Concepts for Self-Cleaning Elastomer Seals for Lunar Surface Applications



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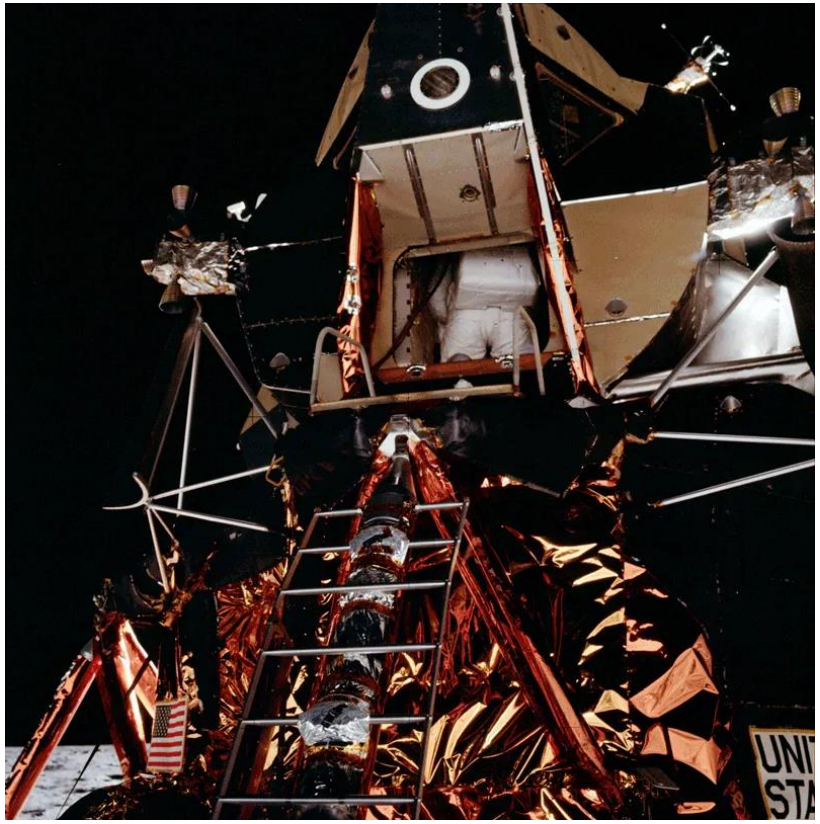
6/12/2024

Outline

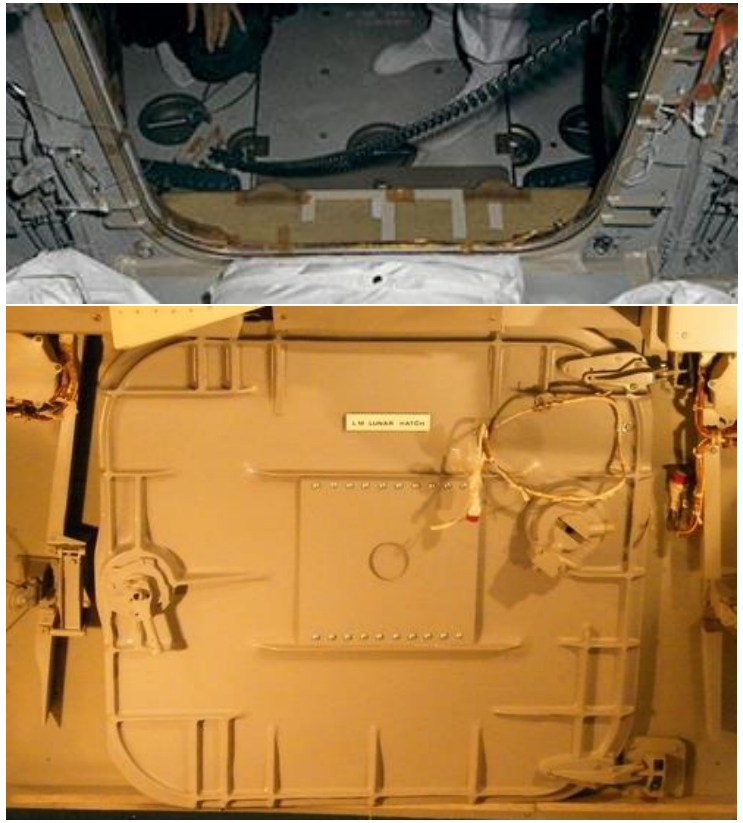
- Background/Problem: Dust on Apollo Seals
- Encapsulated O-ring Concept
- Encapsulated O-ring Prototype Testing Overview
- Multi-Phase O-ring Concepts
- Acknowledgements
- Q&A

Dust on Apollo Seals

- Apollo 12 – P. Conrad's suit, which was tight before the first EVA, developed a leak of 0.25 psi/min after two EVAs (safety limit of 0.30 psi/min)
- All the environmental sample and gas sample seals failed because of dust



Buzz Aldrin, crawls backwards out of the hatch of the Apollo 11 lander, Eagle, on July 20, 1969.
(Credit: NASA)



Apollo 15 LEM Forward Hatch (above) and mock hatch at NASA Kennedy Space Center
(Credit: NASA)

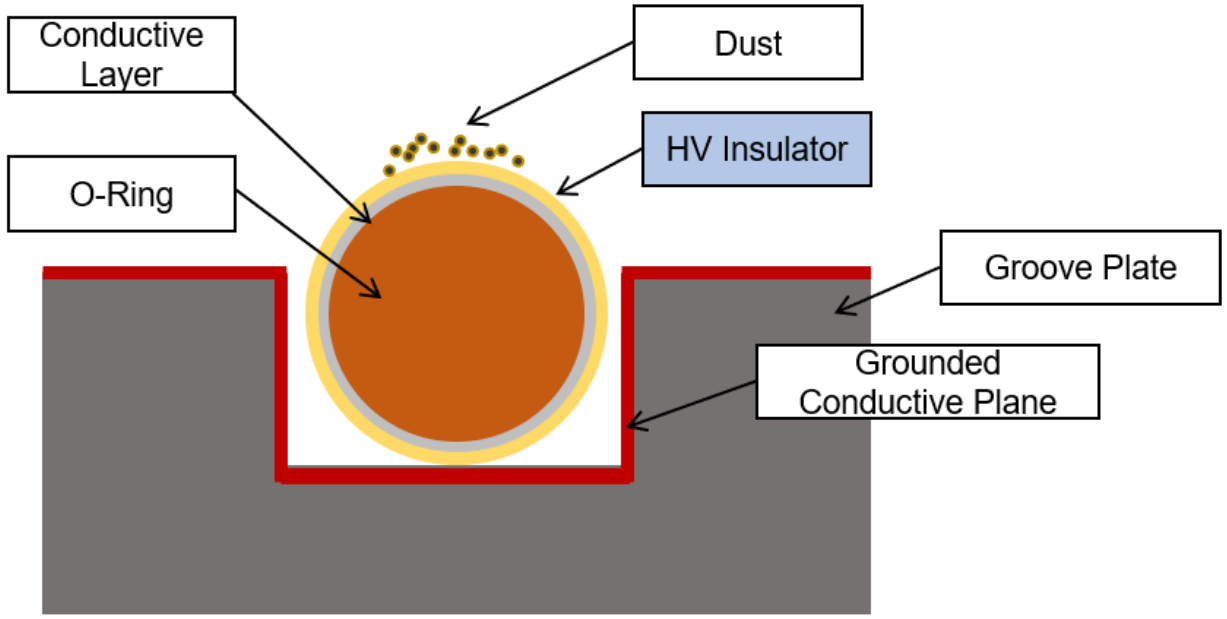


Apollo 17 Astronaut, H.H. Schmitt, in dust covered suit after final EVA, 12/13/1972
(Credit: NASA)

The Effects of Lunar Dust on EVA Systems During the Apollo Missions - NASA/TM—2005-213610 – J. Gaier, Glenn Research Center
Dust Tolerance Characterization of Lunar Docking and Hatch Seals - NASA/TM—20230015308 – N. Jimenez et al, Glenn Research Center

Encapsulated O-ring Concept

- Objectives
  - Determine how the minimum voltage to *clear* dust from an O-ring varies with O.D and insulation thickness in air and in vacuum
  - Attempt continuous dust clearing/repelling
- Test samples
  - 3, 6, and 9* mm O.D silicone rubber O-ring cord stock coated with 91 µm thick aluminum tape and 25**, 89, 178, and 267 µm thick adhesive backed FEP insulation

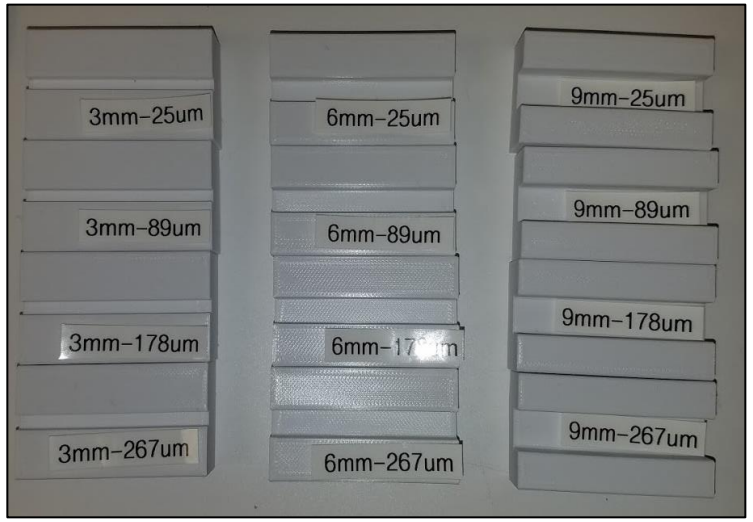


Encapsulated O-Ring in Gland

* Buna-N **Teflon film

Encapsulated O-ring 1-Phase Test Setup

- Test Setup
  - Encapsulated O-ring samples placed in standard representative O-ring glands
    - 25% axial squeeze (compression) / % height above gland surface
    - 95% gland fill
  - Standardized dust loading via dust shaker
    - ~100 mg, 25-75 µm JSC-1A, dust load (~2 x 10^{-2} g/cm^2) applied for each trial
    - 10 Hz shaker repetition rate

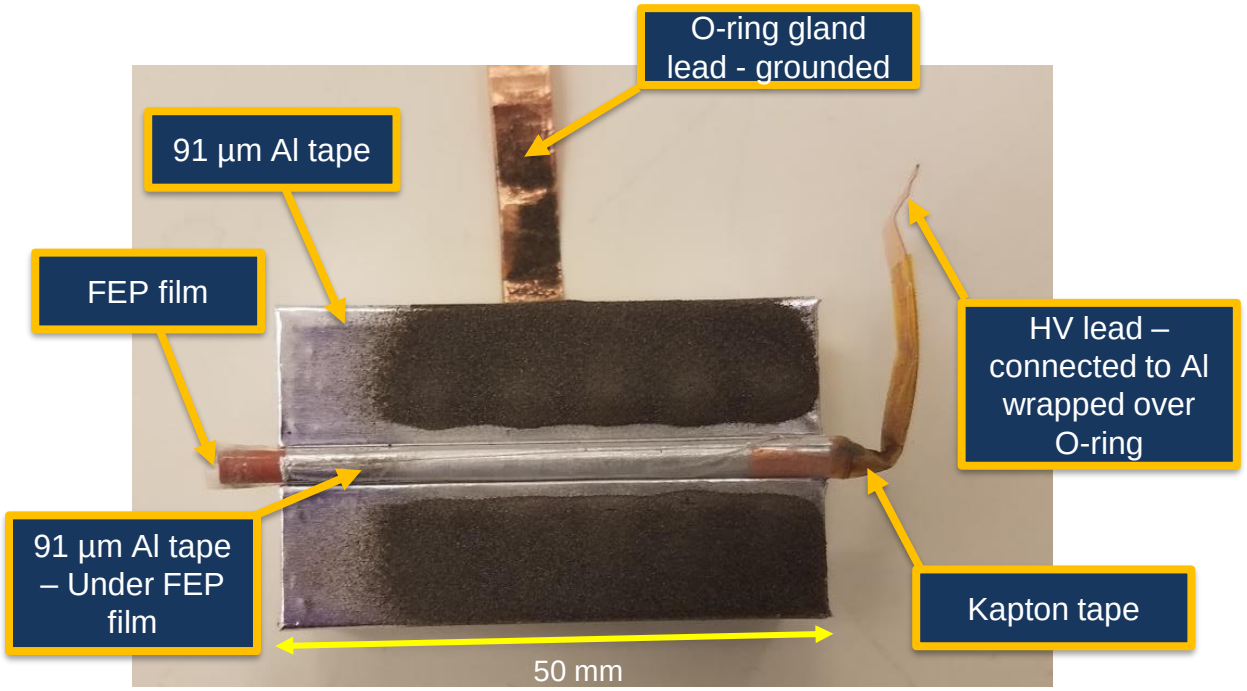


3, 6, and 9 mm O-ring glands for each insulation thickness

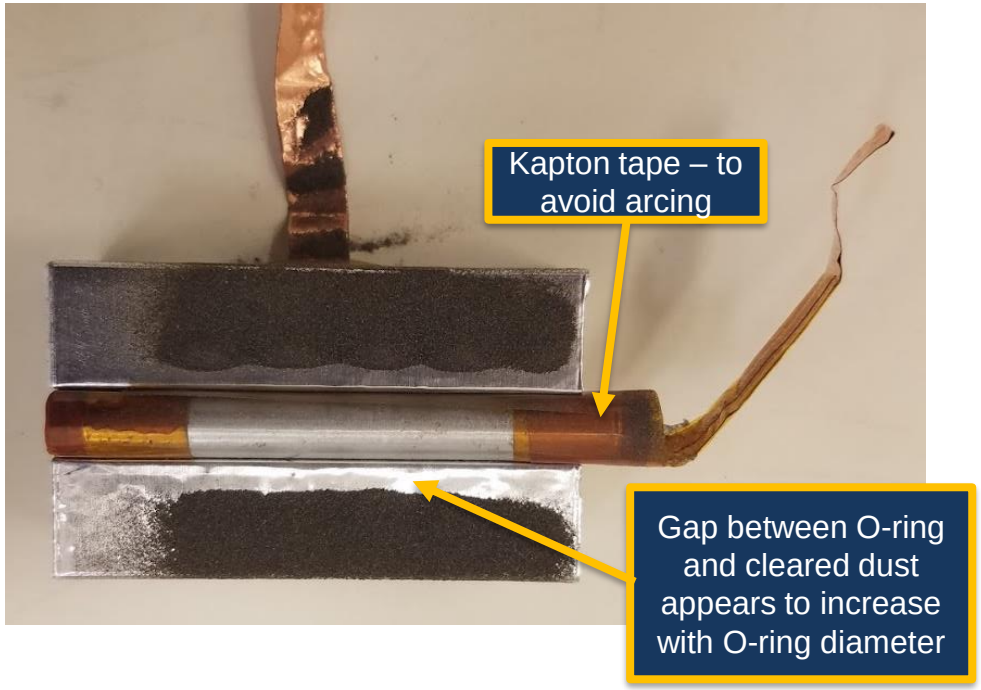


3, 6, and 9 mm O-rings wrapped in 91 µm adhesive backed Al foil

Encapsulated O-ring 1-Phase Test Setup



3 mm Silicone Rubber O-ring wrapped in 91 µm adhesive backed Al and 89 µm adhesive backed FEP film wrapped 3 times (267 µm in total)

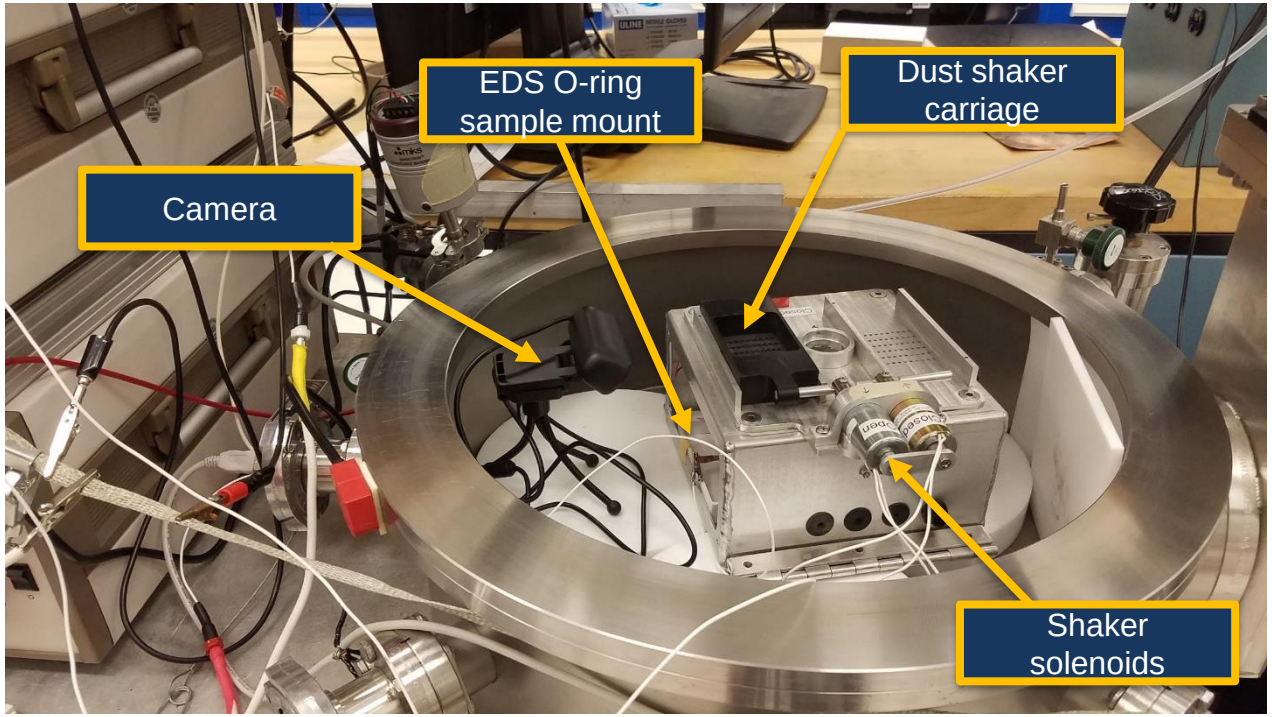


6 mm Silicone Rubber O-ring wrapped in 91 µm adhesive backed Al and 89 µm adhesive backed FEP film wrapped 3 times (267 µm in total)

Encapsulated O-ring 1-Phase Test Setup

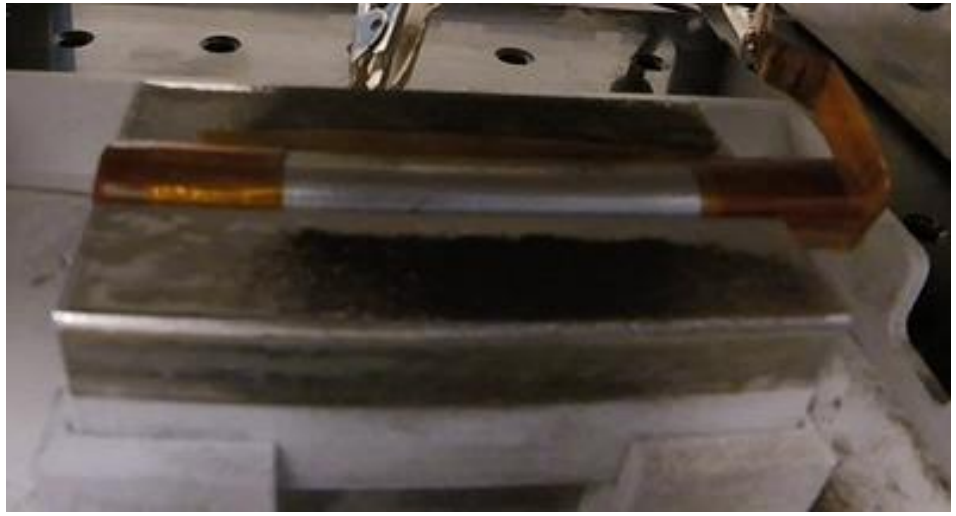


Twelve 3, 6, and 9 mm EDS encapsulated O-rings

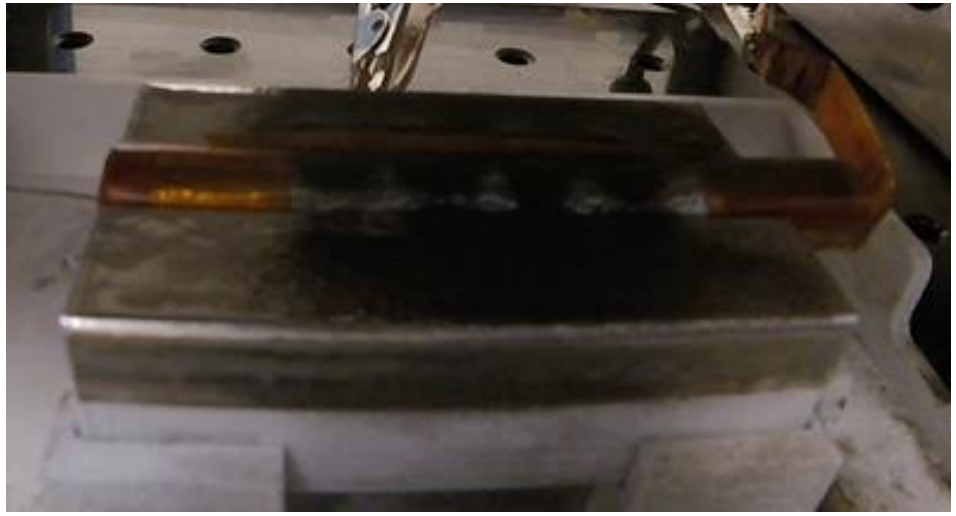


Dust shaker setup in vacuum

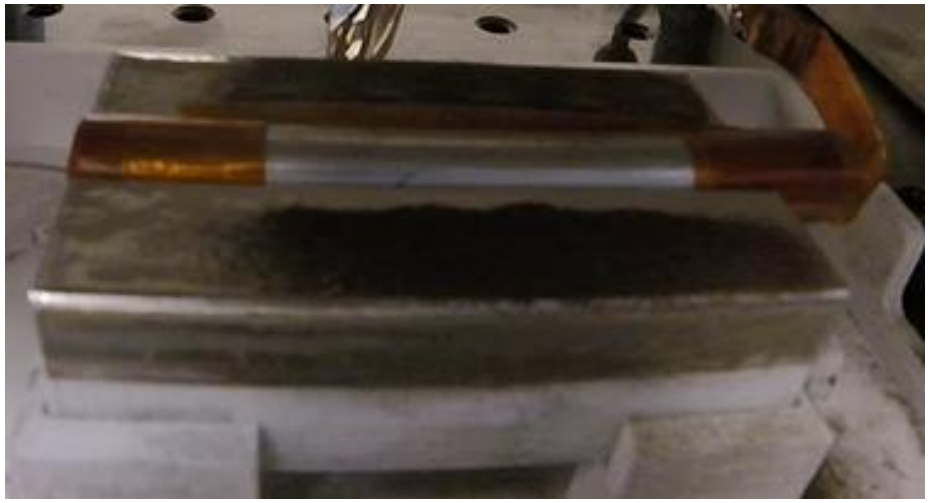
Encapsulated O-ring 1-Phase 6 mm Tests



6 mm – 89 µm – Dust Application



6 mm – 89 µm – 2.5 kV 10 Hz – Clear

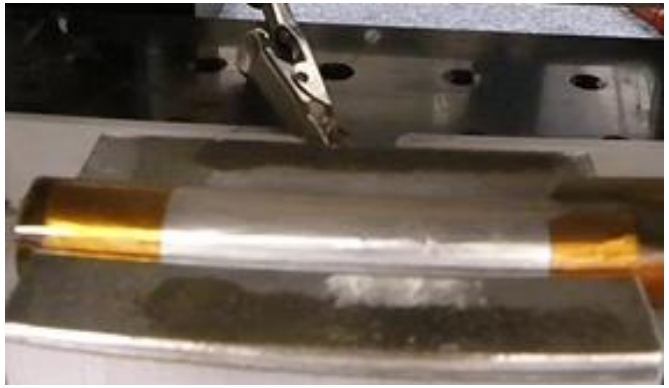


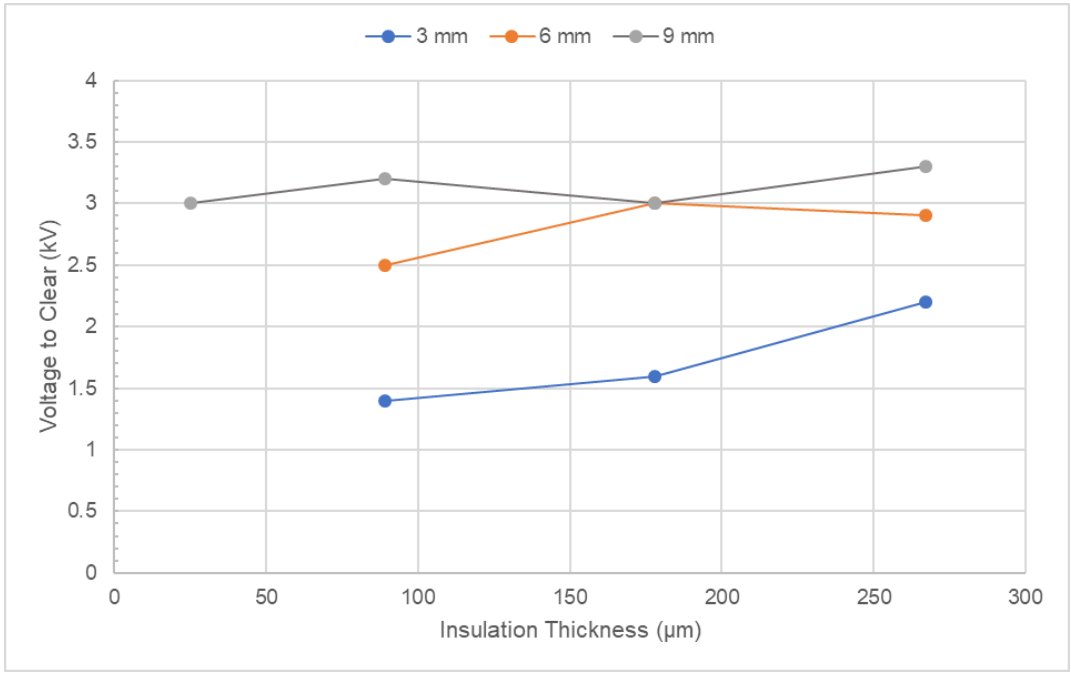
6 mm – 89 µm –
2.5 kV Hz –
Continuous Clear

Encapsulated O-ring 1-Phase Testing Overview

- Test Results to Date
  - Minimum voltage increases with O-ring diameter (expected)
  - Minimum voltage increases with insulation thickness to a lesser degree (also expected)
  - Continuous mode operation clears as good or better than the after exposure/deposition clearing performance
  - Vacuum results – still in progress

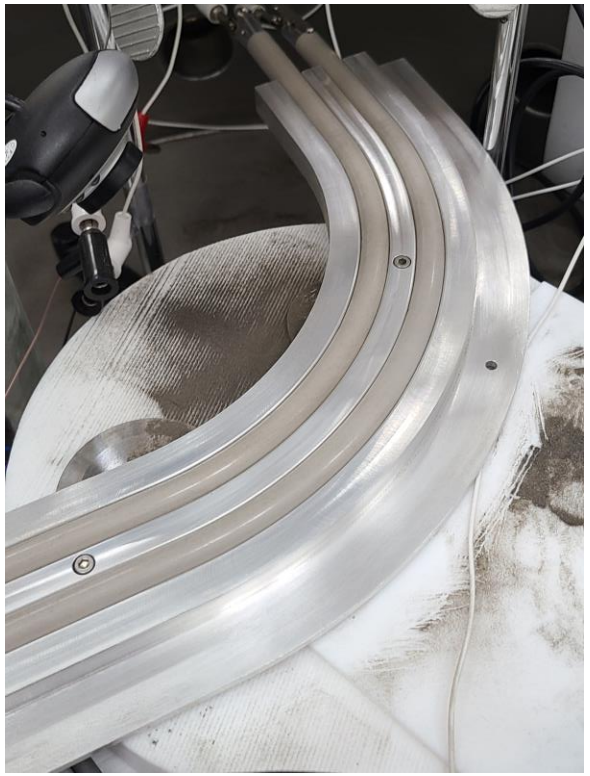
9 mm – 89 µm – 3.2 kV Continuous Clear





Encapsulated O-ring 1-Phase Bulk Removal Test Setup

- Mass Removal Test
  - Four batches of 0.6 g each deposited over 4 cm^2
  - 1.2 g/cm^2 areal coverage
  - +/- 6kV 10Hz square wave applied with Trek HV amplifier at 0.1 mTorr vacuum



11 mm conductive O-ring with FEP insulation – Pre-dust application

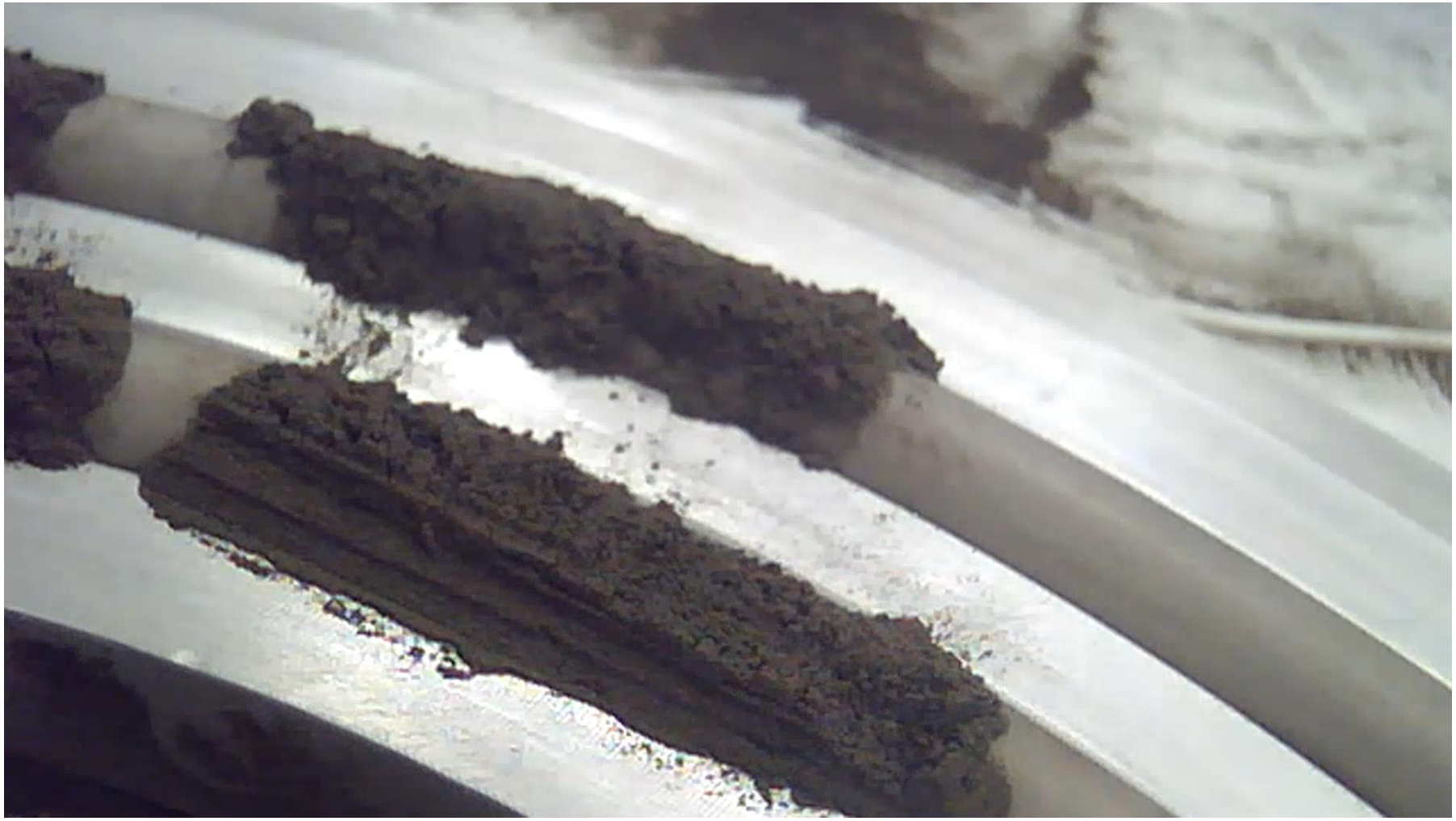




11 mm conductive O-ring with FEP insulation – 2.4 g of dust application with

Encapsulated O-ring 1-Phase Bulk Removal Testing

- Mass Removal Test
  - Four batches of 0.6 g each deposited over 4 cm^2
  - 1.2 g/cm^2 areal coverage
  - +/- 6kV 10Hz square wave applied with Trek HV amplifier at 0.1 mTorr vacuum



11 mm conductive O-ring with FEP insulation – ~88% of dust cleared after 13 minutes

Encapsulated O-ring 1-Phase Bulk Removal Testing Overview

- Mass Removal Test
  - 0.173 g removed from cleared O-rings
  - More material left on O-rings – unclear how much, but certainly less than 2/3 of the removed amount
  - >88% Clear Rate with 1.2 g/cm^2



11 mm conductive O-ring with FEP insulation – dust remaining of clearing attempt

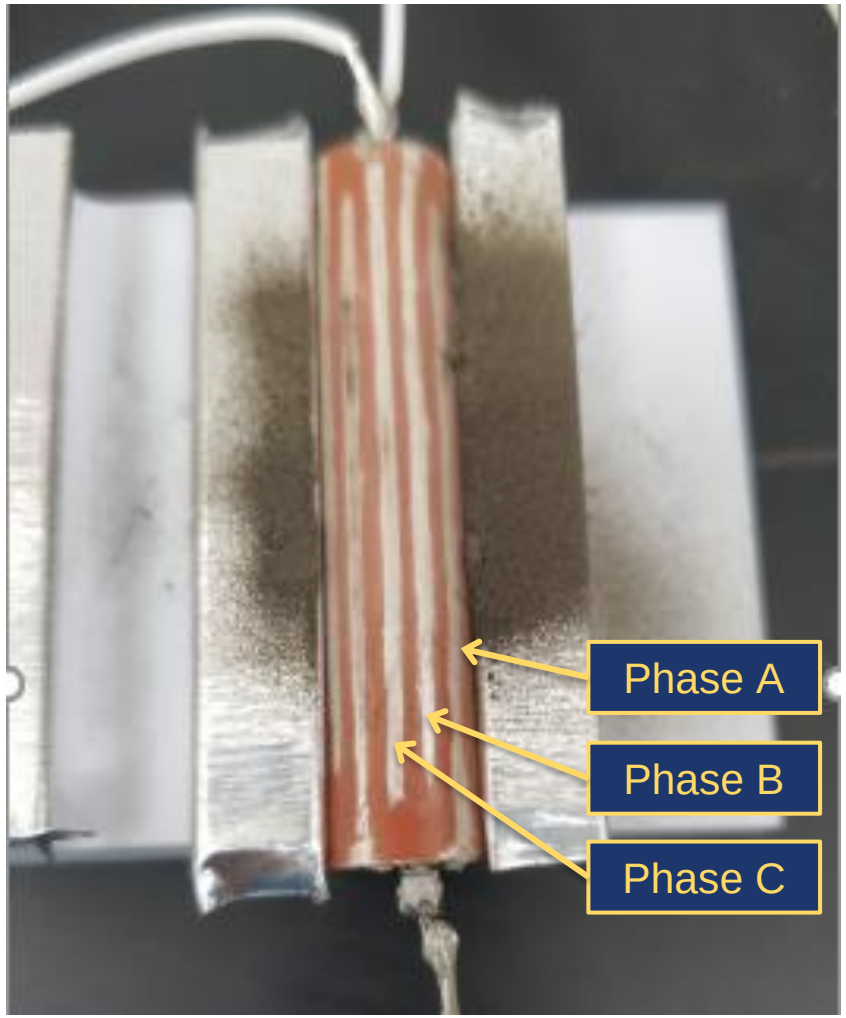


11 mm conductive O-ring with FEP insulation – dust removed from measurement



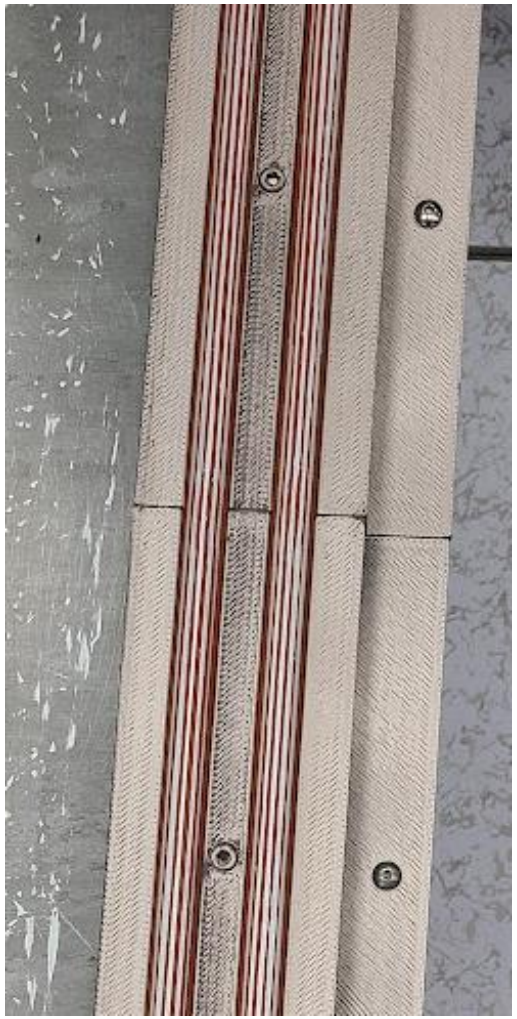
0.173 g of regolith simulant removed from O-rings (after clearing attempt)

Encapsulated O-ring 3-Phase Concept & Testing





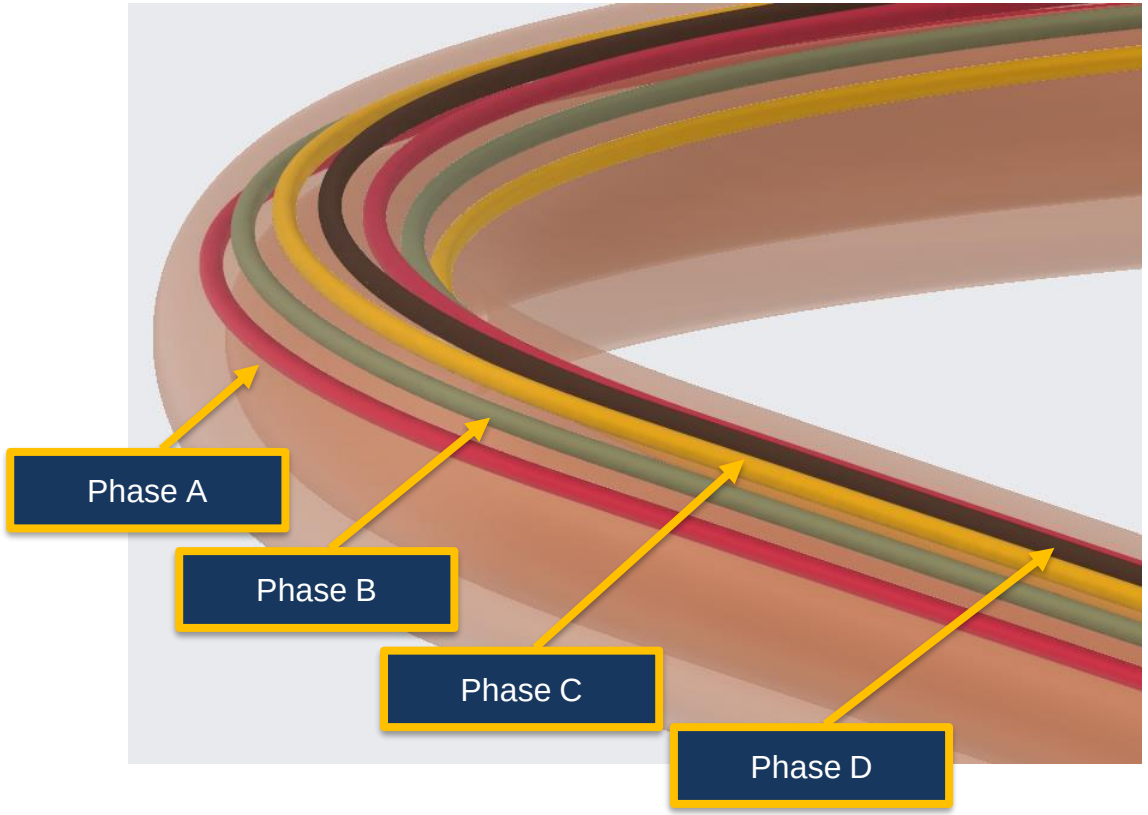
3- phase 11 mm O.D. O-ring with FEP insulation and silver ink electrode traces
Dust cleared at +/- 1.2 kV, 10 Hz square wave



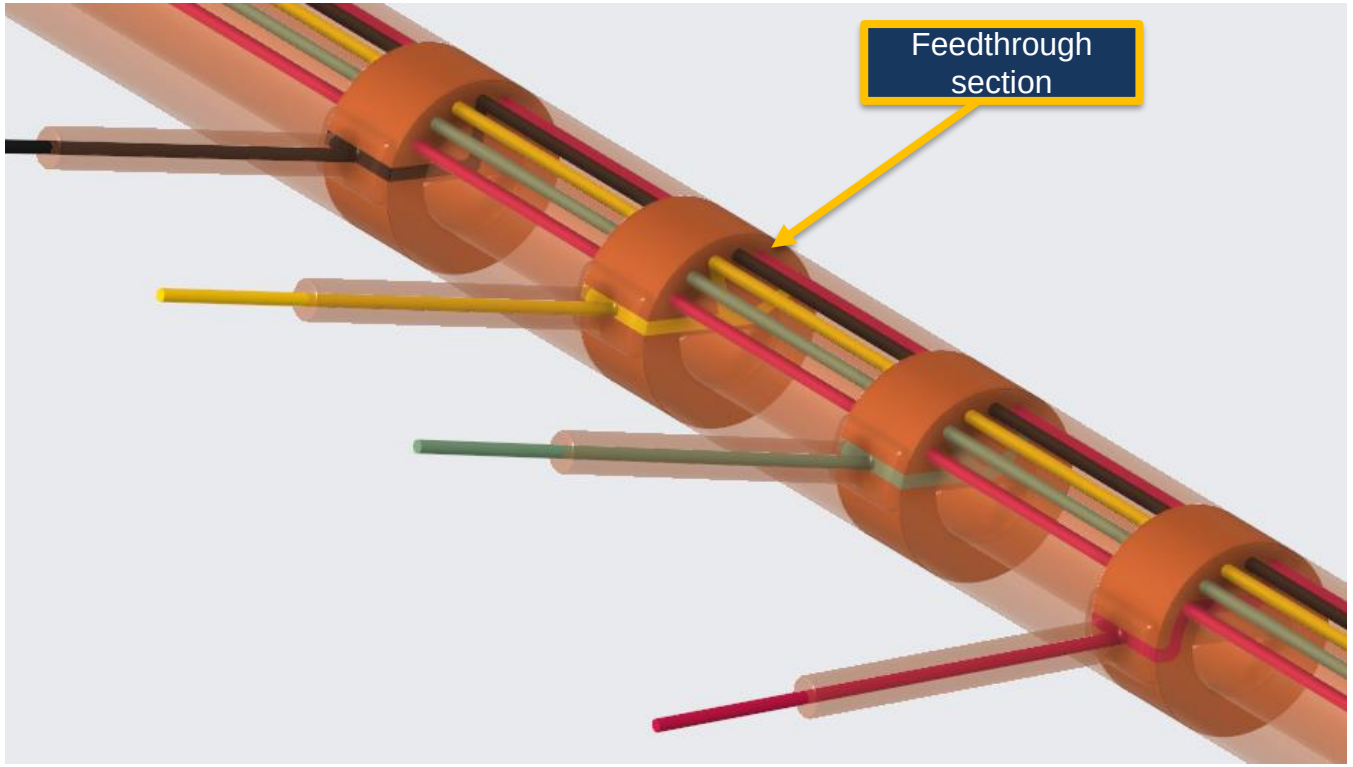


3- phase 11 mm O.D. O-rings on a 60” x 40” mock prototype hatch door

4-Phase Elastomer Encapsulated O-ring Concept



4- phase 11 mm O.D. O-ring with silicone rubber insulation and conductive silicone rubber O-ring cord stock electrodes



Concept of feedthroughs for conductive silicone rubber O-ring cord stock electrodes

Questions

