Designing Spacecraft for Planetary Protection

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3 Generations of Mars Rovers

Gives lots of experience...
Where to Get Started

• **Start with Project Manager Support**
• Design PP into your Project from the very beginning
  – Late design changes cause problems
• Build subsystems/systems in a Class 100000 cleanroom (ISO Class 8) or better
• Regularly clean surfaces using alcohol and cleanroom wipes
  – Both Flight Hardware and GSE
• Apply Dry Heat Microbial Reduction (DHMR) to reduce ‘encapsulated bioburden’ inside components
  – Choose parts and materials that undergo high-temperature processing during manufacture or subsystem assembly
  – MilSpec (e.g.) parts have high temperature *operational* requirements – planetary protection treatment is non-op.
• Use biobarriers to isolate less-clean components and reduce movement of bioburden
  – Seal compartments (this means *airtight*) and apply HEPA filters over vents - allows for pressure changes but reduces particle movement
Contamination Prevention

• People are the biggest contamination generators
• Keeping the hardware clean minimizes large scale recleaning/decontamination activities
  – Clean everything before it enters the cleanroom
  – Use proper clean room techniques and garmenting
  – Keep your tools clean
    • Don’t set them on the floor or other dirty places
    • Don’t let other less-clean projects borrow or handle them

• Clean hardware should be covered as much as possible
  – Ranged from simple draping with clean antistatic material to one of a kind fitted sealable bags during assembly and test operations

• Consider using flight biobarriers
  – Used HEPA filters to isolate hardware
Types of Bioburden

- Surfaces are the easy part
  - Outside surfaces can be cleaned and sampled – when recontaminated, you can reclean and resample
  - Mated surfaces are be cleaned and sampled prior to mating, then the assembled hardware protects them

- What about all those spores buried in internal areas and volumes that cannot be cleaned or sampled?
  - There are specification values for non-metallic materials
    - Electronic piece part volumes
    - Enclosed surface densities
      » Value depends on level of control of the cleanroom
  - Can also measure real life numbers or apply non-standard heat reduction to lower the spec. values
Types of Microbial (Bioburden) Reduction

• Mechanical Removal
  – 0.2um filtration removes particles from liquids/gasses
  – Alcohol Wipes
    • Cleanroom cloth with isopropyl or ethyl alcohol
  – Precision Cleaning
    • Solvent based – usually alcohol or Freon
    • Replace solvent frequently, or you’re just moving dirt...

• Dry Heat Microbial Reduction (DHMR)
  – Standard and non-standard approaches
  – Process specifications given in NPR 8020.12
  – Post-process assays prohibited (assay before treatment)
  – Expanded range: 111°C to 200°C time at temperature
    (<125°C gives 1-3 logs reduction; 125-200°C gives 4-6)
  – Manufacturing processes can give credit to reduce encapsulated bioburden
Contamination Control is Your Friend (mostly...)

- Build Classical (particulate and molecular) Contamination Control into hardware design
  - Particulate and molecular contamination
    - On payload instruments for proper function
    - On total flight system
- Planetary protection (for forward contamination)
  - Biological and organic contamination
    - On all flight hardware that reaches Mars
    - For the protection of the planet for science
    - Critical for life detection experiments
- Overlaps
  - Some but not all methodologies in common
- Disparities
  - May have conflicting requirements
- Work together where possible: e.g., combine CC Bakeouts and PP DHMR
  - Use more restrictive requirements to define temperature, vacuum and time requirements
Spacecraft “Dirt” comes in two forms

- **Particles** — small pieces of organic or inorganic material that are not attached to a surface

- **Non-Volatile Residue (NVR) or Molecular contamination** — deposits of thin films or droplets of organic material that adhere to a surface

- **Sources of particles on spacecraft hardware are same as for any contamination sensitive hardware**
  - Processes that degrade surface finishes: abrasion, friction, corrosion, cutting, heat, UV light, loss of plasticizers
  - Materials that easily shed particles: woven textiles, foams, highly textured surfaces, insulation, etc.
  - Common dust (combination of minerals, fibers, bacteria, mites, etc.)
  - Humans
Particles on Spacecraft

- In space, the particle movement and redistribution mechanisms differ from those normally encountered on the ground
  - Fewer direct forces (wind, air flow disturbances, movement) to move particles around
  - Movement and redistribution are primarily caused by
    - Launch ascent depressurization (Air rushes out of vents)
    - Greatly reduced gravitational forces (Everything “floats” -- No hiding dirt under the carpet or in the corner!)
    - Absence of forces from air
    - Charging
On Earth, particle fallout can be estimated fairly well; in space, estimating redistribution is much more difficult.

In spacecraft hardware, it is often necessary to extend cleanliness requirements for the most sensitive spacecraft surfaces to large areas of the spacecraft to assure that unexpected particle redistributions will not degrade performance.

Particles that were trapped (in cavities, blind holes, corners, etc.) on the ground are liberated in weightlessness and float according to “Murphy’s Law” of redistribution (that is, they go where they can do the most harm!)

Particles floating in the line of sight between optics/inlets and targets are as much a problem as particles on a surface — for example, particles in the line of sight of an attitude control star tracker will appear to be stars.
Cleaning Spacecraft Hardware?
Hardware Design Considerations I

• Choose materials that can be cleaned or sterilized
  – Paints and other coatings
    • Change color; lose thermal properties; flake
  – Lubricants
    • Can melt and run; may lose lubricating ability or become gummy
  – Adhesives
    • Softening of thermoplastics
  – Insulating materials
    • Melt; flake; become brittle

• Choose materials that can be sampled for bioburden assays:
  – Multilayer insulation has small vent holes that trap liquids
  – White thermal paints can flake off with rubbing
Hardware Design Considerations II

• Consider material service temperature limits:
  – Metals
    • Most can withstand DHMR with no problem
      – Formed or shaped thin pieces may assume unwanted new positions during heating
    • But make sure there are no Coefficient of Thermal Expansion issues when heating dissimilar materials with close tolerances
  – Electronics
    • Selecting Electronics
      – Electronics manufactured in a clean room environment
        » Allows for 1 log lower than spec value initial bioburden
      – Products that can withstand the Dry Heat Microbial Reduction process
      – Use Class S/MIL specification parts
        » Take credit for microbial reduction occurring during part burn due to elevated temperature
Bakeout/DHMR Considerations

• Bakeout costs for critical flight hardware requiring round the clock manning are typically:
  $3000 per day for small chambers
  $5000 to 10000 per day for medium chambers
  $8000 to 12000 or more for larger chambers

• Later in schedule that unplanned bakeout is required the more expensive: Bakeout cost + cost of marching army twiddling thumbs while bakeout continues + snowball effect if is a subassembly that causes a schedule slip at a higher level of assembly

• Design out problem children (silicone gaskets, organics that are thick (diffusion limited)), seal or contain (over tape), or bake them out at lowest level of assembly at highest temperature possible
Designing for Cleanliness I

- **Material Selection**
  - low outgassing
  - minimize quantity of organics (minimize thickness, bond lines)
  - bakeout under vacuum to reduce outgassing
  - low particulating (minimize / avoid bare aluminum, woven textiles, Velcro)

- **Configuration**
  - keep sources of organics out of line of sight of optics/inlets
  - get electronics out of optic cavities whenever possible
  - keep main MSL rover enclosure sealed
  - isolate hazards from sensitive items (e.g., barriers, baffles, doors, covers, vents, etc.) and direct venting into non-sensitive areas

- **Venting**
  - direct effluent away from apertures/inlets

- **Use molecular absorbers**

- **Minimize number of potential vents / unintentional vents**
Designing for Cleanliness II

- Contain (seals, over taping, hermetic boxes, etc.)
- Thermal Control
  - sources lower temperature than collectors (sensitive surfaces)
  - provisions to heat contaminated surfaces so they release condensed contaminants
- UV
  - Avoid / minimize UV impingement (direct sun or albedo) on optics or surfaces in line of sight or near of optics/sensitive surfaces
- Atomic Oxygen
  - avoid use of silicones in orbits with significant atomic oxygen
- Plume / vents
  - direct all thruster plume and backscatter away from sensitive surfaces
  - use high purity fuel (usually most effective)
- Lubricated mechanical devices
  - eliminate, seal, minimize; isolate from sensitive surfaces / volumes
Hardware Acceptance

• Look out for surprises:
  – Solder that melts at lower than hardware design temperature
  – Complex hardware from multiple contractors where one piece cannot meet requirement
    • Not included in bid package
    • They didn’t know or think it was a critical requirement
    • *Assumed they would get a waiver* – *they won’t.*
  – Unplanned late additions to the flight system
  – Hardware from outside vendors

Track supplier processes carefully to make sure hardware is handled correctly!
Consider Access to Hardware when Planning Assay Collection...

Effective communication with ATLO managers and assembly personnel facilitates compliance greatly!
Biosampling

- **Wipe Samples**
  - Sterile polyester cleanroom cloth with distilled water or PP rinse solution

- **Swab Samples**
  - Cotton
  - Polyester
  - Distilled water

- **Supplemental Assays**
  - Rapid techniques used to determine presence of microbial contamination to quickly assess if cleaning or other processing is needed prior to NASA Standard assay
    - Total Adenosine Triphosphate (t-ATP)
    - Limulus Amebocyte Lysate (LAL)
    - Rapid Spore Assay
Sampling

• Many samples are taken over the life of a mission
• NASA Standard Assay
  – Goal is to sample 10% of the surface area to get statistically significant results
• Mars Polar Lander had more than 1200 samples
• MER (2 Rovers) had a total of 3766 swab and 529 wipe samples
• MSL had 3472 swab and 1283 wipe samples (including controls)
  – 47,997 petri dishes
  – Bigger spacecraft meant larger components which allowed use of more wipes and fewer swabs
  – ATP assay was used to assess spacecraft cleanliness prior to final NASA Standard Assays
Late Changes Cause Problems

- Enlist Hardware Leads and Designers to help identify potential challenges or issues to look for:
  - Reworked hardware after closeout cleaning or DHMR
    - Electronic boxes
    - MLI
  - Re-tested hardware
    - Contamination Control sampling
    - Cameras
      - HEPA filters
- Late communication of hardware configuration or handling changes can cause major issues in meeting PP requirements
Encapsulation… and after

• Payload Launch Fairing (PLF)
  – PLF is very large
  – Potential recontamination threat
  – On MSL PLF was thoroughly cleaned and sampled
  – Sampling indicates that the cleaned PLF had a spore bioburden level of less than 4 spores/m²

• Air supply ducting confirmed that the HEPA/ULPA filtered air was very clean with a worst case total bioburden level of less than 0.5 total colony forming units per 100 liters of air.
  • Air samplers can be used to evaluate potential for delivery of bioburden
MSL inside PLF

- Payload Launch Fairing
  - MSL Requirement of <1000 spores per m²
  - PLF was huge
    - Over 400 m²
  - Cleaning with alcohol wipes was very effective at reducing spore levels
Records

- Planetary Protection Equipment List
- Organic Materials Inventory/samples
- Biological and classical contamination control as actually practiced
- Hardware treatment history
  - Data records of any microbial reduction
    - 18, 3 inch notebooks for MSL
- Assay results
  - Data Base, photographs and statistical treatment
- Hardware movement after assays or microbial reduction process
- Recontamination threat mitigation as actually practiced
- PP required plans, documents and reviews from Categorization Request to End of Mission Report
Issues/Problems

• Late evolving systems or subsystems must be followed to ensure PP requirements don’t get lost

• Laboratory equipment malfunctions/breakdowns
  – Quick repairs or having backup equipment available
  – Buying and certifying new equipment takes time

• Other requirements on hardware may impact or conflict with PP requirements/sampling
  – Environmental testing
  – Hardware rework
  – Vertical Integration Facility

• Lots of samples means long hours, weekend and holiday work for the PP team
  – Build in time for team to mentally and physically rejuvenate
Points to Remember

• Introduce PP into the Project and instrument design from the beginning
  – Confer with PP Lead (Be Assertive Up Front!)
  – Incorporate an approach to PP compliance into design
  – Example: Design DHMR into project elements
    • Chose materials carefully
    • Be especially mindful of embedded and shielded components
    • Chose microbial reduction approaches carefully
    • Stay on top of changes to hardware and processes
    • Implementation methods and required activities may impact other assemblies and subsystems
  – Supply PP Lead with information and material samples
  – Get your input into the PP Implementation Document
Controlling Contamination

Most Important Things to Remind Project Personnel

• Cleanliness is EVERYONE’s responsibility

• Design in cleanliness through material selection and process control

• Every time YOU touch or clean components, mission success is in YOUR hands!
Five Strategies for Integrating Cleanliness

(In Order of Preference)

• Forbid
  – Forbid use of contaminating materials and processes (wood, silicones, sanding, etc.)

• Limit
  – Limit quantity / duration of contaminating materials / processes

• Contain
  – Place containment barriers around contaminant sources

• Protect
  – Completely cover and protect sensitive surfaces

• Remove
  – Remove unavoidable contaminants during and after all processes

PREVENTION BEATS ELBOW GREASE
Facilities/Cleanroom Cleanliness

• General reminders
  – Avoid unnecessary movement
  – Do not touch face
  – Change gloves after exposure to solvents
  – Change gloves when they become soiled
  – Keep number of people who have access to work bench or hardware to a minimum
  – Clean whenever you notice something is dirty
  – Keep tools etc. put away (much harder to clean around clutter)
  – VACUUM / WIPE WORK SURFACES OFTEN
Points to Remember (continued)

• Be a student of PP history

• Be innovative in finding ways to reduce spore bioload
  – Look at the “big ticket items” to achieve maximum reduction

• Record-keeping is required for launch approval by Planetary Protection Officer, as well as for Post-Launch, possible Extended Mission, and End of Mission Reports
Compliance Does Not End With Launch