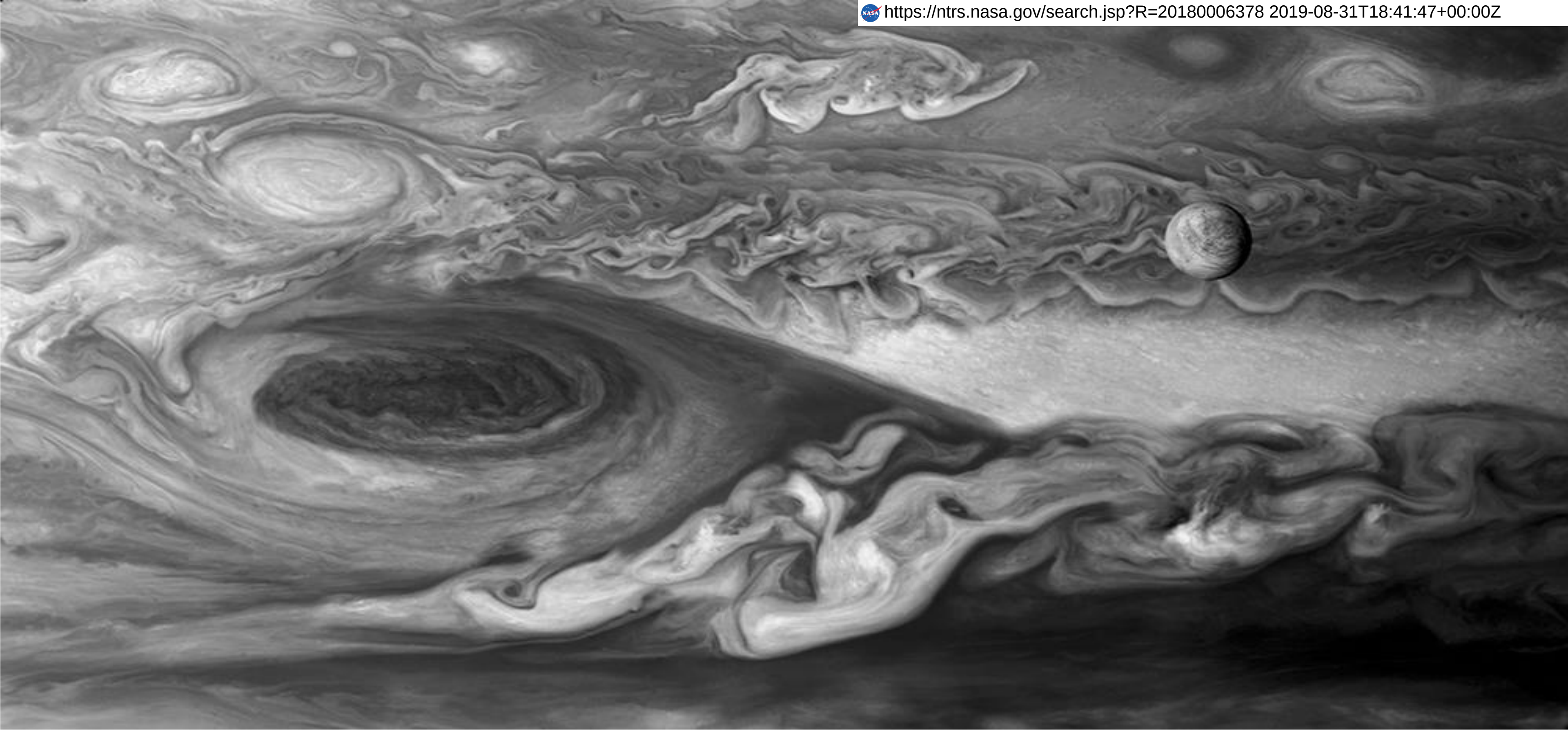

Bioreduction of Solid Rocket Motors for Planetary Protection

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AUBURN UNIVERSITY

NASA

Europa Missions

http://www.collectspace.com/ubb/Forum18/HTML/001363.html

Europa Clipper Mission:

- Put spacecraft in orbit around Jupiter
- Spacecraft will take pictures of Europan surface
- Determine thickness of surface ice
- Measure moon's magnetic field

Europa Lander Mission:

- Send lander to Europan surface
- Lander will be instrumented to search for life

https://www.space.com/39675-nasa-europa-lander-mission-2019-budget.html

Planetary Protection

- Planetary protection requirements stem from a United Nations treaty where all countries involved agreed to conduct exploration in a manner that does not contaminate the visited places
- Objectives
  - Not contaminate explored environments to preserve the ability to look for life
  - Be able to study other places in their natural state
  - Protect Earth's biosphere

https://solarsystem.nasa.gov/resources/545/artists-concept-our-solar-system/

Mission Types

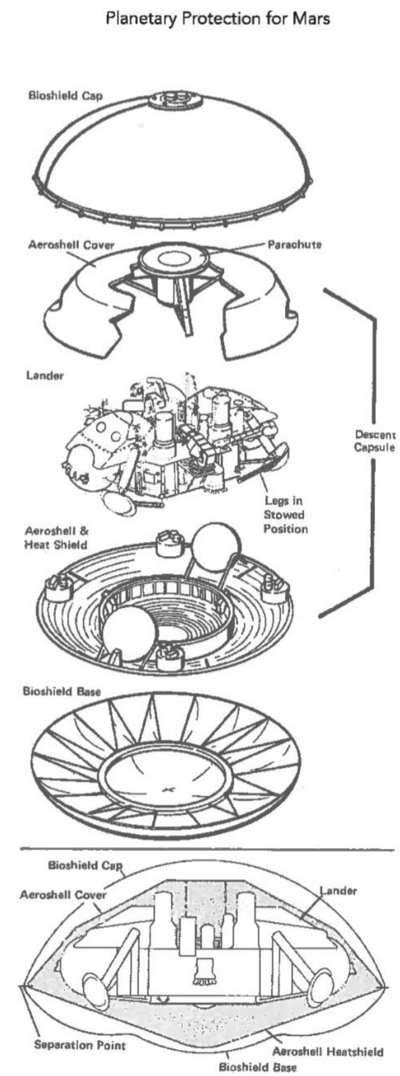
Types of Planetary Bodies	Mission Type[1]	Mission Category[2]
Bodies "not of direct interest for understanding the process of chemical evolution or the origin of life."	Any	I
Bodies of "significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote chance that contamination carried by a spacecraft could compromise future investigations."	Any	II & II*
Bodies of significant interest to the process of "chemical evolution and/or the origin of life", and where "scientific opinion provides a significant chance that contamination could compromise future investigations."	Flyby, Orbiter	III
	Lander, Probe	IV[3]
Earth-return missions from bodies "deemed by scientific opinion to have no indigenous life forms."	unrestricted Earth-Return	V (unrestricted)
Earth-return missions from bodies deemed by scientific opinion to be of significant interest to the process of chemical evolution and/or the origin of life.	restricted Earth-Return	V (restricted)

[1] ***If gravity assist is utilized during a flyby, constraints for the planetary body with the highest degree of protection may be required.***
[2] ***For missions that target or encounter multiple planets, more than one PP category may be specified.***
[3] ***Category IV missions for Mars are subdivided into IVa, IVb, and IVc.***

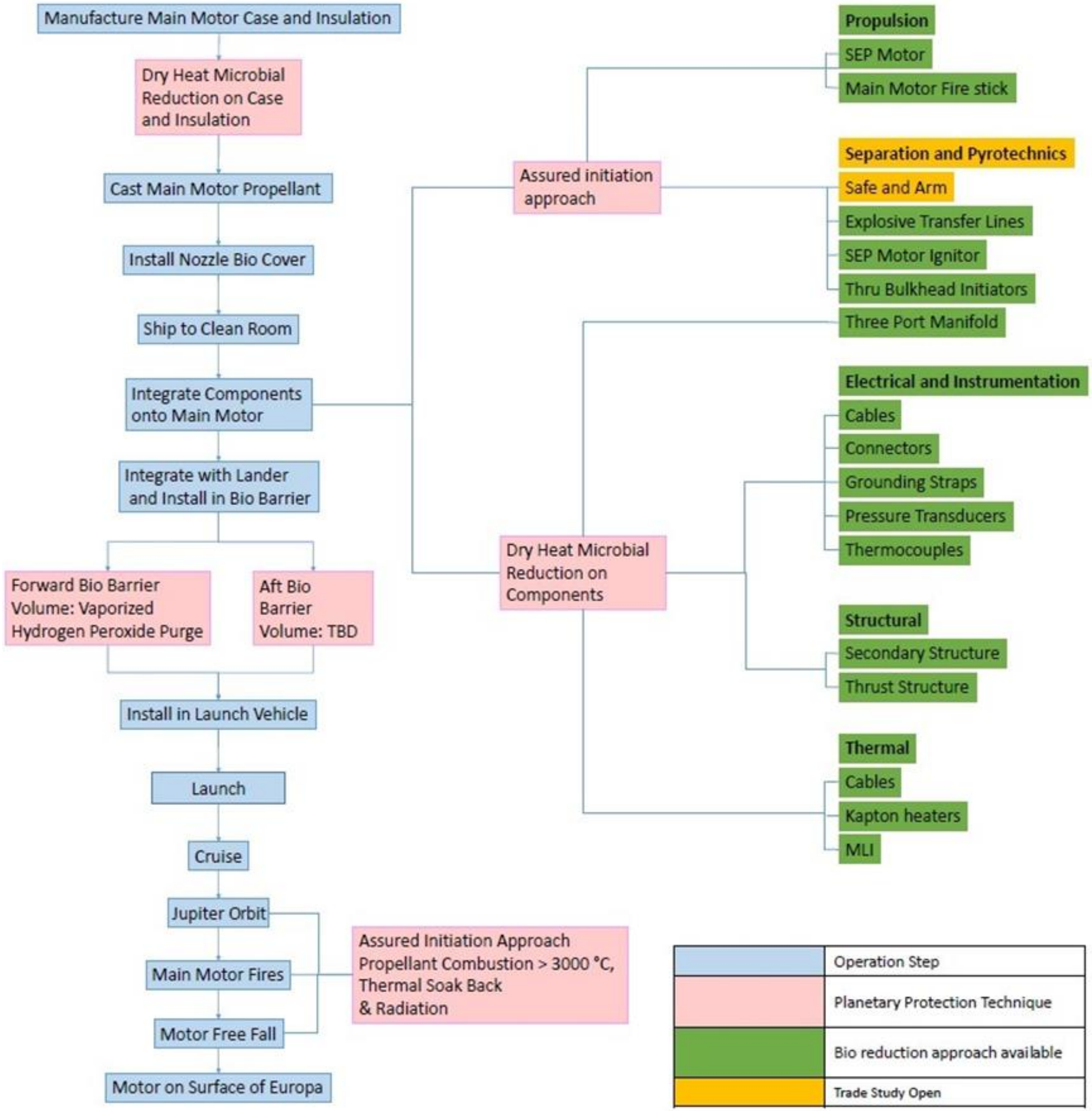
The planetary protection requirement for the Europa Lander is to limit the probability of contamination to no more than **$1x10^{-3}$**

Planetary Protection for Viking

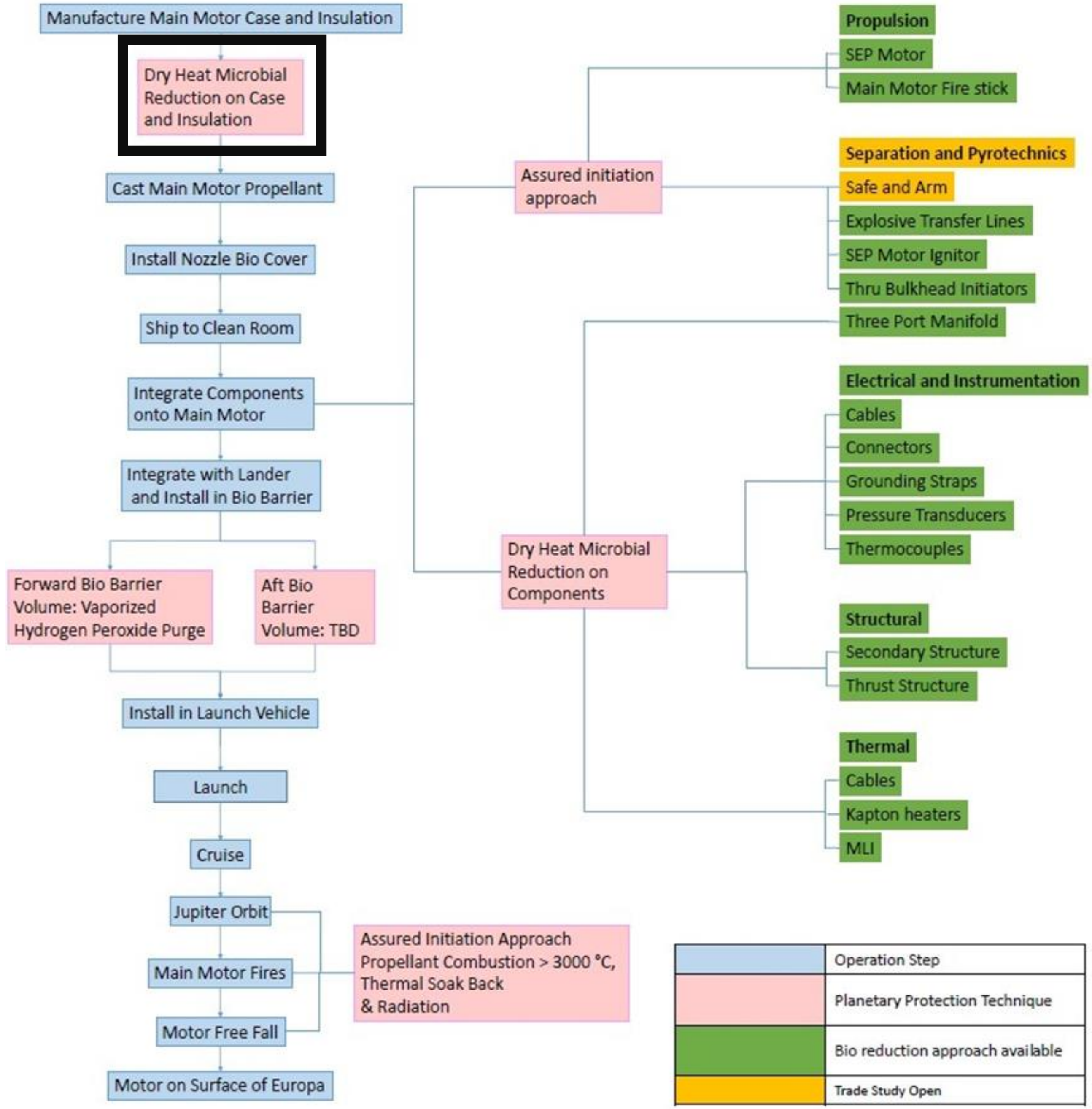
- Viking was the first lander to another planet and most planetary protection techniques are derived from this mission
- The viking missions took four steps in their approach to meet the planetary protection requirements
    1. Use materials that can withstand thermal sterilization techniques
    2. Use manufacturing processes to minimize biological build up
    3. Use heat sterilization techniques on to components and assemblies
    4. Conduct final sterilization and hermetically seal the lander in a capsule to maintain sterilization



Europa DOS Planetary Protection Strategy

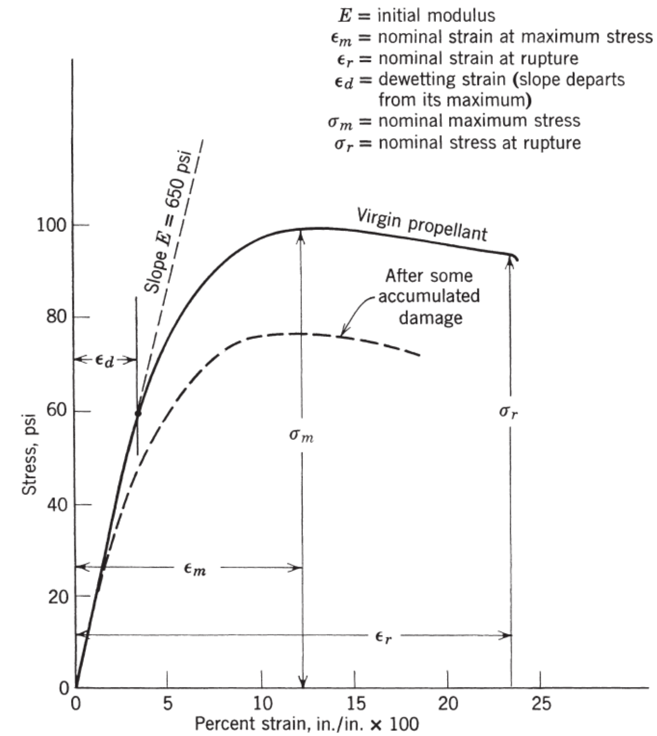


Europa DOS Planetary Protection Strategy

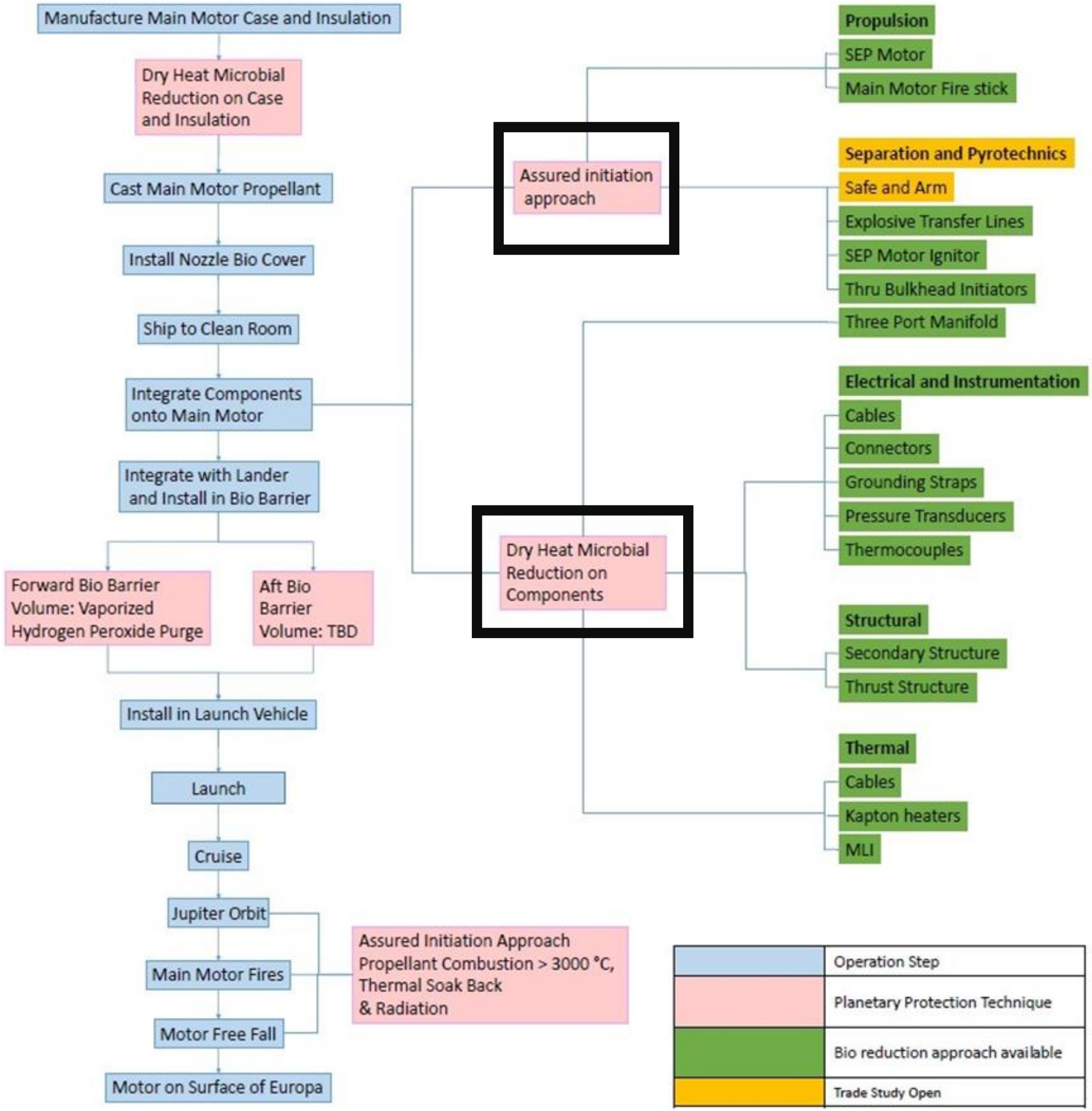


DHMR On Motor

- **Dry Heat Microbial Reduction (DHMR):** involves heating the motor to a specified temperature (above 105°C) for a specified amount of time to achieve sterilization
- DHMR can be effective in sterilizing the motor but it does lead to potentially significant & detrimental motor aging
- There is a tradeoff between reducing the probability of Europa contamination through DHMR and decreasing the reliability of the motor due to aging damage from DHMR



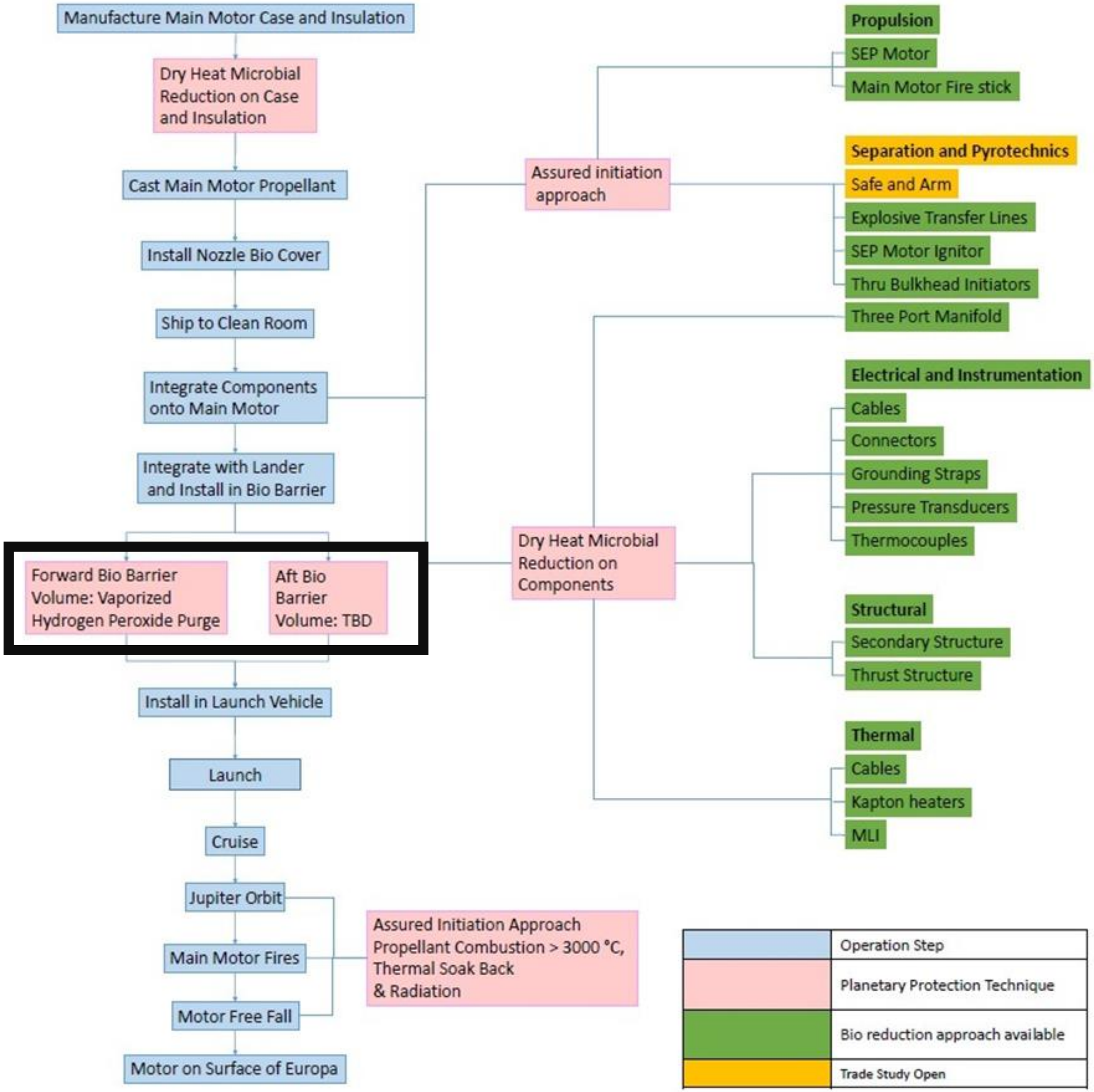
Europa DOS Planetary Protection Strategy



DHMR on Components

- It will be our philosophy to use components that have been identified as DHMR and VHP compatible when possible
- Use mission tested hardware when possible
- Maximize use of common hardware with Juno/Clipper, and components and planetary protection techniques that are common with the rest of the DOV
  - Cabling and harnesses
  - Connectors
  - Thermal protection systems
  - Instrumentation
  - Separation components and pyrotechnics

Europa DOS Planetary Protection Strategy



Vapor Hydrogen Peroxide (35%) Purge of DOS

What is VHP

- The VHP process has been widely used for the routine decontamination of enclosed environments and surfaces. The biocide has been shown to be sporicidal, virucidal, bactericidal, fungicidal.

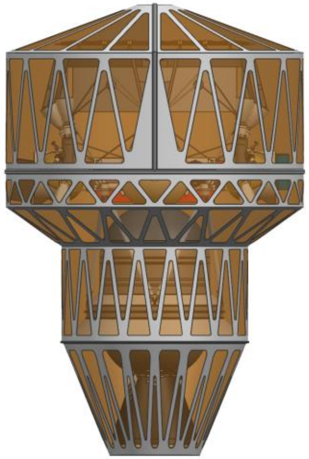
Determine compatibility for all exposed materials

Material	10% H2O2	30% H2O2	50% H2O2
304 stainless steel	Good	Good	Good
316 stainless steel	Good	Good	Good
ABS plastic	Excellent	Excellent	Excellent
Aluminum	Excellent	Excellent	Excellent
Rayon	Good	Good	Good
Copper	Severe Effect	Severe Effect	Severe Effect
EPDM	Excellent	Good	Good
NBR	Severe Effect	Severe Effect	Severe Effect
Natural rubber	Good	Fair	Fair
Titanium	Excellent	Good	Good
Viton	Excellent	Excellent	Excellent

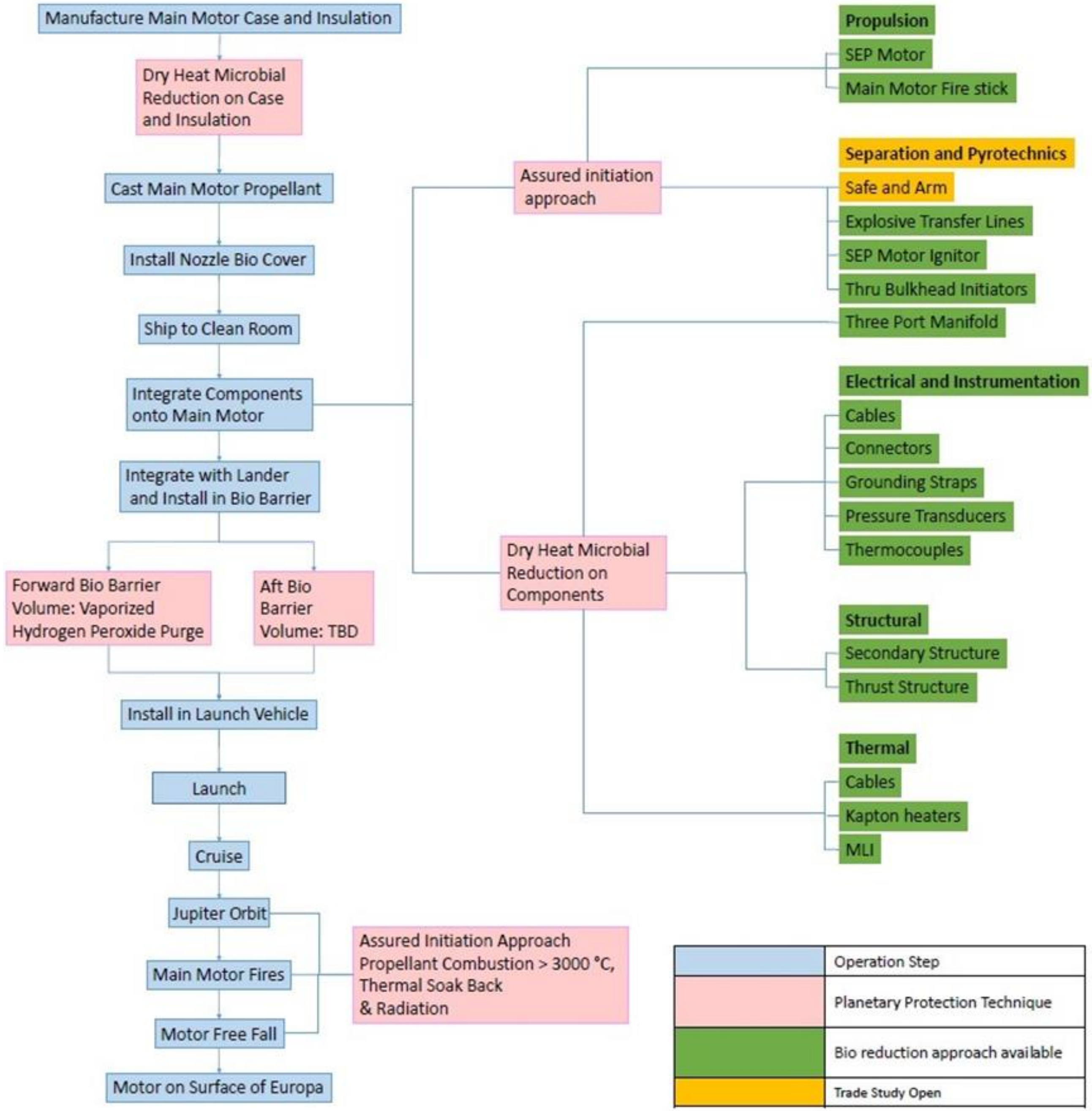
Good -- Minor Effect, slight corrosion or discoloration.
Fair -- Moderate Effect, not recommended for continuous use. Softening, loss of strength, swelling may occur

Results:

- Program is using the same assumptions as Clipper leading to VHP as a viable option
- Sterile external surface within Bio-Barrier
- Purge process
  - Two volume: aft end of motor will be in one volume and forward end will be in a separate volume
  - Both volumes will go through VHP



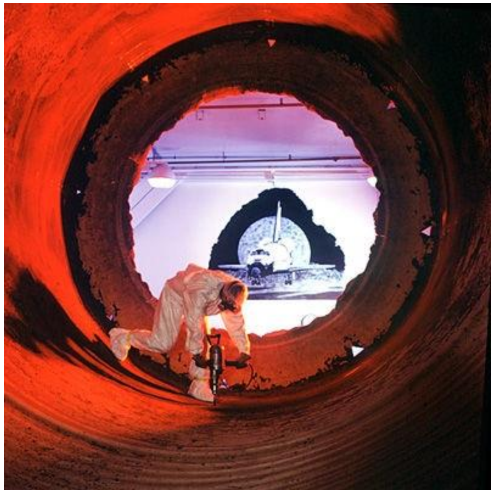
Europa DOS Planetary Protection Strategy



SRM Remaining Inerts

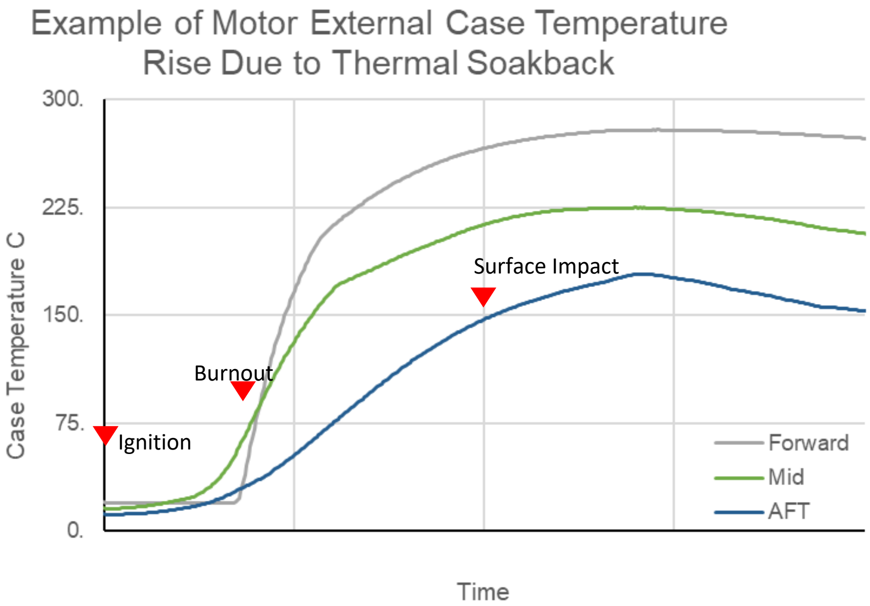
Remaining Inerts

- All solid rocket motors are designed to have small amounts of remaining insulation inside the motor case
- Much of the inert material within the case will be thermally decomposed at 3038 °C and exhausted through the nozzle



Bio Reduction of the Remaining Inerts

- Sterilization has three components
  - Full motor DHMR
  - Radiation environment at the case-insulation bondline
  - Thermal Soakback during motor operation and descent to Europa Surface



Ensuring the Bio Reduction of Remaining Inerts

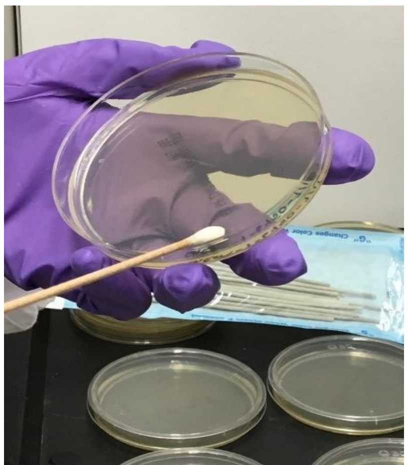
- Thermal model with anchoring testing is needed to determine the internal bond line temperature during thermal soak back
- Will lead to a better understanding of the bio reduction of inerts during motor operation and final bio burden to surface of Europa

Investigation into antimicrobial properties of bond-line materials

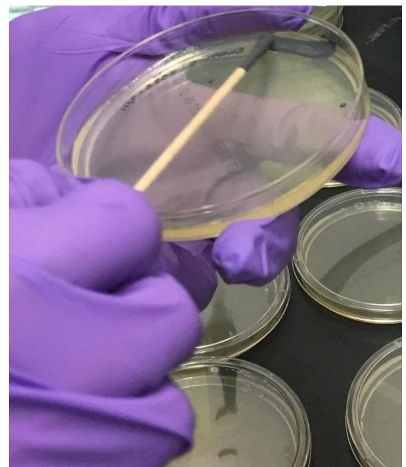
Background

- Microorganisms encapsulated in the polymer matrices of bond-line materials pose an acute risk of forward contamination
- Sterilization of the fully-integrated motor via DHMR could increase the risk to the material integrity of the motor
- An assessment of the inherent antimicrobial properties of bond-line adhesives was conducted as an alternative means of sterilization
- An overlay assay and the Kirby-Bauer method were used to perform a preliminary investigation of antimicrobial properties of the Chemlok primer and several adhesives

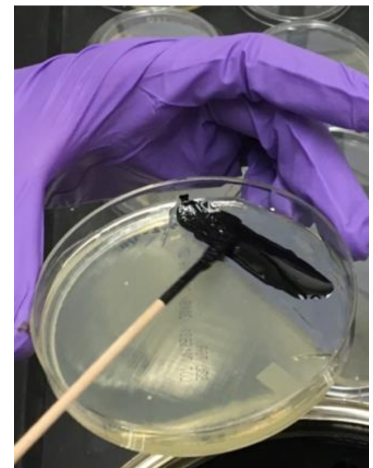
Preliminary Screening



Application of Inoculum



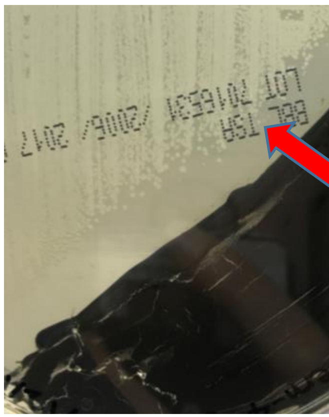
Application of Primer



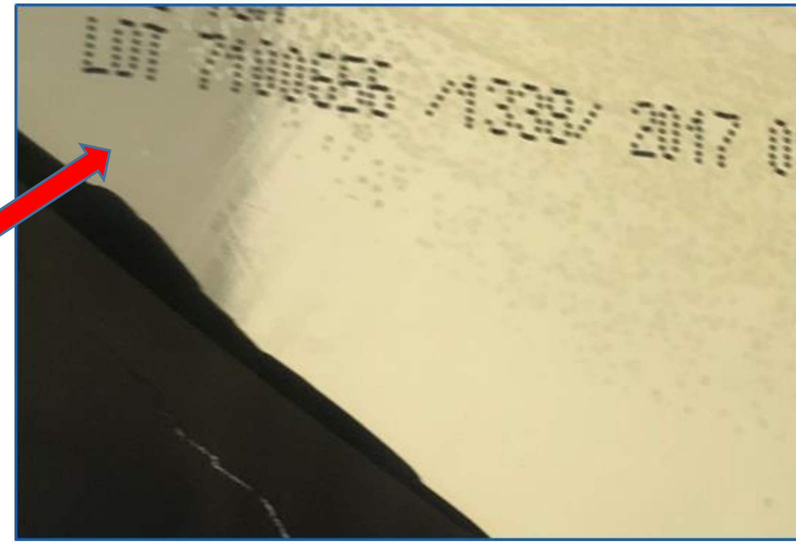
Application of Adhesive

- The preliminary screening was performed using a modified overlay assay (adapted in accordance with adhesive application protocols) with an inoculum derived from a bulk propellant sample
- The adhesives tested include:
  - Primer: Chemlok 205
  - Adhesives: Chemlok 234X, 2332, 6250, and 6450

Results and Conclusions



Significant and Persistent Zones of Inhibition

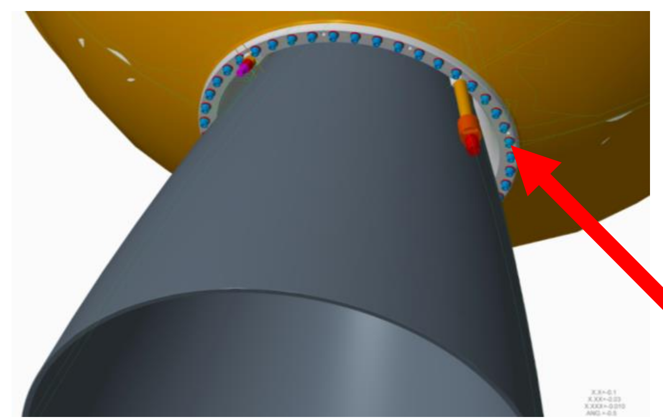


- Observable zone of inhibition of vegetative growth indicated active biocidal or biostatic mechanisms in the Chemlok primer and adhesives
- Further investigations on the quantitative spore reductions expected from Chemlok exposure are underway

Solid-Rocket Motor Mated-Case Studies

Background

- Mated areas of SRMs represent a challenge to integrated sterilization outside of cleanrooms (joints)
- The challenges occur due to the complex geometry in bolts, screws and washers used in the aerospace industry
- Incompatible with oxidizers and the VHP process that may be used in motors which do not undergo DHMR
- A ring of fasteners and washers unite the case and nozzle in solid rocket motors
- For this study it is hypothesized that bolt heads with large irregularities might become safe havens for microbial organisms sealed off between a titanium surface and a grease of choice for cells that could otherwise not survive under pressure



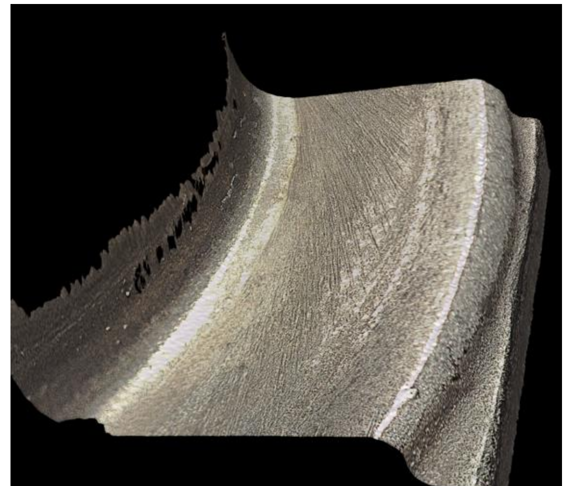
Methods Used

- General mechanical cell lysis analysis:
  - Surface profiling to understand irregularities on the titanium bolt surface (3D scanning methods)
  - Assurance of no safe havens
  - Torque/force array applied on fasteners to see if enough pressure may be sufficient to kill sporulating microorganisms
  - This mock experiment is also useful in understanding and developing sterilization assays and processes
  - Understand if there is any potential antimicrobial activity in grease (Kirby Bauer Method)
  - Understand the organisms that make up the microbial ecosystem of the assembly space by isolating them and testing them against potential sterilizing agents

Results and Conclusions

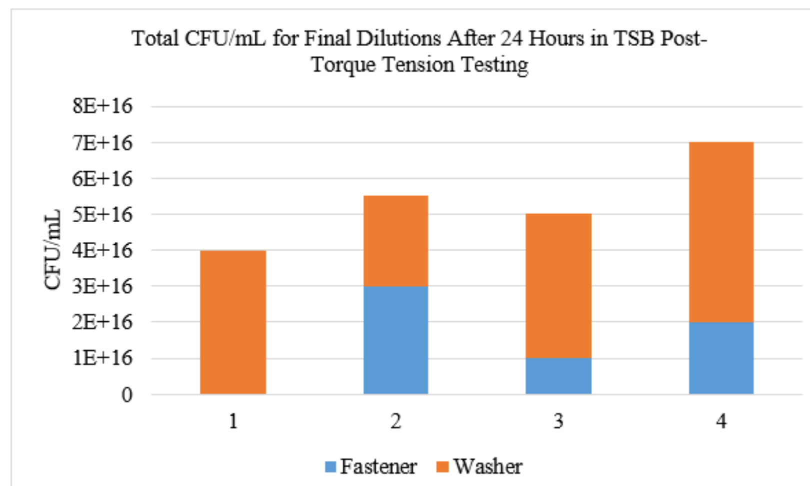
Table 1: Load amount exerted on fasteners labeled by numbers.

Fastener #	Force Array (kip)	Time (s)	Torque (ft-lb)
1	15.0	20	109.2
2	10.6	20	85.2
3	5.0	20	40.9
4	1.0	20	11.8
5	0	20	0



Bolt head surface image taken at 0° with surface profiling equipment

Native bacilli images taken with a Scanning Electron Microscope in MSFC



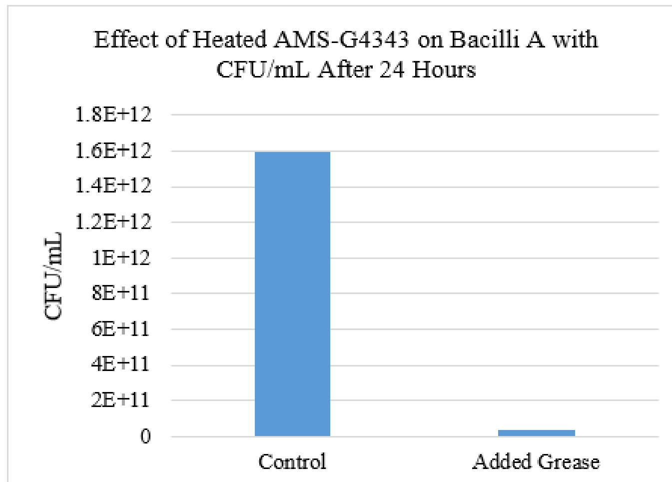
Results and conclusions

- Surface on bolt heads are not even and may harbor enough space for bacilli/spores
- Maximum overall height of peaks of 20.150 µm
- Height difference average of 1.289 µm
- The average two-dimensional height differences were 186.911 µm by 3.398 µm
- To put this in perspective Bacillus subtilis is about 1 x 6 µm
- Increase in colony forming units per milliliter with a decrease in force array/torque

Results and Conclusions

- Royco 43 SAE-AMS-G-4343 (Used by NG)
- The grease doesn't visibly inhibit the growth of the native bacilli species.

- Molykote G-n Metal Assembly Paste
- The used lubricant doesn't visibly inhibit the growth of the native bacilli species.



- Krytox PFPE
- The grease doesn't visibly inhibit the growth of the native bacilli species.

- Braycote 803RP
- The used lubricant doesn't visibly inhibit the growth of the native bacilli species.

Results and Conclusions

- No antimicrobial properties in any of the studied greases
- Some growth inhibition for heated grease with changed chemical properties

Off Nominal Case – No Fire

- Highest remaining mass to surface
- Design to ensure high probability of ignition
  - Redundant igniters
  - Assured fire command
  - Ensure propellant bore surface ignitability (limit radiation effect on bore surface so AP remains and surface is not inert)
    - At least as much protection for bore surface as for motor case

Summary

- Exploratory missions that use solid rocket motors face challenges with traditional planetary protection techniques
- Missions like the Europa lander, the SRM and other sensitive components cannot undergo DHMR and VHP
- To meet the stringent requirements posed on class III, IV and V missions a strategy involving multiple techniques must be used
- The strategy proposed for the Europa Lander uses:
  - DHMR on non-sensitive components prior to full integration
  - A two volume approach with the SRM to allow the internal surfaces to undergo a different technique than the external surfaces
  - VHP once full integration has occurred and sensitive components are protected
- Experiments have been conducted to look at the bioreduction capabilities of motor components as well as areas that may be difficult for some bioreduction techniques to reach
- **The current strategy allows the Europa lander to meet the stringent planetary protection requirements and does not impact the reliability of the motor or jeopardize mission success**

Refrences

1. Fry, R. S. and Peters, S. T., ***Burning Rates of Standard Solid Propellants for Gun Applications***, CPTR 99-69, CPIA/JHU, Columbia, MD (Sep 1999).
2. ***Mission and Vision***, 15 Feburary 2015. [Online]. Available: https://www.nasa.gov/centers/armstrong/about/mission.html. [Accessed 3 August 2018].
3. ***Europa Clipper***, Jet Propulsion Laboratory, [Online]. Available: https://www.jpl.nasa.gov/missions/europa-clipper/. [Accessed 3 August 2018].
4. Office of Planetary Protection, ***About Planetary Protection,*** National Aeronautics and Space Administration, [Online]. Available: https://planetaryprotection.nasa.gov/about. [Accessed 3 August 2018].
5. Office of Planetary Protection, ***Mission Categories***, National Aeronautics and Space Administration, [Online]. Available: https://planetaryprotection.nasa.gov/categories. [Accessed 3 August 2018].
6. Office of Planetary Protection, ***Mission Design & Planning***, National Aeronautics and Space Administration, [Online]. Available: https://planetaryprotection.nasa.gov/missiondesign/. [Accessed 3 August 2018].
7. When Biospheres Collide, ***Planetary Protection For Mars***, National Aeronautics and Space Administration.
8. G. P. Sutton, ***Rocket Propulsion Elements***, New York, Wiley, 2010, p. 474.
9. Stam C.N., Bruckner J., Spry J.A., Venkateswaran K., La Duc M.T. (2012) ***A molecular method to assess bioburden embedded within silicon-based resins used on modern spacecraft materials.*** International Journal of Astrobiology, 11, 141–145 doi: 10.1017/S1473550412000031
10. Bauermeister A, Mahnert A, Auerbach A, et al. ***Quantification of Encapsulated Bioburden in Spacecraft Polymer Materials by Cultivation-Dependent and Molecular Methods***,Janssen PJ, ed. PLoS ONE [online journal], Vol. 9, No. 4, Paper 94265. doi: 10.1371/journal.pone.0094265
11. Waitz, J. A. ***Methods for dilution antimicrobial susceptibility tests for bacteria that grow aerobically, National Committee for Clinical Laboratory Standards***, *Villanova*, PA, 1991.
12. ***NASA standard procedures for the microbial examination of space hardware***, NASA Procedures and Guidelines (NPG) 6022B, 2010, NASA Headquarters, Washington, DC
13. ***Chemlok 205 Primer and/or Adhesive***. LORD Technical Data, LORD Corporation, 2015.
14. ***Chemlok 2332 Primer and/or Adhesive***. LORD Technical Data, LORD Corporation, 2016.
15. NCCLS. ***Methods for Determining Bactericidal Activity of Antimicrobial Agents; Approved Guideline***. NCCLS document M26-A [ISBN 1-56238-384-1]. NCCLS, 940 West Valley Road, Suite 1400, Wayne, Pennsylvania 19087 USA, 1999.
16. Jet Propulsion Laboratory, ***Technology Development***, National Aeronautics and Space Administration [Online]. URL: https://planetaryprotection.jpl.nasa.gov/technology-development [retrieved 25 July 2018].
17. Office of Planetary Protection, ***Mission Requirements***, National Aeronautics and Space Administration [Online]. URL: https://planetaryprotection.nasa.gov/requirements [retrieved 25 July 2018].
18. Foster D.,***Cell Disruption: Breaking Up is Hard to do***, Nature Biotechnology [online journal], Vol. 10, 1992, pp. 1539-1541. doi: 10.1038/nbt1292-1539 [retrieved 25 July 2018].
19. Soule, M. H., ***Identity of bacillus subtilis***, Cohn 1872" The Journal of Infectuous Diseases, vol. 1, No. 5, 1932, pp. 191–215. doi: https://doi.org/10.1093/infdis/51.2.191 [retrieved 25 July 2018].
20. Horneck G., Moeller R., Cadet Jean, Douki T., Rocco L. Mancinelli, W. L. N., Panitz C., Rabbow E., Rettberg P., Spry A., E. S., and Vaishampayan, P. and K. J. V.,***Resistance of Bacterial Endospores to Outer Space for Planetary Protection Purposes—Experiment PROTECT of the EXPOSE-E Mission***, Astrobiology [online journal], Vol. 12, No. 5, 2012. doi: 10.1089/ast.2011.0737 [retrieved 25 July 2018].

Backup Slides

Risk reduction activities at contractor

- Sterilization effect
- Environmental radiation effect

Assumptions

- Desire to stay below 135 degrees C to avoid chemical changes in propellant (AP crystals)
- Minimum Bake-out temperature is 110 degrees C
- Equivalent Motor Age is the age of the motor after bake-out process
  - Calculations in these charts are for hold time only.
    - Do not account for additional time to reach thermal equilibrium (2-3 weeks)
  - Calculations do not include integration time, or transit time from Earth to Europa (2-8 years)
- Question: With the type of propellant proposed for the Europa mission, what SRM age has already been demonstrated and found to be acceptable?
  - I'd like to be able to draw lines on the graphs for:
    - Demonstrated to be acceptable
    - Demonstrated to be unacceptable

Risk Reduction Activities for DHMR

- Necessary to stay below 150 degrees C to avoid chemical changes in propellant (AP crystals)
- Minimum Bake-out temperature is 110 degrees C
- Equivalent Motor Age is the age of the motor after bake-out process
  - Calculations in these charts are for hold time only.
    - Do not account for additional time to reach thermal equilibrium (2-3 weeks)
  - Calculations do not include integration time, or transit time from Earth to Europa (2-8 years)
- With the type of propellant proposed for the Europa mission, what SRM age has already been demonstrated and found to be acceptable?
- Are there alternate propellant formulations could be developed to mitigate aging effects?

	3-Order Reduction		4-Order Reduction	
	Encap (Hours)	SRM Equivalent Age (Years)	Encap (Hours)	SRM Equivalent Age (Years)
T (C)				
110	-		704.56	44.91
115	-		601.14	51.45
116	74.65	6.77	582.64	52.84
120	40.40	4.61	514.97	58.73
125	18.75	2.83	442.88	66.82
130	10.84	2.15	382.63	75.85
135	6.26	1.62	213.68	55.28
140	3.62	1.21	121.03	40.60
145	2.24	0.97	69.49	30.04
150	1.43	0.13	40.42	3.67
155	0.94		23.82	
160	0.63		14.20	
165	0.43		8.57	
170	0.31		5.23	
175	0.22		3.23	
180	0.16		2.01	
185	0.12		1.27	
190	0.09		0.81	
195	0.07		0.52	
200	0.05		0.34	

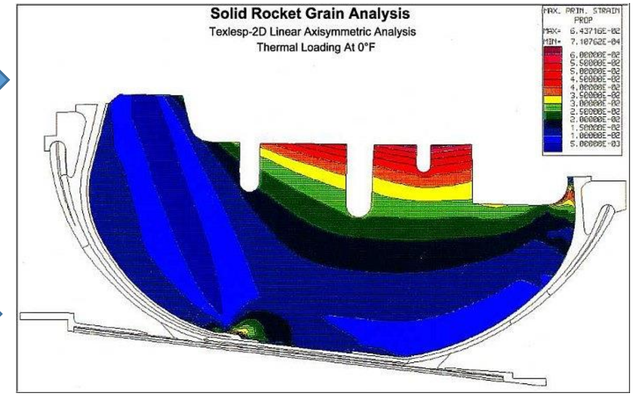
DOS Mission Success Risk (Capability vs. Load)

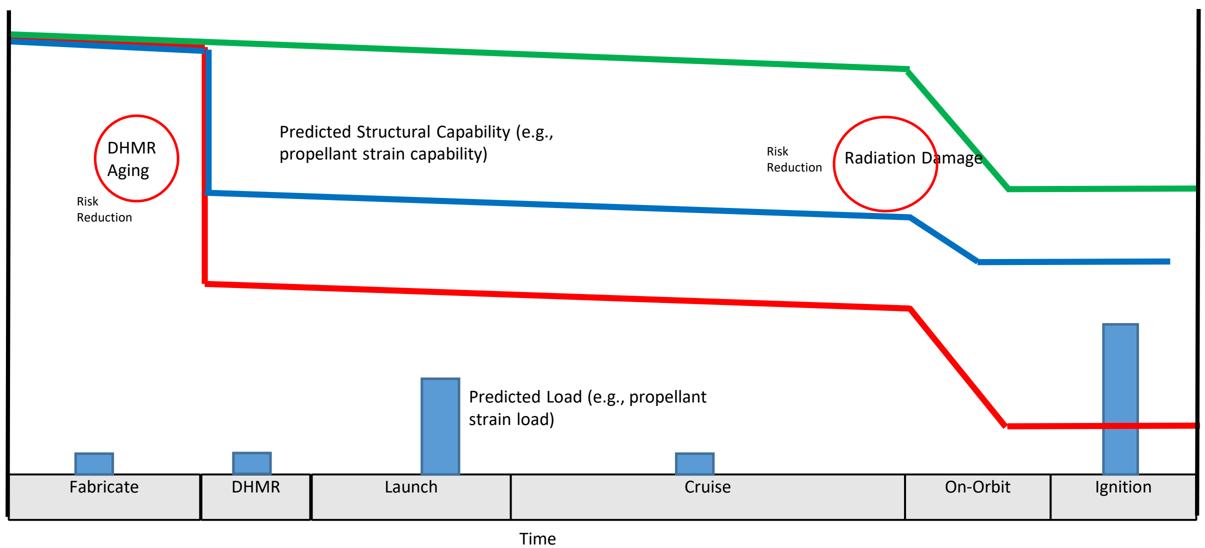
Induced Loads

Natural Environments

Degraded Material Properties due to Environments

Material Properties





DHMR, Thermal Soak back, and Radiation on Residual Propellant - area we are still working

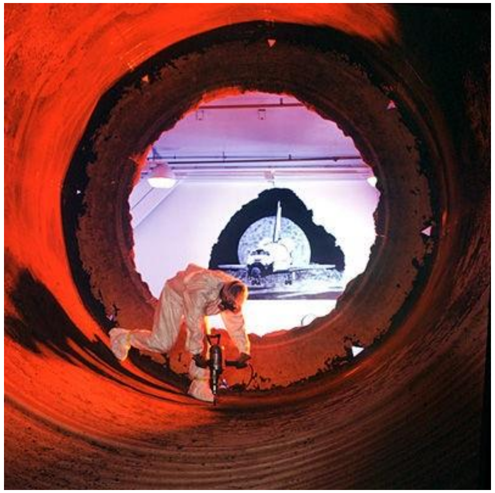
- Assumption
- Time Calculations
- Temperature Graph
- Thermal soak back and radiation post fire motor sterilization


Propellant
Liner 1-2 mils
Insulation (30 or 40 mils case acreage, 500 mils for nozzle/case joint)
Case = 10 mils

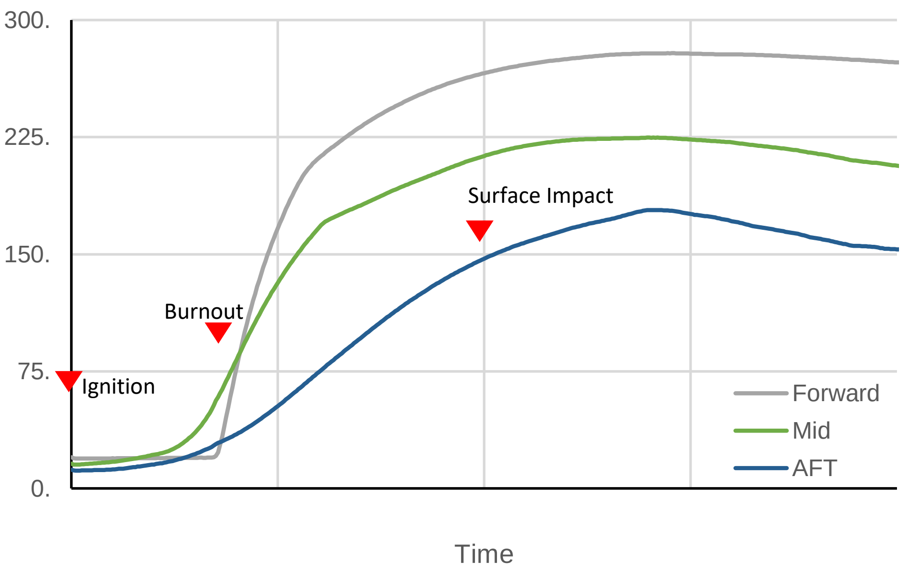
SRM Remaining Inerts

Remaining Inerts

- All solid rocket motors are designed to have small amounts of remaining insulation inside the motor case
- Much of the inert material within the case will be thermally decomposed at 3038 °C and exhausted through the nozzle



Example of Motor External Case Temperature Rise Due to Thermal Soakback



Bio Reduction of the Remaining Inerts

- Sterilization has three components
  - Full motor DHMR
  - Radiation environment at the case-insulation bondline
  - Thermal Soakback during motor operation and descent to Europa Surface

Ensuring the Bio Reduction of Remaining Inerts

- Thermal model with anchoring testing is needed to determine the internal bond line temperature during thermal soak back
- Will lead to a better understanding of the bio reduction of inerts during motor operation and final bio burden to surface of Europa