Jet Propulsion Laboratory
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JPL Spacecraft Contamination Control

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Overview

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Why Bother With Contamination Control?

Contamination is the presence of unwanted matter leading to degradation in performance of a component or system

- **Contamination causes:**
  - Reduced throughput in optical systems
  - Losses in power generation systems
  - Degradation of thermal control systems
  - Noise in electrical systems
  - ESD effects
  - Failure of precision mechanisms
  - Degraded or failed science

CONTAMINATION MAKES BAD THINGS HAPPEN

- **Contamination Control:**
  - Identifies risks associated with materials and processes
  - Assesses contamination effects related to performance
  - Provides plans and procedures for preventing or reducing contamination
  - Establishes contamination limits at all build/operating stages

CONTAMINATION CONTROL IS RISK MANAGEMENT

Why Bother With Contamination Control?

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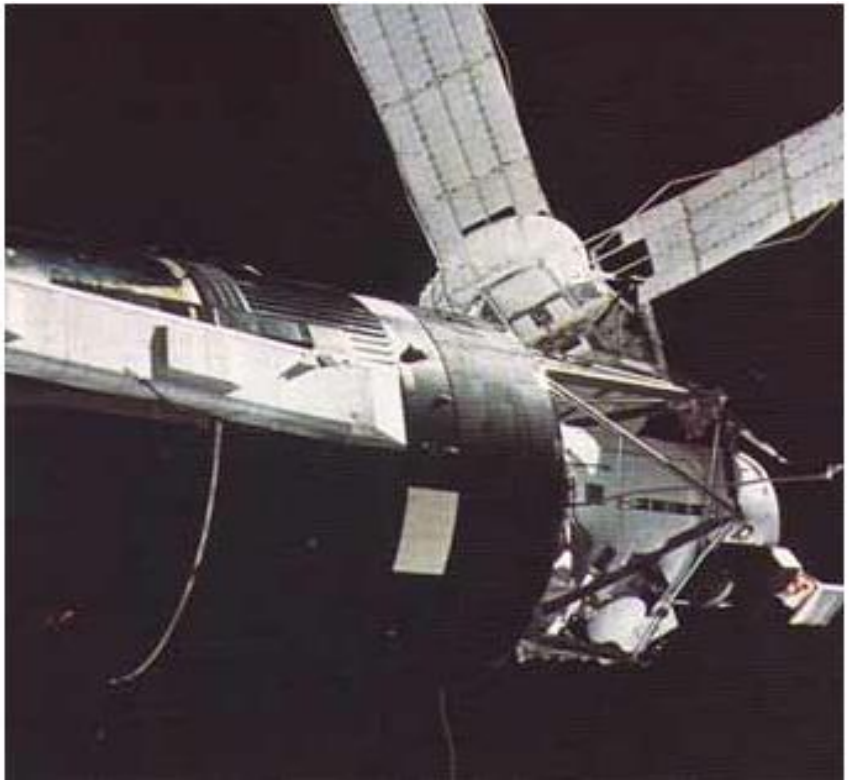
Spaceflight Contamination Anomalies

(Excerpted from: Contamination Engineering Design Guidelines, VERSION: STAGE IV by: Nancy Carosso (Swales and Associates Inc.)

OGO-6 (1969)	Excessive build-up on QCMs due to solar array outgassing
Nimbus IV (1970)	Water build-up on cooled detectors caused failure of a spectrometer early in the mission
OSO-8 (1971)	Lost 3 orders of magnitude in throughput at Lyman-Alpha after 9 days due to electronics box outgassing
NOAA, TIROS, and DMSP (1970s)	Thermal control problems due to outgassing and engine plume deposition
RCA and GE Spacecraft (1970s)	Thermal control problems due to contamination build-up on OSRs.
Skylab and Voyager (1970s)	Visual observations of particle clouds on Skylab; star tracker interference due to particle clouds on both missions
LES 8 and 9 (1970s)	Plumes from retro rockets impinged on payloads during stage II separation.
SCATHA (1979)	Continual accumulations of 200 Angstroms/year were permanently photo-fixed due to photopolymerization
SMM (1980)	Improved version of OSO-8 Lyman-Alpha instrument lost 2 orders of magnitude in throughput at Lyman Alpha within 40 days.

SBUV (1980s)	Accretion and photopolymerization of contaminants on scatter plate calibration system.
DE A&B (1981)	Vent effluents deposited on solar-lit radiator surface, causing permanent deposition and high temperatures.
Landsat (1980s)	Degradation of 500-600 nm channel shortly after launch, due to contaminant build-up.
IECM (1980s)	Measured Shuttle contamination levels; used to identify problems with particle clouds and payload outgassing.
CMP (1980s)	Measured contaminant accretions in the Shuttle bay; measured materials erosion rates due to atomic oxygen exposure
SUSIM (1980s)	Internal box outgassing caused arcing and electronics burn-out, and failure of the instrument mission.
HRTS/Sunlab (1980s)	Immediate loss of 1200-1600 Angstrom bandwidth due to build-up of silicones, caprolactan, and DOP.
INSAT1B (1983)	Visible range instrument degraded 40% (in throughput).
HST (1990s)	WFPC- I UV capability lost due to contamination build-up on cold CCDs combined with UV (from earth albedo) exposure.

Solar UV-induced darkening (out-gassing) contamination present on white thermal control paint



NASA Skylab

http://history.nasa.gov/SP-404/ch7.htm

PARTICULATE

Airborne particle
Insulation threads
Clothing fibers
Human induced substances
Trapped particles

Effects on optical surfaces

Obscuration
Light scattering

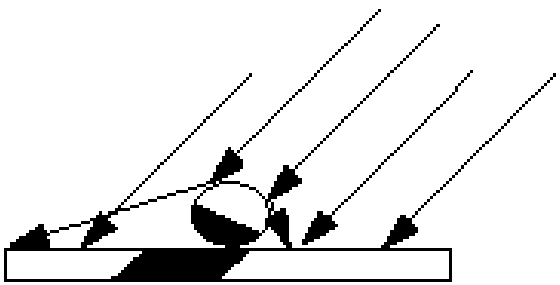


Figure 3-1. A particle on a surface.

MOLECULAR

Deposit of outgassed products
Lubricants
Exposed organics
Volatile condensable materials

Effects on optical surfaces

Light absorption
Thin film interference
Modify polarization characteristics

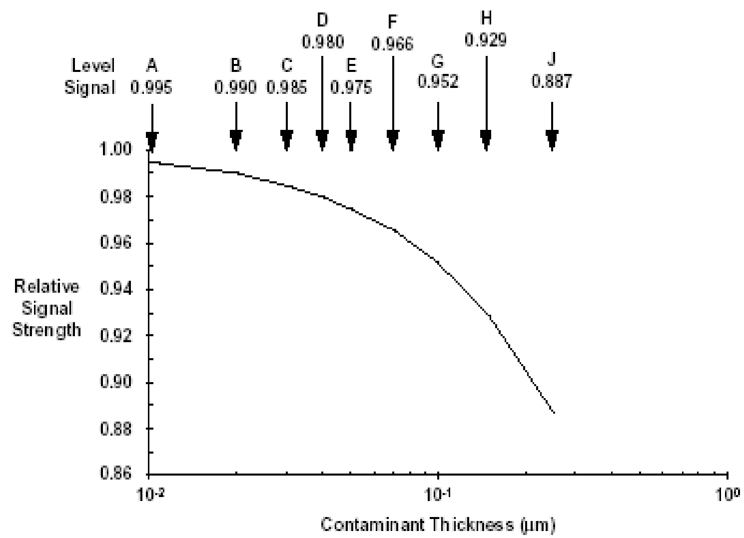


Figure 2-24. Degradation in signal strength as a function of MIL STD 1246C cleanliness level for a broadband visible sensor.

Contamination Sources and Mechanisms

For contamination to occur, two conditions must be met:

- **A contamination source must be present**
  - Inherent in the material (such as volatiles in a material)
  - Induced from a external source (such as human contaminants)
  - Generated as a process result (such as fabrication)

- **A transport mechanism by which a contaminant is transferred to or distributed over sensitive surfaces**
  - Outgassing (temperature, pressure effects, cure)
  - Environmental (assembly areas, test environments)
  - Physical characteristics or contact (migration, handling)
  - Operations (function of a device)

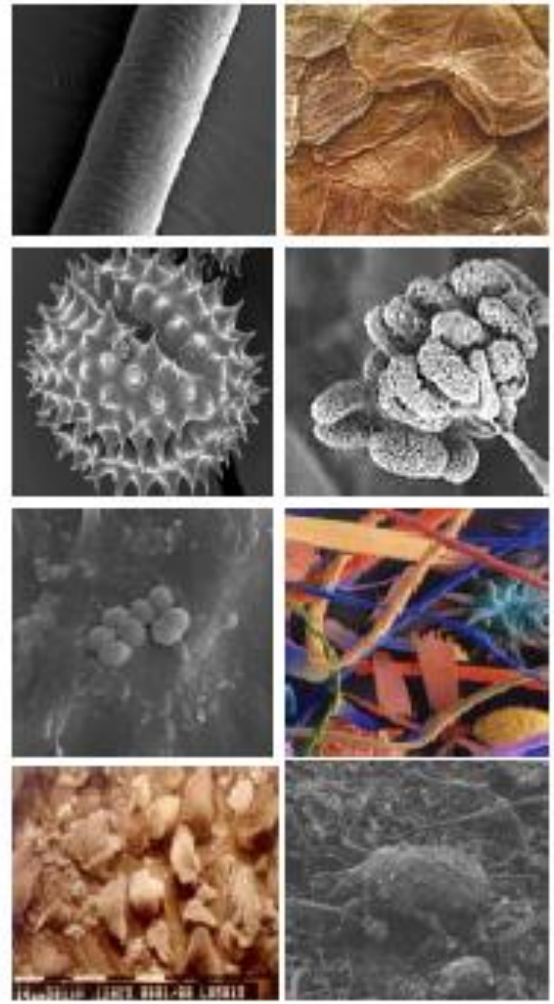
Common Particulate Contaminants

Contaminant Type	Size (µm)
Human hair	70-100
Human skin flakes	0.4-10
Pollen	5-100
Mold	2-20
Smoke	0.01-1
House dust	0.05-100
Bacteria	0.25-10

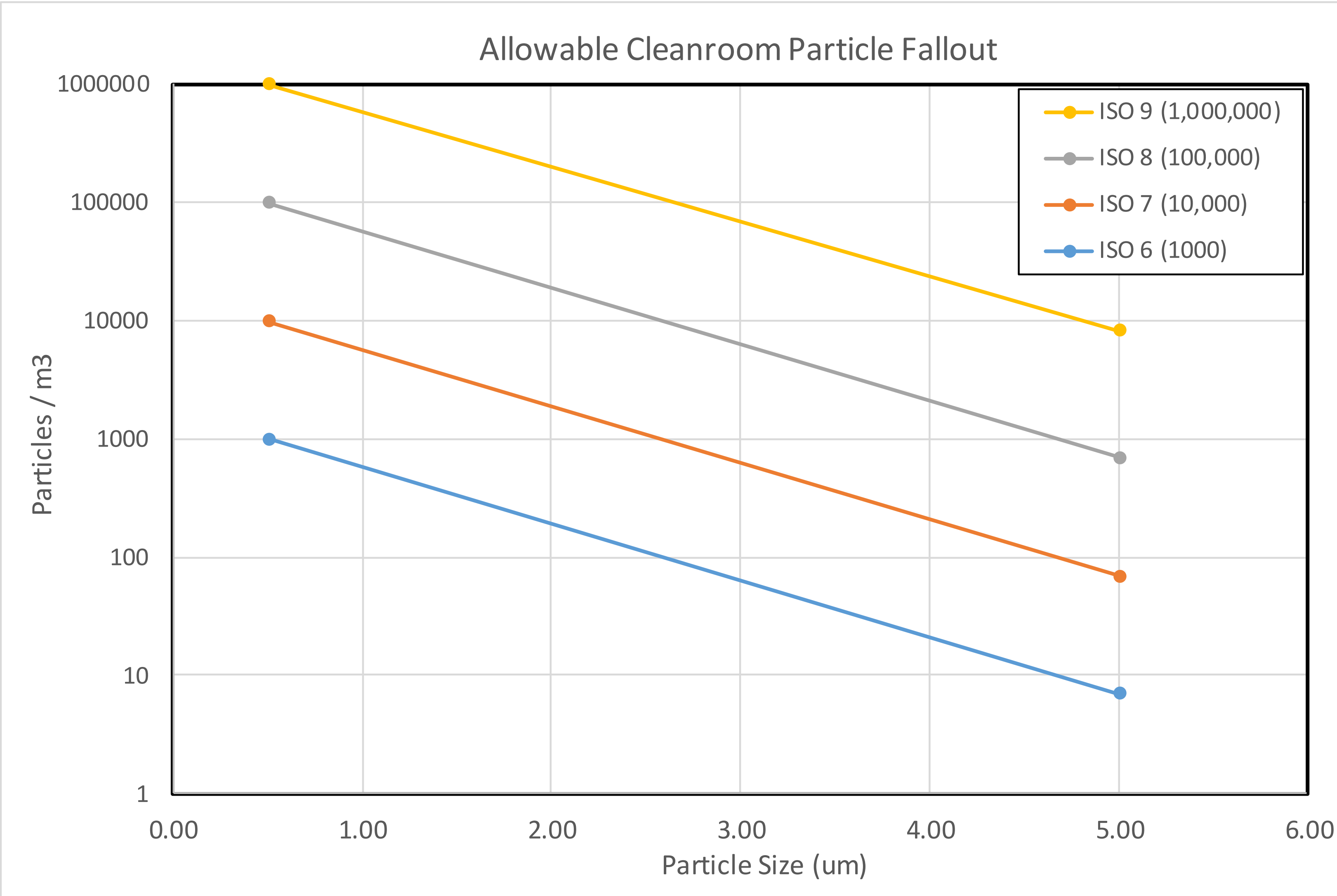
Sizes of a number of common cleanroom contaminants

Activity	Rate (>0.3µm/min)
Motionless/Sitting/Standing	100,000
Head/Arm/Neck/Leg motion	500,000
All above with foot motion	1,000,000
Standing to Sitting Position	2,500,000
Walking (2 mph)	5,000,000
Walking (3.5 mph)	7,500,000
Walking (5 mph)	10,000,000

Particle generation rates for a number of human activities



Contamination Sources and Mechanisms



Spacecraft Integration Contamination Threats

- **Integration:**
  - **People, tools, environments, transport; surface contact with contaminated GSE/EGSE: oils, grease and Solithane, thread locking adhesives, antistatic agents, inks**

- **Environmental Exposure During Testing:**
  - **Poor thermal-vacuum stability: Plasticized polymers**
  - **Sub-standard workmanship: Off-nominal cure of potting and sealants**
  - **Insufficient requirements/specification: Off-the-shelf commercial products**

- **Testing:**
  - **Thermal vacuum environments, vibration; shedding due to abrasion: friable foams, marginal surface adhesion of surface conversion coatings; GSE/EGSE**

Contamination Control – Maintaining Hardware Cleanliness

How do you control contamination during spacecraft assembly?

- Contamination Control.
  - Limits contamination-induced performance degradation of engineering and science payload to predetermined allowable levels.
- Start with the End in Mind –
  - Identify contamination sensitive components.
  - Determine end of life allowable contamination levels.
  - Work backwards and allocate a contamination budget for each phase of the Project that ensures end of life requirements are met.
- The contamination budget ultimately determines what contamination controls are required during spacecraft integration and test.
  - Control and monitor the Spacecraft assembly environment to stay within the allowable contamination budget limit.

Contamination Control – Maintaining Hardware Cleanliness

- Maintaining hardware cleanliness can be achieved thru appropriate handling, bagging, purge (if required), and storage.

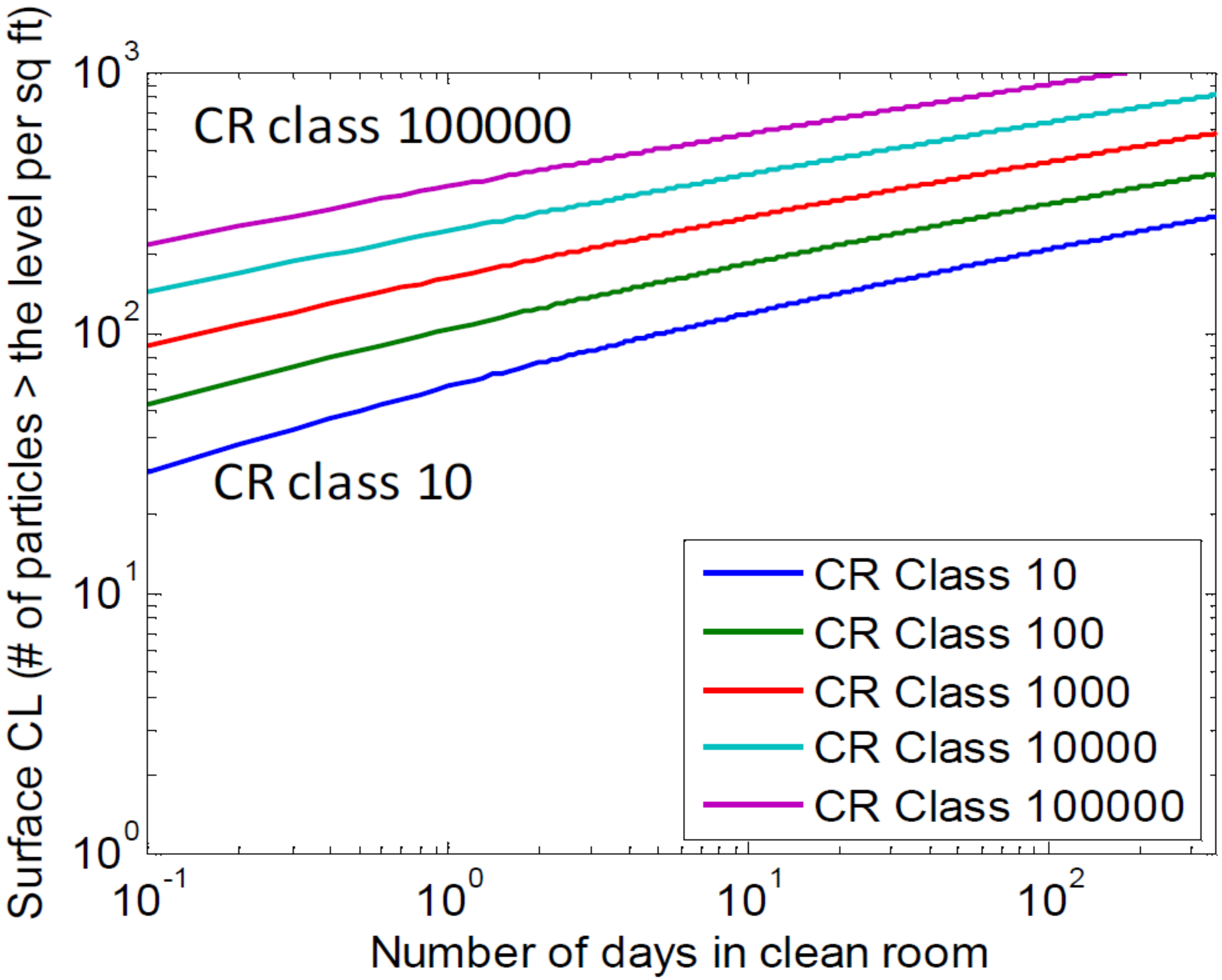
- Handling
  - Standard JPL Gloves: Ansell Nitrile Gloves
- Bagging
  - Standard JPL Bagging Material: CP-stat-100, 3M SCC 1000 Static Shield Bag (contact transfer PCL200, 0.03 ug/cm2 dry contact transfer)
- Purge
  - Inert gas, usually nitrogen.
- Hardware Storage
  - Shipping container or cleanroom

- If appropriate measures are implemented to preserve surface cleanliness, the hardware may be stored indefinitely without invalidating cleaning, and bakeout/certification

Contamination Control - Cleanrooms

- **Final spacecraft assembly at JPL typically takes place in the ISO 7 (Class 10,000) Spacecraft Assembly Facility (SAF)**
- **All equipment must be properly cleaned and cleared by Contamination Control prior to being moved into a cleanroom.**
  - **Observe restrictions or prohibited items; maintain cleanliness level in effect**
  - **Use cleanroom bagging where appropriate**
- **When sharing a cleanroom between multiple hardware items, the most contamination sensitive hardware in cleanroom drives garmenting protocols**

Cleanroom Fallout Impact on Surface Cleanliness



Contamination Control – Cleanrooms

- Typical Approved Materials
  - Cleanroom papers, notebooks, pens
  - Cleaned EGSE with no forced air systems (fans)
  - Cleaned dedicated tooling
  - Approved cleaning agents (alcohols, acetone (<100 ml))
  - Kapton tape with acrylic adhesive
  - Cleaned hardware (per Project requirements)
  - Approved ESD bags (metalized)
  - Nitrile gloves
  - Teflon wires, hoses properly cleaned

Note: Any material cleaning must follow defined cleaning procedures and be inspected and approved prior to entry into cleanroom

- Typical Banned Materials
  - Cardboard, non cleanroom paper
  - Food and drink
  - Cosmetics, perfumes, deoderants
  - Computers, forced air equipment except by approved use and cleaned
  - Silica gels, bags (typically used as desiccants)
  - Masking, insulation, cellophane tapes
  - Silicone adhesive tapes (including Kapton)
  - Oils and lubricants unless approved in type and quantity
  - Bubble wraps
  - Black or pink ESD bags
  - Open cell foams
  - Powders, aerosols, DOPs
  - Non-HEPA vacuum cleaners (non-cleanroom approved, non-certified)
  - Non-approved solvents (ask first)

Contamination Control - Personnel

- **People and the activities they accomplish pose the greatest contamination generation and transfer hazards; they also offer the best contamination control mechanisms by exercising contamination awareness and control/remediation practices.**

- **All personnel must complete cleanroom orientation prior to entry and be trained on the tasks they will perform.**

- **All personnel must be gowned properly before entering a cleanroom and working on the Spacecraft**
  - **Smock, bunnysuit, hoods, hair covers, face masks, beard covers, gloves**
  - **The garments protect the cleanroom and spacecraft from you**
  - **Gloves – Need to be aware of touching anything that will contaminate the gloves and creates a contamination transfer hazard.**

Cleanroom Garment Protocols

Garment / Cleanroom Class	300K	100K	10K	1K	≤1K	100 Flow Bench
Smock	M	M	NA	NA	NA	X
Shoe covers	O	M	NA	NA	NA	O
Hair/beard cover	NA	O	M	NA	NA	O
Full Bunny Suit	NA	O	O	M	M	O
Gloves Taped	O	O	M*	M*	M*	M*
NA=Not applicable; O=Optional; M=Mandatory						

A properly worn cleanroom suit can reduce particulate generation by up to 300x

Contamination Control - Testing

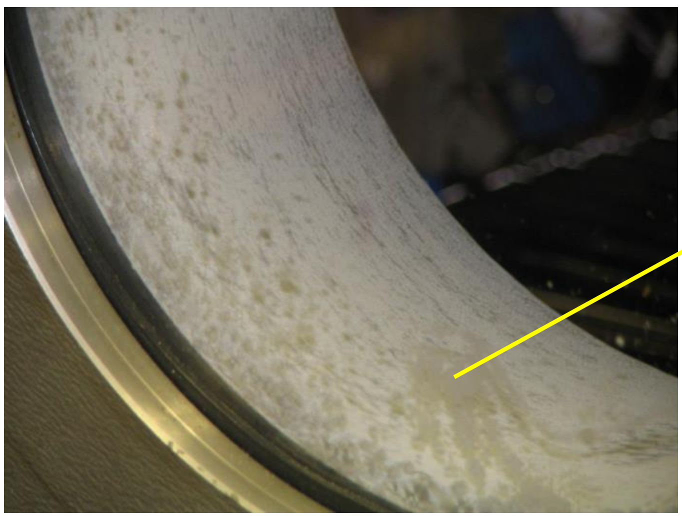
- Most instrument and system integration (ATLO) takes place in certified cleanrooms or controlled work areas, but spacecrafts may also encounter other environments during Electrical, Mechanical, and Environmental testing

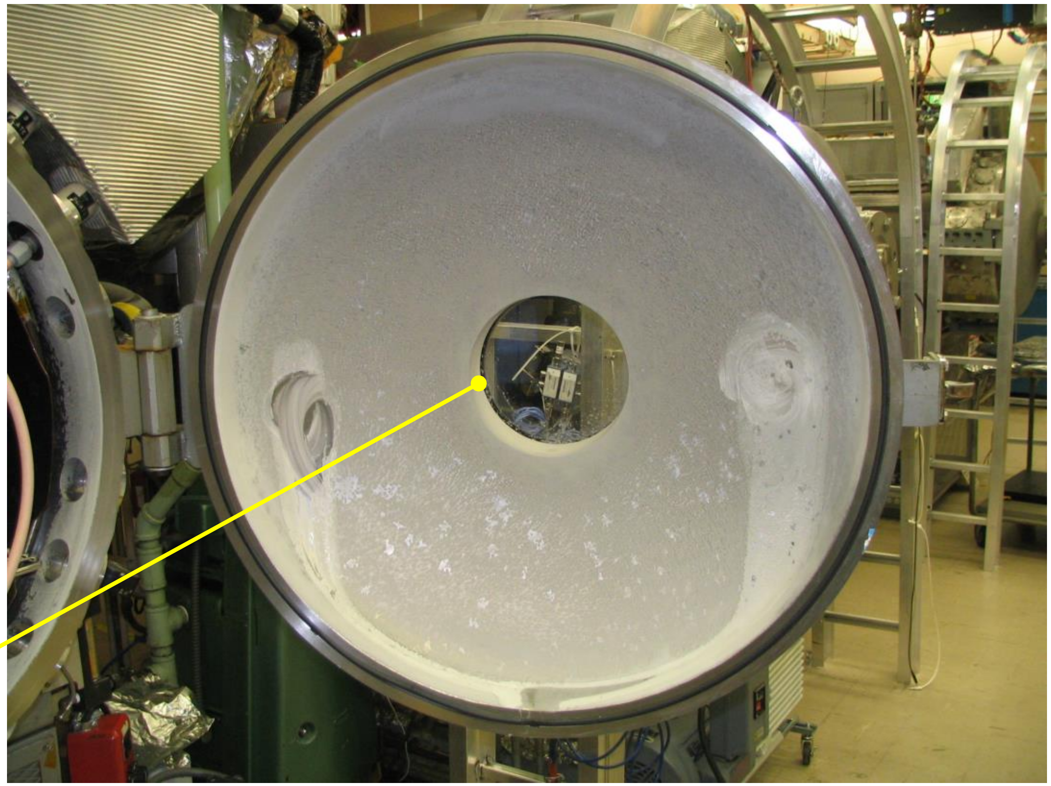
- Test environments typically pose a threat to spacecraft cleanliness and require specific contamination control measures such as bagging or purging to maintain required cleanliness levels

- Vacuum bake-outs are generally required for most spacecraft components and GSE before performing thermal vacuum testing to remove volatile organic compounds that would otherwise be outgassed during thermal vacuum testing and potentially collect on Spacecraft sensitive surfaces

This Could be Your Flight Hardware

Bakeout of an off-the-shelf GSE cable: Electrically, the cable was suitable for the application, but materials of construction were incompatible with the thermal-vacuum environment.





GSE must be as clean as the hardware it interfaces with.

Spacecraft Contamination Control Summary

- Control the environment in which the hardware will reside
- Know what hardware is sensitive and what the sensitivity level is
- Keep contamination sources away from sensitive hardware
- Expose sensitive hardware for the minimum possible time