Building a Clean Spacecraft Tips and Tricks

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Pre-decisional – for planning and Discussion Purposes Only

Agenda

- Where do you start?
- Microbial Reduction
- Dry Heat Microbial Reduction (DHMR)
- Cleaning
- Hardware Design
- Sampling
- Embedded Bioburden
- PP Studies
- Recontamination Prevention
- Points to Remember

Where we start a mission

- Start with Project Manager Support
- Ideally design PP into your Project from the very beginning
- Develop a concept, design and drawings
- Example - Structure
  - Get your block of metal
  - Send to the metal shop for fabrication
  - Clean the metal part
    - Degreasing
    - Precision cleaning

  Or
  - Get honeycomb material
  - Manufacture honeycomb structure
  - Dry Heat Microbial Reduction
    - Cover edges

  - Protect from recontamination

Where we start a mission

- 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
- Dry heat Microbial reduction for encapsulated (internal) components
- Biobarriers used to isolate spores and prevent movement
  - Sealed - airtight
  - HEPA filters - allows for pressure changes but prevents spore transportation

Where we would start JEO

- JEO would need to use a technique to sterilize the spacecraft
  - Dry Heat Microbial Reduction
  - Jovian radiation environment
  - Other modalities
    - Surface
      - VHP
      - UV
      - Chemical
    - Penetrating
      - Irradiation
- Incorporate approaches into design
  - At a minimum, ALL hardware must be able to withstand 110 -125 C in partial vacuum or GN2
- Make sure approach is compatible other systems/subsystems
- Looking at a possible System level DHMR similar to what was done on the Viking Landers

Where we would start JEO

- 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 (forward contamination)
  - Biological and organic contamination
    - On all flight hardware that reaches another planet/moon of biological interest
    - For the protection of the planet for science
    - PP interest in life detection
- Overlaps
  - Some but not all methodologies in common
- Work together to combine CC Bakeouts and PP DHMR where possible
  - Use more restrictive requirements to define temperature, vacuum and time requirements

Microbial Reduction

- Mechanical Cleaning
  - Alcohol Wipes
- Dry heat microbial reduction
  - Process specs exist
  - No assays required (but pretreated assays may be used)
  - Optimal in range 110°C to 125°C (50 to 5 hours = 1 log reduction)
- High Temperature DHMR
  - Actual temperature/time/d-values still under discussion
  - Relative humidity effect seems to end at 135C
  - Data indicates effective on hardy organisms
  - Higher temperatures may be used with approval of PPO
- Hydrogen peroxide plasma
  - Requires bioindicator or proxy
- Other modalities (radiation, UV etc.)
  - Require validation

Dry Heat Microbial Reduction

- Two critical issues with dry heat microbial reduction
  - How to monitor and verify absolute humidity
  - How to monitor and verify minimum temperature
    - Coldest surface if only surface burdens accountable
    - Coldest point in volume of any non-metallic if encapsulated burden requirements apply
- Standard
  - Controlled temperature, humidity and time
    - Use lowest thermocouple temperature
  - "Dry" is "an absolute humidity corresponding to a relative humidity of less than 25 % referenced to the standard conditions of 0 C and 760 torr pressure"
    - Practical approaches
      - Use vacuum of of 1 torr or less pressure
      - Dry nitrogen purge (filtered)

Dry Heat Microbial Reduction

- Non-Standard
  - High temperatures
    - Greater than 125 C
  - Uncontrolled humidity
    - Cure cycles
      - Adhesives
      - Coatings
      - Ceramic insulation
- Current PP practice does not allow for more than a 4 log total reduction
  - under review based on new data produced at JPL that supports policy revision that might allow 6 log or more reduction to be accounted

Cleaning

- Precision Cleaning
  - Solvent based – usually alcohol or freon
  - Issue - Must replace solvent frequently
- Alcohol Wipes
  - Cleanroom cloth with isopropyl or ethyl alcohol
  - Mechanical removal process
  - Issue - Some commonly used paints cannot be wiped
- 0.3 micron filtration
  - Fluids
    - Freon in cooling loop
  - Purge gasses
    - Nitrogen
  - ULPA filtered air on transporter and at the Launch Complex
- Pre-sterilization spore density needs to be less than 300/square meter

Hardware Design

- Choose materials carefully to withstand chosen sterilization process(es)
  - Paints and other coatings
    - Change color
    - Lose thermal properties
    - Flake
  - Lubricants
    - Can melt and run
    - May lose lubricating ability
    - Become gummy
  - Adhesives
    - Softening of thermoplastics
  - Insulating materials
    - Melt
    - Flake
    - Brittle

Hardware Design

- Material service temperature limit
- 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

Hardware Design

- 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
  - Unplanned late additions to the flight system
    - Ground wires
    - Cache on MSL
      - Later removed but was an issue for quite a while
- Choose materials that can be cleaned
- Choose materials that can be biosampled

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)

Sampling

- Many samples are taken over the life of a mission
- Goal is to sample 10 % of the surface area to get statistically significant results
- Mars Polar Lander had more than 1200 samples
- On MER (2 Rovers) we had a total of 3766 swab and 529 wipe samples
- To date on MSL we have taken 1580 swabs and 373 wipe samples with almost 1 ½ years to go!
  - Bigger spacecraft means larger components which allows us to use more wipes and fewer swabs

Swab Sampling

Wipe Sampling

Embedded Bioburden

- Surfaces would be the easy part
  - Outside surfaces could be cleaned, sampled and even if a bit of recontamination occurs, you could reclean and ultimately the Jovian radiation fields would take care of it
  - Mated Surfaces would be cleaned and sampled prior to mating
- What about all those spores buried in internal areas and volumes that could not be cleaned or sampled?
  - There are specification values
    - For non-metallic materials
      - Electronic piece part volumes
      - Enclosed surface densities
        - » Number is dependent by level of control of the cleanroom
  - What could be done to get a real life numbers lower than the spec values?

MSL PP Studies

- Due to large size of the hardware specification values gave an extremely large spore burden
  - Hydrazine
  - Carbon Fiber
  - Thermal Paint
  - Adhesive
  - Insulation
- Sounds simple but getting there requires creativity, perseverance and lots of hard work!

Sampling & Grinding of Carbon Fiber

Suspension Processing

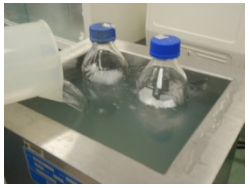
Cured Paint and Adhesive Grating Assays

A. Experimental Design –

Wiped cured paint and adhesive using sterile wipes and 2-propanol.

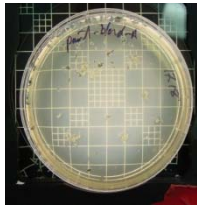
Grinding – Household box grater, small grading plane

~40g was distributed between three 500mL bottles, 300mL PP rinse solution added



Sonicate 2 min. (NASA HDBK 6022)

80°C, 15'



175mL (pf=0.58) assayed for spores

B. Controls –

- The positive controls consisted of cured that was spiked with a known amount of *Bacillus atrophaeus* (BSN) ATCC 9372 spores.
- For each batch of media poured, a set of six media controls (4 non-spiked, 2 spiked) were analyzed.
- The negative control was a buffer control – PP rinse solution

Study Results

Study	Specification Value	Final Bioburden
Hydrazine Vapor	30 spores/cm^3	0
Carbon Fiber	30 spores/cm^3	2.37 spores/cm^3
Thermal Paint	30 spores/cm^3	2.16 spores/cm^3
Cured Adhesive	30 spores/cm^3	0.13 spores/cm^3
Insulation	30 spores/cm^3	0.012 spores/cm^3

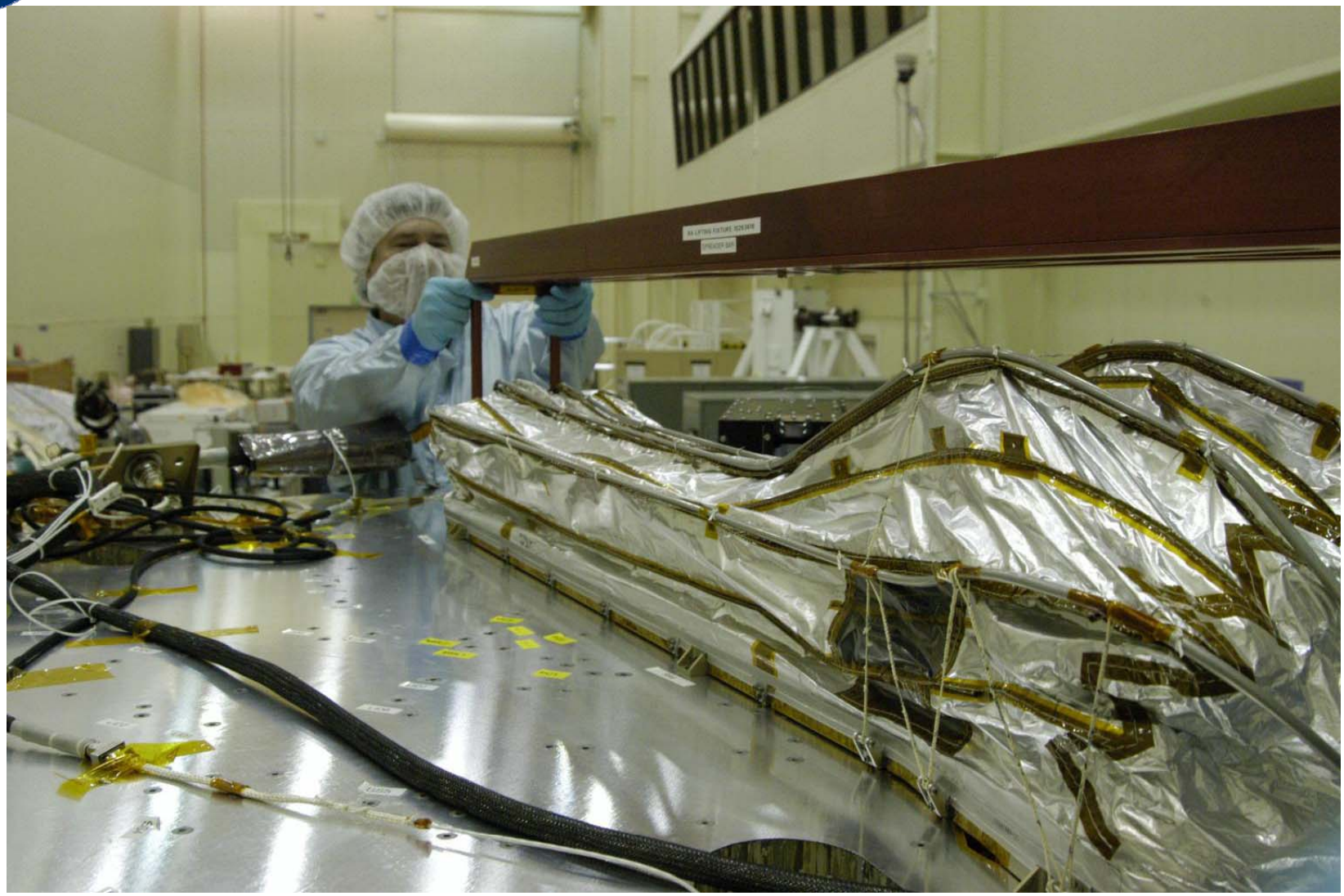
Focused JEO Study Activities

- Studies like those performed by MSL are of immense value to a project in meeting PP requirements
- Build on the legacy of previous missions
- Use materials with known low bioburden levels if possible
- Find the proposed JEO non-metallic volume “tall tent poles” and focus on studies which would deliver the maximum reduction in spec value bioburden
- Work with the PP lead to obtain acceptance for the exception from the NASA PPO

Contamination Prevention

- People are the biggest contamination generators
- Keeping the hardware clean minimizes large scale recleaning/decontamination activities
  - Clean <u>everything</u> before it enters the cleanroom
  - Use proper clean room techniques and garmenting
  - Keep your tools clean
    - Don't set them on the floor
- Clean hardware should be covered as much as possible
  - Ranges from simple draping with clean antistatic material to one of a kind fitted sealable bags during assembly and test operations
- Consider using flight biobarriers
  - Sterilize instrument or other hardware inside of biobarrier

Phoenix Spacecraft Robotic Arm in Sealed Bio-Barrier



Recontamination Prevention

- Definition- undesired increase of burden after value established by assay, microbial reduction spec, or clean room burden spec, or clean room spec, which invalidates the established value

Threats	Recommended Practice
fallout in subsystem areas after microbial reduction; clean room fallout*; clean room handling	packaging; self-protection (int surfaces); assay at last access; draping; remove before flight covers; critical PP handling; system assay just before transport canister
rework in clean room	
exposure of assayed int. surfaces to handling	critical PP handling; reassay
exposure of microbially reduced surfaces to handling	critical PP handling; clean (IPA wipe) and assay
rework out of clean room	
exposure of assayed int. surfaces to handling	prefer packaging; ops on clean bench; or critical PP handling; reassay
exposure of microbially reduced surfaces to handling	packaging; ops on clean bench; & assay

*yes, there is fallout in clean rooms ☹

Recontamination Prevention
(cont.)

Threat	Recommended Practice
system transport to pad	canister interior clean & assay; HEPA purge
pad white room fallout	limits on leaving fairing access ports open; HEPA a/c air (both room and fairing); spot assays through fairing access ports
launch recontamination	fairing interior clean & assay; analysis of worst case transfer; prefer HEPA aeroshell depress vent;

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
    - Currently 10, 3 inch notebooks for MSL (and growing!)
- Assay results
  - Data Base 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

Points to Remember

- Introduce PP into the Project and instrument design in the beginning
  - Work with Project PP Lead
  - Design DHMR into all project elements
    - Chose materials carefully
    - Be especially mindful of embedded and shielded components
    - Chose microbial reduction approaches carefully
- Supply PP Lead with information and material samples
- Be innovative in finding ways to reduce the spore bioload
  - Look at the “big ticket items” to achieve maximum reduction
- Record-keeping required for launch approval by Planetary Protection Officer and for End of Mission Report*

* PP compliance for Project does not end with launch

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