

Assessing MMOD Impacts on Seal Performance

by

Henry C. de Groh III, C. Daniels*, P. Dunlap, B. Steinetz

Abstract

The elastomer seal needed to seal in cabin air when NASA's Crew Exploration Vehicle is docked is exposed to space prior to docking. While open to space, the seal might be hit by orbital debris or meteoroids. The likelihood of damage of this type depends on the size of the particle. Our campaign is designed to find the smallest particle that will cause seal failure resulting in loss of mission. We will then be able to estimate environmental risks to the seal. Preliminary tests indicate seals can withstand a surprising amount of damage and still function. Collaborations with internal and external partners are in place and include seal leak testing, modeling of the space environment using a computer code known as BUMPER, and hypervelocity impact (HVI) studies at Caltech. Preliminary work at White Sands Test Facility showed a 0.5 mm diameter HVI damaged areas about 7 times that diameter, boring deep (5 mm) into elastomer specimens. BUMPER simulations indicate there is a 1 in 1440 chance of getting hit by a particle of diameter 0.08 cm for current Lunar missions; and 0.27 cm for a 10 year ISS LIDS seal area exposure.

2007 NASA Seal/Secondary Air System Workshop

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Nov. 13-14, 2007



Outline



- **Introduction**

- Low Impact Docking System (LIDS) and candidate elastomers;
- The expected space environment and mission;
- Key questions to answer.

- **Campaign Flow Chart, Phase I and Phase II**

- **Phase I**

- Hypervelocity Impact testing;
- Feasibility Testing of seal specimens and simulated damage;
- BUMPER MMOD environment analysis.

- **Phase II**

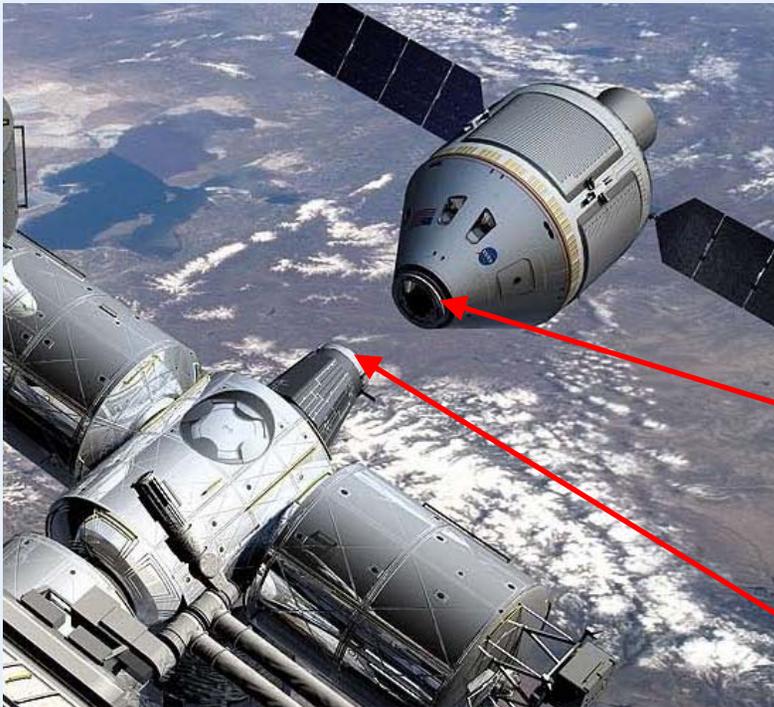
- Specimen manufacture, and leak testing;
- Hypervelocity Impacts at Caltech.

- **Conclusions**



Introduction

CEV w/ elastomer Low Impact Docking System (LIDS)
seal docking to ISS w/ metal flange.



Very low leakage requirements:

- CEV < 0.02 lb_m/day
- Apollo ~ 4.5 lb_m/day

LIDS primary seal

Seal Leakage to be < 2.5 x 10⁻³ lb_m/day
(~0.001 kg/day)

Metal flange



LIDS Primary Seal: Expected space environment and mission



- **Mission Duration (and Temperature)**

- LIDS elastomers on CEV, 3 to 5 days and Lunar missions (~230 day max);
- LIDS metal flange on ISS, 10 years.

- **Vacuum:**

- Total mass loss (TML) < 1 %
- Collected volatile condensable materials (CVCM) < 0.1 %

- **Atomic Oxygen**

- 1 year exposure = 5×10^{21} atoms/cm² fluence, exposures planned up to 6×10^{22} atoms/cm² = 12 years exposure

- **Ultraviolet Radiation**

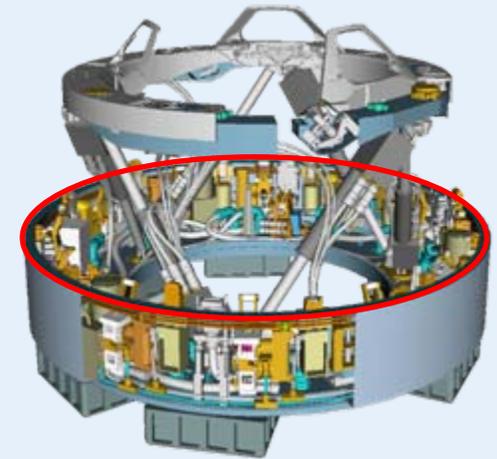
- Simultaneous Near Ultraviolet (NUV, 220-400 nm) and Vacuum Ultraviolet (VUV 115-200 nm) exposures to ~1500 ESH completed.

- **Ionizing Radiation**

- Maximum mission dose ~ 0.6 Mrad (Si), electron particle radiation used (3 Mrad completed).

- **Micro Meteoroid and Orbital Debris (MMOD)**

- Particle size depends on mission and risk allocation; mass on particle density.



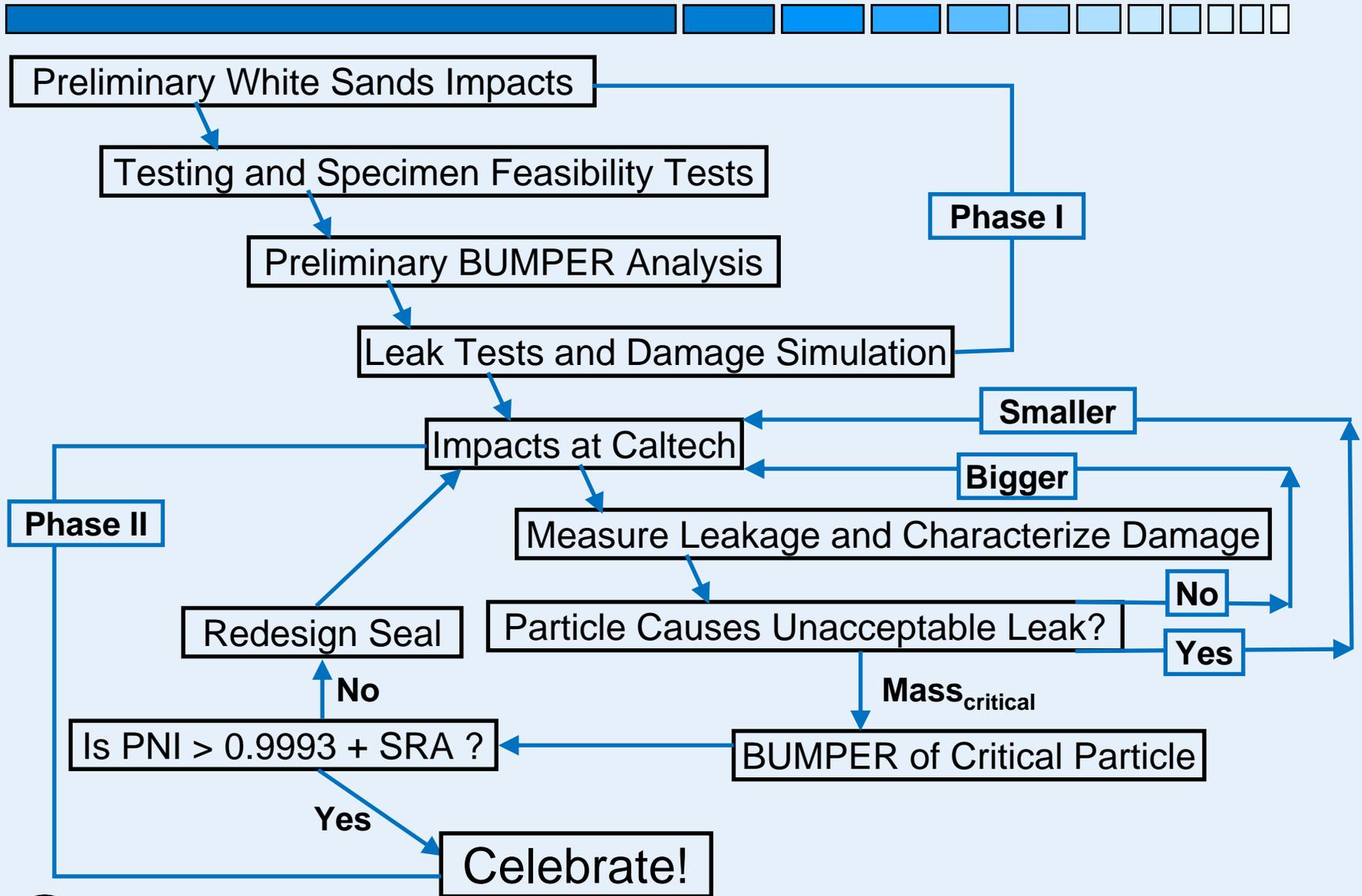
Key Questions to Answer



1. **What size MMOD particle are we likely to encounter, and**
2. **Will it cause a seal/mission failure?**
 - “Likely” relates to risk, the line between acceptable and unacceptable being set at 1 in 1400 for CEV as a whole. For our seal, expressed as a Probability of No Impact (PNI): 0.9993 + SRA (seal risk allocation).
 - Seal failure defined as damage that leads to mission failure.
3. **What size particle will cause seal/mission failure, and**
4. **What is the likelihood of encountering that particle?**



Campaign Flow Chart



Simulating the space environment's MMOD



- Phase I: White Sands & NASA Johnson, Karen Rodriguez POC
- Phase II: California Institute of Technology & JPL
 - Marc Adams at Caltech
 - Virendra Sarohia JPL-Caltech liaison.

	Caltech	White Sands
Max Velocity	10.5 km/s ?	7.5 km/s
Particle Size	~0.1 to 2.0 mm	~0.05 to 3.6 mm
Success Rate	~99%	80 to 65 %
Number of Particles per shot	1 to 6	1
Analysis Support	Extensive	Good



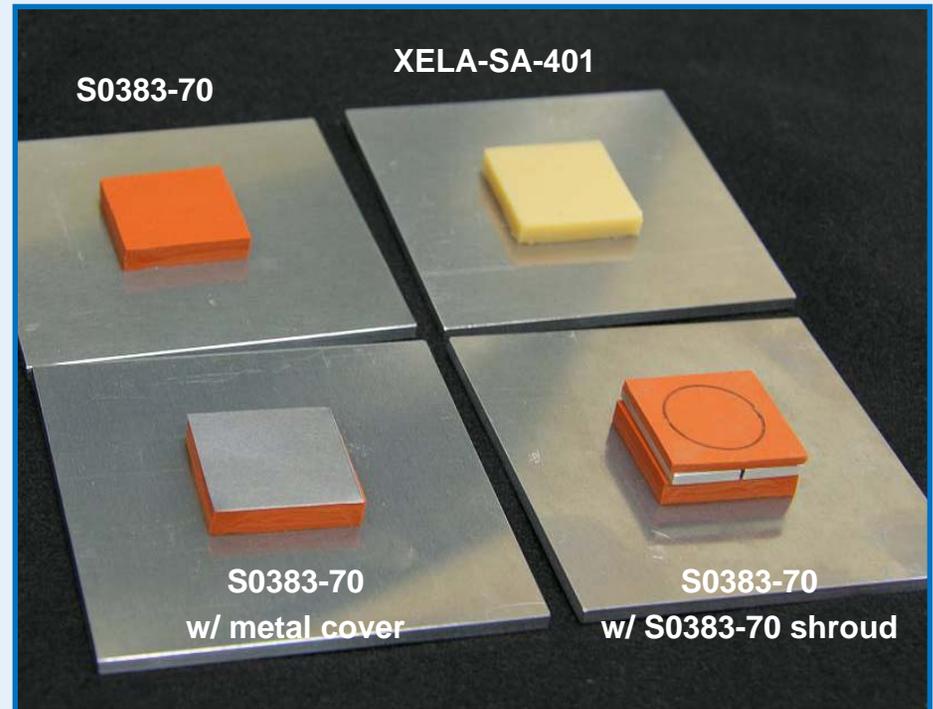
Phase I Hypervelocity Testing at White Sands

Simulating the space environment's MMOD

Six test specimens:

- Parker S0383-70
- Kirkhill ELA-SA-401
- S0383-70 covered with 0.003 inch thick SS shim (proprietary)
- S0383-70 with 0.080 inch thick S0383-70 shroud, 0.09" stand-off (proprietary)
- Ceramic SiC 0.125 inch thick
- SS plate (0.125 inch thick)

Impacted with 0.5 mm stainless steel particle at 7.5 km/sec



Elastomer samples were glued onto 3"x3"x1/8" thick Al 7075 plates.



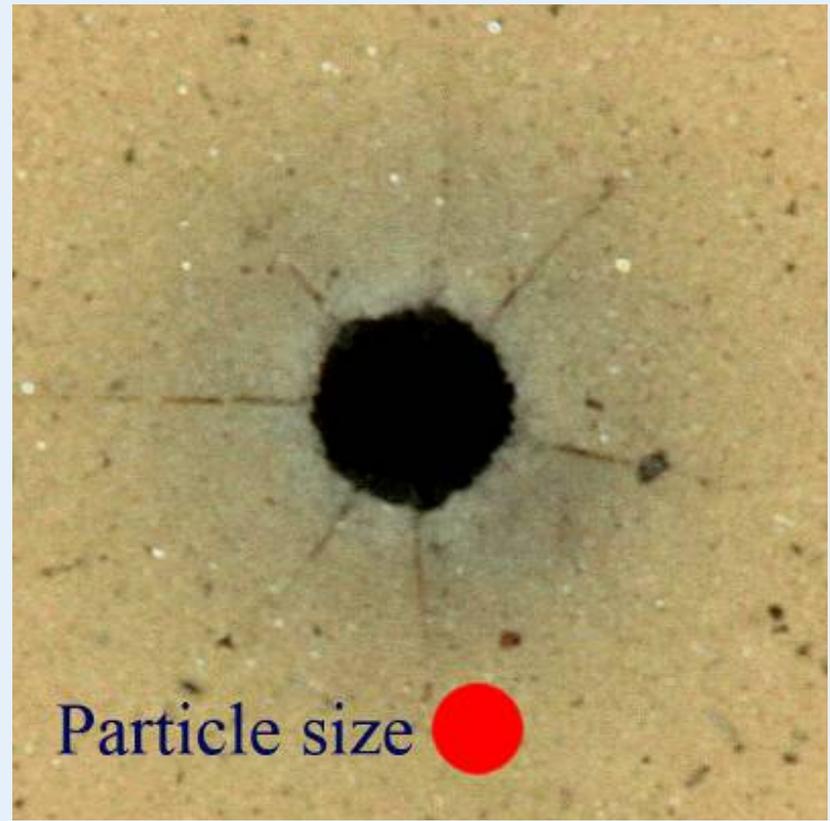
Results, Phase I



Hypervelocity Impacts in Sheet (White Sands)



Parker S0383-70



Kirkhill ELA-SA-401

Projectile: SS, 0.5 mm, 7.5 km/s



Results, Phase I



Hypervelocity Impact on Stainless Steel (White Sands)



Stainless Steel Target

Projectile: SS, 0.5 mm, 7.5 km/s

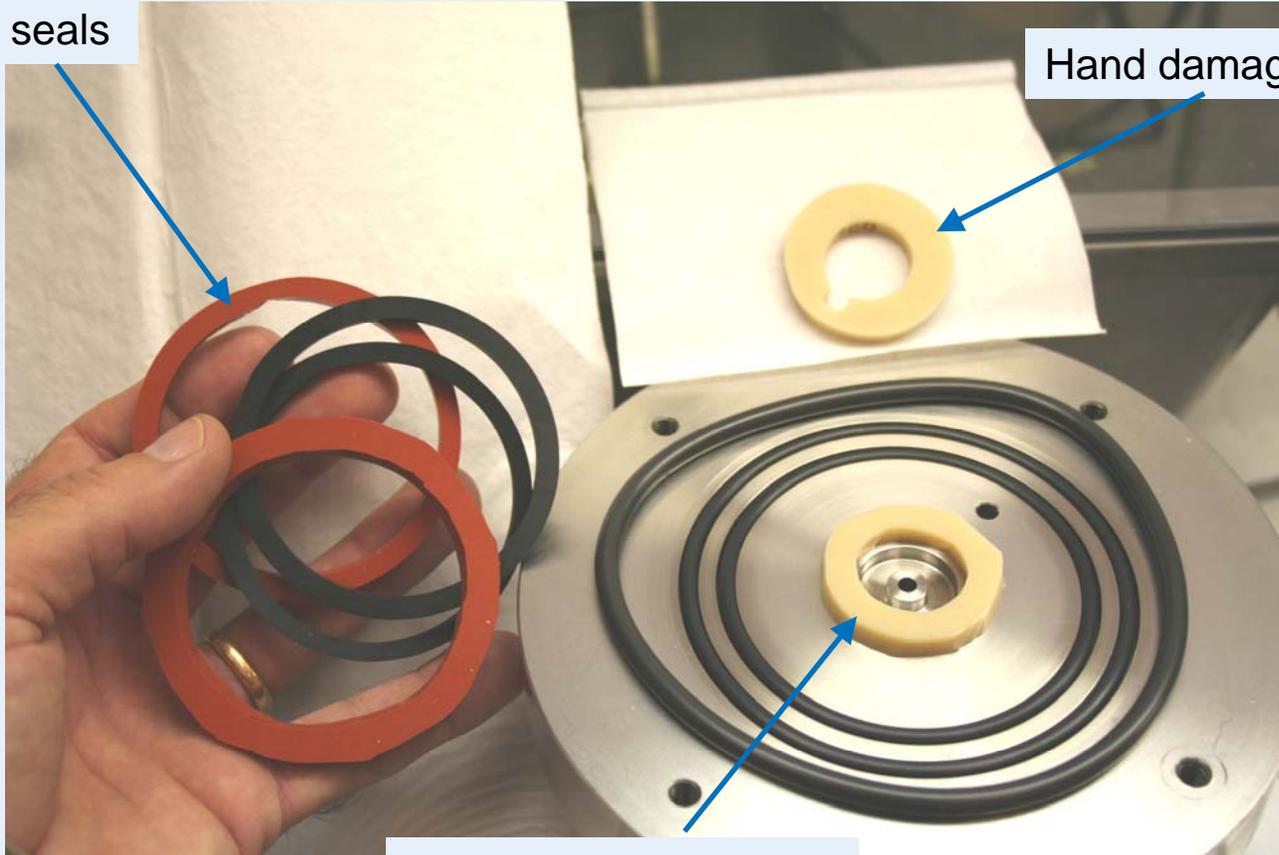


Phase I Feasibility Testing

Leak Testing & Specimen Feasibility

Practice cut seals

Hand damaged seal



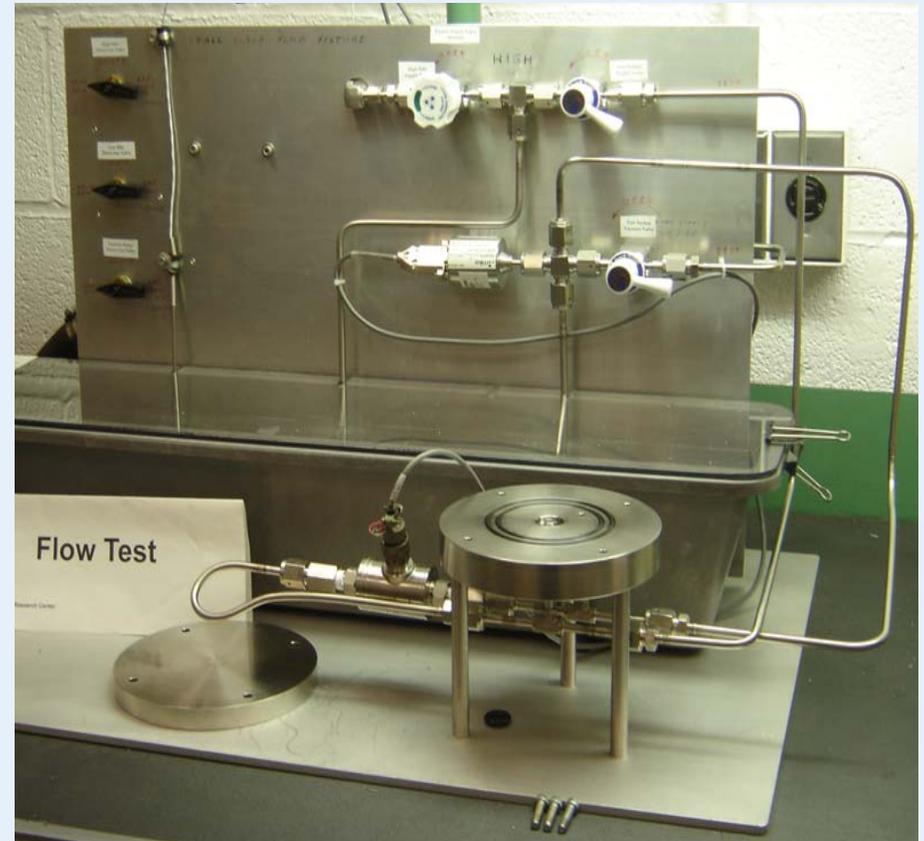
Feasibility specimen in
Retro-fitted SSFF



Small Scale Flow Fixture (SSFF), Phase I leak testing

SSFF was retro-fitted to test feasibility of impact specimens and test procedures

- Normally used to quantify leakage past 2-309 size o-rings.
- Test conditions
 - 25% O-ring compression
 - Seal against flat plate
 - $P_{\text{HIGH}} = 14.7$ psia
 - $P_{\text{LOW}} = 0.0$ psia
- Specimen are connected to a leak decay system to accurately quantify leakage rate.



Phase I Seal leakage and damage assessment



Sculpted damage in Esterline washer style o-ring



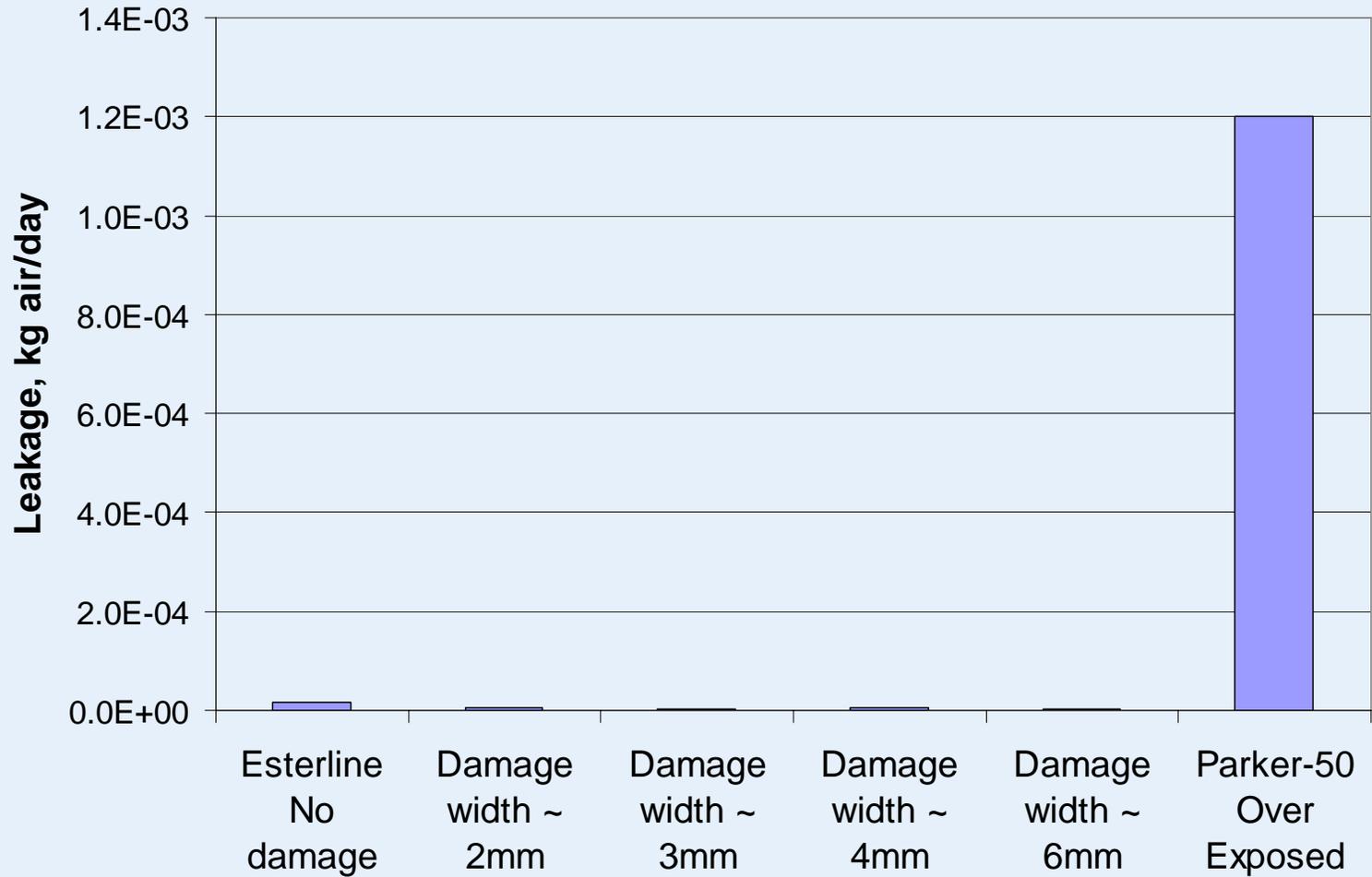
Increasing Damage ↓



Phase I Leakage Results



Leakage of as received and damaged washer style seals.



Phase I BUMPER modeling inputs



- Area calculations, inner seal, outer seal, metal ring, whole area.
- CEV nose, inner seal, outer seal, and metal ring areas;
- Altitude – 400 km for LEO, 192,200 km for Lunar;
- Orbit inclination – 51.65°;
- Year exposure starts – 2014;
- Time in space
 - CEV approach to ISS, 3 days;
 - Lunar mission, 228 days;
 - ISS node 2 ram for 10 years.
- Impact angle cut off – 89°;
- Density – 1.15 g/cc +/- 0.05 g/cc (0.0415 lb/in³)
- Yield Strength – Tensile Strength = UTS = 1050 psi
- Speed of sound in silicone rubber = 3280 ft/s
- Brinnell Hardness (BH)
 - Parker 70 durometer Shore A ~ 15 BH;
 - Esterline 38 durometer Shore A ~ 9 BH.

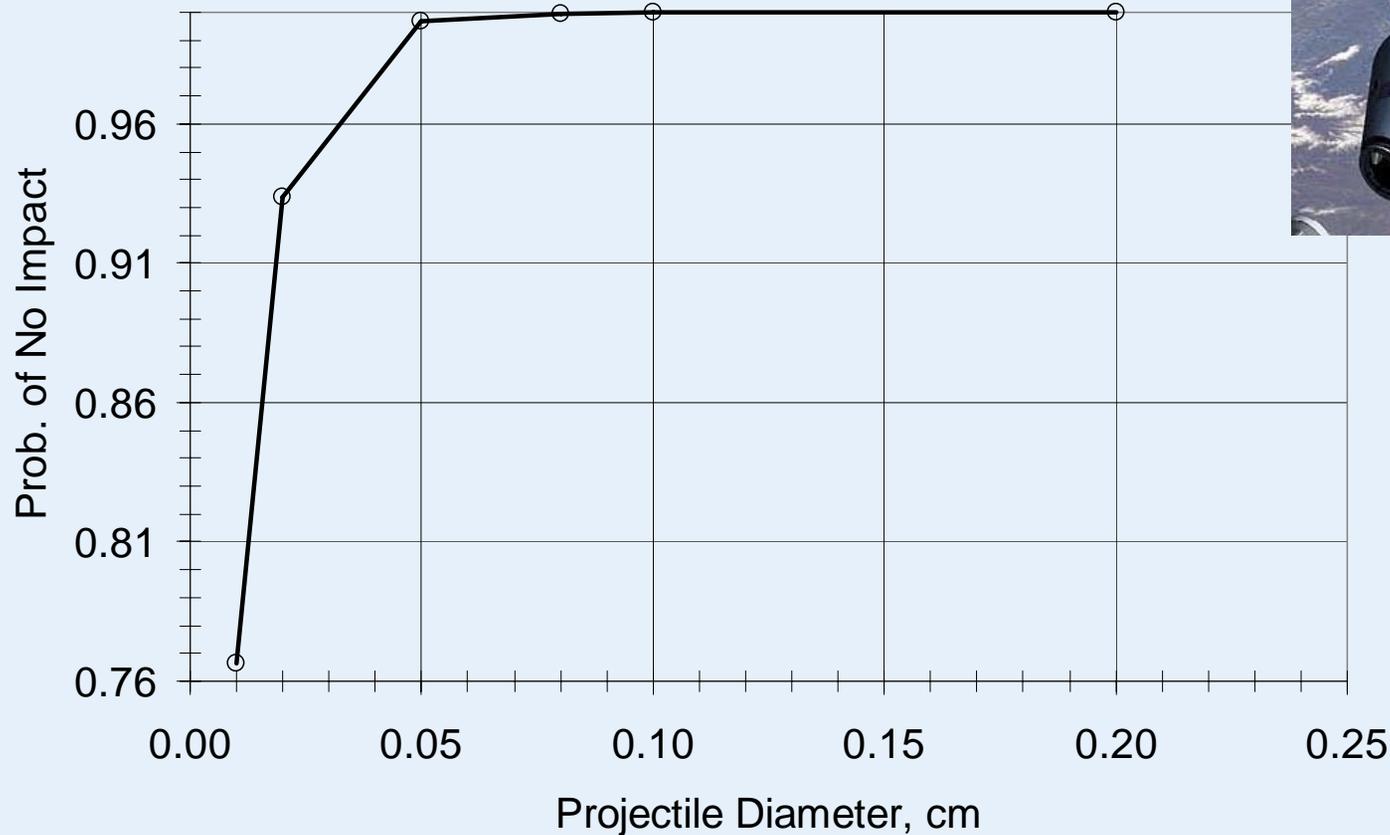


Phase I Results, BUMPER analysis for a Lunar mission



Probability of an impact near the LIDS seals during a lunar mission

3 days LEO + 228 days Lunar

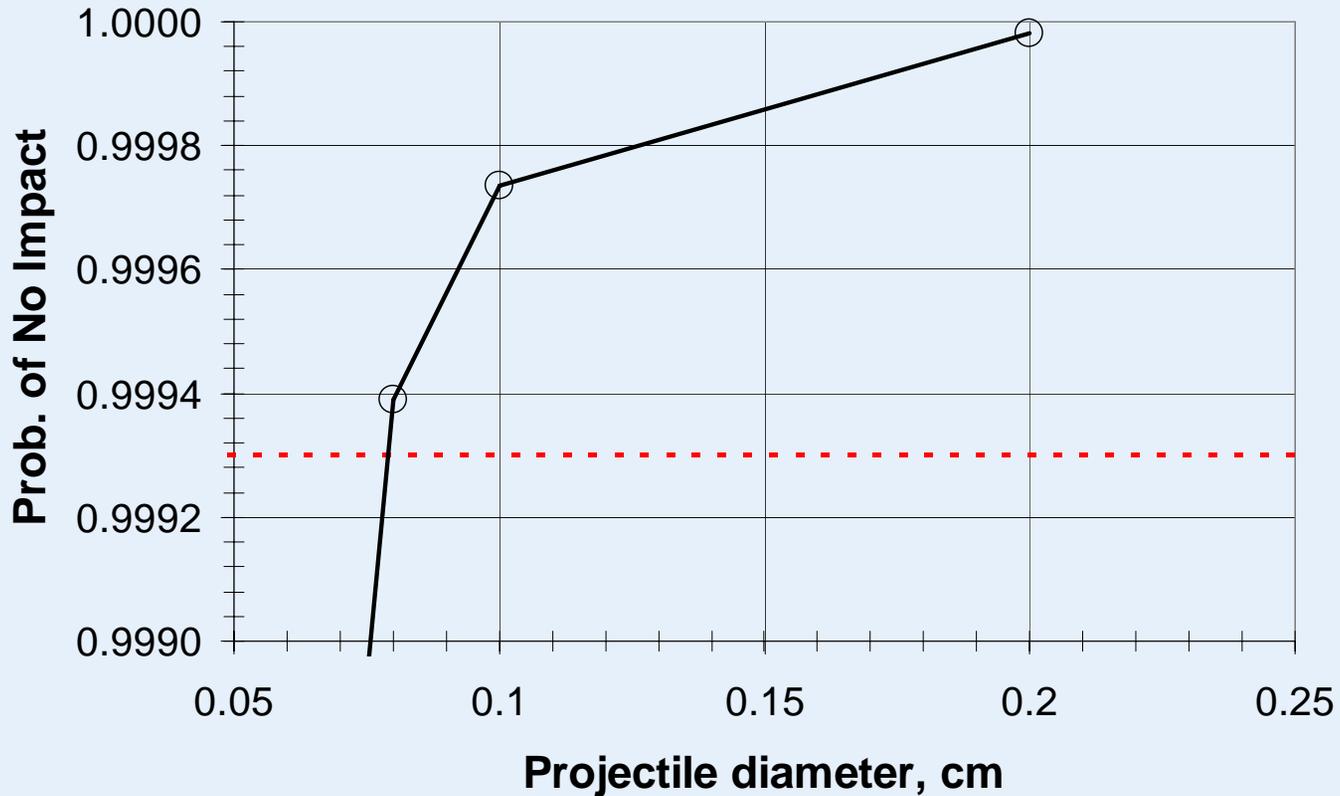


BUMPER analysis of LIDS seal for a lunar mission



BUMPER analysis showing the current 0.9993 risk specification.

3 Days LEO + 228 Days Lunar



Impact Particle Density Selection



- Nylon 66 = 1.14
- Basalt ~ 2.5
- Pyroxene, augite ~ 3.4
- Borosilicate glass ~ 2.4
- Quartz = 2.6
- Paint ~ 1.3

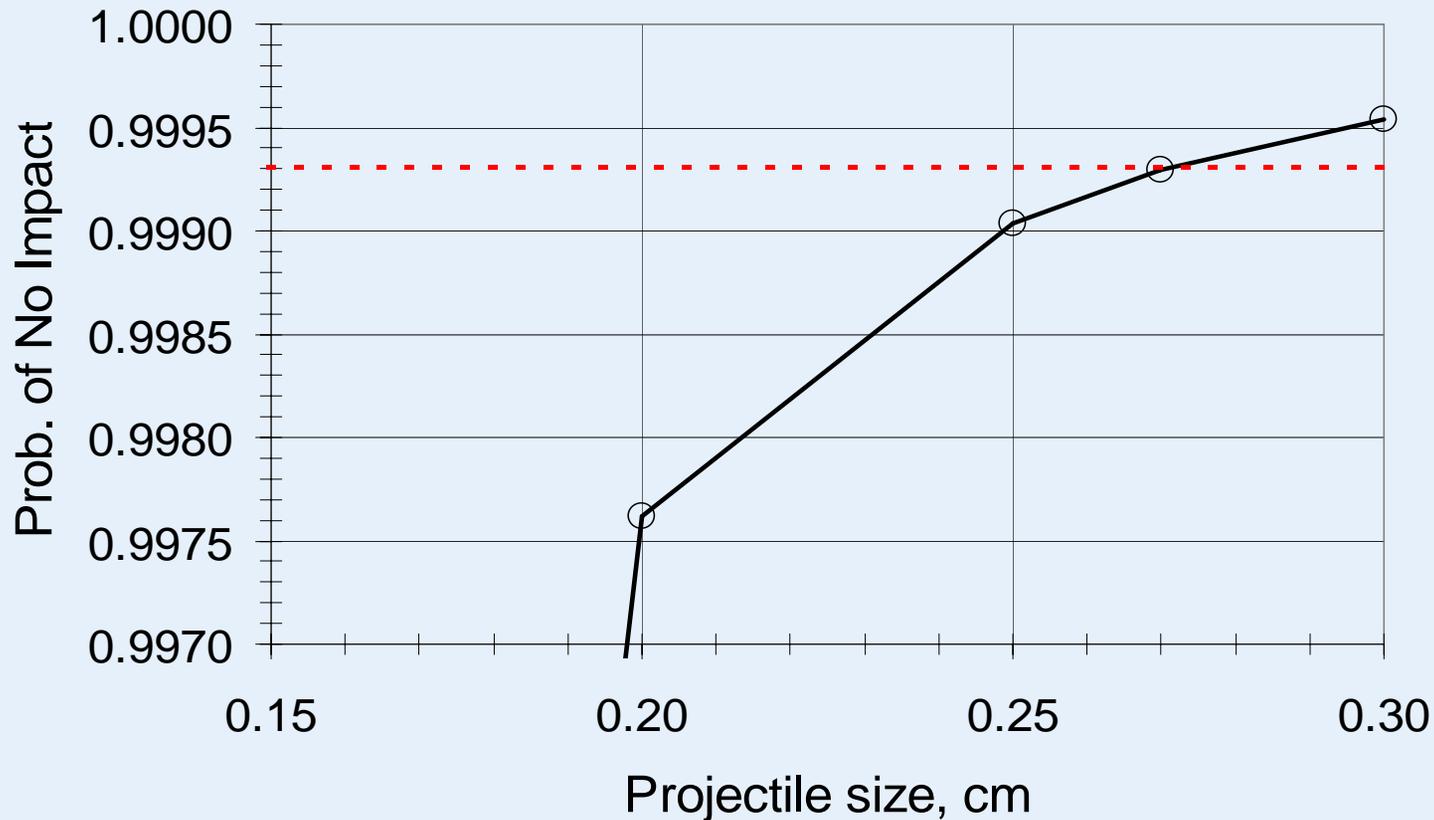


BUMPER analysis for ISS's node 2, ram flight mode

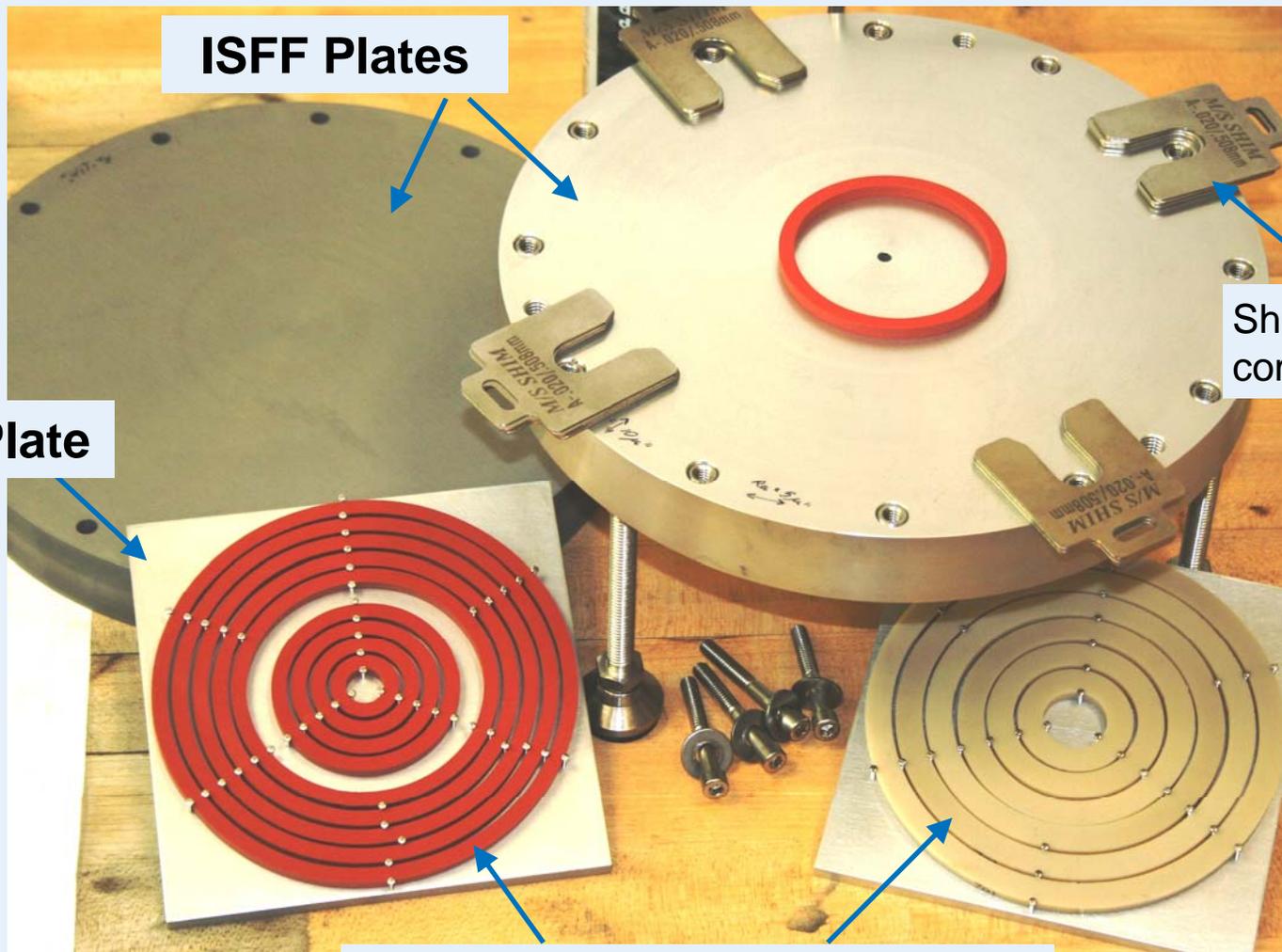


Phase I results for the LIDS flange on ISS

10 years in LEO



Phase II, Impact Specimen Flow Fixture and Seal Specimens



ISFF Plates

Shims for 25% compression

6" Al Plate

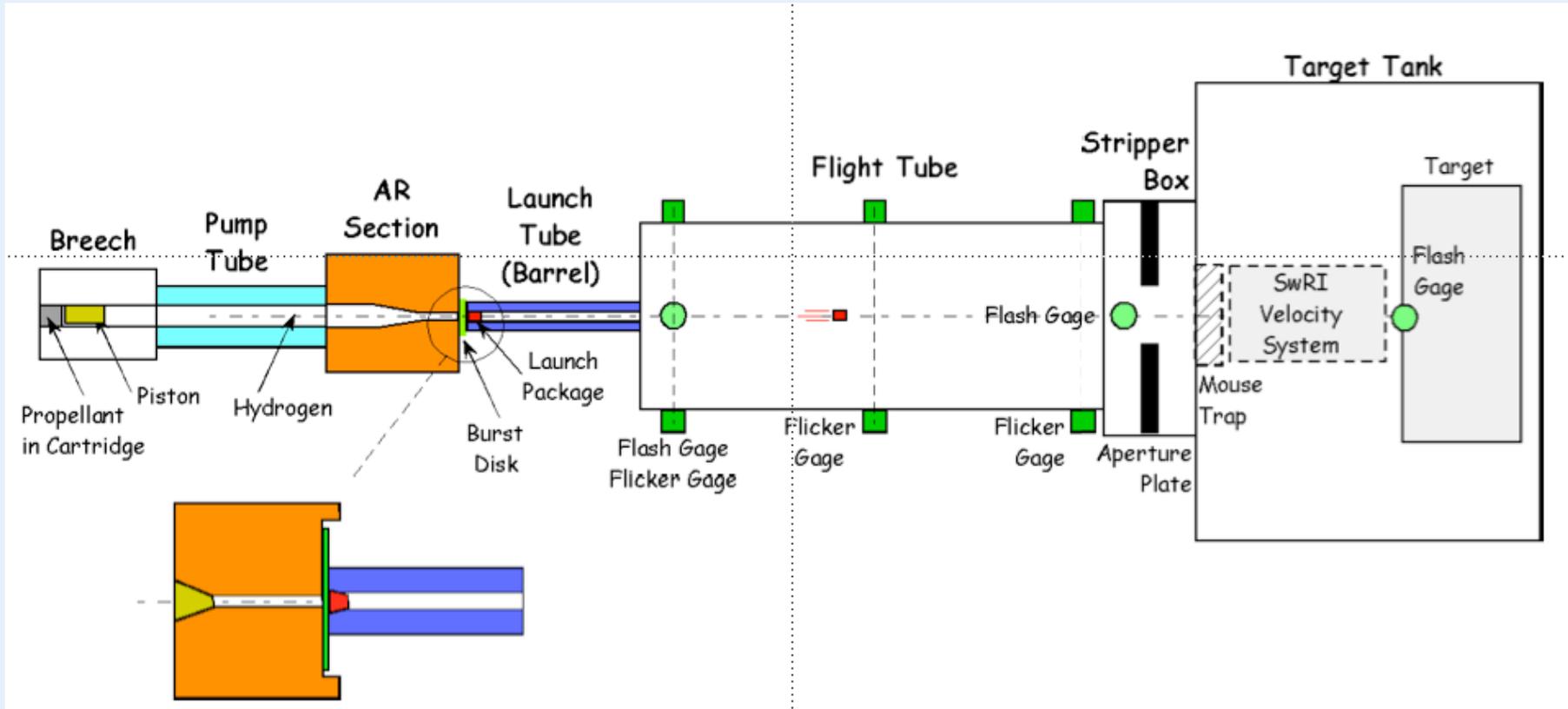
Nested washer style o-rings



Phase II Hypervelocity Impacts



Small Particle Hypervelocity Impact Range at Caltech



Conclusions/Summary



- Our campaign is designed to find the smallest particle that will cause seal failure resulting in loss of mission. We will then be able to estimate environmental MMOD risk.
- Preliminary tests indicate seals can withstand a surprising amount of damage and still function.
- Collaborations with internal and external partners are in place and proceeding (Seal testing, BUMPER, and HVI at Caltech).
- White Sands work showed a 0.5 mm diameter HVI damaged areas about 7 times that diameter, boring deep (5 mm) into elastomer specimens.
- BUMPER simulations indicate $PNI = 0.9993$ for $d_L = 0.08$ cm for current Lunar missions; and $PNI = 0.9993$ for $d_{ISS} = 0.27$ cm for a 10 year ISS LIDS seal area exposure.

