4
		Chromium (Cr)	<3	Nickel (Ni)	<2
Monovalent & Divaient Cations by IC		Cobalt (Co)	<0.5	Potassium (K)	<10
Lithium (Li+)	<10			Silver (Ag)	<1
Sodium (Na+)	<10			Sodium (Na)	<5
Ammonium (NH4+)	<50			Strontium (Sr)	<0.5
Potassium (K+)	<20			Tin (Sn)	<3
Magnesium (Mg++)	<20				
Calcium (Ca++)	<20				

[1] Balazs Analytical Laboratories, Fremont, CA

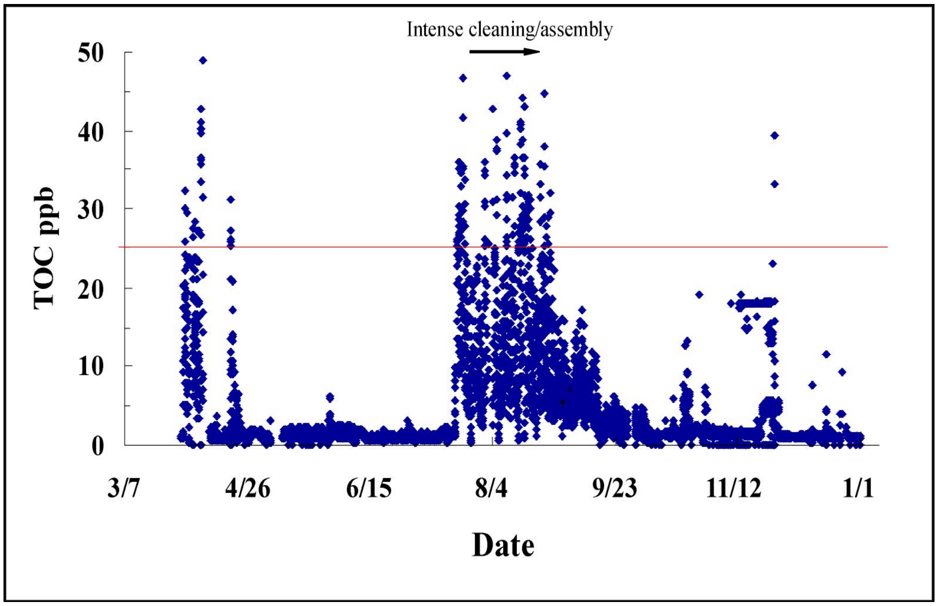


Fig. 4-1. *Total oxidizable carbon content of UPW during year 2000. TOC rises during periods of heavy usage because water completes fewer cleanup cycles.*

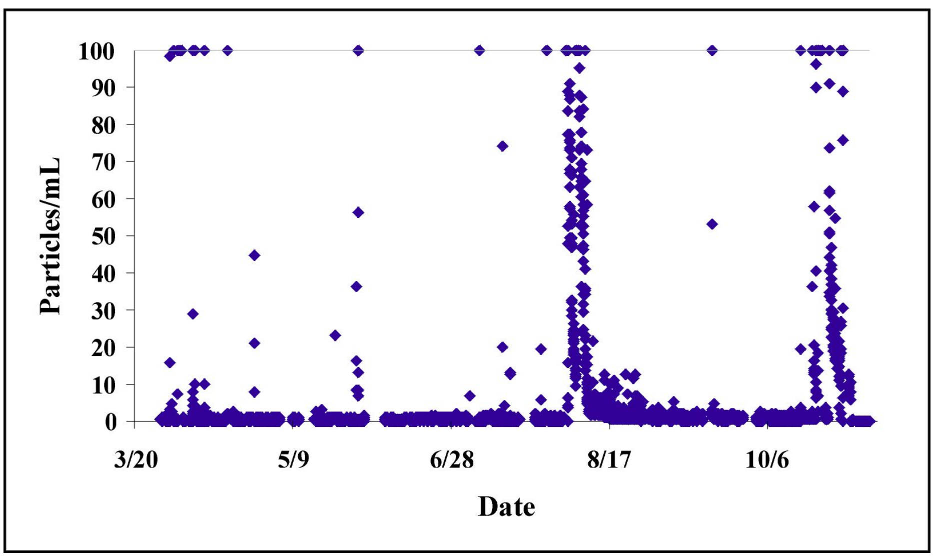


Fig. 4-2. *Total oxidizable carbon content of UPW during year 2000.*

4.2 Cleaning Approaches

The approaches used for cleaning the various Genesis canister components depended on material composition:

Table 4-2

Material/Configuration	Cleaning Approach
Aluminum, structural; 6061, 7075	Cold UPW (15, 30C) ultrasonic, megasonic cascade
Fasteners, stainless steels some with dry lubricant	Hot UPW (65-75C) ultrasonic cascade
Polished collectors: aluminum, gold, vitreloy	UPW rinse or cascade at various temperatures
Elastomers (o-rings)	Cold UPW (15-20C) rinse with agitation
Enclosed mechanisms, electronic boxes, filter housing, exterior cabling	Reagent grade isopropanol (ipa) wipe
Exterior painted surfaces	Vacuum brush under black light

There is a distinction in the levels of cleanliness achievable for those materials inside the canister and those on the exterior. The elastomer o-rings are at the boundaries between exterior and interior.

4.3 Precleaning

The UPW cleaning plan was initially based on the assumption that hardware would have been precleaned by standard aerospace guidelines (MIL-STD-1246C) using degreasers, arriving at the Johnson cleaning laboratory ready for final cleaning. In actuality, many of the components required a precleaning and degreasing process before final cleaning. Isopropanol (IPA) was selected as the organic solvent for degreasing because it is obtainable in a highly pure form relative to other solvents. The surfactant of choice for the metal surfaces was Brulin 815 GD. The preferred technique for scrubbing in surfactant solution is to keep the piece submerged to preclude detergent drying on the piece, and thus, creating particles which are hard to remove (Fig.4-3).

Fig. 4-3. *Precleaning by scrubbing in surfactant solution. Item remained submerged until rinsing to preclude drying of detergent on surface.*

Fig. 4-4. *Cascade both flow of UPW is 2 gallons/min. An array frame is being cleaned in this view. Below the array frame, the rectangular ultrasonic generator is visible.*

4.4 Typical Procedures for Cleaning

For final cleaning, the water flow in the cascade baths is 2 gallons per minute (Fig. 4-4). The water flow is designed to sweep away particles. Additionally, the bath is agitated by bubbling nitrogen gas introduced into the bottom of the tank.

4.4.1 Aluminum

Procedure:

a) wipe surface with knit polyester wipe dampened with IPA (2 cycles)
b) scrub surface 10 times with knit polyester wipe using 20% Brulin 815 GD, rinse between scrubs (2 scrub/rinse cycles)
c) 30 minutes in UPW cascade bath at 30ºC, rinse, and dry using pressurized N_2.

Aluminum was difficult to clean with UPW, due to formation of oxides and hydroxides. The aluminum hardware for Genesis canister interior was not finished by anodization after fabrication. The reason for the use of bare, machined aluminum was to exclude contaminants from anodization baths and to minimize the specific surface area resulting from a thick oxide coating capable of holding airborne molecular contaminants (science requirement).

It was quickly apparent that cleaning bare aluminum in hot UPW resulted in formation of a gold to bronze coloration. A cleaning time and temperature test matrix[2] ranging from 30°C to 75°C and 15 minutes to 30 minutes was conducted for both aluminum 6061 and aluminum 7075. The results indicated that aluminum could be cleaned at low temperature without discoloration. The 7075 alloy was more susceptible to discoloration, hinting that the larger proportion of alloying elements in 7075, compared to 6061, influenced the discoloration. Morphology of surfaces at high magnification showed two forms: larger needle laths nucleating at regular intervals and total coverage of wrinkled structure (Fig. 4-5, 4-6).

In addition to the oxide/hydroxide formation, evidence of UPW erosion around inclusions in the aluminum is apparent, creating a roughened surface (Fig. 4-7). The increased pitting and the increased specific surface area due to fine-grained hydroxide formation demonstrate that aluminum is not cleanable with UPW. The pitting allows traps for particles and the increased chemically active surface allows for sorption and concentration of ionic species from cleaning fluid and of gaseous molecular species in storage and flight environments. Further, Basic *et al.* [3]

[2] Caution should be used in extrapolating these observations. Surface finish and batch variations were not taken into account. This test was performed on 1/8" sheet coupons. Discoloration was not quantified. Many months later the discoloration remained, but differences were less apparent.

[3] Improved cleaning methods for planetary protection bioburden reduction (2000). C. Basic, K.

have demonstrated that aluminum is not biologically cleanable by other methods.

Therefore, aluminum surfaces are not recommended when extremely clean surfaces are required.

4.4.2 Stainless Steel

Procedure:

a) wipe surface with knit polyester wipe dampened with IPA (2 cycles)
b) scrub surface 10 times with knit polyester wipe using 20% Brulin 815 GD, rinse between scrubs (2 scrub/rinse cycles)
c) 30 minutes in UPW cascade bath at 70-80ºC, rinse, and dry using pressurized N_2

The finish on stainless steel structural pieces was generally good and ability to use hot UPW allowed pieces to be easily cleaned. Threaded stainless steel fasteners were precleaned by ultrasonic treatments in IPA followed by Brulin detergent.

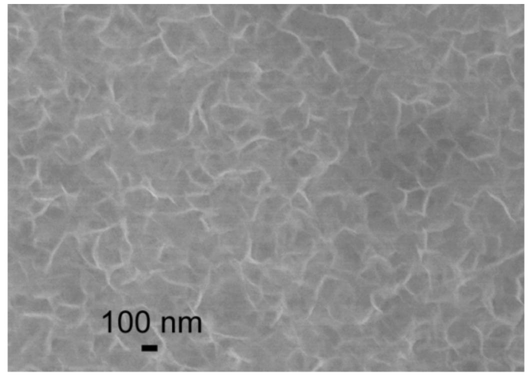


Fig. 4-5. *The wrinkled texture of hydroxides (boehmite?) resulting from UPW cleaning of aluminum 6061 at 75°C for 30 min. Scale bar is 100 nm.*

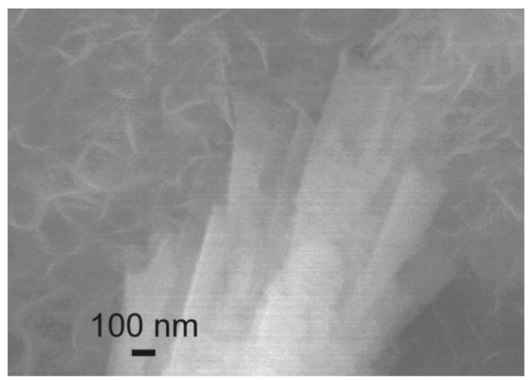


Fig. 4-6. *The needle laths (bayerite?) radiating from single point. The view is from same coupon in fig. 4-5. Scale bar is 100nm.*

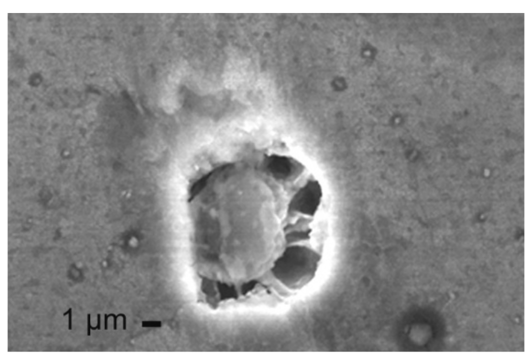


Fig. 4-7. *Erosion pit around inclusion in aluminum 6061 cleaned in UPW at 50°C for 30 minutes. Scale bar is 1 µm.*

Venkateswaran, S. Chung, W. Schubert, G. Kazarians, C. Echeverria, A. Okonko, M. Musick, R. Kern, Mark Anderson, J. Allton, C. Allen, N. Wainwright, R. Mancinelli, and D.C. White. First Annual Astrobiology Science Conference, Ames, CA.

Fig 4-8. *Electronics Box cleaning with IPA-dampened swabs.*

4.4.3 Electronic Boxes, Enclosed Mechanisms, Filter Housing, Exterior Cabling

Procedure:

Cleanroom polyester wipes and foam-tipped swabs were used for wiping the surface with IPA to remove particles and films (Fig. 4-8).

4.4.4 Elastomers (O-rings)

Procedure:

a) wipe with knit polyester wipe dampened with IPA
b) UPW cascade bath for five minutes at 45ºC. air dry

4.4.5 Exterior Painted Surfaces

Procedure:

Brush surface with sable brush while vacuuming with HEPA filtered cleanroom vacuum. This is performed under black light to assure all visible particles are removed.

4.5 Cleaning Verification Approaches

The challenge confronting verification of extreme levels of cleanliness is that direct methods of measuring cleanliness will result in degradation of the cleanliness. Thus, the indirect methods of rinse water analysis for each piece and process validation by means of coupons was used. (Table 4-3).

Our approach differed from the standard form of setting pass/fail limits on cleanliness levels. The cleanliness level was capability driven. Because each piece cleaned presented unique challenges, items were cleaned until TOC and particle levels could not be further lowered.

Table 4.3

Material/Configuration	Verification Approach
Aluminum, structural; 6061, 7075	Analysis of rinse water for TOC and particles >1µm
Fasteners, Stainless steels, some with dry lubricant	Analysis of rinse water for TOC and particles >1µm
Polished collectors: aluminum, gold	Analysis of rinse water for TOC and particles >1µm
Elastomers (o-rings)	Binocular microscope inspection
Enclosed mechanisms, filter housing, Electronic boxes, exterior cabling	Inspection of wipes
Exterior painted surfaces	Inspection with high intensity light, black light

The cleaning processes are further validated by detailed analysis of the surfaces of coupons cleaned along with the hardware. These studies are ongoing and consist of scanning electron microscopy (SEM) at high magnification, x-ray photoelectron spectroscopy (XPS) and other surface measurements.

4.6 Major Components: Cleaning Results

4.6.1 Canister Base and Cover

4.6.1.1 *Canister base*

The canister base was carved from a solid block of Al 7075 T73 stock, with the exterior having a hard anodized finish. Cleaning the canister base (Fig. 4-9) was relatively straightforward, compared to cleaning the cover, and demonstrated the effectiveness of using a megasonic cleaning wand on objects which cannot be submerged in an ultrasonic bath (Fig. 4-10).

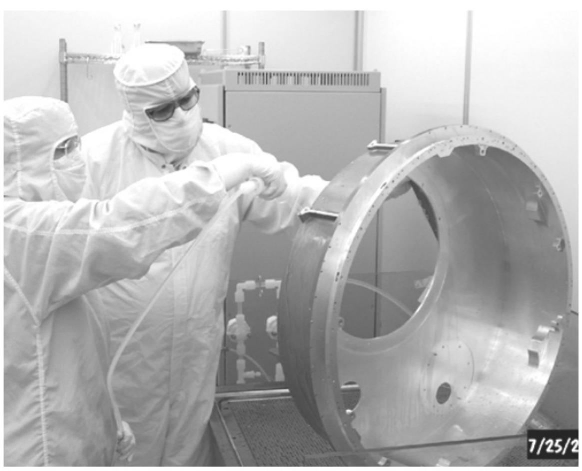


Fig. 4-9. *Canister base is rinsed with ultrapure water (UPW)*

Fig. 4-10. *A stream of megasonically energized UPW generated by a portable wand is used to clean the canister base.*

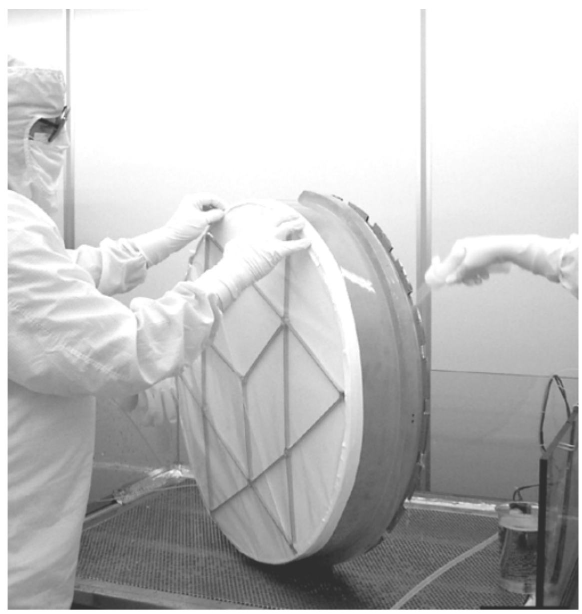


Fig. 4-11. *Unpainted portion of canister cover is rinsed with UPW. Painted portion is covered with film Teflon taped at rim.*

4.6.1.2 *Canister Cover*

The Genesis canister cover (Fig. 4-11) was also carved from a single block of aluminum 7075 T73. Two features of the cover required extra care in cleaning:

a) The exterior top surface was coated with a fragile white thermal paint (Hughes Aircraft M-1).
b) The flange with the sealing surface was coated with an electroless nickel plating to prevent the silicone rubber seal from adhering to the aluminum.

This configuration of having a relatively dirty and uncleanable painted surface on the exterior precluded a final cleaning by total immersion in a cascade bath (particles from paint would only be redistributed on the interior is such a process). The approach taken was to clean the exterior, followed by cleaning of the interior in such a way that material from the paint could not be transferred to the interior.

Precleaning included the wiping of the surface with IPA and removing the RTV staking compound from threaded holes. The cover exhibited pitting from oxide corrosion and etched finger prints, which upon testing a small area, was improved by wiping with 10% phosphoric acid solution. Then, the painted surface was cleaned by vacuum-brushing under a black light. The painted surface was kept dry by taping a teflon plastic cover around the circumference.

A team of 5 was required to clean the cover. The non-painted exterior portion was scrubbed with Brulin in small patches immediately followed by copious flushing with UPW. Likewise, a 10% phosphoric acid solution was wiped in small patches followed by UPW flushing. When a darkening of the nickel surface was observed, the cover was flushed thoroughly and dried for further examination. Extensive analysis and experimentation determined that the discoloration was due to formation of nickel-phosphorous compounds, which could be removed by polishing with 0.05 µm aluminum oxide (Fig. 4-12). Therefore, the discoloration was polished off and the cover was re-cleaned. The final UPW rinsing was done with the megasonic wand.

The effectiveness of the megasonic wand is demonstrated in the high level of particulate cleanliness achieved for the canister base and cover (Fig. 4-13)

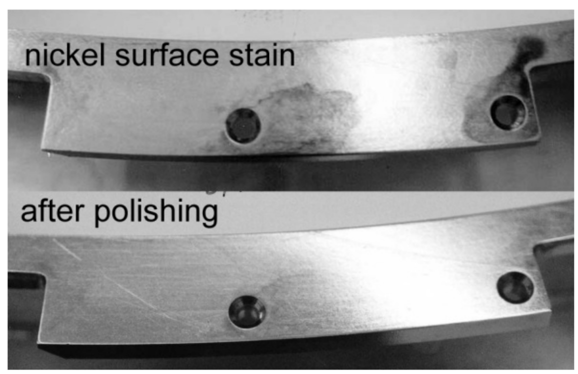


Fig. 4-12. *Electroless nickel coating on cover sealing surface was darkened during cleaning. The nickel-phosphorous material was polished off with aluminum oxide and the cover recleaned.*

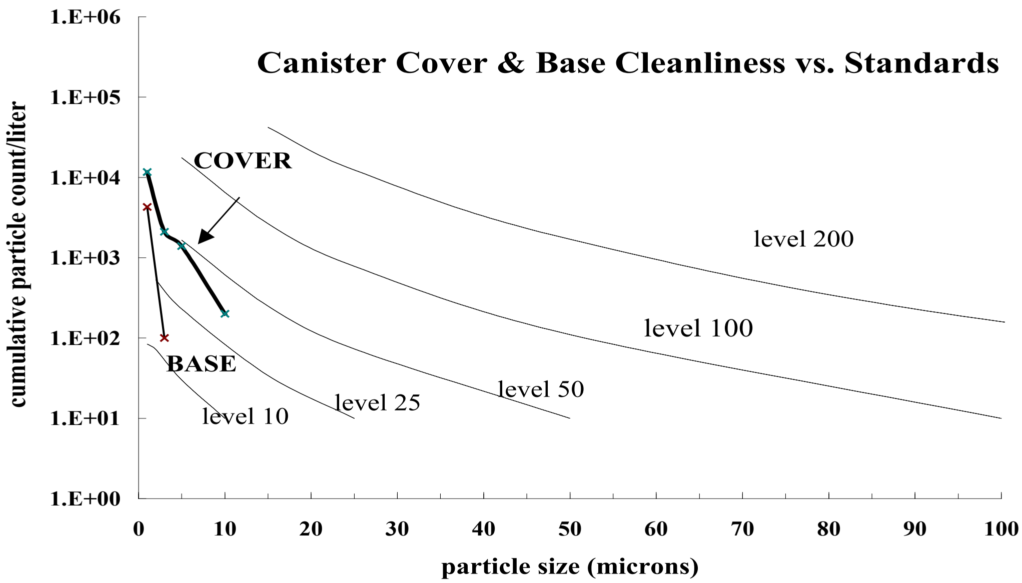


Fig. 4-13. *Canister Cover & Base Cleanliness vs. Standards (MIL-STD-1246C)*

4.6.2 <u>Array Frames – Al 6061 plate</u>

The array frames are the delicate, airy structures that hold the collector hexagonal wafer firmly in place (Fig. 4-14 and 4-20). Two lessons from cleaning of the intricate array frames were notable:

a) The intricate structure of the array frames was cut by electric discharge machining (EDM). The difficulty of cleaning an EDM surface was not appreciated until the surface texture and chemistry were examined in detail.
b) The design required about 100 blind, threaded holes per frame, 67 of which had locking inserts installed. A detailed cleaning and drying sequence for these holes was developed.

Procedure:

a) JPL clean to MIL-STD 1246B, level 300
b) JSC visual inspection and mapping using otoscope in blind, threaded holes mechanically clean frames and holes with IPA swabs and wipes
c) return frames to JPL for removal of EDM surface by PhosBrite dip
d) JPL installation of ss inserts
e) JSC visual inspection and mapping using otoscope in blind, threaded holes
f) UPW cascade bath with individual jetting of water into every hole
g) Cascade 15 min. with ultrasonic ON, followed by 15 min. ultrasonic OFF
h) Repeat step h) for reverse side
i) Spray rinse
j) Blow dry with purified nitrogen

k) Dry in HEPA-filtered nitrogen oven for 15 minutes
m) Dry each hole with a heated, filtered nitrogen probe inserted into the hole
n) Verify hole dryness with moisture probe inserted into hole
o) JSC visual inspection and mapping using otoscope in blind, threaded holes
p) Store under purified nitrogen

4.6.2.1 Electric Discharge Machining

Electric discharge machining (EDM,) high voltage from a cutting wire to the work piece, was used to cut the intricate form of the aluminum 6061 array frames. The cutting wires used for Genesis frames were brass or zinc-coated brass. The process produced molten aluminum from the work piece and molten wire material and typically took place under an organic-laden cooling fluid in a shop environment (Fig. 4-15).

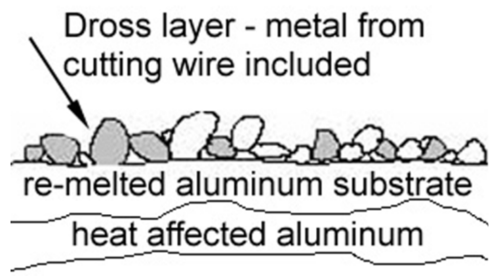


Fig. 4-15. *Typical EDM surface cross-section.*

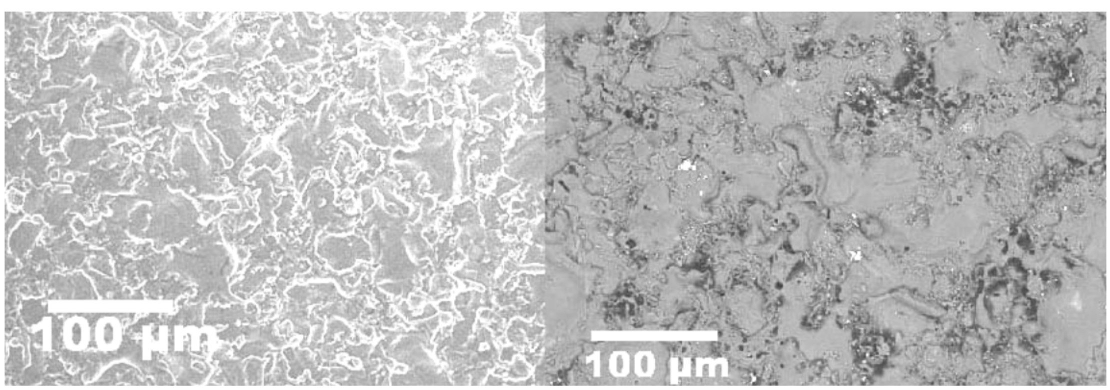


Fig. 4-16. *Scanning electron microscope (SEM) images of EDM cut surface of array frame. Left image shows texture. Right image is same view in backscatter mode. It shows dark, carbon-rich areas and bright copper areas.*

The molten blobs adhering to the cut surface were very re-entrant and overlapping. They trapped contaminants, making the surface uncleanable (Fig. 4-16). Typically EDM molten rind and heat-altered aluminum substrate, for aluminum 6061, is 5 to 15 µm thick. The molten wire material contained Cu, Zn and Ag, which needed to be removed (Fig 4-17). Experimentation with several phosphoric acid brightening dips resulted in the decision to use Albright & Wilson's

Phosbrite 174 dip for 6 minutes[1]. The resulting surface was much improved in cleanability (Fig. 4-18, 4-19).

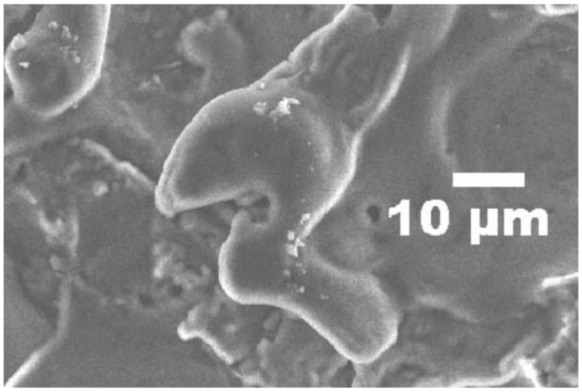


Fig. 4-17. *Molten copper blob from EDM cutting wire deposited on array frame surface.*

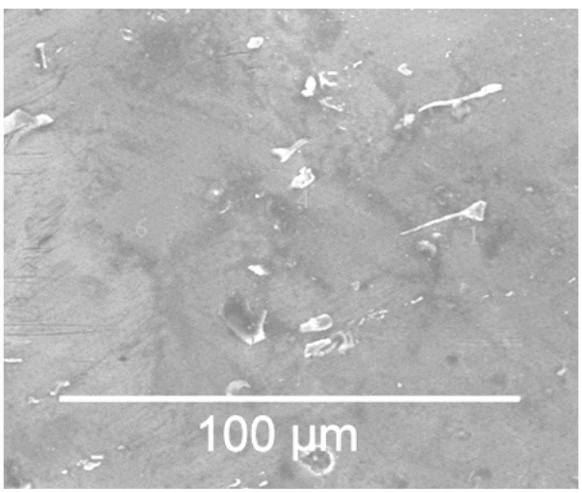


Fig. 4-18. *Much improved array frame surface after treatment in phosphoric acid to remove molten EDM rind.*

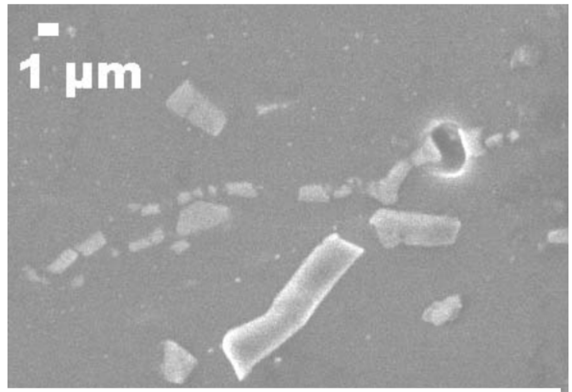


Fig. 4-19. *Only remnants of molten metal remain on array frame after phosphoric acid treatment.*

Fig. 4-20 shows an array frame being rinsed prior to catching particle and TOC sample. The array frames, with the numerous blind threaded holes, were cleanable to better than MIL-STD 1246B level 50 (Fig. 4-21).

Fig. 4-20. *Rinse water from array frame is captured in beaker for particle counting analysis.*

[1] Performed at George Industries, Pasadena, CA.

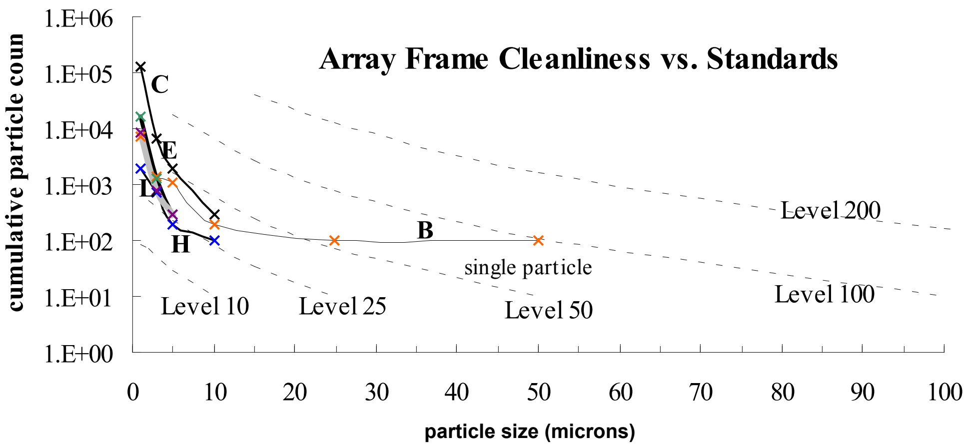


Fig. 4-21. *Particle count results from rinse water for array frames C, B, E, L and H indicate that the frames, with exception of one particle, were cleanable to better than level 50.*

4.6.3 Gap Shields – Al 6061 T6 sheet, 0.015 inches thick

The gap shields were thin sheets of aluminum between the array frame and the attached hexagonal wafers. Their purpose was to shield the arrays below from solar wind; thus keeping the regime collections separate.

Procedure:

a) Pre-clean visual inspection and mapping
b) IPA wipe (2 cycles)
c) Brulin GD815 scrub and rinse (2 cycles)
d) UPW cascade bath with ultrasonic, 15 min. each side
e) UPW cascade bath with nitrogen bubbles, 15 min. each side
f) Spray rinse and sample rinse water
g) Blow dry with purified nitrogen
h) Repeat steps d-g until TOC and particle counts are reduced to best levels
i) Post-clean visual inspection and mapping

The cleaning of the gap shields illustrated cleaning to best levels. Figures 4-22 and 4-23 show a gap shield being placed into the cascade bath and in the bath. Initial cleaning results resulted in quite high TOC values in the rinse water (Fig 4-24), the source of which was uncertain but might have been residual detergent. The process was repeated 2 or 3 times and the final results were much improved. Figure 4-24 shows that MIL-STD 1246B level 25 or less was achieved. In addition an analysis of rinse water for 17 metals, 7 anions and 6 cations at the 1 ppb level revealed 3 ppb aluminum only. The TOC was 50 ppb above baseline.

Fig. 4-22. *Gap shield being lowered into UPW cascade bath.*

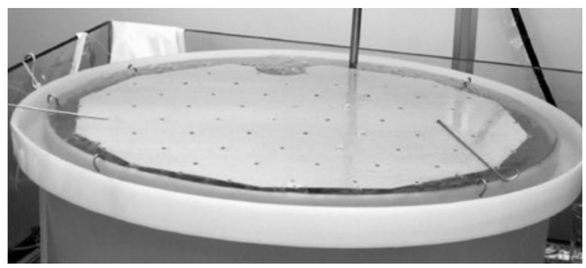


Fig. 4-23. *Gap Shield in cascade bath*

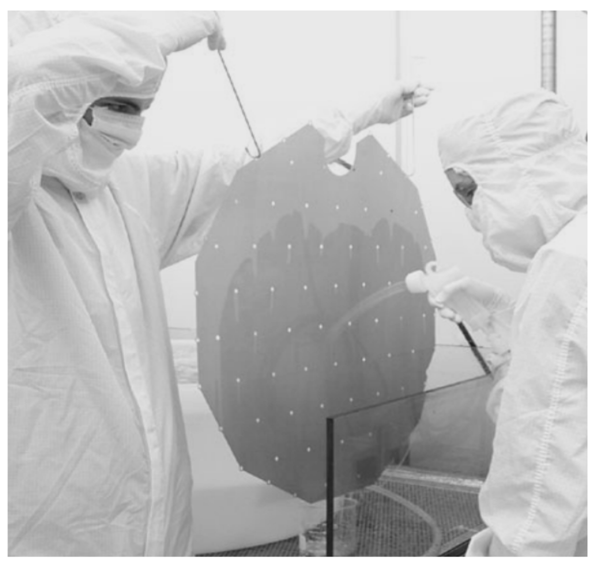


Fig. 4-24. *Rinse water being captured for particle count analysis and measurement of organic content.*

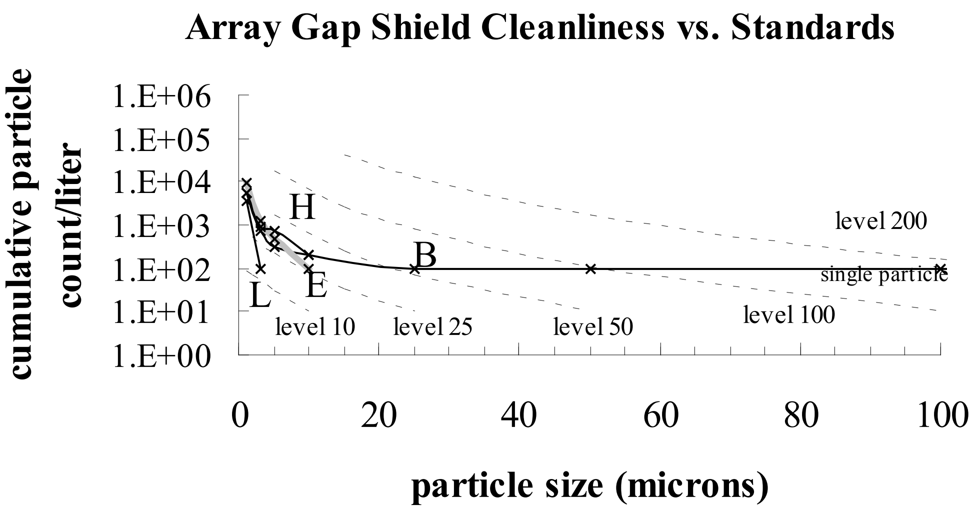


Fig. 4-25. *Particle count results from rinse water for gap shields B, E, H and L indicate that the shields, with exception of a single particle, were cleanable to better than level 50 (MIL-STD-1246C).*

4.7 Comparison of surface cleanliness at the atomic level

Representative coupons cleaned in the same manner as the flight hardware can be assessed for contamination using an extremely low-level method of detection. Some preliminary results are presented here. Four Genesis coupons were compared using x-ray photoelectron spectroscopy (XPS) (Table 4-4). This technique penetrates only about 4 nm into the surface, thus, analyzing the monolayer contaminants. Comparison of the numerical results is highly model dependent and surface texture greatly influences the interpretation (Fig. 4-26). A solar wind collector was made from gold foil, which was cleaned in hot UPW. The aluminum array frame, gap shield, and thermal shield were cleaned in cold UPW. The array frame had been stripped in phosphoric acid brightener and shows different results than the two aluminum sheet pieces (gap shield and thermal shield).

Using XPS, Mickelson *et al* have quantified known amounts of carbon contaminant on smooth stainless steel finishes cleaned by the JSC-UPW method. They determined that a No. 7 finish, 304 stainless steel can be cleaned to a level of $\leq 10^{15}$ carbon atoms/cm^2; however, surface finish is critical to effectiveness.[1]

[1] Mickelson, E. et all (2002) Cleaning and Cleanliness Verification Techniques for Mars Returned Sample Handling in LPSC 33 abstracts, Houston, TX

Table 4-4. XPS measures of surface contaminants on 4 Genesis coupons[2]

Coupon	Atomic % Carbon (as 1s)	Atomic % Oxygen (as 1s)	Atomic % Substrate aluminum (as 2p) or gold (as 4f)
Gold foil	44.48	14.33	41.19
Array frame	55.46	27.01	12.98
Gap Shield	18.71	51.97	19.68
Thermal Shield	16.01	51.81	20.24

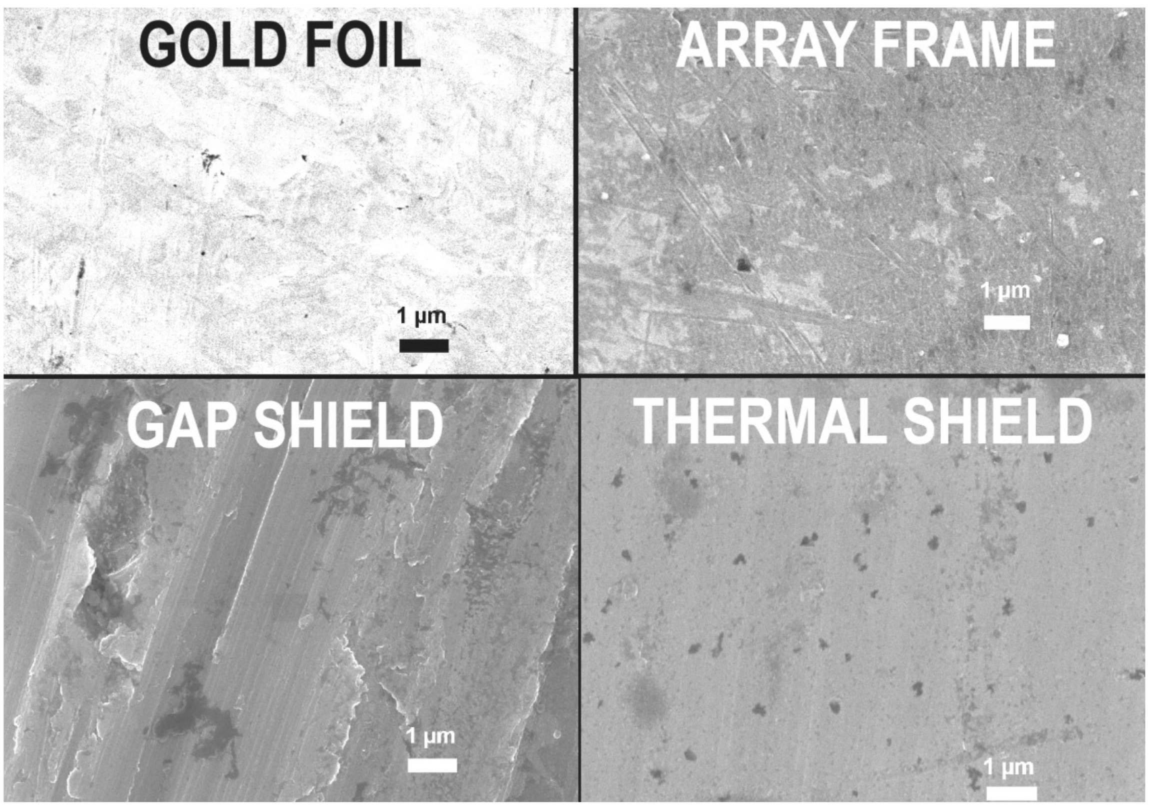


Fig. 4-26. *SEM image of surface textures of cleaned coupons for gold foil, array frame, gap shield and thermal shield.*

[2] Analyses performed at MERSEC-University of Houston, Houston, TX

SECTION 5: CLEAN ASSEMBLY TECHNIQUES

Previous hardware assembly experience for the JSC Genesis team consisted of assembling relatively simple, and smaller, pieces in laminar flow benches, laminar flow Class 100 tunnel and nitrogen atmosphere gloveboxes (Figs. 5-1, 5-2).

Fig. 5-1. *Class 100 laminar flow tunnel for preparing and examining interplanetary dust particles captured in the stratosphere*

Fig. 5-2. *Lunar rocks are examined, prepared and stored in positive pressure gloveboxes continually purged with pure nitrogen.*

In these small environments the material composition, material cleanliness and personnel traffic and equipment are strictly controlled and minimized. Typical spacecraft assembly facilities are larger multi-story Class 100,000 room in which a wide range of materials and complex motorized equipment is required. At low activity levels these rooms can be operated cleaner than Class 100,000 (Fig. 5-3). However, the assembly of the Genesis science canister took place in a small tightly controlled Class 10 room, 15 ft x 15 ft with an 8-ft high ceiling. The assembly team consisted of Jet Propulsion Laboratory (JPL) engineers, technicians and Quality Assurance, scientists from JSC and engineers from Los Alamos National Laboratory. Clean assembly of the Genesis science canister was achieved by rigorous adherence to personnel training, controlled access, and controlled materials.

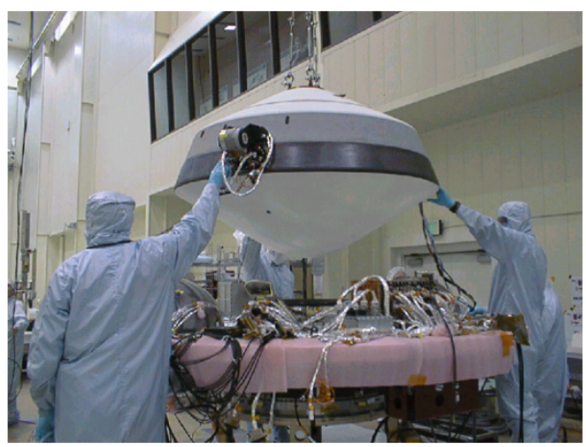


Fig. 5-3. *The sample return capsule for Genesis was assembled and tested within several multi-story spacecraft assembly rooms at Lockheed Martin Astronautics in Denver, Colorado.*

Fig. 5-4. *Dryden suit completely envelops person. Self-contained battery motor forces exhaled breath through HEPA filters.*

Fig. 5-5. *Class 1000 Viewing Corridor provided quality observation opportunities without compromising the Class 10 cleanroom. Observers were required to don full cleanroom suits.*

5.1 Personnel Training

All persons entering the Genesis assembly area completed JSC cleanroom certification and JPL electrostatic discharge training. Additional Genesis cleanroom training included annual sessions in 'Behavior in Cleanrooms', 'Working in Laminar Flow', and 'Gowning for the Cleanroom'[1]. All persons working within 2 meters of the payload were contained in Dryden suits (Fig. 5-4). These Gore-Tex suits completely enclosed the body. A full face hood and small air pump ensured that exhaled breath and other metabolic products were released only through a HEPA filter at the rear of the suit, away from the work surface.

5.2 Controlled Access

Only 3 persons were allowed in the assembly room at one time. Managers, science observers and support personnel were restricted to the Class 1000 corridor, including photographers with only a very few, documented exceptions (Fig. 5-5).

[1] Micron video training series

5.3 Controlled Materials

The amount and cleanliness of materials entering the cleanroom was restricted and documented. Quality assurance documents and engineering drawings were minimized and used only in the corridor, with the exception of a few sheets printed on cleanroom paper. All tools used in the cleanroom and for assembly were precision cleaned and stripped of lubricant. Use of lubricant on the payload was extremely minimized and applied with great care.

5.4 Examples of clean assembly

- The extensive viewing windows from the corridor allowed observers and the QA and engineering documentation to be maintained outside the Class 10 room.
- The hands-on assembly technicians learned not to touch the hardware, even with gloved hands. Fasteners were installed using tweezers, and larger pieces of hardware were handled using cleaned aluminum foil ‘potholders’ (Fig. 5-6).
- Technicians learned not to work over the clean hardware, but to approach from below or the side so that filtered airflow could sweep contaminants away.
- Application of the lubricant Braycote, to a few critical surfaces in limited amounts, was very strictly controlled. The Braycote was prepared in small quantities and brought into the cleanroom in a sealed container immediately prior to use and removed upon completion of task. Because this lubricant is extremely persistent on surfaces, a designated “lubricant” holder was the only person to touch the container. Users were extremely careful not to touch other surfaces or clothes or door knobs while applying the Braycote. Total glove changeout and lab work surface wipedown were done at completion of lubricant application.

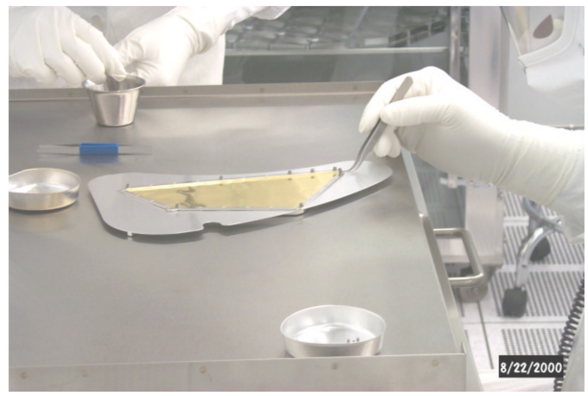


Fig. 5-6. *During assembly, fasteners were handled with tweezers, not gloved fingers.*

5.5 Examples of Activities vs Air Particle Counts

Detailed examination of the airborne particle concentration, as measured underneath the canister (reference Fig. 3-4), showed: 1) that any particulate contamination is quickly swept away and 2) intricate procedures and even movement of large pieces can be accomplished with minimum particle generation. The particle counts shown in Figures 5-7 and 5-8 which were taken in 10 minute intervals and accounted for all particle >0.1 µm. Particles generated during replacement of collectors on an array (Fig. 5-7) were minimal. This was a delicate procedure involving 2 persons and was typical of sub-assembly work. A range of particle concentrations was generated for activities shown in Fig. 5-8. Removing “ramps” and installation of the lock ring (a large diameter device) generated measurable particles, most of which were <0.1 µm diameter. This activity involved removing and inserting threaded fasteners. However, later in that day the electrical connectors were mated on the exterior and associated cabling was tied with a highly particle-generating woven Dacron tape. Use of this material on the exterior of the canister is reflected in the very high particle counts. Cable tying was always done downstream of the science canister so particles were swept away from sensitive surfaces.

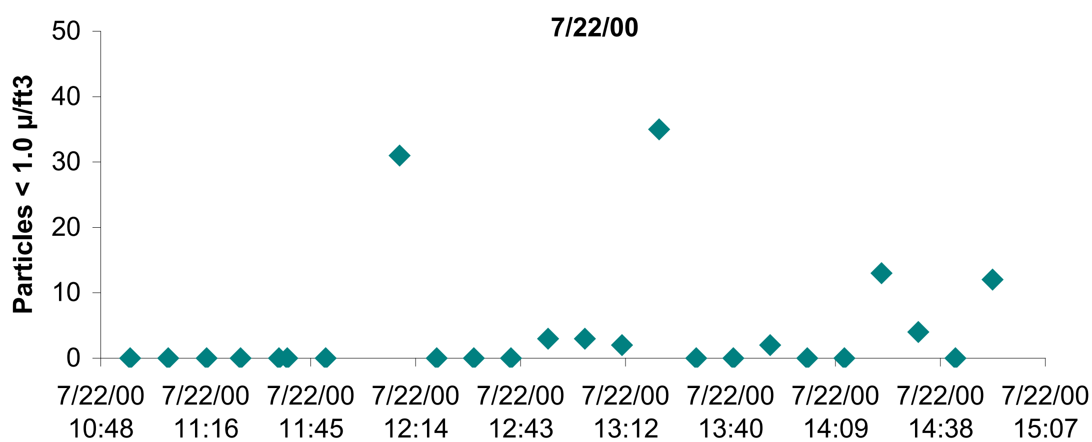


Fig. 5-7. *Particle counts taken downstream from the assembly work space during replacement of wafers on the B array.*

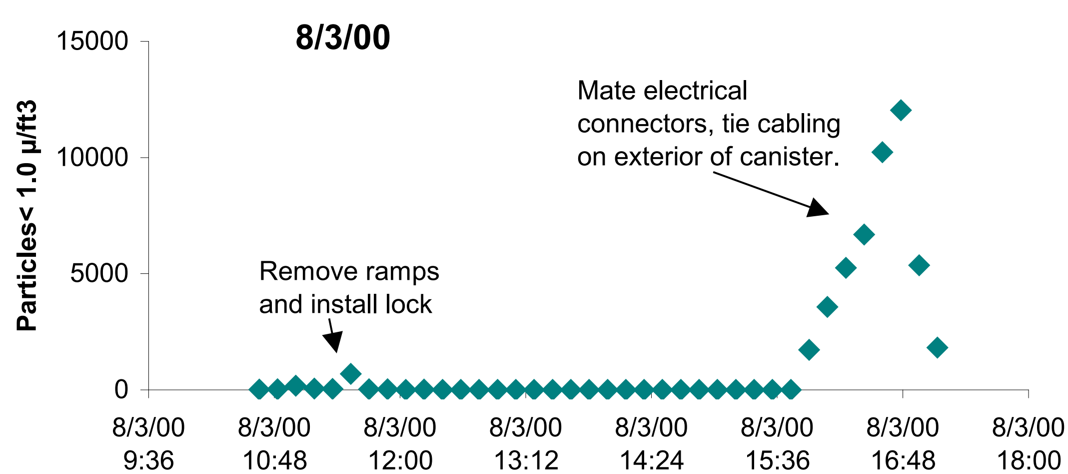


Fig. 5-8. *Particle counts taken immediately downstream from assembly workspace. Installation of lock ring, a large component, illustrates fast clean-up in airflow. Use of Dacron tape to tie cables was dirty work performed on the canister exterior and done downstream from clean surfaces.*

SECTION 6: DOCUMENTATION

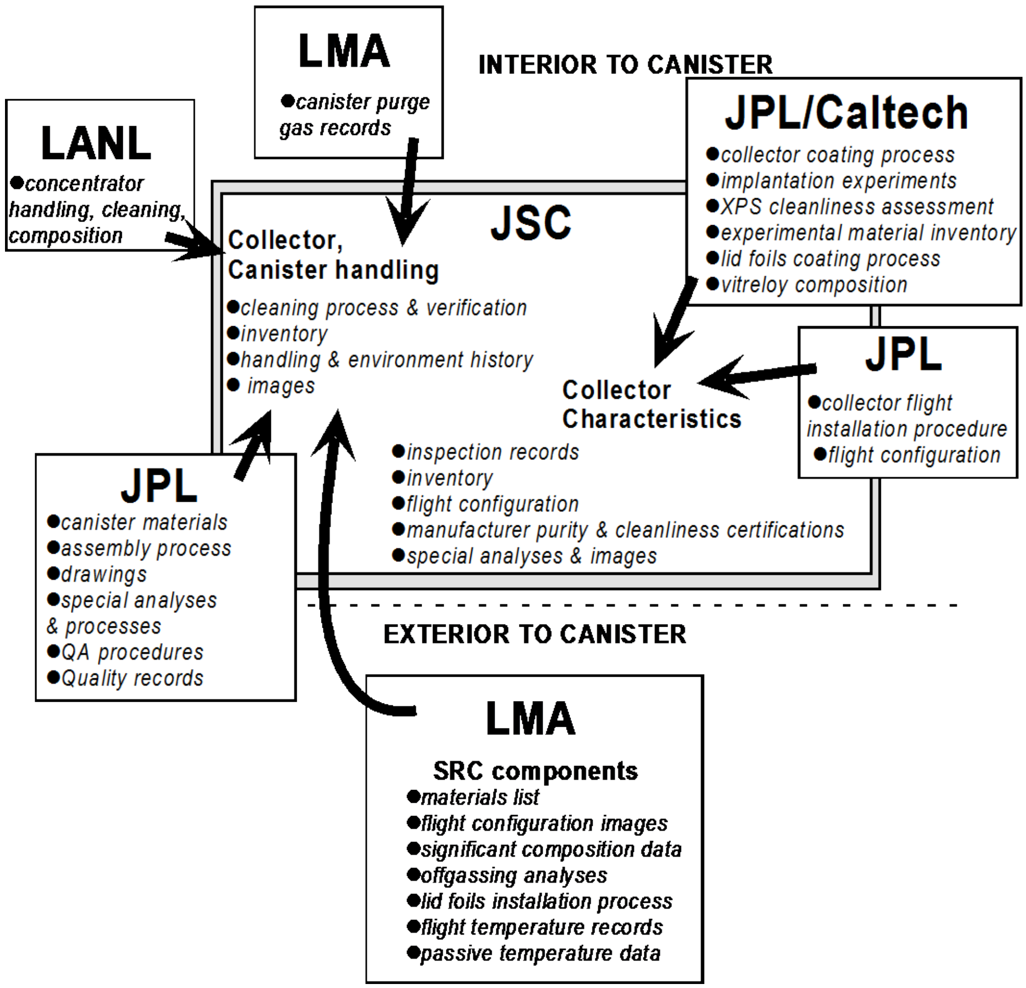


Fig. 6-1. Pre-flight Documents. The database essential to interpretation of analytical results for Genesis solar wind samples is comprised of documents from several institutions. These documents must be managed by one archive responsible for long-term preservation and ease of access to future scientists.

The goal of being able to interpret the analytical results on returned Genesis samples require detailed documentation of the cleaning process for each piece, cleaning verification results and room environment at time of cleaning and assembly. These historical records need to be matched to a set of coupons and reference materials preserved for future comparison analyses. Documentation from early in the fabrication process of the science canister, collectors, Sample Return Capsule and Genesis laboratory construction comprise a portion of the essential data needed; thus, documents from several institutions need to be managed, preserved and made easily available over the next few decades, if not longer (Figs. 6-1 and 6-2.). JSC Genesis personnel realized from the beginning that personnel dedicated to document management were a high priority, but resources did not allow for this. Documentation had to be organized at the end of the process.

At JSC the principal document for each Genesis collection surface (silicon wafers and other polished surfaces) and science canister structural components is the data pack. The data pack for each piece contains the specific cleaning process, cleaning verification results and time and location history, plus observational notes and images. These documents are stored in a controlled data vault. Summary documentation includes hardware inventories, cleaning process logs, cleanroom use logs and environmental monitoring records. In addition to the JSC records, the JPL, LANL and LMA records are needed to maintain complete histories.

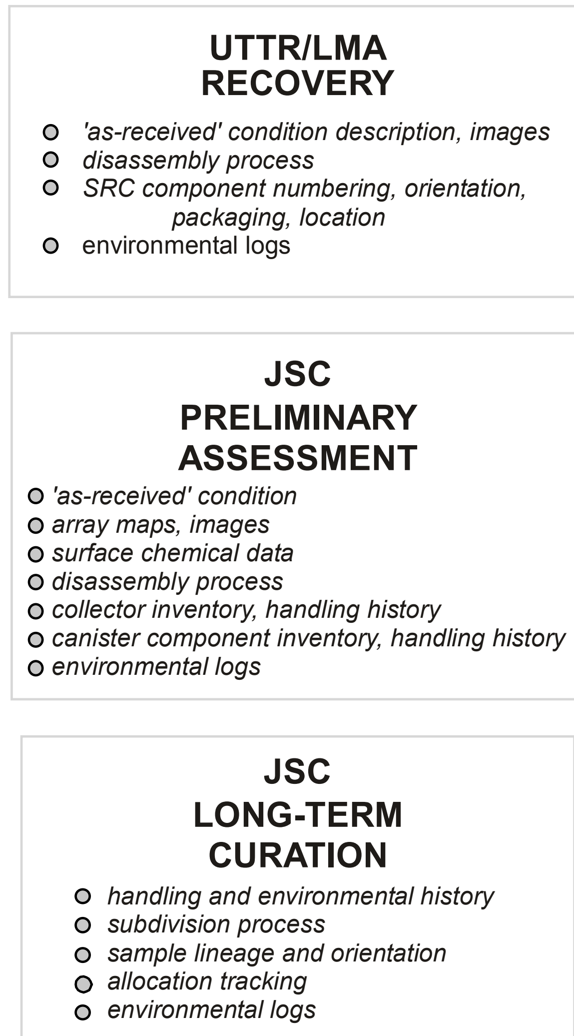


Fig. 6-2. *Anticipated post-flight documentation.*

SECTION 7: COUPONS AND REFERENCE MATERIALS

Because of the very low levels of detection necessary to measure the solar wind, trace contamination from any source may interfere with interpretation of post flight analysis of the returned samples. Thus, it is critical to maintain an archive of coupons representative of both bulk and collector-surface materials prior to flight for comparison with the returned samples. It is equally essential to have coupons of spacecraft materials, which have been cleaned and handled in the same manner as flight components for comparison. Several types of coupons and materials are being archived at the curation facility.

7.1 Solar wind collectors (non-flight)

Genesis collectors are comprised of very specialized materials, and it is important to archive samples of each material. In some cases, it was necessary to obtain collectors composed of the same material from different vendors, resulting in variations in important trace impurities and surface contamination. Because of this, extensive analysis was conducted prior to selection of flight materials. Furthermore, detailed optical examination was conducted prior to selection of flight collectors from each lot. The archives contain many specimens of collector materials, and the associated documentation, from the same manufacturing lots as the flight specimens. The collector materials are stored in the manufacturer-cleaned cassettes for which Genesis curators measured the organic off-gas products of a typical cassette.

7.2 Canister material coupons

Clean canister interior coupons are extremely important. The Genesis Contamination Control Plan emphasized this importance and specified that such coupons be acquired. These coupons are materials, which are not only from the same material type and surface finish as the flight components, but were also cut from the same parent material, preferably cut at the time. Likewise, it is desirable that the pieces were cleaned together. Once obtained, it is critical that the coupons be stored in a manner that preserves their cleanliness for many years. Such clean storage is not trivial and requires storage under nitrogen of the purity specified in Table 2-1, or better, and storage inside of containers and storage vaults for which organic off-gassing is extremely low and well-characterized. For Genesis coupons, the storage enclosures were electropolished stainless steel, maintained in the Class 10 environment and purged with the point-of-use-purified nitrogen.

In practice, it was difficult to obtain materials meeting all the criteria above because coupons were not individually specified in the fabrication drawings and quality monitoring documents. Two strong recommendations from the Genesis experience are 1) that a contamination control representative be on-site at the design and fabrication process to modify coupon acquisition requirements as ongoing processing changes demand it, and 2) that representative coupons be incorporated into the engineering drawings.

7.3 Spacecraft reference materials

Reference materials are pieces of collector or spacecraft materials, not especially handled specifically in the manner to preserve the highest level of surface contamination information, but still containing information pertaining to impurities and contamination associated with specific manufacturing lots of material.

In addition to hardware and cleaning coupons, certain reference materials need to be archived for future comparison. These include samples of lubricants, staking compounds, cleaning fluids, fabrication-cutting fluids, handling gloves and cleanroom materials which have been in contact with collectors and spacecraft parts. Though a number of such samples were preserved and archived for the Genesis mission, the process was less systematic than desired.

Again, it is recommended that a detailed plan for obtaining and tracking such materials be incorporated into procedural requirements and that curatorial personnel establish some on-site monitoring at the spacecraft assembly site.

7.4 Witness Plates

The purpose of witness plates is to obtain an assessment of airborne contamination in real time. Since witness plates are used to measure very low levels of contamination during a particular time or process, their value and accuracy decreases with time and storage. For that reason, witness plates are generally not archived, but analyzed immediately. The results are documented. This was true for Genesis witness plates in general, however, a number of airborne organic witness plates were archived in the event they might prove useful.

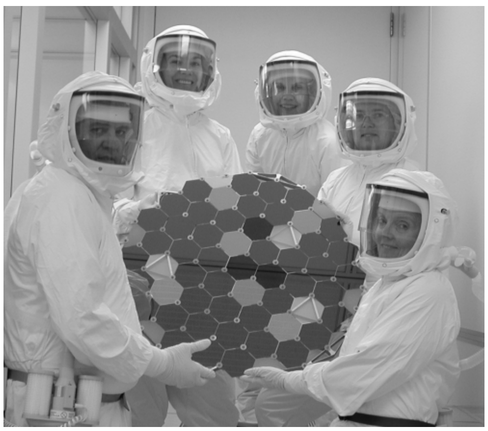
7.5 Experimentally Implanted Sample Analogs

In order to prepare for analysis of returned solar wind samples, scientists require sample analogs to verify both the analysis and surface cleaning methods proposed for use on flight materials. These analogs are collector or similar materials that have been experimentally implanted with nuclei to simulate the implantation of the solar wind in space. These pieces are curated and allocated by the Genesis curators in the same manner as flight materials. This includes clean storage, sample subdivision, allocation and documentation.

ACKNOWLEDGEMENTS

The cleaning of the Genesis science canister for flight was done by a relatively small group of people sincerely interested in "doing it right". The common goal knit together the diverse cultures of sample curators and spacecraft designers.

- Dr. Eileen K. Stansbery very effectively recruited personnel and led the JSC effort from laboratory construction through payload cleaning and canister sealing, contributing significant personal energy to getting things done.



- JSC Cleanroom Construction Team: Dr. Eileen Stansbery, Jack Warren, Judy Allton, Carol Schwarz
- JSC Canister Cleaning Team: Dr. Eileen K. Stansbery, Dr. Kimberly Cyr, Jack Warren, Judy Allton, Carol Schwarz, Jerome Hittle, Craig Schwandt, Mary Sue Bell.
- Solar Wind Collector Inspection and Installation Team: Dr. Kimberly Cyr, Andy Stone, Carol Schwarz, Richard Paynter
- JPL Canister Assembly Team: Jim Baughman, Richard Paynter, Charles Foehlinger, Andy Stone, Louise Jandura, Robert Troy

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