



# Internal Electrostatic Discharge Testing *of* Inert Solid Rocket Motor Materials

**Todd Schneider, Jason Vaughn, Erin Hayward, Brandon Phillips and Ken Wright**

NASA Marshall Space Flight Center

Huntsville, Alabama USA

May 17, 2019

# Motivation

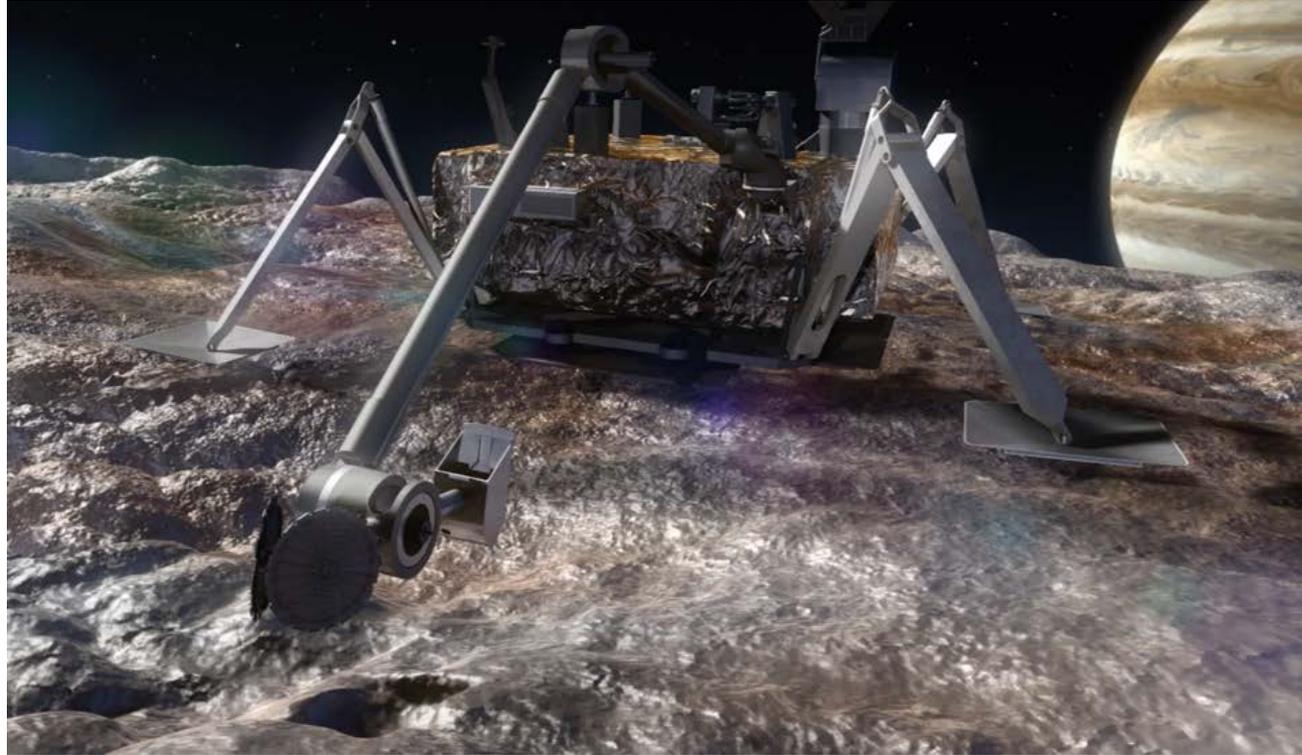
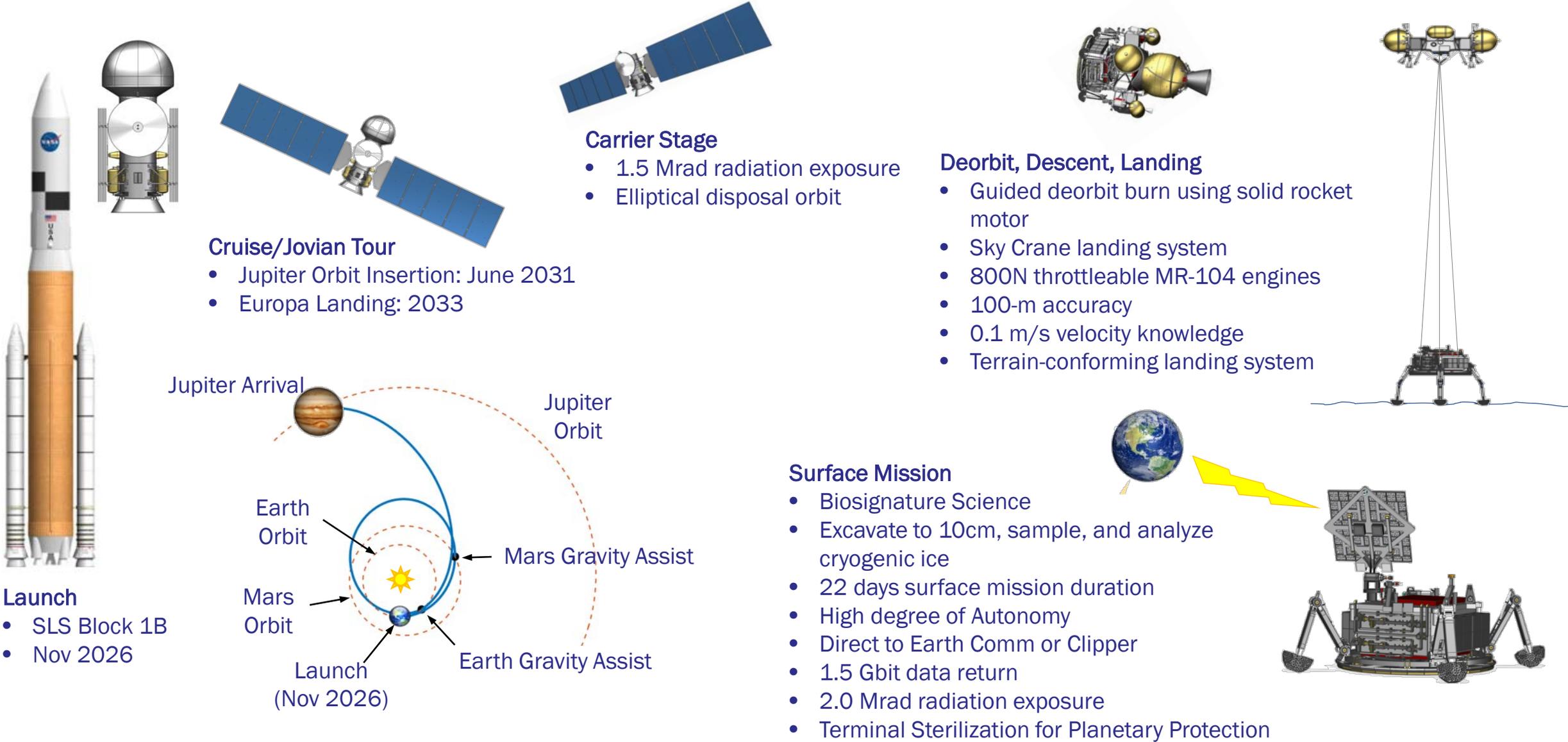


Image Credit: NASA/JPL-Caltech

- Europa Lander Mission
  - To place a spacecraft on the surface of Jupiter's moon Europa
- The Jupiter (Jovian) Environment is characterized by high radiation levels
  - Including a spectrum of high energy charged particles
- A successful mission to Europa requires verification through analysis and test that all elements of the spacecraft will survive the space environment
  - Radiation dose issues
  - Material charging concerns

# Europa Lander Mission Concept as of November 2018



- Launch**
- SLS Block 1B
  - Nov 2026

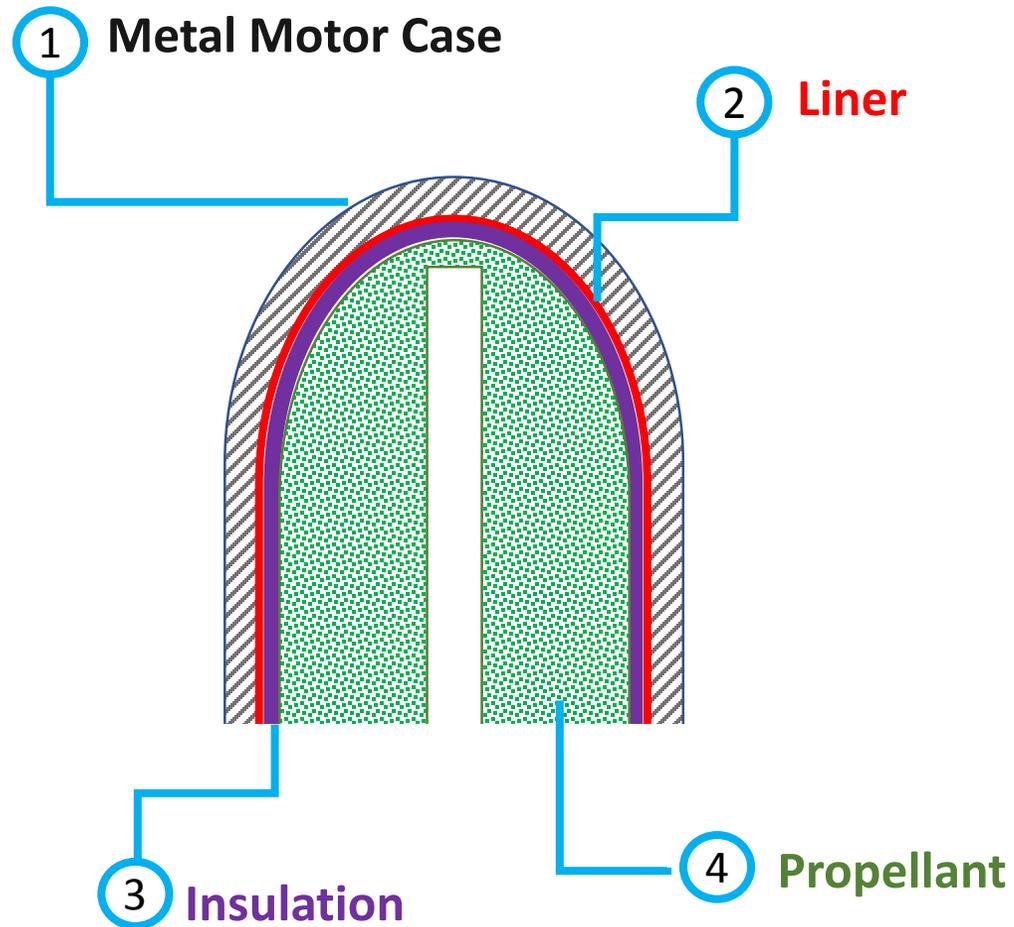
- Cruise/Jovian Tour**
- Jupiter Orbit Insertion: June 2031
  - Europa Landing: 2033

- Carrier Stage**
- 1.5 Mrad radiation exposure
  - Elliptical disposal orbit

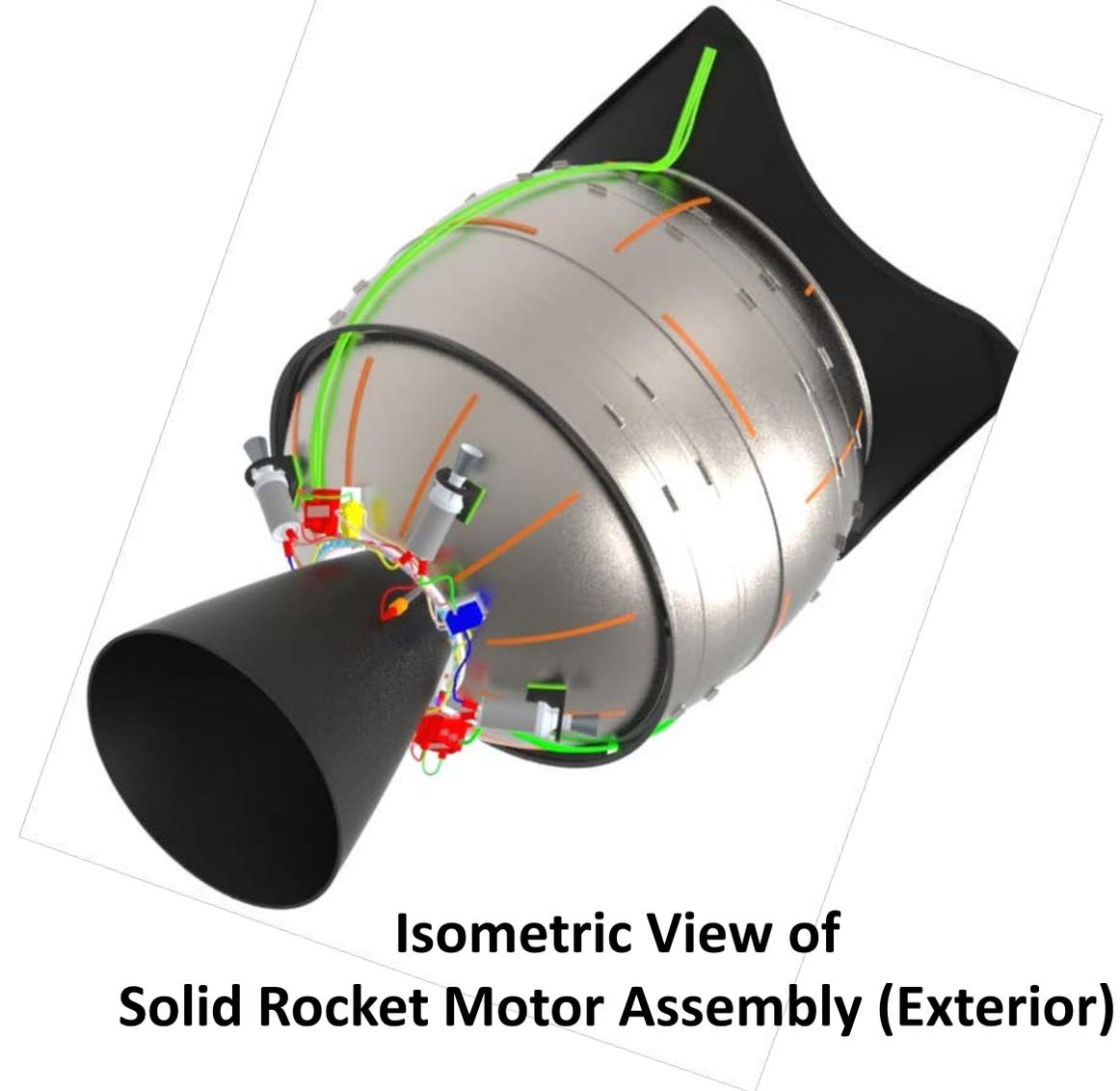
- Deorbit, Descent, Landing**
- Guided deorbit burn using solid rocket motor
  - Sky Crane landing system
  - 800N throttleable MR-104 engines
  - 100-m accuracy
  - 0.1 m/s velocity knowledge
  - Terrain-conforming landing system

- Surface Mission**
- Biosignature Science
  - Excavate to 10cm, sample, and analyze cryogenic ice
  - 22 days surface mission duration
  - High degree of Autonomy
  - Direct to Earth Comm or Clipper
  - 1.5 Gbit data return
  - 2.0 Mrad radiation exposure
  - Terminal Sterilization for Planetary Protection

# Solid Rocket Motor for the De-Orbit Stage (DOS)

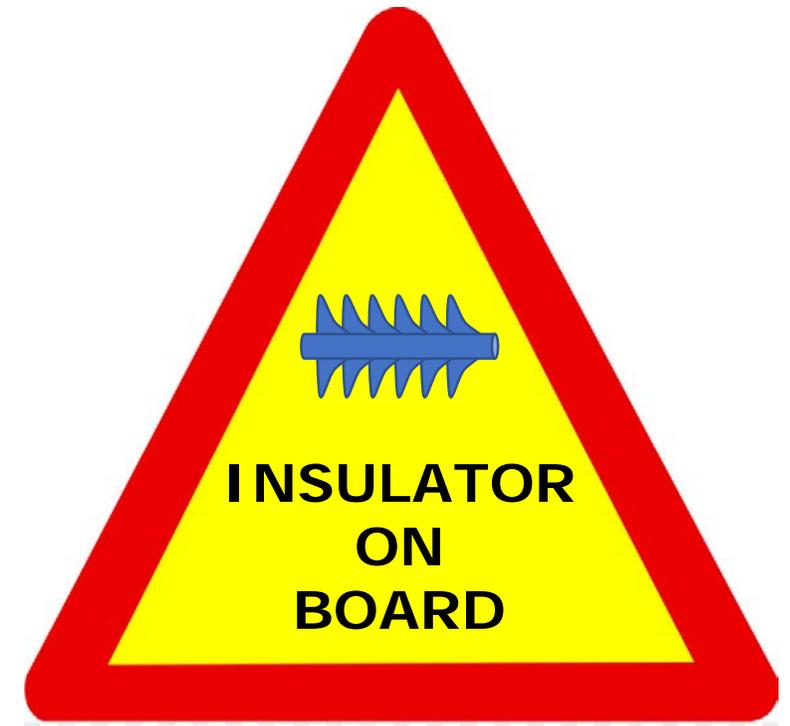


**Cross-Section of  
Typical Solid Rocket Motor Layout**



# Caution: Insulating Materials Identified

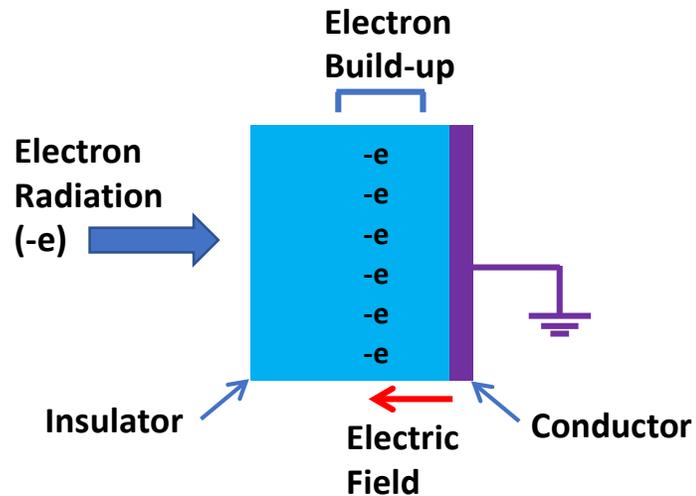
- Insulation material
  - SF-EPDM
    - **Silica Filled** EPDM (Synthetic Rubber)
    - EPDM: Ethylene Propylene Diene Monomer
  - KF-EPDM
    - **Kevlar Filled** EPDM (Synthetic Rubber)
    - EPDM: Ethylene Propylene Diene Monomer
- Liner
  - Rubberized bonding agent
  - Adheres insulation to propellant
    - 2018 0801-Europa (custom mixture based on HTPB R45)
- Inert propellant
  - Ammonium Sulfate, Aluminum, and HTPB Binder R45
    - Hydroxyl Terminated Poly Butadiene R45
  - By contrast, live propellant contains Ammonium Perchlorate as the oxidizer



# Internal Electrostatic Discharge (iESD)

Arcing occurs when the electric field, created by the build-up of electrons in a region of the material, exceeds the dielectric strength of the material

## *Deep Charging (Internal Charging) Scenario*



## Contributing Factors

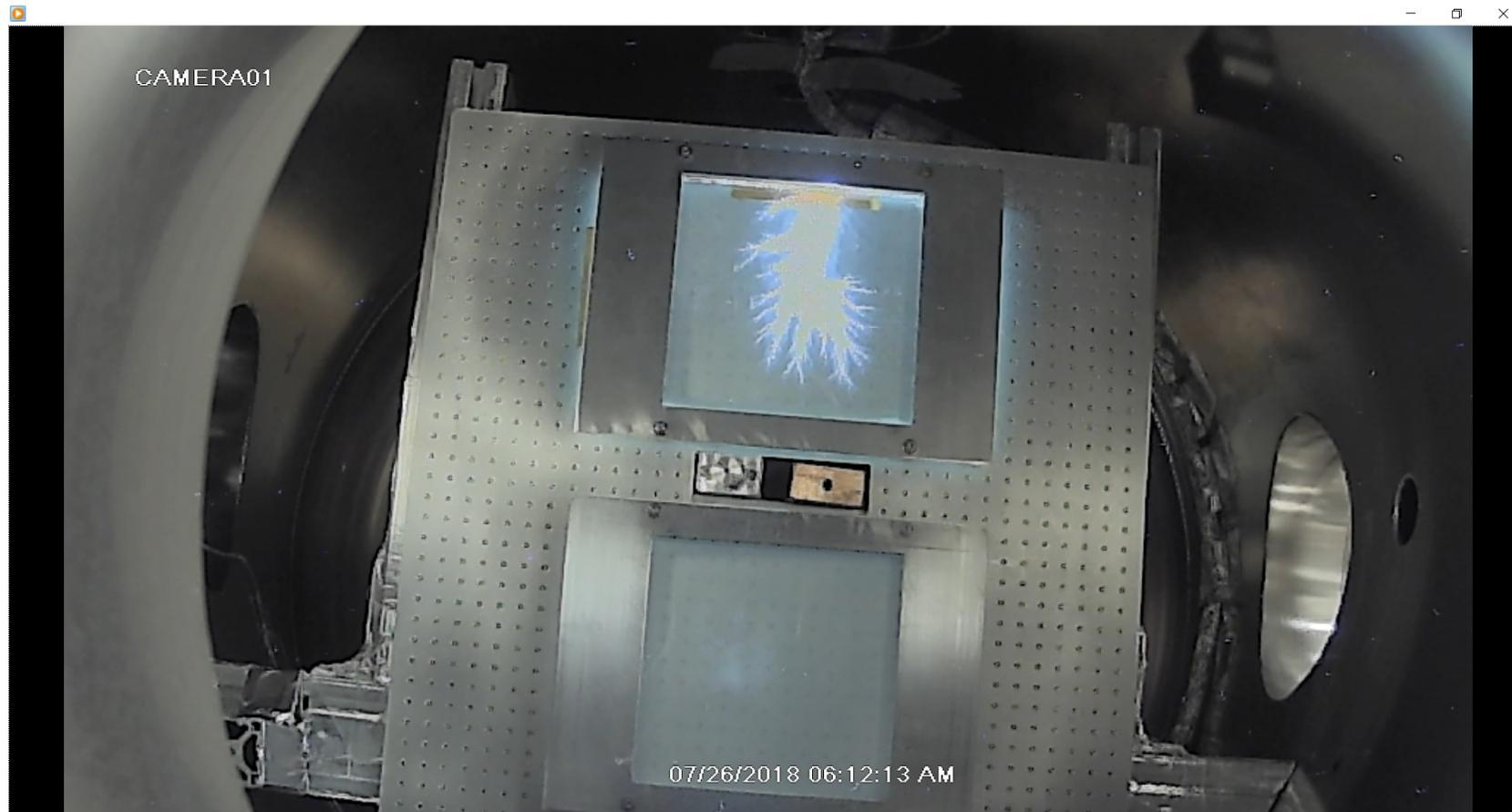
- Insulating materials
  - High Resistivity Materials
- High energy electron radiation
- High flux stream of electron radiation
- Grounded conductors adjacent to high resistivity material
- Charging imbalance within the dielectric material

## Mitigating Factors

- Conductive materials
  - Low Resistivity Materials
- Shielding of high energy electrons
- Low flux stream of electrons
- Large separation distance between charged and grounded surface
- Uniform distribution of charge

# iESD Example on Clear Material

2.4 MeV electrons applied to 1.3 cm thick Acrylic (PMMA)



# Material Property Degradation Due to iESD

- When an iESD occurs in a material, it can leave tracks or “Lichtenberg Patterns” which can degrade material properties if a sufficient number of arcs occur
- It is critical to gain insight into the charging and discharging (arcing) properties of SRM materials to determine if the arc frequency and arc magnitude are sufficient to damage or degrade the materials which could effect motor performance

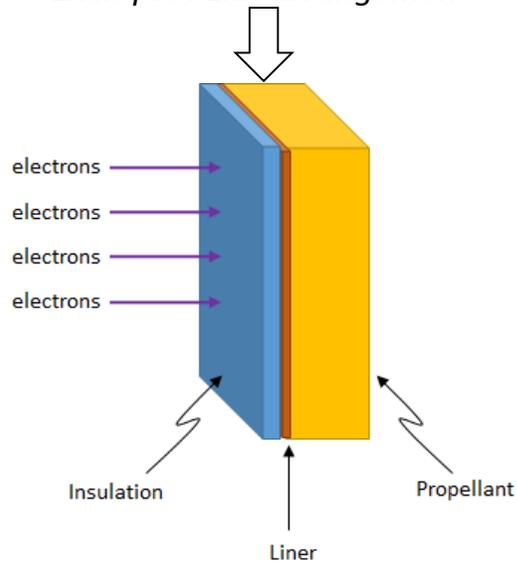


***Example of Multiple iESD Events in a Material***

# Example 1D Model Results from Early Analysis

## Propellant-Liner-Insulation-Matrix "PLIM"

Example PLIM arrangement

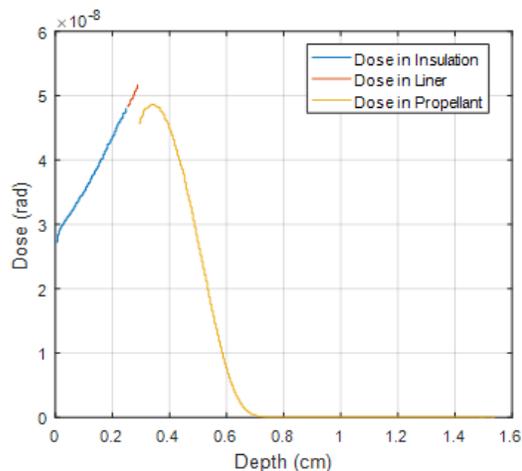


### NUMIT Modeling Tool

- Developed by JPL
- Used by MSFC to establish testing conditions/limits
- Results subject to normal modeling constraints of idealized materials with well known properties

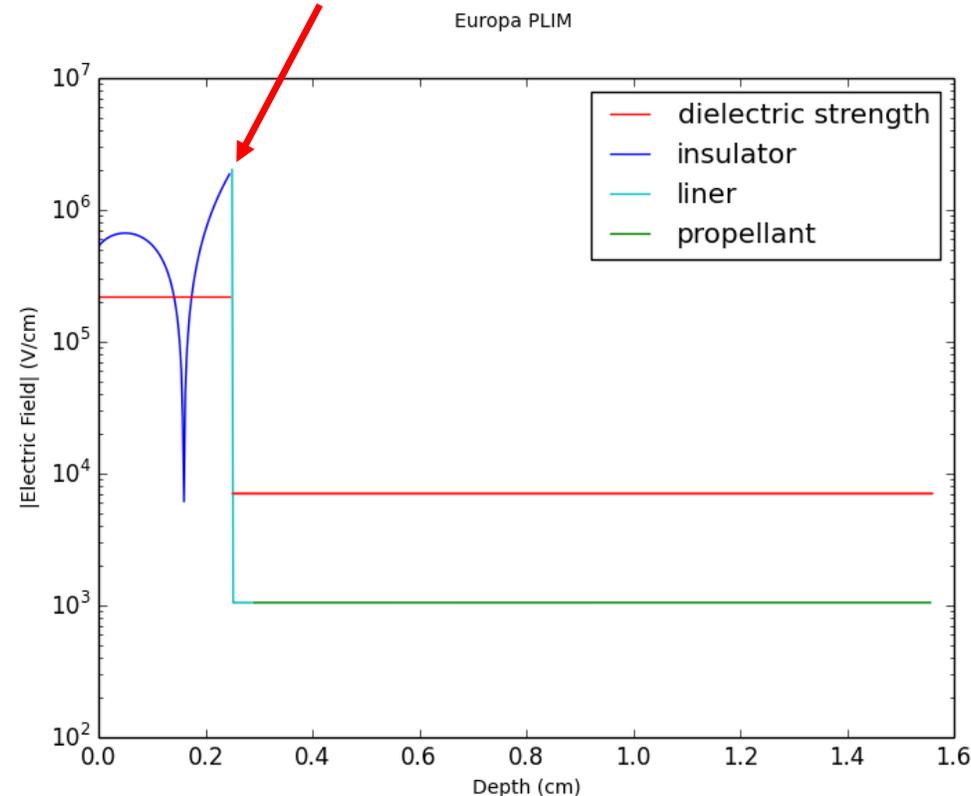
### Model Input

- 3 layers **Insulator**, **Liner**, **Propellant**
- 2.0 MeV electron beam
- **2nA/cm<sup>2</sup> current density**



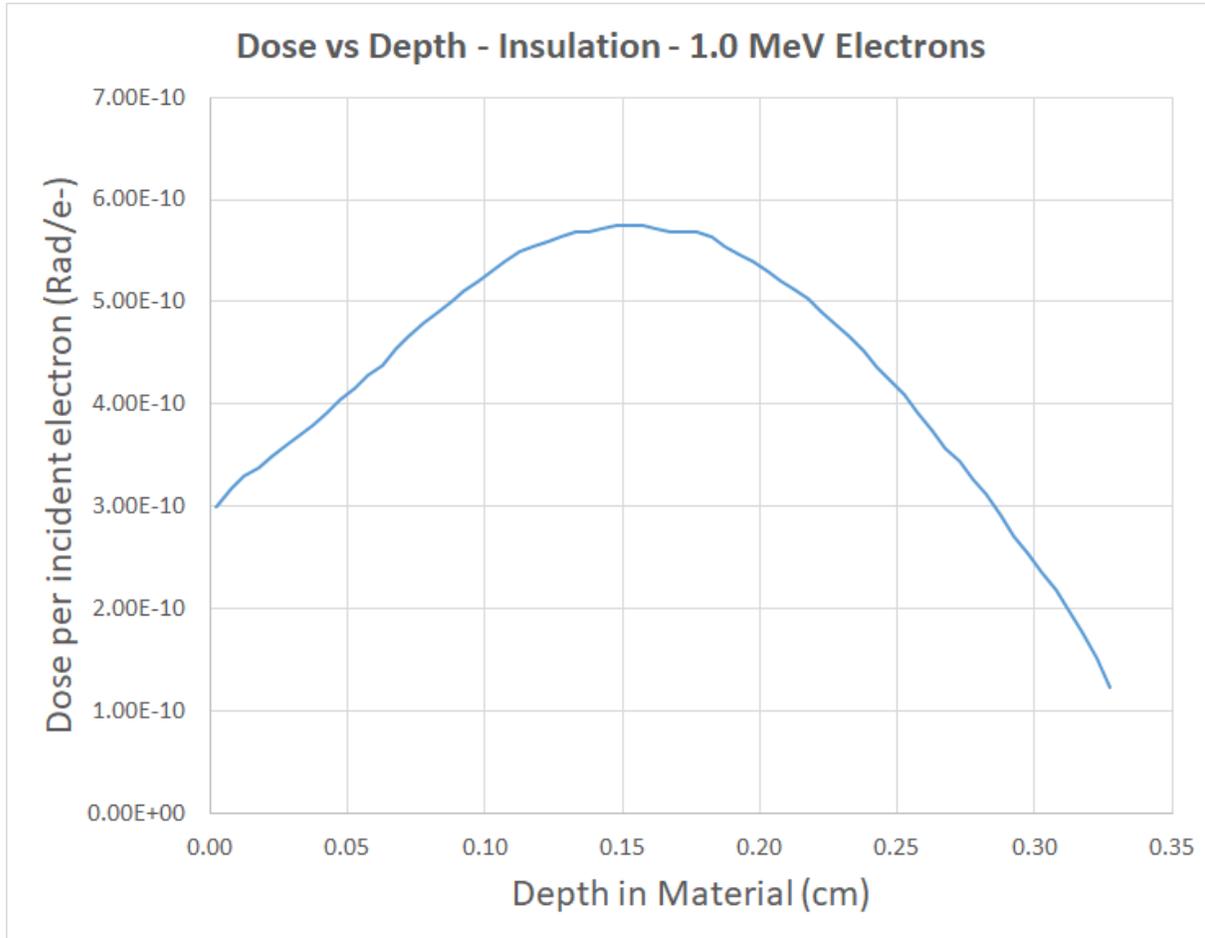
From Dr. Jarvis Caffrey (MSFC)– November 2017

High Fields in Insulator!  
The insulator retains charge. Build-up exceeds dielectric strength. Arcing likely to occur.

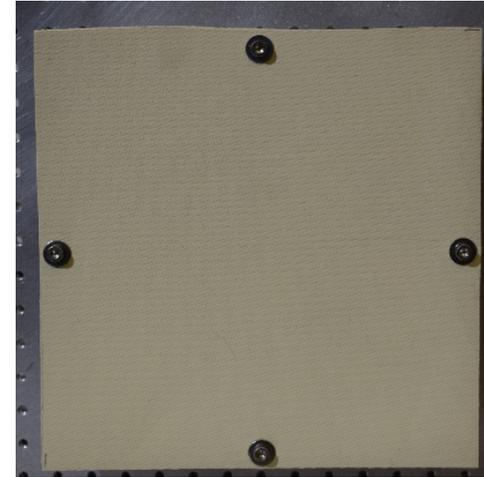


From Dr. Emily Willis (MSFC/EV44) – November 2017

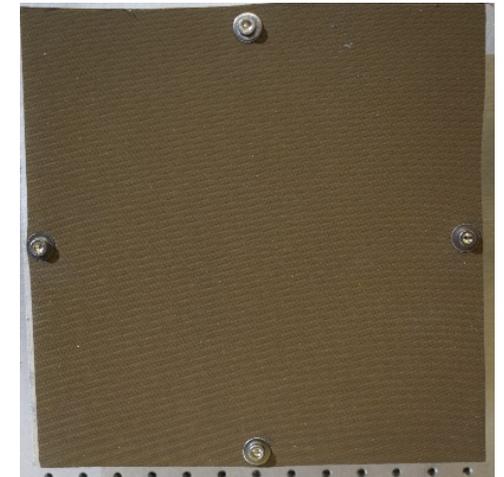
# Sample Pictures and Example Dose-Depth Curve



Model Results Courtesy Dr. Jarvis Caffrey, NASA/MSFC



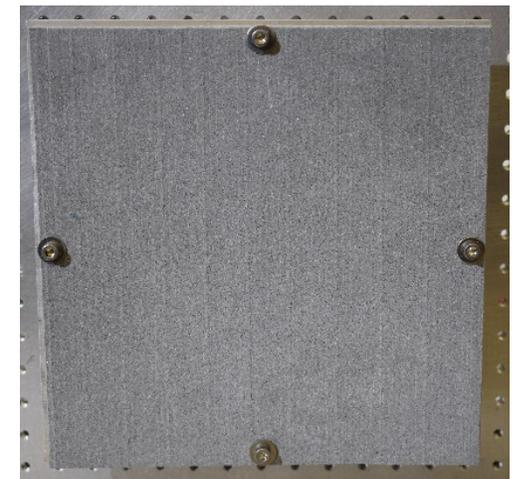
**Insulation Material: SF-EPDM**



**Insulation Material: KF-EPDM**



**Liner Material**



**Inert Propellant Material**

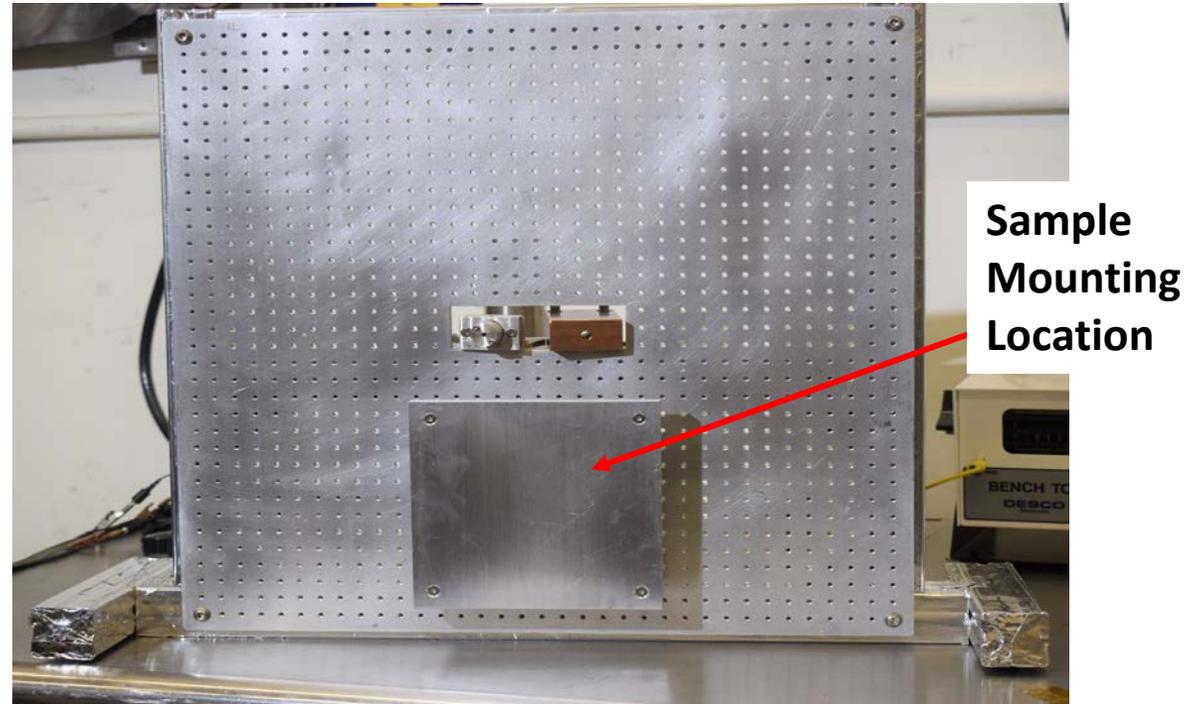
# iESD Test Plan



## Marshall Space Flight Center's Combined Environmental Effects Facility (CEEF)

- Conduct tests in MSFC's CEEF using high-energy Pelletron accelerator
- All iESD tests require high energy electrons ( $> 0.8$  MeV) to penetrate deep into the sample
  - Scattering foil creates large diameter electron beam to uniformly cover sample area [up to 16 inch (40 cm) diameter beam spot]

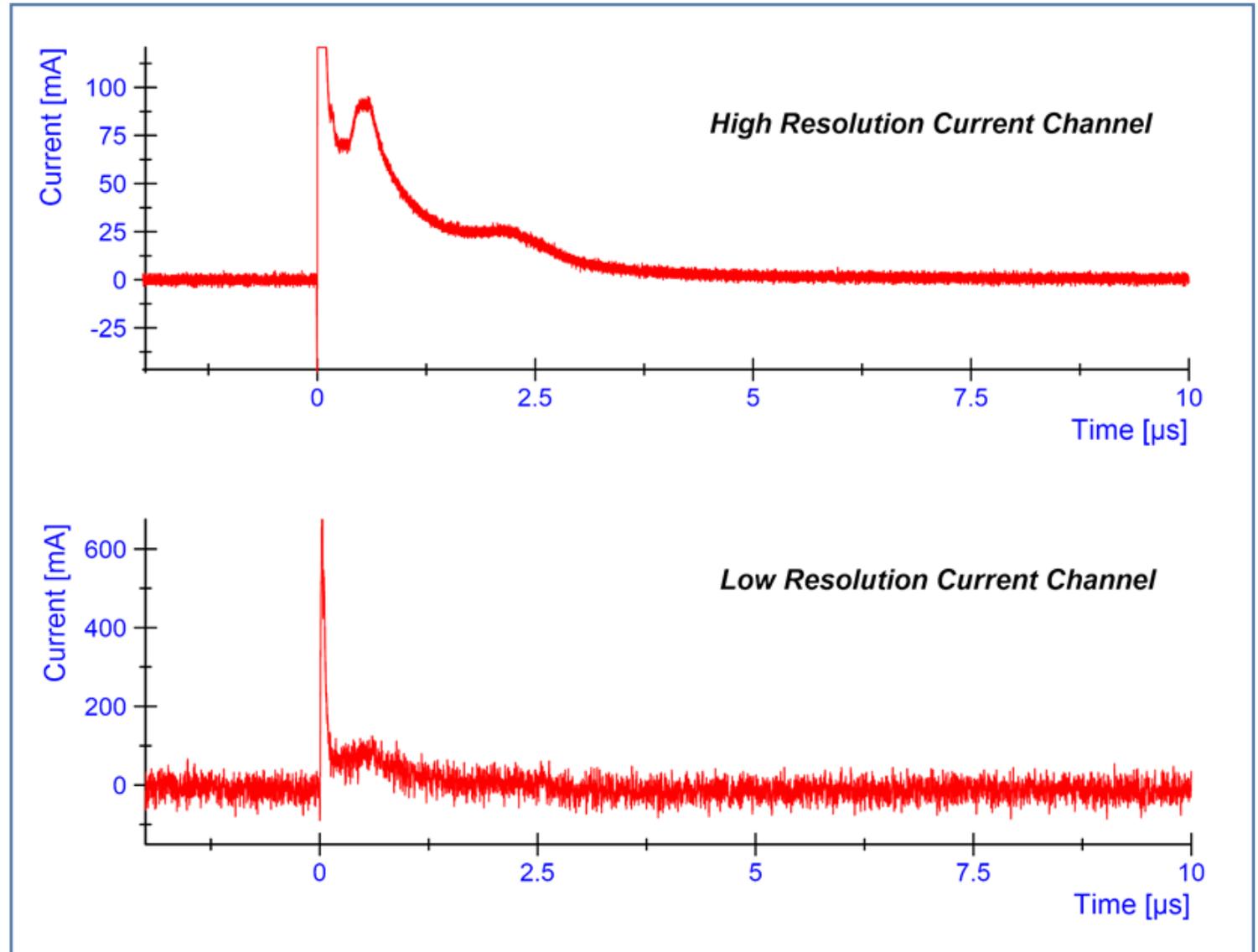
- Expose inert solid rocket motor materials to high energy electrons and measure the arc frequency, arc current magnitude, and duration
  - Measure iESD activity by monitoring sample mounting plate current
    - Ground sample mounting plate externally through 50-ohm high-frequency load



Sample Holder (with Faraday cups for beam flux measurement)

# Example Waveform

- SF-EPDM Sample
- 1 MeV electrons
- 1 nA/cm<sup>2</sup>
- Peak Current = 700 mA
- Total Pulse Duration = 3  $\mu$ s



# iESD Test Summary: Silica-Filled EPDM Insulation

**Most sensitive to generating iESD of the four sample types tested**

Date	Sample under Test	Energy (MeV)	Flux (nA/cm <sup>2</sup> )	Average time between arcs
10/25/2018	Silica-Filled EPDM	1	0.1	900 sec/1 arc = 900 sec/arc
		1	0.25	900 sec/6 arcs = 150 sec/arc
		1	0.5	900 sec/16 arcs = 56.3 sec/arc
		1	1	2038 sec/200 arcs = 10.2 sec/arc
10/29/2018	Silica-Filled EPDM	1	0.1	3600 sec/12 arcs = 300 sec/arc
		1	0.25	1560 sec/14 arcs = 111.4 sec/arc
		1	0.5	6170 sec/84 arcs = 73.5 sec/arc

Total fluence after both days =  $5.26 \times 10^{13}$  e-/cm<sup>2</sup> => 3 Mrads  
 (Mission Requirement: 3 Mrads)

# iESD Test Summary: Kevlar-Filled EPDM Insulation

**iESD not detected until flux raised to 2 nA/cm<sup>2</sup>**

Date	Sample under Test	Energy (MeV)	Flux (nA/cm <sup>2</sup> )	Average time between arcs
11/1/2018	Kevlar-Filled EPDM	1	0.1	No arcs in 3600 sec
		1	0.25	No arcs in 3600 sec
		1	0.5	No arcs in 2100 sec
		1	1	No arcs in 1200 sec
		1	2	1260 sec/ 21 arcs = 60 sec/arc
		1	5	600 sec/40 arcs = 15 sec/arc
11/2/2018	Kevlar-Filled EPDM	1	1	No arcs in 1200 sec
		1	2	1800 sec/12 arcs = 150 sec/arc
		1	3	1800 sec/35 arcs = 51.5 sec/arc

Total fluence after both days =  $1.21 \times 10^{14}$  e-/cm<sup>2</sup> => 6.9 Mrads  
 Mission Requirement: 3 Mrads

# iESD Test Summary: Liner

## iESD detection threshold at 2 nA/cm<sup>2</sup>

Date	Sample under Test	Energy (MeV)	Flux (nA/cm <sup>2</sup> )	Average time between arcs
11/8/2018	Liner (HTPB)	0.8	0.1	No arcs in 1800 sec
		0.8	0.25	No arcs in 1800 sec
		0.8	0.5	No arcs in 1800 sec
		0.8	1	No arcs in 1800 sec
		0.8	2	1800 sec/1 arc
		0.8	3	1800 sec/1 arc
		0.8	4	1800 sec/4 arc = 450 sec/arc
		0.8	5	1800 sec/2 arc = 900 sec/arc
		0.8	5.5	900 sec/2 arcs = 450 sec/arc

Total fluence =  $2.08 \times 10^{14}$  e-/cm<sup>2</sup> =>4.09 Mrads  
Requirement: 3 Mrads

# iESD Test Summary: Inert Propellant

**Highly resistant to iESD generation**

Date	Sample under Test	Energy (MeV)	Flux (nA/cm <sup>2</sup> )	Average time between arcs
11/5/2018	Inert Propellant	2.4	0.1	No arcs in 2580 sec
		2.4	0.2	No arcs in 1800 sec
		2.4	0.5	No arcs in 1800 sec
		2.4	1	No arcs in 1800 sec
		2.4	2	No arcs in 1800 sec
		2.4	5	No arcs in 1980 sec
		2.4	10	3600 sec/1 arc
11/6/2018	Inert Propellant	2.4	15 +/-2	1200 sec/4 arcs = 300 sec/arc

Total fluence after both days =  $5.45 \times 10^{14}$  e-/cm<sup>2</sup> => 8.54 Mrads  
Mission Requirement: 3 Mrads

# Summary

- Missions to the Jovian environment are challenging due to the high radiation levels
- The current Europa Lander Mission design utilizes a solid rocket motor to provide the high thrust needed for the de-orbit stage
- The use of electrically insulating materials in the construction of a solid rocket motor raised concerns about the possible generation of internal Electrostatic Discharge (iESD) events and potential damage to materials leading to diminished motor performance
- **A series of evaluation tests of inert solid rocket motor materials was conducted at the Marshall Space Flight Center**
  - **With the possible exception of Silica-Filled EPDM Insulation, the tests indicated minimal susceptibility to iESD generation – particularly compared to the predicted flux levels in the Jovian environment**
- Future iESD evaluation tests will focus on external de-orbit stage components which will be exposed to higher flux levels due to minimal shielding

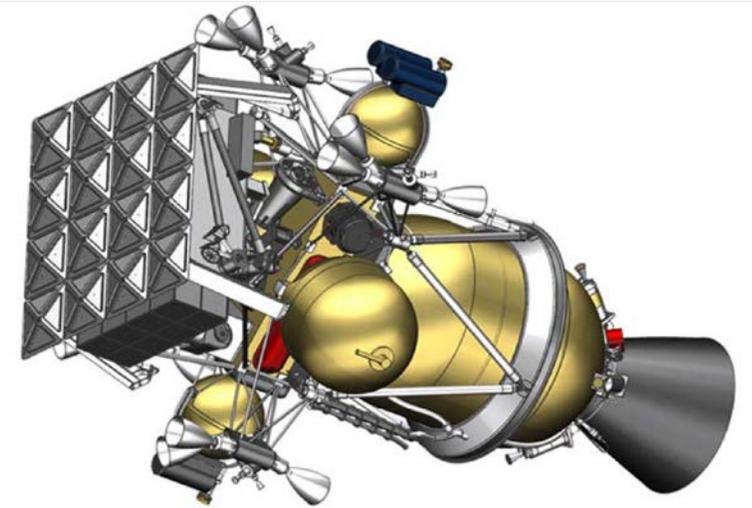


Image Credit: NASA JPL-Caltech

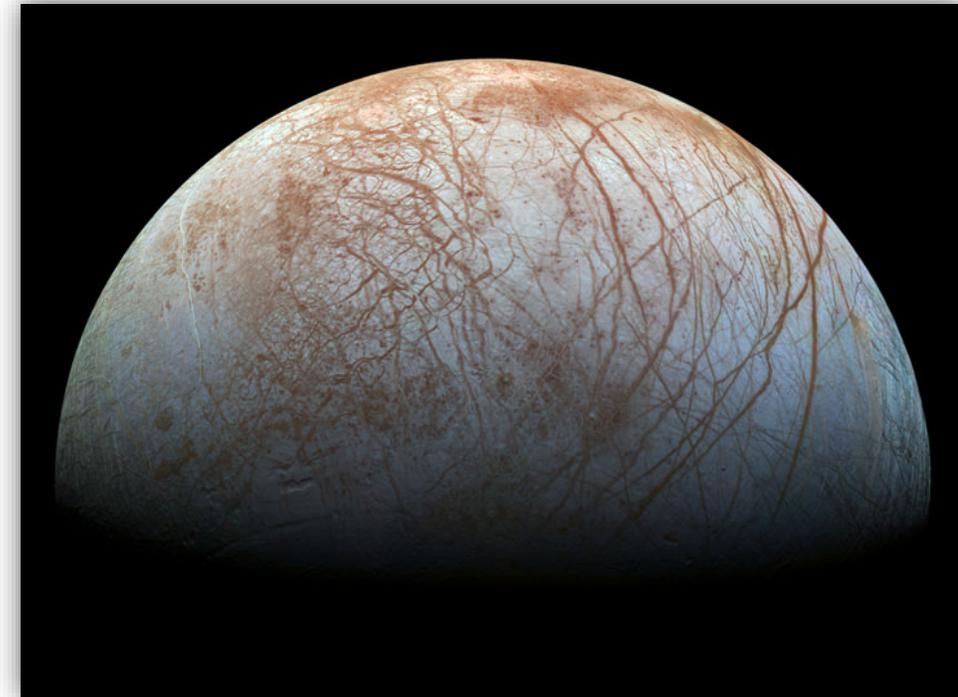


Image Credit: NASA JPL-Caltech