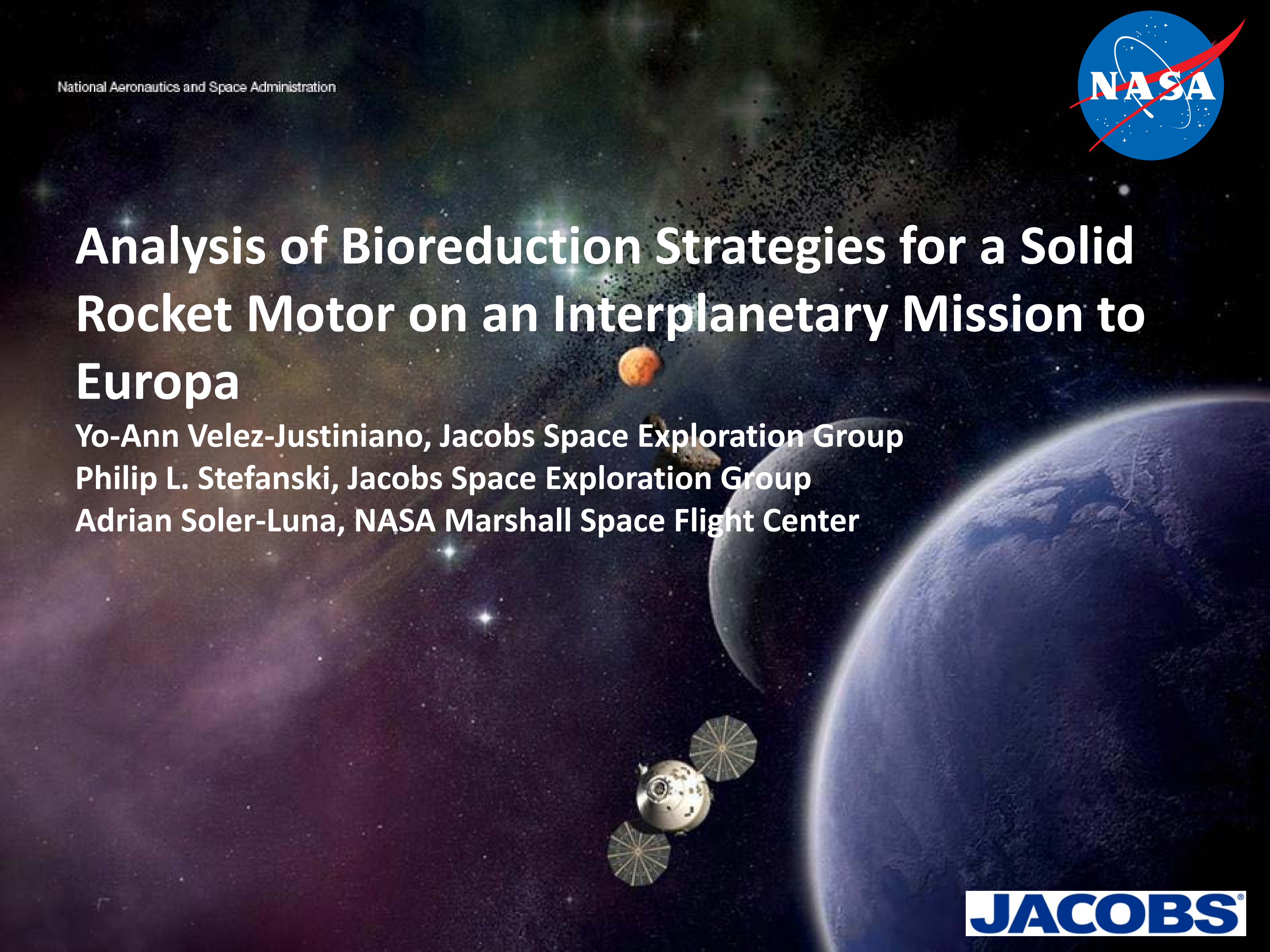

Analysis of Bioreduction Strategies for a Solid Rocket Motor on an Interplanetary Mission to Europa

Yo-Ann Velez-Justiniano, Jacobs Space Exploration Group
Philip L. Stefanski, Jacobs Space Exploration Group
Adrian Soler-Luna, NASA Marshall Space Flight Center

Mission Background

- The Jovian environment has high levels of ionizing radiation, extreme temperatures and debris [1].
- NASA will embark on extensive studies and planning of missions to explore Europa.
- Recurrent sightings of active water plumes spewing water to the icy surface has garnered more interest around the moon's habitability aspect.
- The Europa Lander concept will be designed to carry a miniaturized laboratory that will analyze Europan surface samples for its chemical composition and other geological data from the moon [2].
- The lander's search for any biosignature might be endangered by the lander's own contaminated body, also a contamination threat to any future landers to come from other space agencies with similar astrobiological interest.
- Cleaning the systems poses a special challenge to propulsion subsystem planning and manufacturing, since it may introduce harsh bioreduction techniques to the process of a motor that is destined to age.

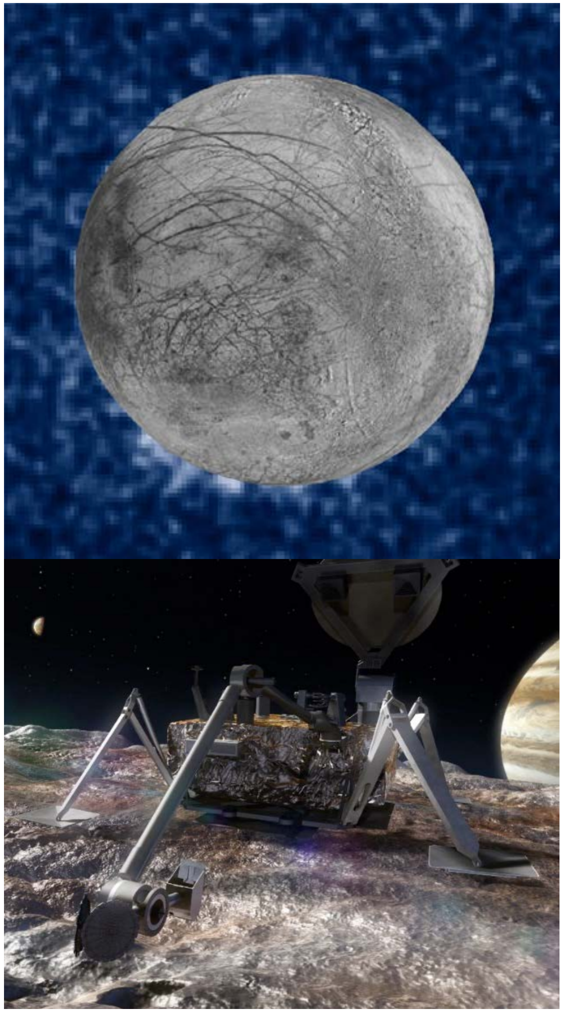

Figure 1(a) Europa plumes found in 2016 (image) and(b) Europa lander concept illustration [3,4].

Mission Background

- The De-Orbit Stage of robotic exploration of far-away bodies are historically assisted by SRMs due to their high reliability and low-cost functionality.
- The Star 48B propellant for example, survived the Magellan flight 15-month space storage and more than 5 years without material degradation in a long-duration exposure facility (LDEF) [5].
- Aside from the challenges put forth by propulsion subsystem flybys through a high-radiation Jovian environment, raising the probabilities of motor aging, Planetary Protection techniques will amplify any material degradation or malfunction probability [6].

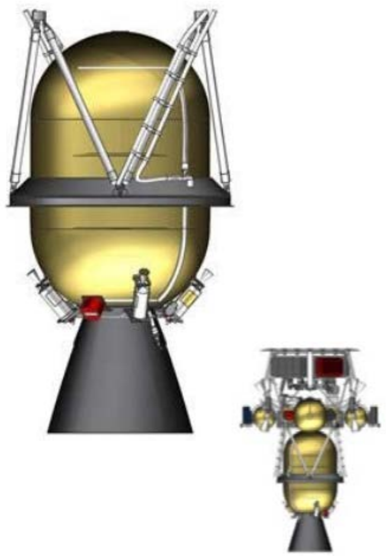

Figure 2. The De-Orbit Stage is part of the De-Orbit Stage Vehicle[7].

Mission Background

- The mission and philosophy of Planetary Protection is to establish a levelled ground.
- NASA has a set of requirements specific for all mission types, guided by COSPAR and the OSMA, with the experience brought forth by missions to Mars [8].
- At KSC in 2003 two large spacecraft components used in MER underwent dry heat microbial reduction (DHMR) in “tolerable” environment conditions for the materials [9].
- **Trade-offs**: At some point in the development of a propulsion subsystem these techniques are applied and modified to fit the requirements for Planetary Protection without affecting system performance.
- Building a Planetary Protection Plan and process for the propulsion subsystems of a category IV mission to Europa has never been done before, the biggest complications being attached to the presence of large quantities of solid rocket propellant in some of the larger SRMs.

NPR 8020.12D -- TOC

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NASA
Procedural
Requirements

NPR 8020.12D
Effective Date: April 20, 2011
Expiration Date: December 20, 2019

COMPLIANCE IS MANDATORY

Planetary Protection Provisions for Robotic Extraterrestrial Missions

Responsible Office: Office of Safety and Mission Assurance

SPECIAL ATTENTION: ONLY USE NID 8020.109A, Planetary Protection Provisions for Robotic Extraterrestrial Mission

Figure 3. NPR 8020 by NASA.

Solid Rocket Motors

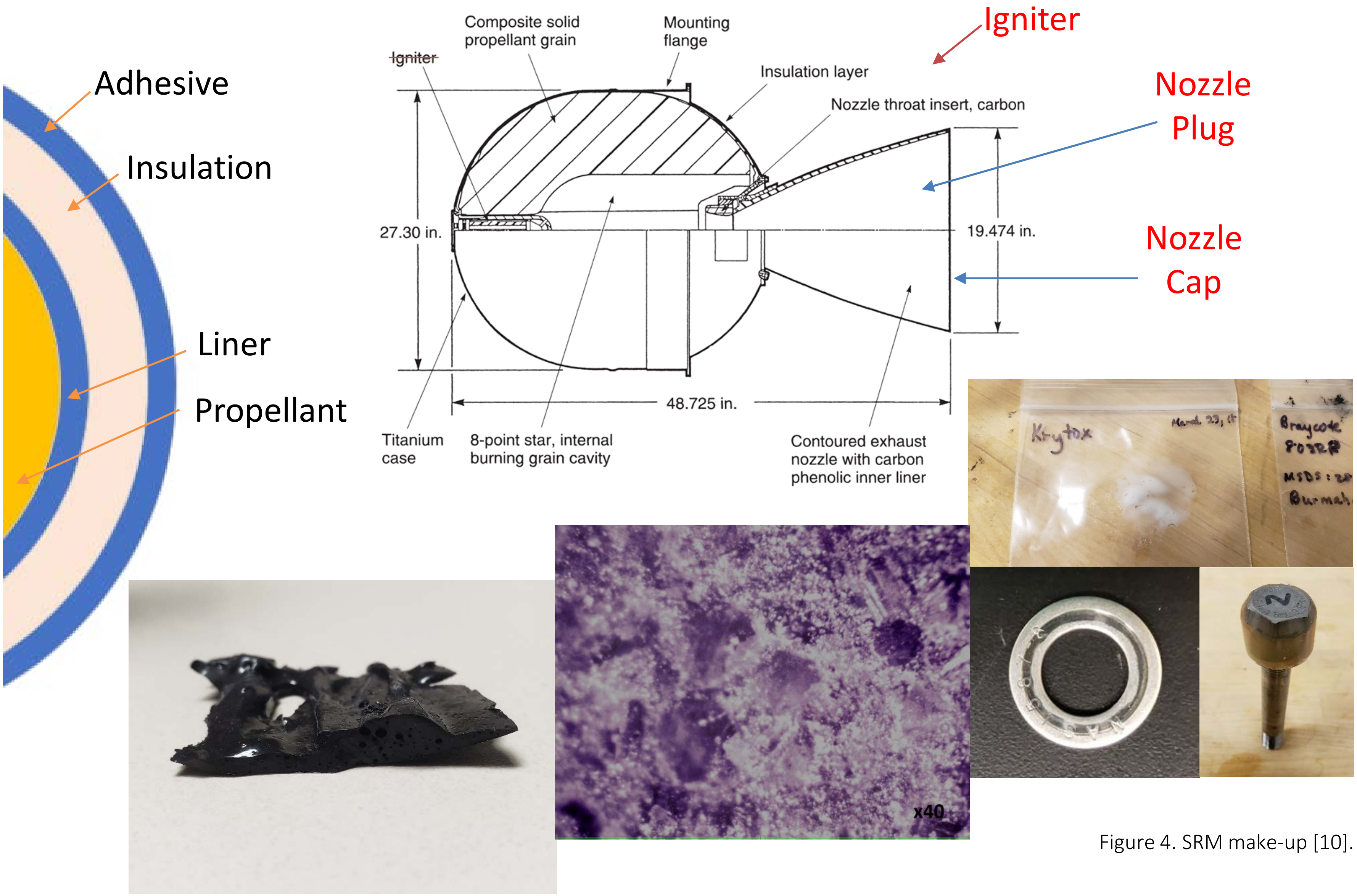
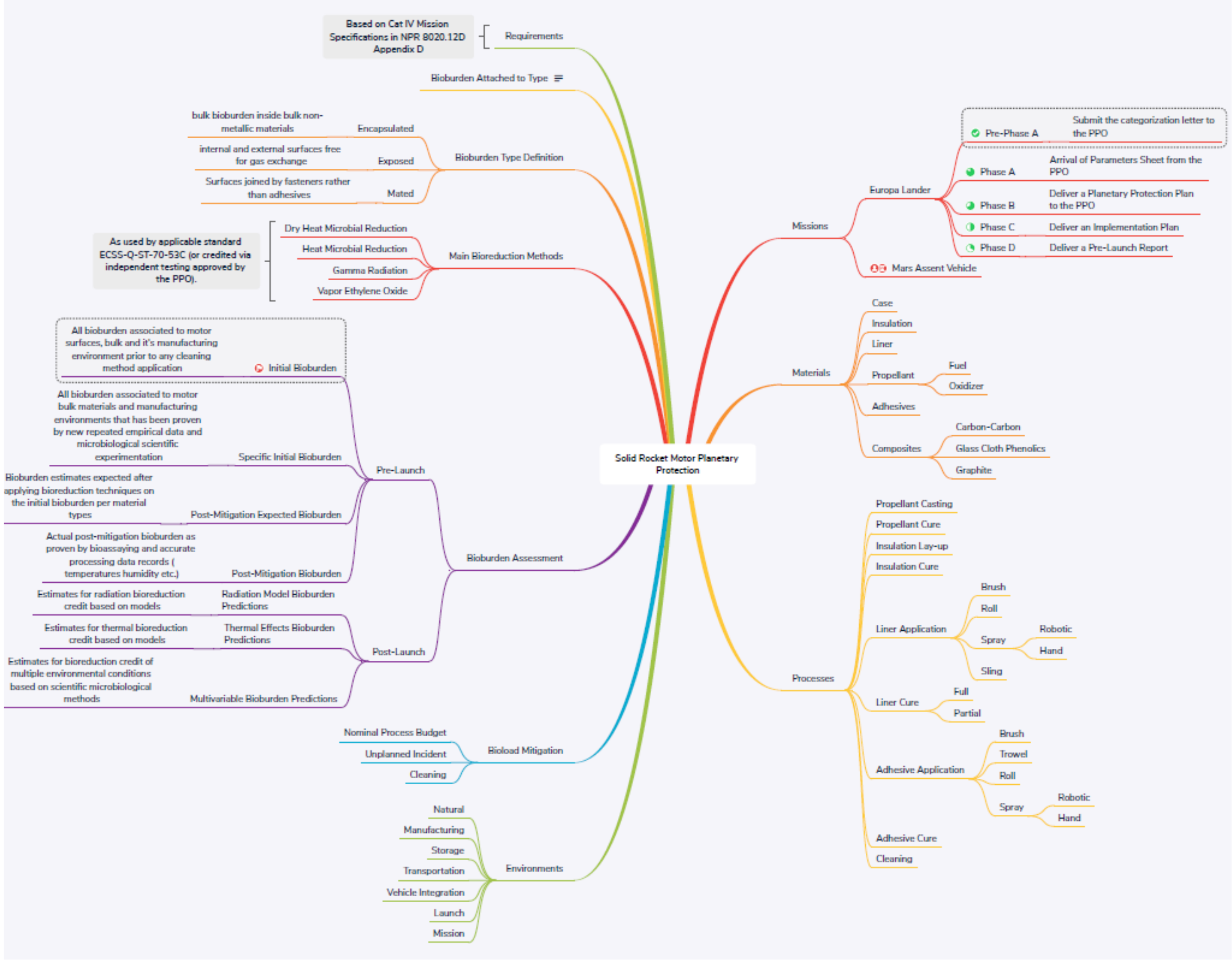


Figure 4. SRM make-up [10].

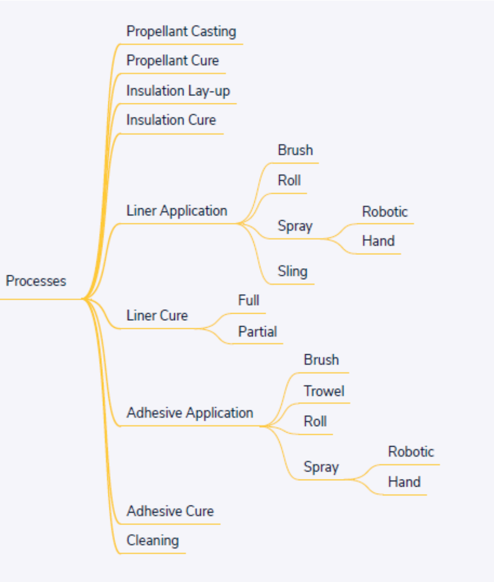
Planetary Protection Process



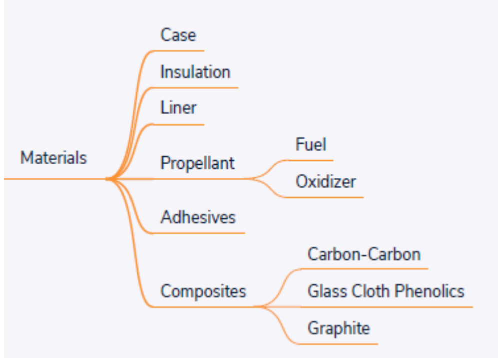
- Solid Rocket Motor Planetary Protection
  - Requirements
    - Based on Cat IV Mission Specifications in NPR 8020.12D Appendix D
  - Bioburden Attached to Type
  - Bioburden Type Definition
    - Encapsulated
      - bulk bioburden inside bulk non-metallic materials
    - Exposed
      - internal and external surfaces free for gas exchange
    - Mated
      - Surfaces joined by fasteners rather than adhesives
  - Main Bioreduction Methods
    - Dry Heat Microbial Reduction
    - Heat Microbial Reduction
    - Gamma Radiation
    - Vapor Ethylene Oxide
    - As used by applicable standard ECSS-Q-ST-70-53C (or credited via independent testing approved by the PPO).
  - Bioburden Assessment
    - Pre-Launch
      - Initial Bioburden
        - All bioburden associated to motor surfaces, bulk and it's manufacturing environment prior to any cleaning method application
      - Specific Initial Bioburden
        - All bioburden associated to motor bulk materials and manufacturing environments that has been proven by new repeated empirical data and microbiological scientific experimentation
      - Post-Mitigation Expected Bioburden
        - Bioburden estimates expected after applying bioreduction techniques on the initial bioburden per material types
      - Post-Mitigation Bioburden
        - Actual post-mitigation bioburden as proven by bioassaying and accurate processing data records (temperatures humidity etc.)
    - Post-Launch
      - Radiation Model Bioburden Predictions
        - Estimates for radiation bioreduction credit based on models
      - Thermal Effects Bioburden Predictions
        - Estimates for thermal bioreduction credit based on models
      - Multivariable Bioburden Predictions
        - Estimates for bioreduction credit of multiple environmental conditions based on scientific microbiological methods
  - Bioload Mitigation
    - Nominal Process Budget
    - Unplanned Incident
    - Cleaning
  - Environments
    - Natural
    - Manufacturing
    - Storage
    - Transportation
    - Vehicle Integration
    - Launch
    - Mission
  - Missions
    - Europa Lander
      - ✓ Pre-Phase A — Submit the categorization letter to the PPO
      - ● Phase A — Arrival of Parameters Sheet from the PPO
      - ● Phase B — Deliver a Planetary Protection Plan to the PPO
      - ◑ Phase C — Deliver an Implementation Plan
      - ◔ Phase D — Deliver a Pre-Launch Report
    - Mars Assent Vehicle
  - Materials
    - Case
    - Insulation
    - Liner
    - Propellant
      - Fuel
      - Oxidizer
    - Adhesives
    - Composites
      - Carbon-Carbon
      - Glass Cloth Phenolics
      - Graphite
  - Processes
    - Propellant Casting
    - Propellant Cure
    - Insulation Lay-up
    - Insulation Cure
    - Liner Application
      - Brush
      - Roll
      - Spray
        - Robotic
        - Hand
      - Sling
    - Liner Cure
      - Full
      - Partial
    - Adhesive Application
      - Brush
      - Trowel
      - Roll
      - Spray
        - Robotic
        - Hand
    - Adhesive Cure
    - Cleaning

Figure 5. Mindmap of SRM PP.

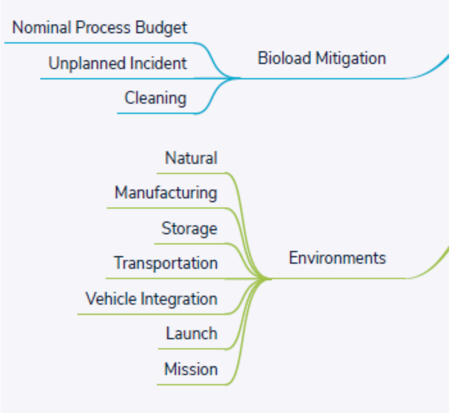
Planetary Protection Process



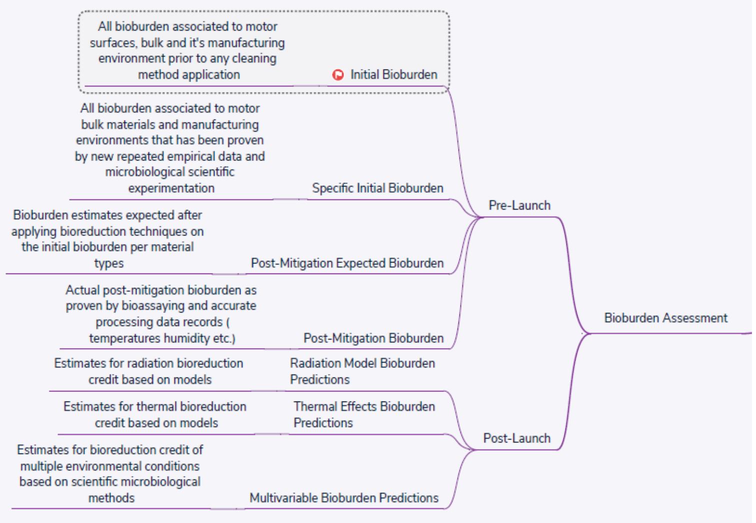
Processes



Materials

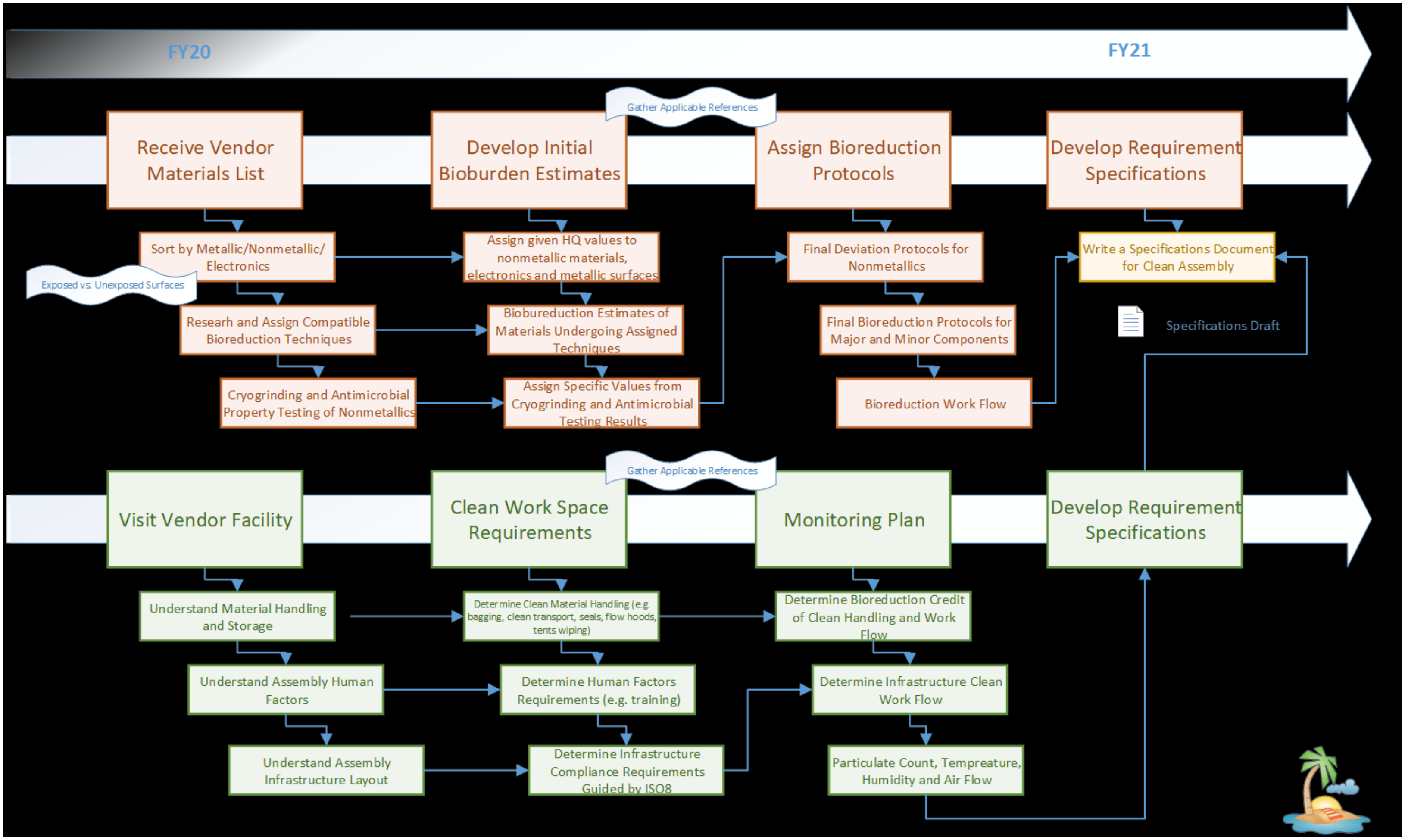


Environments



Bioburden Assessment

Planetary Protection Process



FY20

FY21

Receive Vendor Materials List

- Sort by Metallic/Nonmetallic/ Electronics
- Exposed vs. Unexposed Surfaces
- Researh and Assign Compatible Bioreduction Techniques
- Cryogrinding and Antimicrobial Property Testing of Nonmetallics

Develop Initial Bioburden Estimates

- Assign given HQ values to nonmetallic materials, electronics and metallic surfaces
- Bioburedution Estimates of Materials Undergoing Assigned Techniques
- Assign Specific Values from Cryogrinding and Antimicrobial Testing Results

Gather Applicable References

Assign Bioreduction Protocols

- Final Deviation Protocols for Nonmetallics
- Final Bioreduction Protocols for Major and Minor Components
- Bioreduction Work Flow

Develop Requirement Specifications

- Write a Specifications Document for Clean Assembly
- Specifications Draft

Visit Vendor Facility

- Understand Material Handling and Storage
- Understand Assembly Human Factors
- Understand Assembly Infrastructure Layout

Clean Work Space Requirements

- Determine Clean Material Handling (e.g. bagging, clean transport, seals, flow hoods, tents wiping)
- Determine Human Factors Requirements (e.g. training)
- Determine Infrastructure Compliance Requirements Guided by ISO8

Gather Applicable References

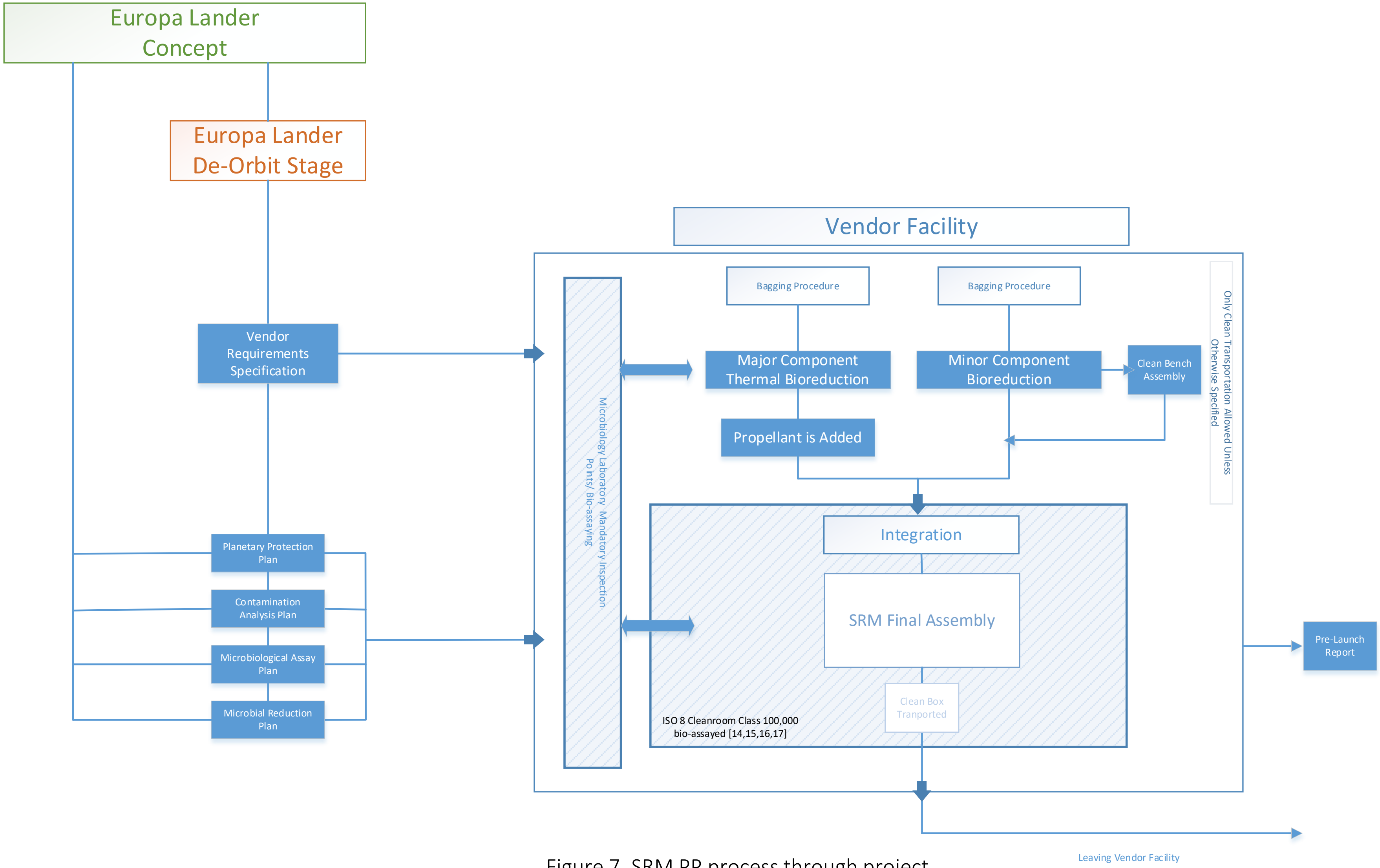
Monitoring Plan

- Determine Bioreduction Credit of Clean Handling and Work Flow
- Determine Infrastructure Clean Work Flow
- Particulate Count, Tempreature, Humidity and Air Flow

Develop Requirement Specifications

Figure 6. Roadmap of SRM PP procurement requirements [11].

Planetary Protection Process (Non-VHP)



Europa Lander Concept

Europa Lander De-Orbit Stage

Vendor Requirements Specification

Planetary Protection Plan

Contamination Analysis Plan

Microbiological Assay Plan

Microbial Reduction Plan

Vendor Facility

Microbiology Laboratory Mandatory Inspection Points/ Bio-assaying

Bagging Procedure

Bagging Procedure

Major Component Thermal Bioreduction

Minor Component Bioreduction

Clean Bench Assembly

Propellant is Added

Only Clean Transportation Allowed Unless Otherwise Specified

Integration

SRM Final Assembly

Clean Box Tranported

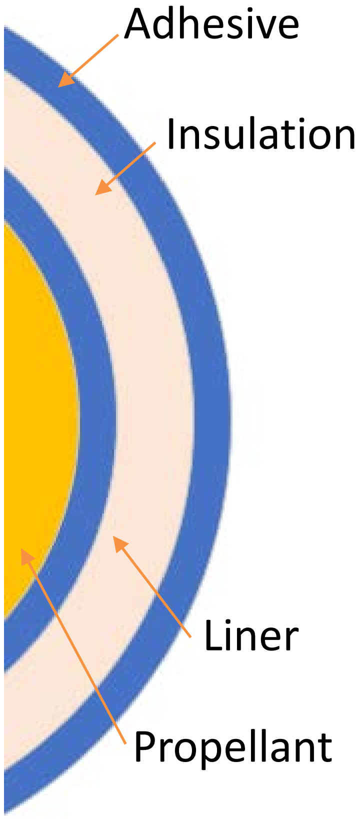
ISO 8 Cleanroom Class 100,000 bio-assayed [14,15,16,17]

Pre-Launch Report

Leaving Vendor Facility

Figure 7. SRM PP process through project stages without including the use of VHP.

Planetary Protection Process



Adhesive

Insulation

Liner

Propellant

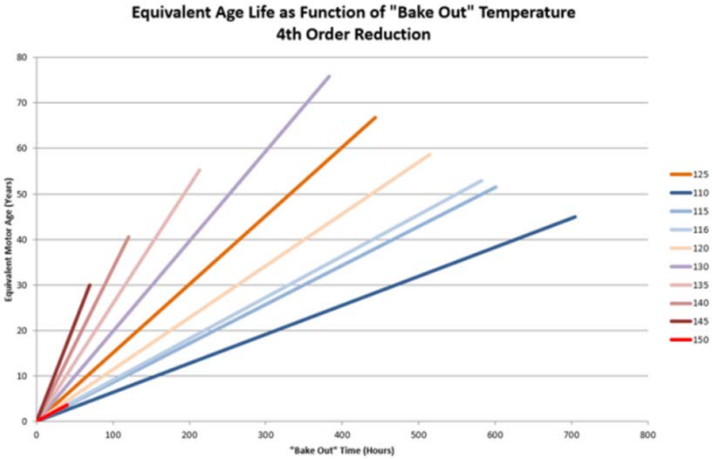
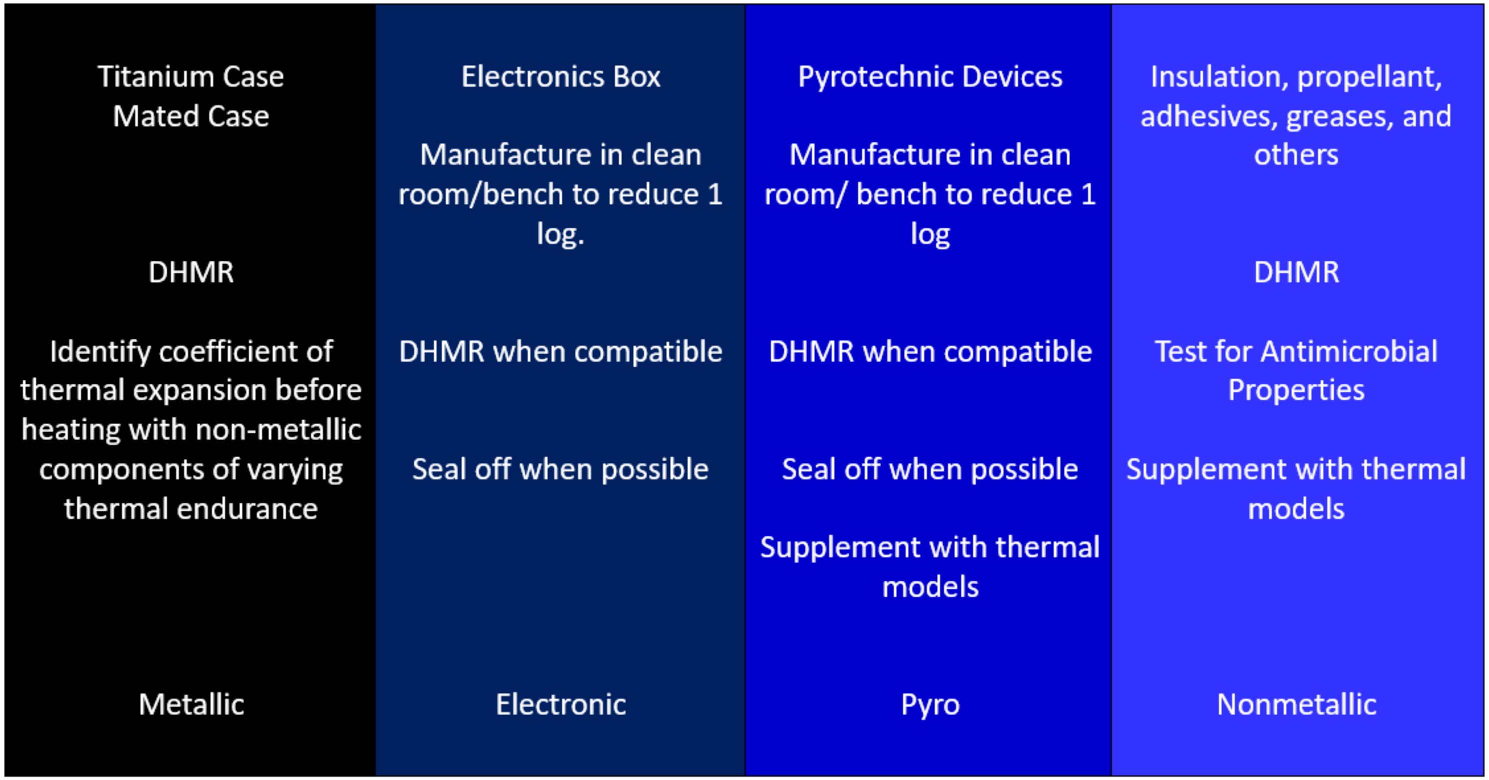


Figure 8. Age equivalency to bake-out temperatures at 4th order reduction [12].

3000-degrees

Planetary Protection Techniques



Titanium Case Mated Case	Electronics Box	Pyrotechnic Devices	Insulation, propellant, adhesives, greases, and others
	Manufacture in clean room/bench to reduce 1 log.	Manufacture in clean room/ bench to reduce 1 log	
DHMR			DHMR
Identify coefficient of thermal expansion before heating with non-metallic components of varying thermal endurance	DHMR when compatible	DHMR when compatible	Test for Antimicrobial Properties
	Seal off when possible	Seal off when possible	Supplement with thermal models
		Supplement with thermal models	
Metallic	Electronic	Pyro	Nonmetallic

Figure 9. SRM PP simple techniques applicable.

Conclusions

- DHMR of the entire motor at once does not appear to be the way to achieve targeted bioreduction for the braking motor's propellant and liner.
- Scenarios with a sacrificial thermal liner inside the metallic case may benefit from antimicrobial testing and irradiation pre-application.
- Inner-case: bagging procedures scenarios that occur can be used to the advantage of Planetary Protection.
- No-grease design change: eliminating the use of greases and increasing the risk of a rigid mated case unless greases are proven to cause a logarithmic reduction of microbial load.
- Nozzle: sealing mechanisms should be used, and verification of sealant performance and nozzle cap performance should be provided.
- Scenario with no VHP: component integration in a class 8 cleanroom environment and components divided by material compatibility to PP techniques.

Future Work

- Thermal models shall support the Planetary Protection deviation to use motor firing as mode of sterilization in future studies.
- Aside from this, small quantities of propellant, insulation, nozzle and other nonmetallics may be shipped and utilized in cryogrinding procedures to determine initial encapsulated bioburden numbers, different from those assigned by the Planetary Protection Provisions document.
- Future motor burning failure probability studies may corroborate if motor-firing is a viable option for a final probability of contamination for the mission that remains under less than 10-4 with unsterilized propellant.

Acknowledgements

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