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Best Practices and Protocols in Cleanroom Processing for Contamination and Biological Sensitive Spacecraft

T. Arakelian and J. Benardini, Jet Propulsion Laboratory, 2017

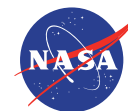
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Best Cleanroom Practices and Protocols for Contamination and Biological Sensitive Spacecraft



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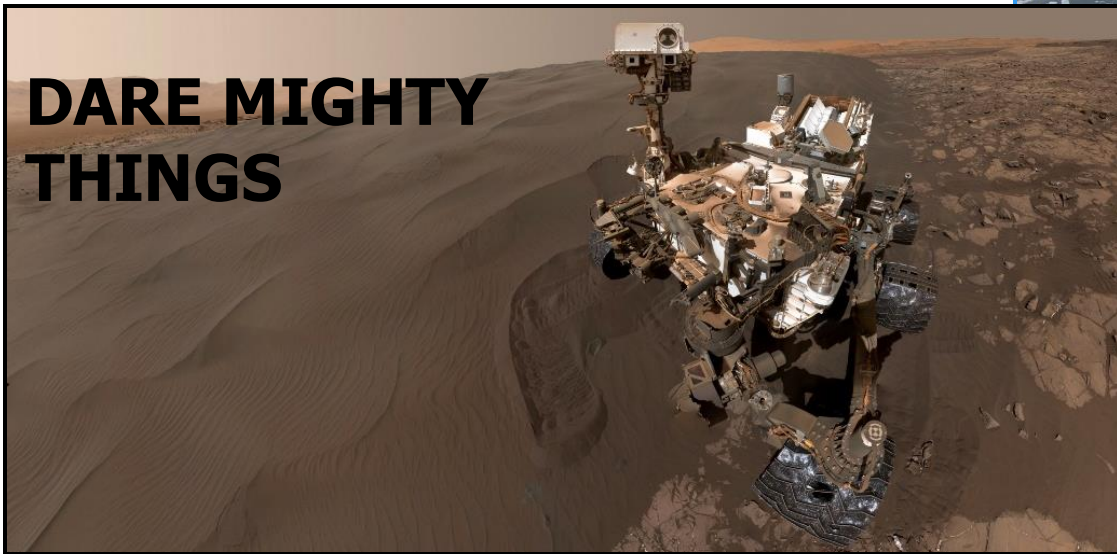
- Has over 100 cleanrooms
- Varies from ISO 1 to ISO 8.5



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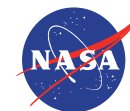
Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

Some are for research



Others are for spacecraft and instrument assembly

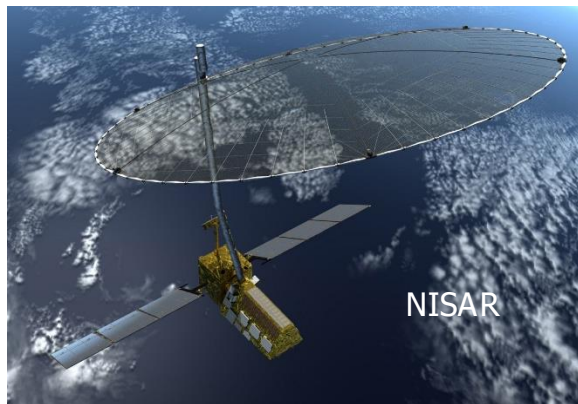
Making uniform Contamination Control (CC) requirements complex and difficult



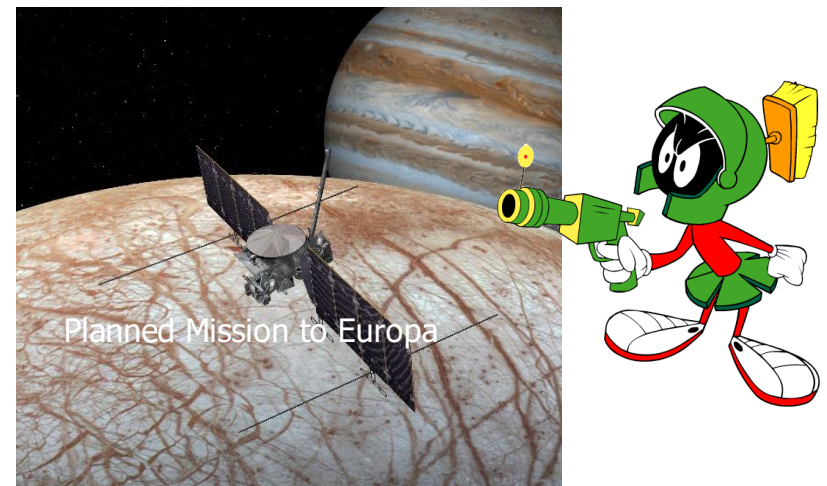
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Some spacecraft slated to study the Earth

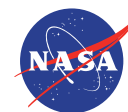


Others will explore bodies that have the possibility of harboring alien life



With varying CC requirements.

And additional Planetary Protection (PP) requirements for some



Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

Technical Facilities Management (TFM)

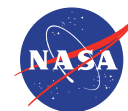
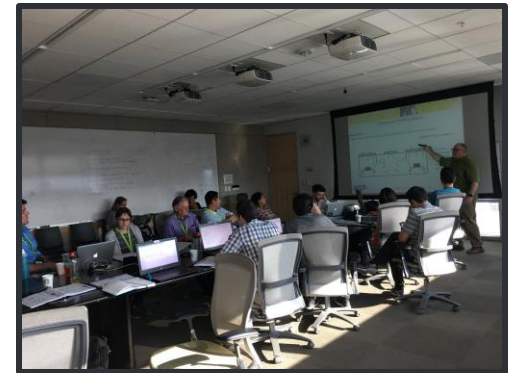
- Team of scientists, engineers, technicians and administrative staff
- Provide cleanroom cleaning, certification, garment service, disposable garments (shoe covers, gloves, etc.), new cleanroom design and construction consulting to Facilities, and more
- Collaborate with process CC engineers, PP scientists, missions and cleanroom managers and users



Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

Training and expertise

- TFM:
 - ISO 14644, IEST RP's, ASTM
- PP:
 - Biological contamination control
 - JPL cleanroom managers, users
 - Cleanroom Fundamentals
 - Electrostatic discharge (ESD)
- Mission specific biological training
 - ATLO specific training (e.g. MSL, InSight)
 - Tailored, site specific training (e.g. Mars 2020 avionics)
 - Launch Operations training for project supporting personnel (e.g. InSight)



Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

“We are in this together”

- Training includes protocols for users
 - Know who to ask
 - Is a given material ok in the cleanroom?
 - Teaming

In-class training is complete,
now what?

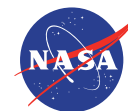
- Allowed items
 - Poster, list or pictorial
 - Lockers, hangers, etc.
- Commonly discouraged activities
 - Poster, list or pictorial

Do's:

- Make sure you have the proper garments for the area you are entering
- Use only Bic roller-ball pens and Sharpie markers
- Wear cleanroom gloves when working with critical hardware, and tape the wrists
- Clean all hardware, tools, laptops and cell phones before entry
- Work areas must be neat and orderly at the end of each shift
- Walk slowly – Maintain deliberate actions and behavior

Don't:

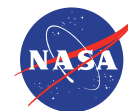
- Never eat, drink or chew gum in the cleanroom. Don't bring food or drinks into the Gowning Area or Airlock.
- Don't wear cosmetics, perfume or cologne in the cleanroom
- Never bring cardboard or unexposed wood into the cleanroom.
- Cleanroom paper use required in Critical Cleanrooms, and recommended in other grades of cleanroom
- Never use unapproved cleanroom wipers, pens or markers
- Never expose any skin or open the cleanroom garment in the cleanroom
- Never touch your face with cleanroom gloves on
- Don't enter a cleanroom if you are ill



Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

Communication Flow

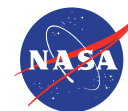
- Communication - project to facility engineers.
- PP and CC engineering key.
- Planning, development and implementation.
- Timely communication of performance results for any adjustment.
- Establishing cleanroom working group.
 - Reporting activities daily.



Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

Enhanced Cleanroom Protocols and Procedures

- Biologically sensitive missions:
 - CC, PP and TFM team work:
 - Increased gowning protocols.
 - Increased cleaning protocols.
 - Tighter controls in gowning room flow.



Best Cleanroom Practices and Protocols

| | | Non Bioburden Mission | MER | MSL | InSight – Flight System, Denver, prior to 2016 storage |
|---------------------------------|---|-----------------------|-----|-----|--|
| General Facility Considerations | ISO Class Assembly | 8.5 | 8 | 8 | 8 |
| | Bioburden Control Area | - | - | - | ✓ |
| | Utilization of Sporicide | - | - | - | - |
| Anteroom/ Garment Prep | ESD-like shoe covers | - | ✓ | ✓ | ✓ |
| | Hairnet | - | ✓ | ✓ | ✓ |
| | Face Masks | - | - | ✓ | ✓ |
| | Surgical Face Masks | - | - | ✓ | - |
| | Street Clothes Allowed | ✓ | ✓ | ✓ | ✓ |
| | Cleanroom Underwear | - | - | - | - |
| | Personal Electronics Allowed | ✓ | ✓ | ✓ | ✓ |
| | Personal Hygiene Plans | - | - | - | - |
| | Medical Screening | - | - | - | - |
| Garmenting | Smocks | ✓ | ✓ | - | - |
| | Full Bunny Suits | - | - | ✓ | ✓ |
| | Show Covers | ✓ | ✓ | ✓ | ✓ |
| | Gloves | - | ✓ | ✓ | ✓ |
| | Taped Gloves | - | - | ✓ | ✓ |
| Processing of Hardware | Solvent Cleaning | - | ✓ | ✓ | ✓ |
| | Sterilized Tooling | - | - | - | - |
| Biological Performance | Average Spores m ² on hardware surface | ~1,600 | 74 | 36 | 124 |



Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

Cleanroom set-up

- Gowning room:
 - Shoe cleaners
 - Tack-mats
 - Defined dirty and clean sides
 - Gowning & de-gowning instructions
 - Cleaning supplies for small items
- Airlock
 - Defined dirty and clean sides
 - Cleaning supplies
- Air shower
 - Number of people allowed

Cleanroom Gowning Process – Full Suit



1. Place disposable shoe covers over each street shoe



2. Put on a face mask and head cover. All hair must be completely covered



3. Put on a hood, turning it right side out. Adjust the neck and head snaps for a snug fit



4. Put on the coverall, assuring that the clean garment does not touch the floor



5. Make sure that the hood apron is tucked into the coverall at the neck



6. Snap the neck and legs closed to contain loose particles



7. Put on the boots. Adjust the straps for a snug fit



8. Check your garments using the mirror



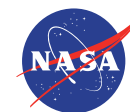
9. Put on clean gloves. Tape the wrists if possible.



10. Step on the tack mat several times



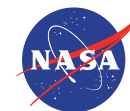
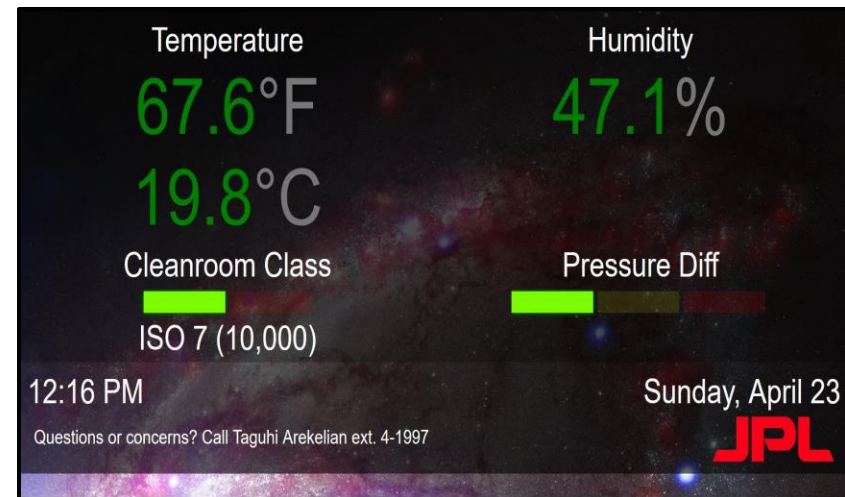
11. Enter the air shower, slowly turn 360 degrees



Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

Cleanroom monitoring

- Certification
 - Cleanrooms
 - Cleanroom HEPA vacuum cleaners
 - Frequency
- Remote continuous airborne particulate, temperature, relative humidity and differential pressure monitoring
 - Reduced frequency of certification
 - Reporting to customers



Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

Cleanroom monitoring (continued)

- Witness plates
 - Particulate
 - Organic
 - Biological coupons (PP)

- Walk through's
 - Quarterly
 - Check on housekeeping

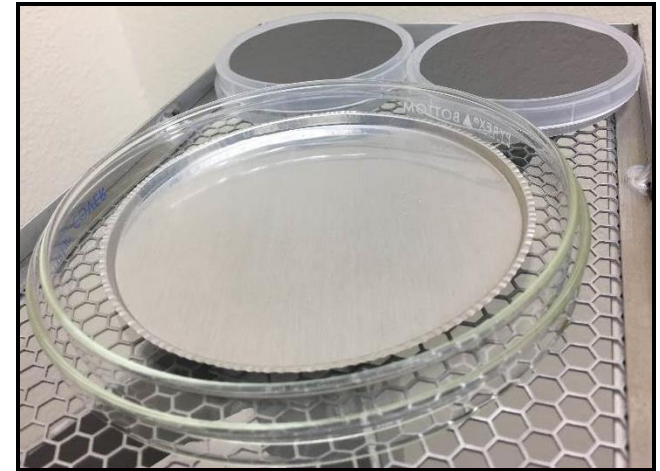
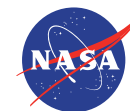


Table 1. Witness Plates - Low Volatility Residue Deposition

| Sample | Chemical Functional Group | Total Amount ($\mu\text{g}/\text{cm}^2$) |
|--------------------|---------------------------|--|
| South East | AHC | < 0.02 |
| North East Corner | AHC | < 0.02 |
| North Middle Shelf | AHC | < 0.02 |
| South Middle Shelf | AHC | < 0.02 |

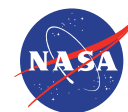
| Sample | Particle Size Range (μm) and Counts (per 0.1 m^3) | | | | | | | | | | PAC (%) | FPAC (%) | PCL |
|--------------------|---|-------|-------|--------|---------|---------|---------|----------|-----------|--------|---------|----------|-----|
| | 5-15 | 15-25 | 25-50 | 50-100 | 100-250 | 250-500 | 500-750 | 750-1000 | 1000-1250 | > 1250 | | | |
| South East | 211 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00001 | 0 | 100 |
| North East Corner | 693 | 181 | 151 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0002 | 0 | 200 |
| North Middle Shelf | 60 | 0 | 60 | 0 | 60 | 0 | 0 | 0 | 0 | 0 | 0.0009 | 0 | 300 |
| South Middle Shelf | 331 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00002 | 0 | 100 |



Best Practices and Protocols in Cleanroom Contamination and Biological Sensitive Spacecraft

Biological Cleanroom Monitoring

- Assessment by PP technical staff for biological requirements (e.g. ISO 8 = 1,000 spores/m² on surfaces and <88 cfu/m³ for air) prior to hardware assembly/test and during the hardware processing.
- Additional assessments conducted during critical biological operations (e.g. spacecraft stack or more stringent hardware requirements)
- Anomaly testing conducted in the event of cleanroom procedure or process being compromised.
- Monitoring includes (refer to N. Benardini presentation)
 - Standard monitoring includes – surface sampling using wipes and air sampling (e.g. direct impaction onto plates)
 - Additional monitoring includes – rapid monitoring adenosine tri-phosphate (ATP) swabs, genetic inventory DNA signature mapping, and air sampling to include impingement into buffer solution for multiple analysis.



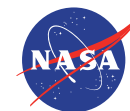
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HEPA Filters

- Evaluated
- Frequency
- Tracking air velocity through the filters
- Frequency

| Date | 02/05/2016 | 8/3/2016 | 1/30/2017 |
|-----------------|------------|----------|-----------|
| HEPA # | Velocity | Velocity | Velocity |
| Bldg.#-Rm.#-001 | 99 | 97 | 101 |
| Bldg.#-Rm.#-002 | 110 | 105 | 108 |
| Bldg.#-Rm.#-003 | 107 | 99 | 103 |
| Bldg.#-Rm.#-004 | 102 | 101 | 103 |
| Bldg.#-Rm.#-005 | 98 | 99 | 98 |
| Bldg.#-Rm.#-006 | 111 | 109 | 109 |
| Bldg.#-Rm.#-007 | 93 | 98 | 94 |
| Bldg.#-Rm.#-008 | 104 | 104 | 106 |
| Bldg.#-Rm.#-009 | 97 | 101 | 100 |
| Bldg.#-Rm.#-010 | 106 | 101 | 103 |
| Bldg.#-Rm.#-011 | 101 | 102 | 103 |
| Bldg.#-Rm.#-012 | 99 | 95 | 95 |

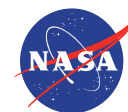
| System # | Facility ID or System with HEPA Filters | Effectively a Cleanroom Yes/No | Last Installation Date | Cleanroom Contact | Qty | Planned Total Cost \$k | Risk Est | #### FY17 In Svc | Deferred ? | Previously Evaluated ? | Comments for Jan & Jun |
|----------|---|--------------------------------|------------------------|-------------------|-----|------------------------|----------|------------------------|------------|------------------------|---|
| 1 | | Yes | 5/15/09 | | 26 | \$22.9 | 1 | 8 | Yes | N/A | Replace January 2018 Go to building & investigate access to HEPA's |
| 2 | | Yes | 1/1/08 | | 1 | | 1 | 9 | | No | Unknown # of years in service, so evaluate annually until needs replacement |
| 3 | | Yes | 1/1/08 | | 12 | | 1 | 9 | | Yes | Unknown # of years in service, so evaluate annually until needs replacement |
| 4 | | Yes | 1/1/08 | | 7 | | 1 | 9 | | No | Unknown # of years in service, so evaluate annually until needs replacement |
| 5 | | Yes | 2/4/05 | | 8 | \$5.6 | 1 | 12 | | No | Replace |
| 6 | | No | 8/16/06 | | 1 | \$2.8 | 1 | 10 | | No | Replacing |
| 7 | | Yes | 5/7/07 | | 8 | \$5.8 | 1 | 10 | | Yes | Evaluate soon |
| 8 | | No | 4/15/09 | | 6 | \$4.6 | 1 | 8 | | Yes | Ignore |
| 9 | | No | 9/24/07 | | 6 | \$4.6 | 1 | 9 | | Yes | Ignore |
| 10 | | Yes | 4/6/07 | | 2 | \$3.1 | 1 | 10 | | Yes | |
| 11 | | No | 3/20/07 | | 6 | \$5.0 | 1 | 10 | | No | Inactive |
| 12 | | No | 3/19/07 | | 2 | \$3.2 | 1 | 10 | | No | Inactive |
| 13 | | Yes | 2/1/08 | | 3 | \$4.9 | 1 | 9 | | No | Evaluate |
| 14 | | Yes | 4/1/08 | | 1 | \$2.8 | 1 | 9 | | N/A | Ignore |
| 15 | | Yes | 4/1/08 | | 1 | \$2.8 | 1 | 9 | | N/A | Ignore |
| 16 | | Yes | 9/22/06 | | 6 | \$5.1 | 1 | 10 | | N/A | Ignore |
| 17 | | No | 9/18/07 | | 1 | \$2.7 | 1 | 9 | Yes | N/A | Cassini project ends this year |
| 18 | | Yes | 8/15/06 | | 94 | \$45.7 | 1 | 10 | Yes | N/A | Can't replace until FY18 |
| 19 | | No | 6/1/08 | | 8 | \$6.0 | 1 | 8 | Yes | N/A | Can't replace until FY18 |
| 20 | | Yes | 6/8/07 | | 1 | \$2.7 | 1 | 9 | | N/A | Ignore |
| 21 | | No | 9/29/08 | | 108 | \$52.2 | 1 | 8 | | N/A | Ignore |
| 22 | | Yes | 6/1/08 | | 8 | \$6.0 | 1 | 8 | Yes | N/A | Can't replace until FY18 |
| 23 | | Yes | 6/1/08 | | 3 | \$3.7 | 1 | 8 | Yes | N/A | Can't replace until FY18 |
| 24 | | Yes | 5/30/07 | | 3 | \$3.5 | 1 | 9 | Yes | N/A | Can't replace until FY18 |
| 25 | | Yes | 5/25/07 | | 1 | \$3.2 | 1 | 9 | | Yes | Evaluate |
| 26 | | Yes | 3/13/09 | | 2 | \$3.3 | 1 | 8 | | Yes | Evaluate |
| 27 | | No | 8/25/06 | | 28 | \$15.3 | 1 | 10 | | Yes | On hold, waiting on longevity |
| 28 | | No | 11/29/06 | | 1 | \$2.8 | 1 | 10 | | N/A | On hold, waiting on longevity |
| 29 | | No | 3/26/07 | | 8 | \$11.7 | 1 | 10 | | N/A | Ignore |
| 30 | | No | 3/11/09 | | 6 | \$5.9 | 1 | 8 | | No | Evaluate |
| 31 | | Yes | 2/5/09 | | 654 | \$293.7 | 1 | 8 | | N/A | Begin evals FY18 |
| 32 | | No | 2/10/09 | | 1 | \$2.8 | 1 | 8 | | No | Evaluate |
| 33 | | No | 2/11/09 | | 1 | \$2.8 | 1 | 8 | | No | Evaluate |
| 34 | | No | 2/12/09 | | 8 | \$6.2 | 1 | 8 | | N/A | |
| 35 | | No | 9/23/08 | | 12 | \$7.4 | 1 | 8 | | N/A | |
| 36 | | No | 3/8/07 | | 1 | \$2.7 | 1 | 10 | | N/A | |
| 37 | | No | 4/27/07 | | 1 | \$2.8 | 1 | 10 | | N/A | |
| 38 | | No | 4/14/06 | | 4 | \$3.7 | 1 | 8 | | N/A | |



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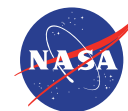
Challenges

- ESD materials and contamination control in cleanrooms
 - Always searching for materials that particulate and outgas less
 - This increases cost, sometimes to unacceptable levels
- Relative humidity control
 - Not all air handlers are able to keep up with Southern California warm and dry days
- Meet both material CC and biological requirements

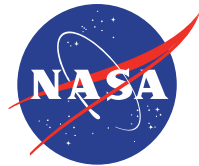


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Questions?



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