Effect of MMOD Threats on LIDS Seal Design

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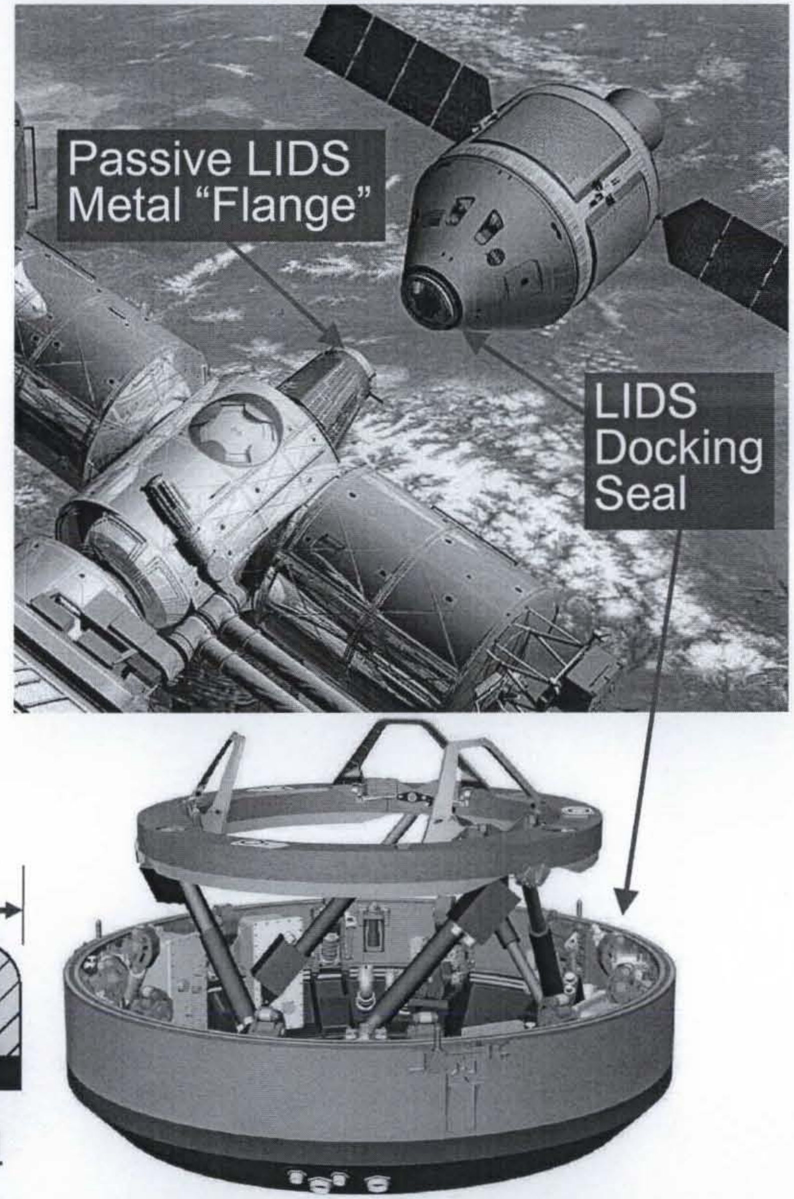
Missions & Sealing Elements

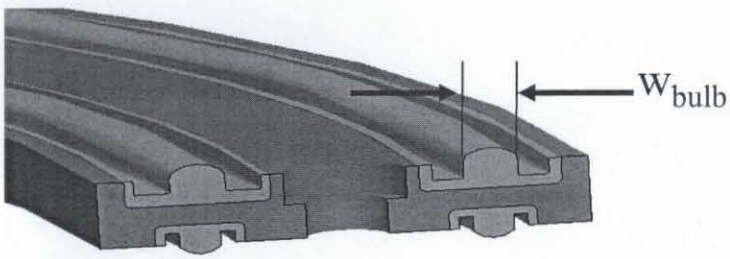
Missions:

- Mission to ISS: 210 days long, taking place over the next 10 years.
- Lunar Sortie mission: 31 days long, docking to Altair.
- Lunar Outpost mission: 210 days long

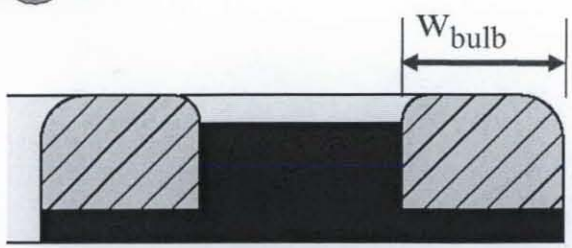
Sealing Elements:

- CEV side (rubber):
  - Parker (Primary) or Esterline (Alternate)
- Flange side (aluminum): ISS or Altair



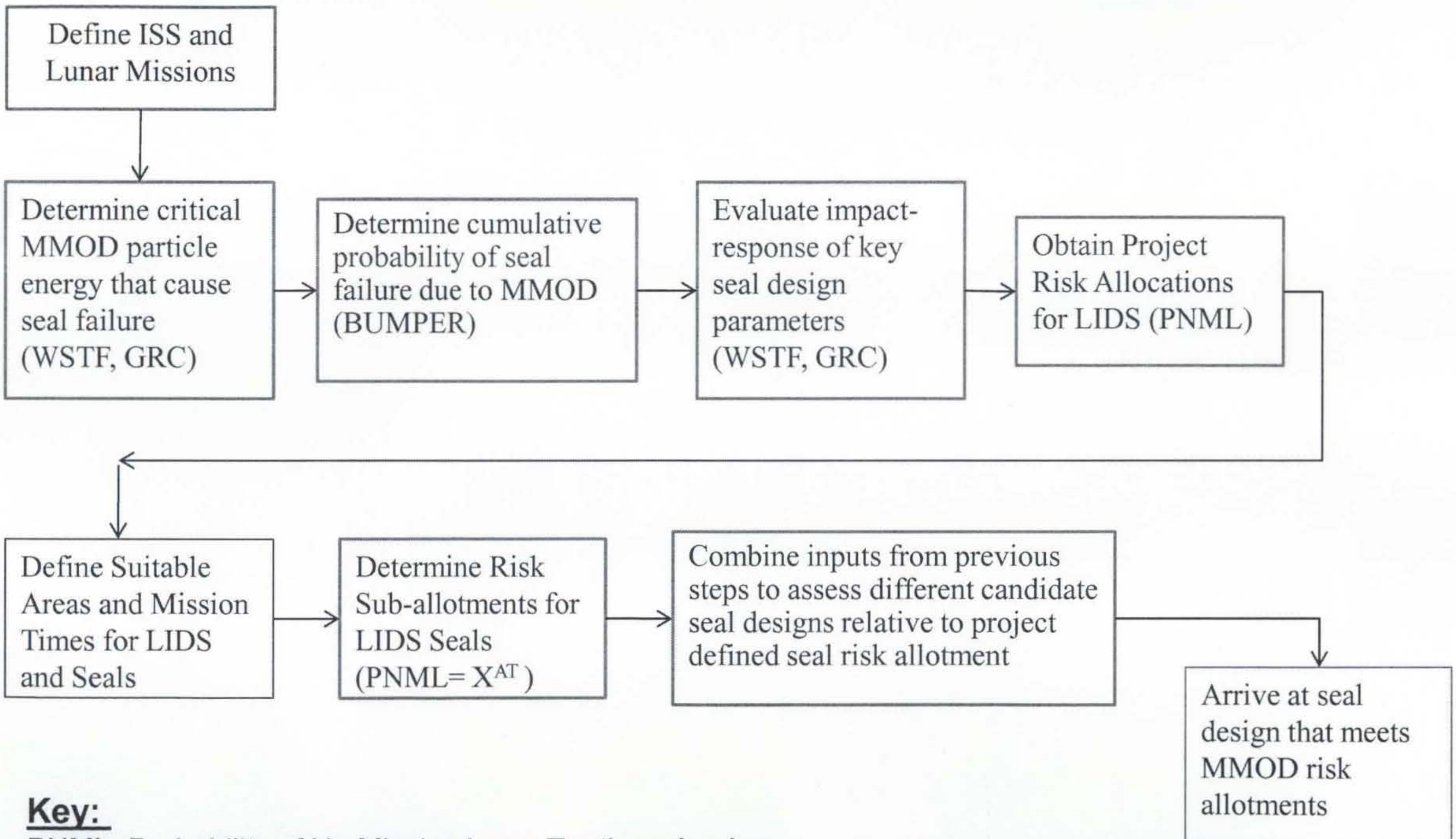


Parker Gask-O-Seal
S0383-70 compound



Esterline/NASA 2-Piece Seal
ELA-SA-401compound

Flow Chart of Method Development: Effect of MMOD Threats on LIDS Seal Design

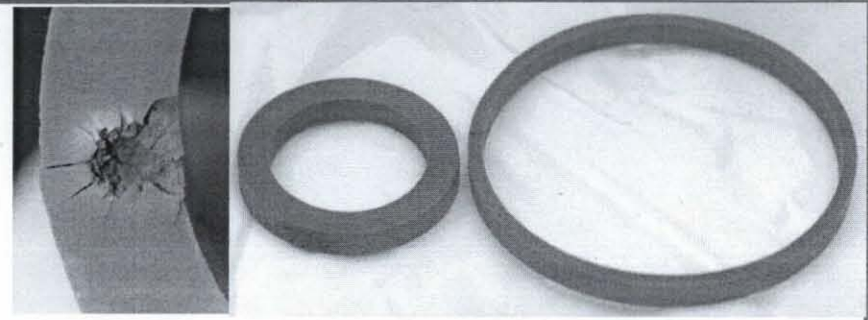


Key:
PNML: Probability of No Mission Loss; T = time, A = Area
WSTF: White Sands Test Facility
BUMPER: Computer Code used to assess probability of MMOD impact/failure

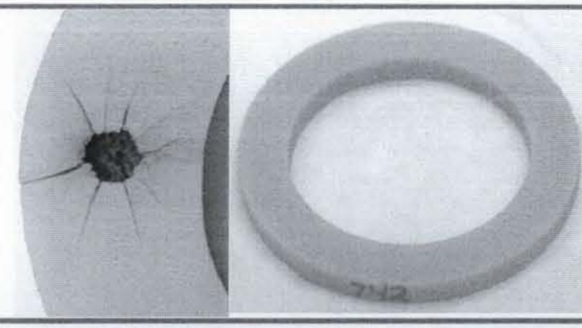
Experimental Investigations

Seal Specimens and How They Were Paired

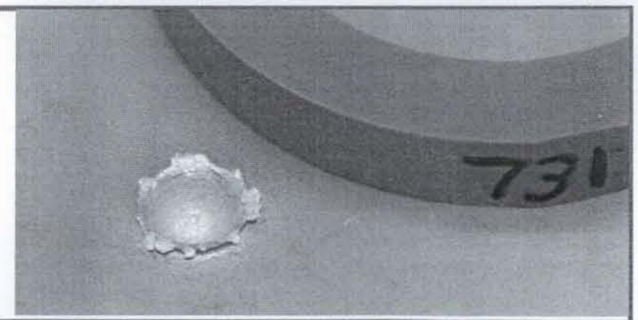
- Primary Design:
  Parker washer style seal rings,
  5.1 mm wide (0.2"), and
  2.5 mm (0.1") wide against
  anodized aluminum



- Alternate Design: Esterline seal rings
  9.1mm (0.36") wide against anodized
  aluminum.

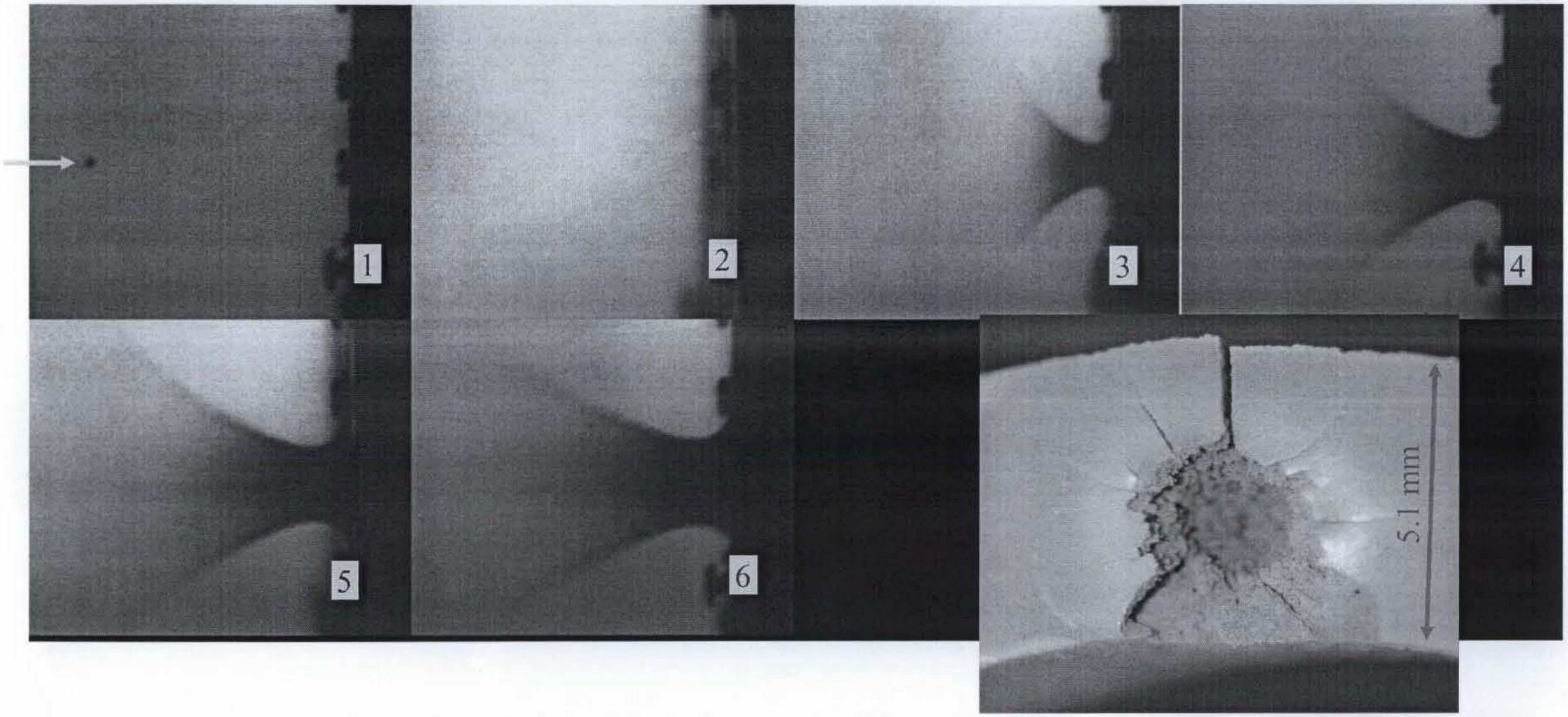


- Aluminum, 6061 T651, with either Parker
  or Esterline seal rings.



- Seals were not available for this phase of MMOD studies
- "Surrogate" elastomer seal rings of proper width and height cut from elastomer sheet

Image of Hypervelocity Impact at WSTF: Elastomer

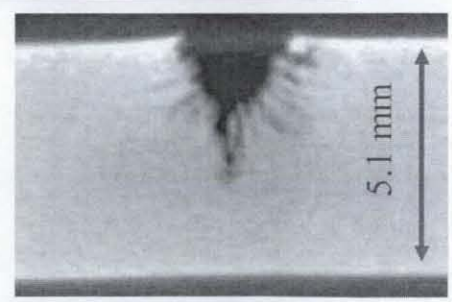


Test parameters: Particle: Al sphere 0.48 mg, 0.7 mm dia., 8.17 km/s, 0° angle

Target: Parker S0383-70; 5.1 mm (middle right)

CT scan of resulting crater (lower right)

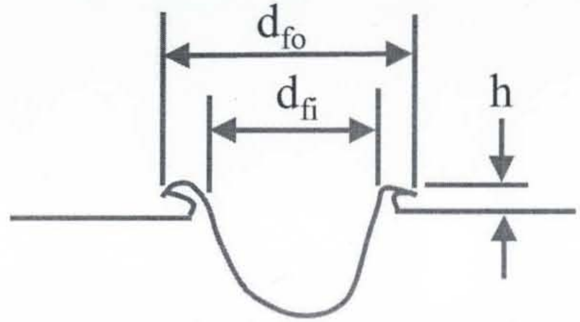
Finding: Leakage same as undamaged seal

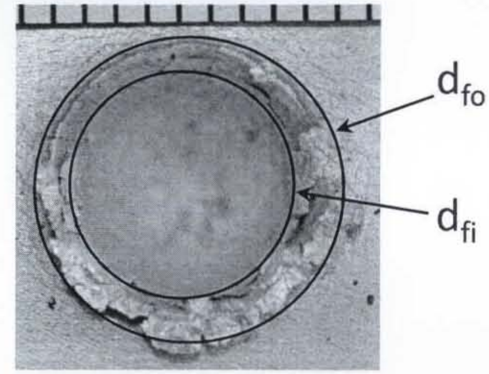


Measuring Impact Damage

Aluminum Flange:

- Crater hole diameter in Aluminum: inner diameter, near inflection point; outer diameter. Crown Height, h.
- $D_f = (d_{fi} + d_{fo})/2$

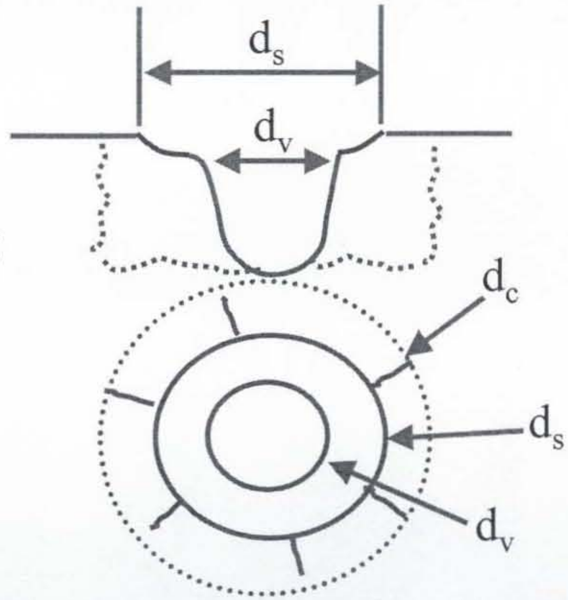


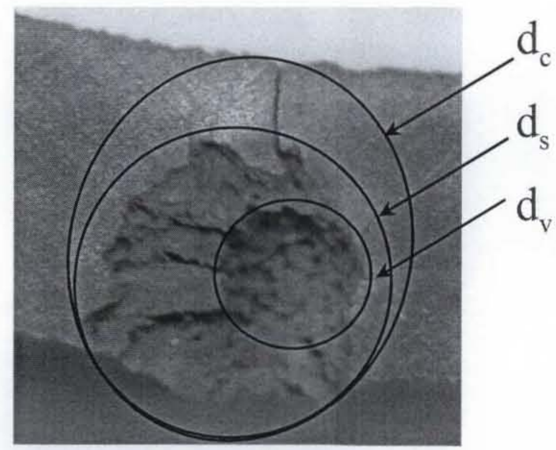


Elastomer:

Crater hole diameter in Elastomer:

- d_v = dia. of vaporized hole;
- d_s = dia. of secondary damage;
- d_c = dia. of radial cracks.
- $D_{Seal} = (d_v + d_s + d_c)/3$



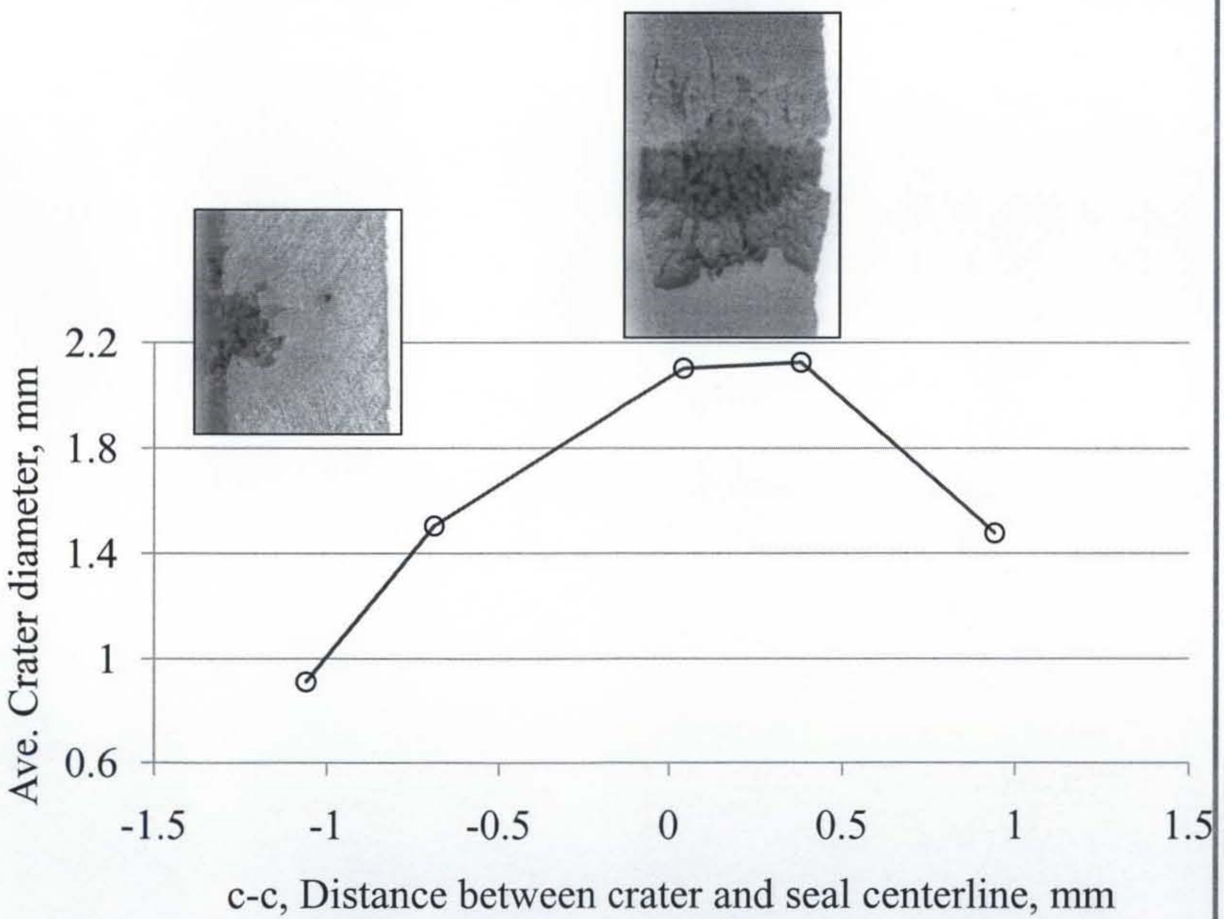


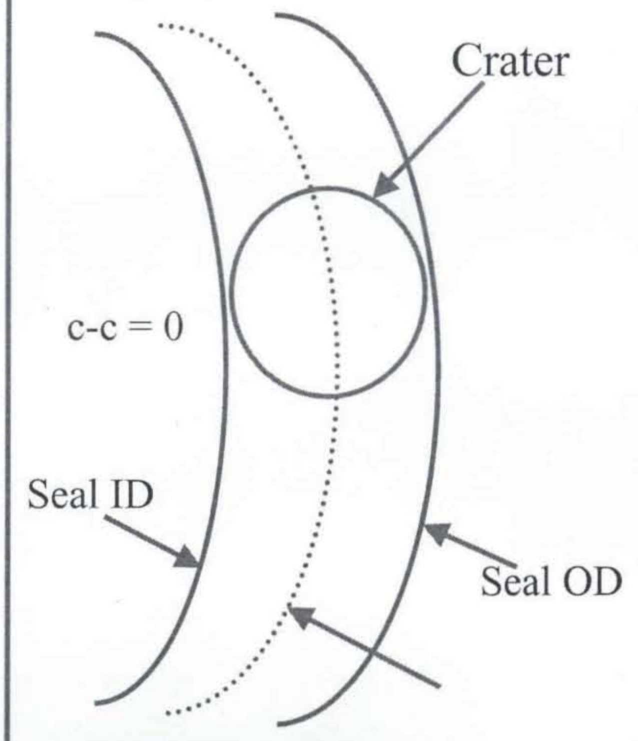
- Measured values for craters in flange (D_f) and elastomer (D_{seal}) correlated with particle Kinetic Energy for subsequent design calculations

Parker Seal Ring Damage Dependence on Hit Location

Damage to the elastomers dependent on hit location

- Impacts near the center-line (c-c = 0) are most damaging as shown by hits of similar kinetic energy:

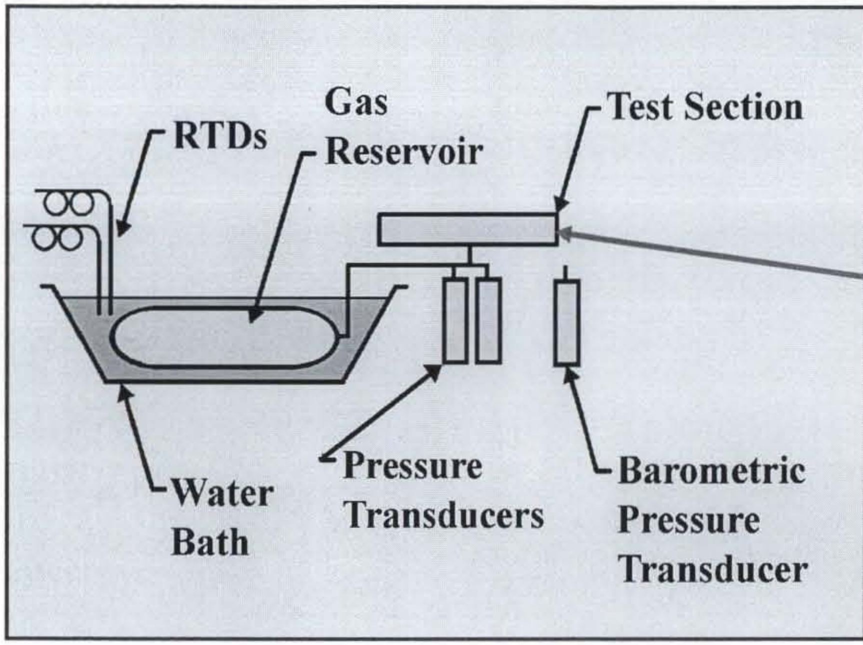


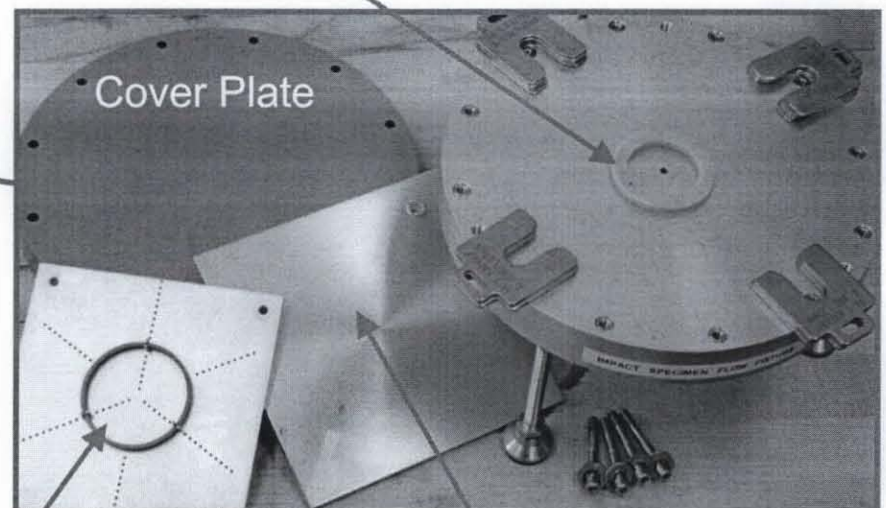


Crater in Seal Ring
("c-c defined as positive if crater "outside" seal centerline)

Leak Testing Damaged Seal Rings and Plates

Esterline ELA-SA-401 seal ring simulates Esterline/NASA 2-piece seal.





Parker S0383-70 seal ring simulates Gask-O-Seal.

Aluminum plates

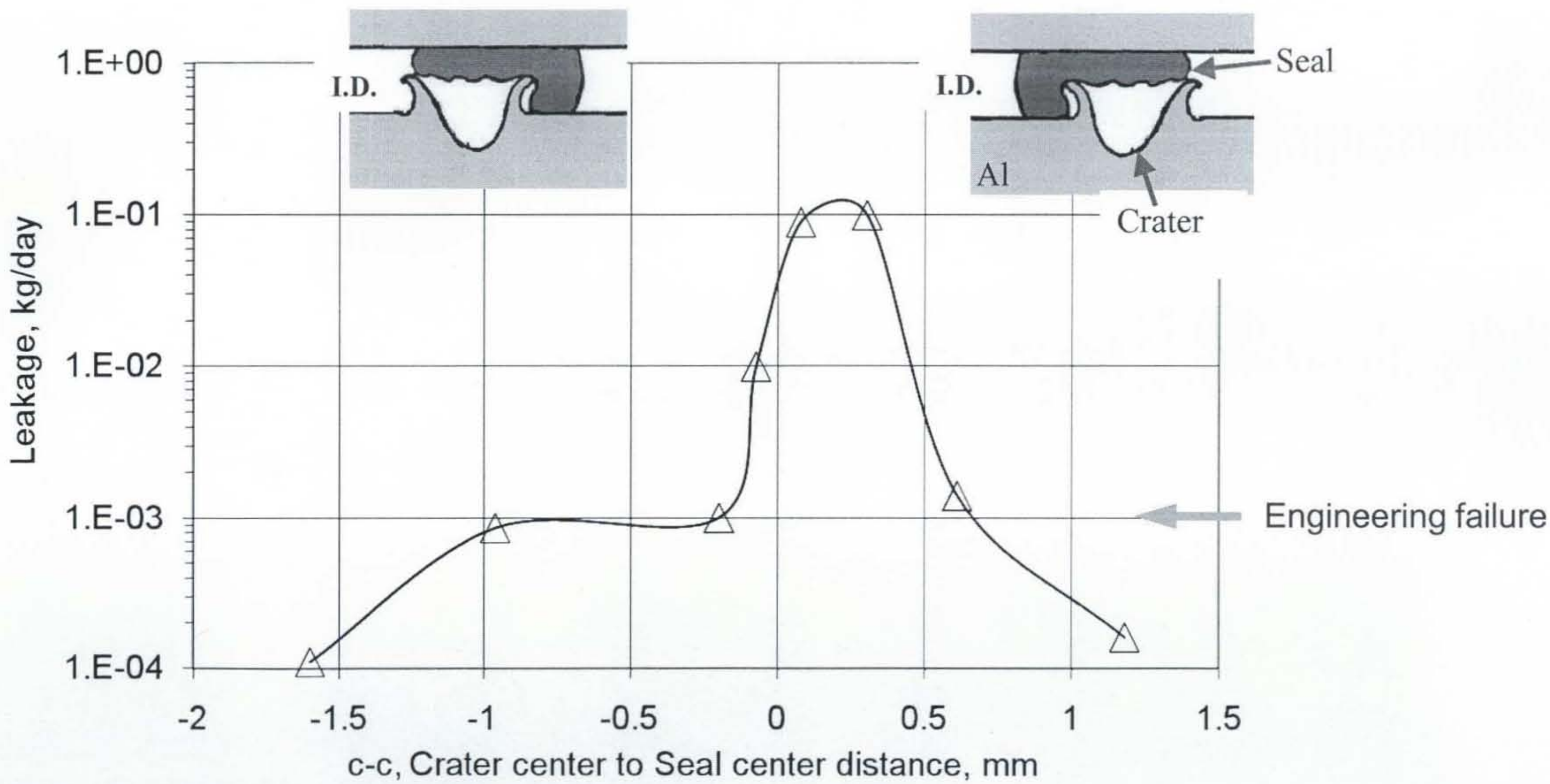
Pressure Decay Apparatus

Flow Fixture Test Section

Flow tests performed before and after impact hits to quantify leakage change and compare to leakage limit. Failure defined: leakage > 0.001 kg air /day

Leakage of Parker Seal Ring over Cratered Aluminum Flange vs. Location

- Crater caused by 0.5 mm Al sphere at 8.14 km/s, resulting in a 2.5 mm dia. crater
- Leak tested using a 2.5 mm wide Parker seal.

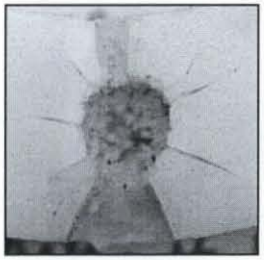


What Damage Size Will Cause Seal Failure?

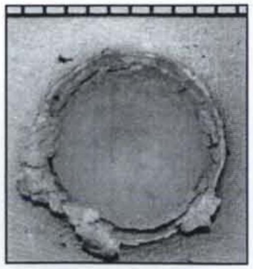
Parker seal: when $D_{seal} > 84\% \ w_{bulb}$

Parker seal over cratered aluminum: $D_{flange} > 80\% \ w_{bulb}$

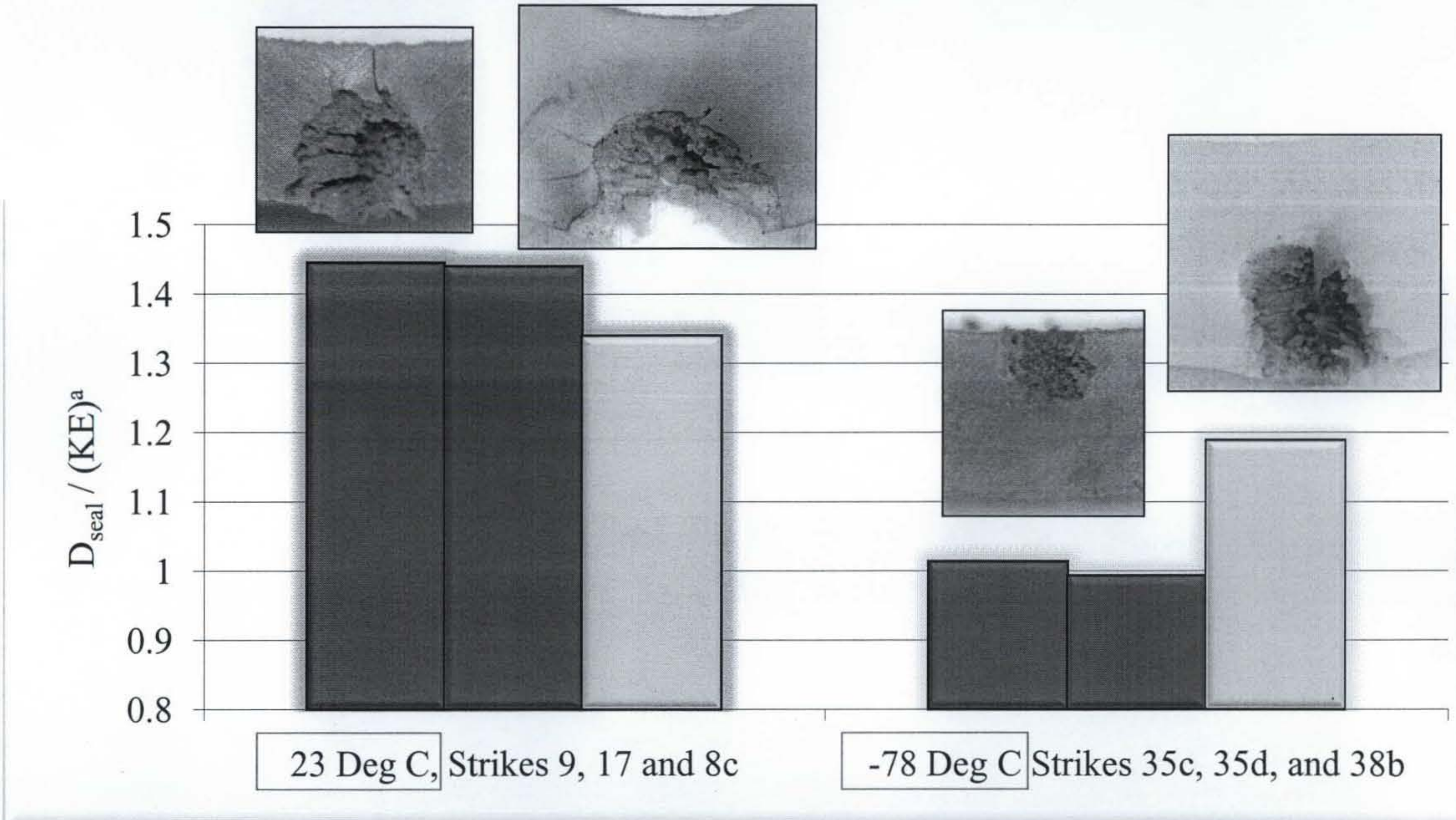
Esterline seal: when $D_{seal} > 84\% \ w_{bulb}$



Esterline seal over cratered aluminum: $D_{flange} > 90\% \ w_{bulb}$



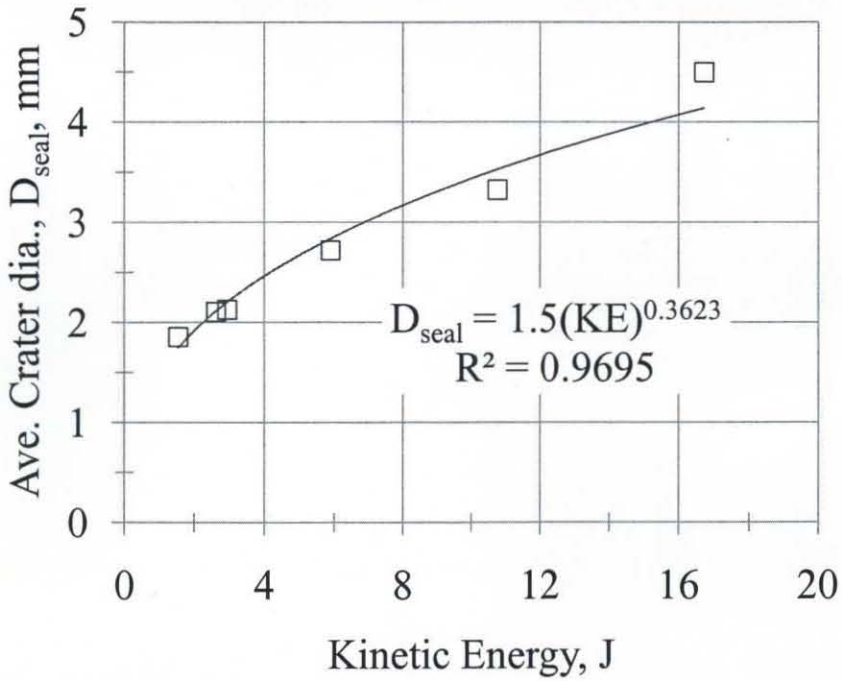
Damage Dependence on Temperature



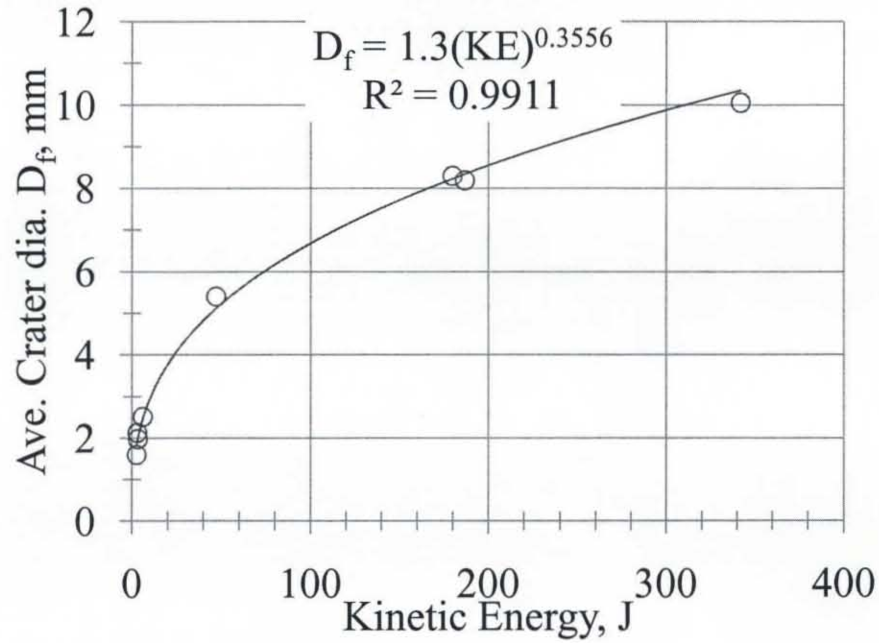
- Damage less at lower temperature (-78°C) due to less secondary damage and less cracking.

Crater Diameters vs. Kinetic Energy

Parker S0383-70: Avg. crater diameter



6061 T651 aluminum: Avg. crater diameter



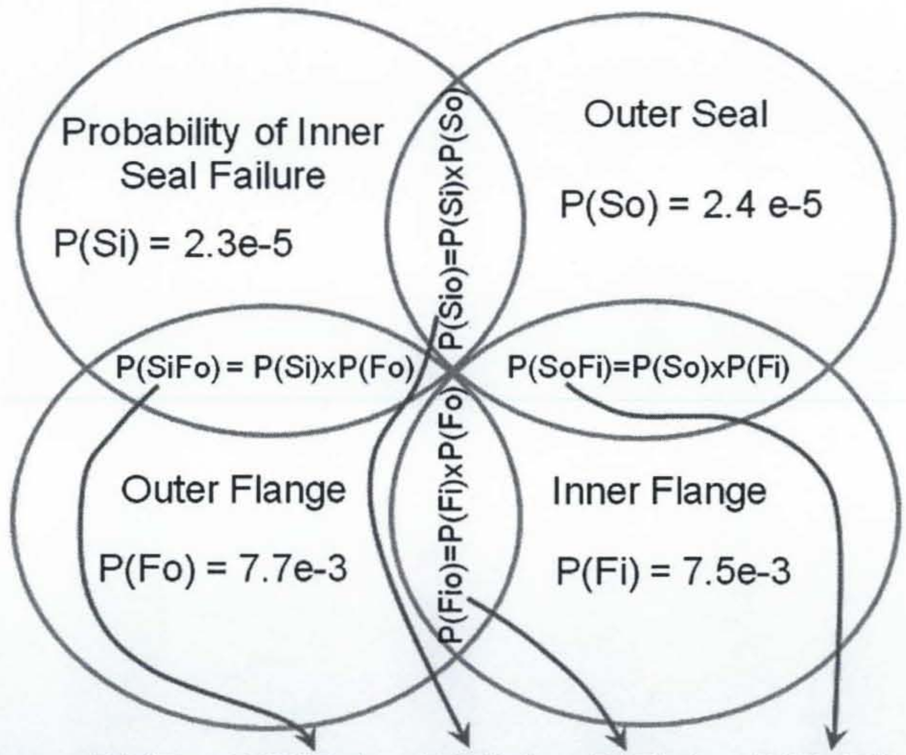
- Avg. crater diameter generally follows power law relationship
- Relationships used to support subsequent BUMPER computer code analyses

Analytical Assessment of Risk and Risk Allotment

Modeling Risks from MMOD

FORTRAN program known as BUMPER is used to calculate the Probability of Impact (PoI) for the LIDS seal. BUMPER uses the sub-programs ORDEM2000 and Meteoroid Engineering Model (MEM) to define the MMOD environment.

Venn Diagram illustrating the 4 failure modes, and Seal and Flange Failure Probabilities for LIDS seal exposed for 4 days, and ISS flange for 5 years.



Prob. of mission failure = PMF = P(SiFo) + P(Sio) + P(Fio) + P(SoFi)

Notation: S: Seal, F: Flange; i,/o.: Inner, Outer locations

Time, Area and Risk Allocation: ISS Mission

NASA allocates risk with the formula:

$$PNML = X^{At}$$

A = area exposed to space (m^2),

t = time of exposure (yr)

PNML = Probability of No Mission Loss

X = Constant determined programmatically through the definition of a specific case.

LIDS System MMOD Risk Allocations and Solution of X using.					
	LIDS Risk	LIDS PNML	LIDS Area m^2	LIDS time yr	X
ISS	1 in 2000*	0.9995	2.72	0.5749 (210 days)	0.99968

* Received risk levels from MMOD Analysis Group (Eric Christiansen, William Bohl, Kevin Deighton, Michael Bjorkman, + others)

LIDS Seal Sub-allotment PNML: ISS Mission

- With "X" for LIDS defined, we can now determine allowable PNML levels for various missions scenarios.
- Note: mission times play role here

LIDS Seal MMOD PNML allocations for the LIDS seal and LIDS seal/ISS flange, (area = 0.172 m^2), with margins of 50% and 100% above the requirement found using X from for LIDS system.

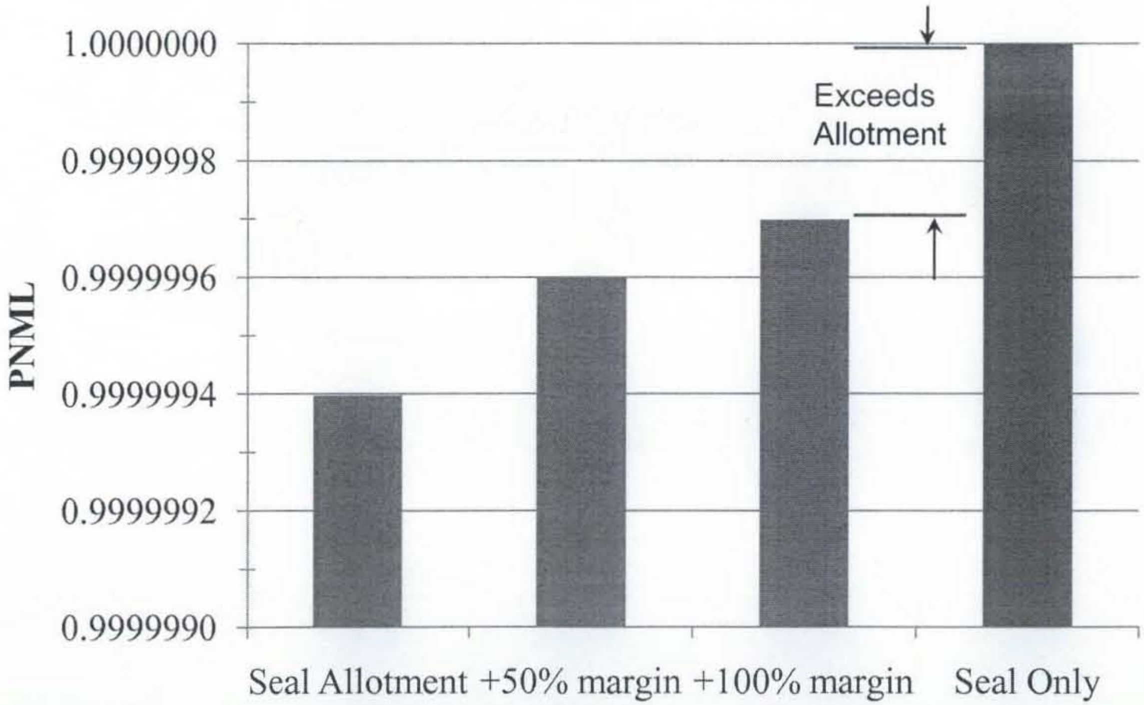
				+ 50% Margin		+ 100% Margin	
"Case"	Time yr	PNML	Risk 1 in:	Seal PNML	Risk 1 in:	Seal PNML	Risk 1 in:
$ISS_{Seal\ only 4days}$	0.01095	0.99999940	1,660,050	0.999999598	2,490,076	0.99999970	3,320,101
$ISS_{Flange 210day}$	0.57495	0.99996837	31,620	0.999978917	47,431	0.99998419	63,241
$ISS_{Flange 10yr}$	5	0.99972501	3,636	0.999816672	5,455	0.99986250	7,273

Seal PNML needs to be higher than sub-allotment PNML (+ margin)

Assessment of Seal Design:
Comparison of Expected Seal PNML to Allotment

Comparison of "Seal Only" PNML to Allotment

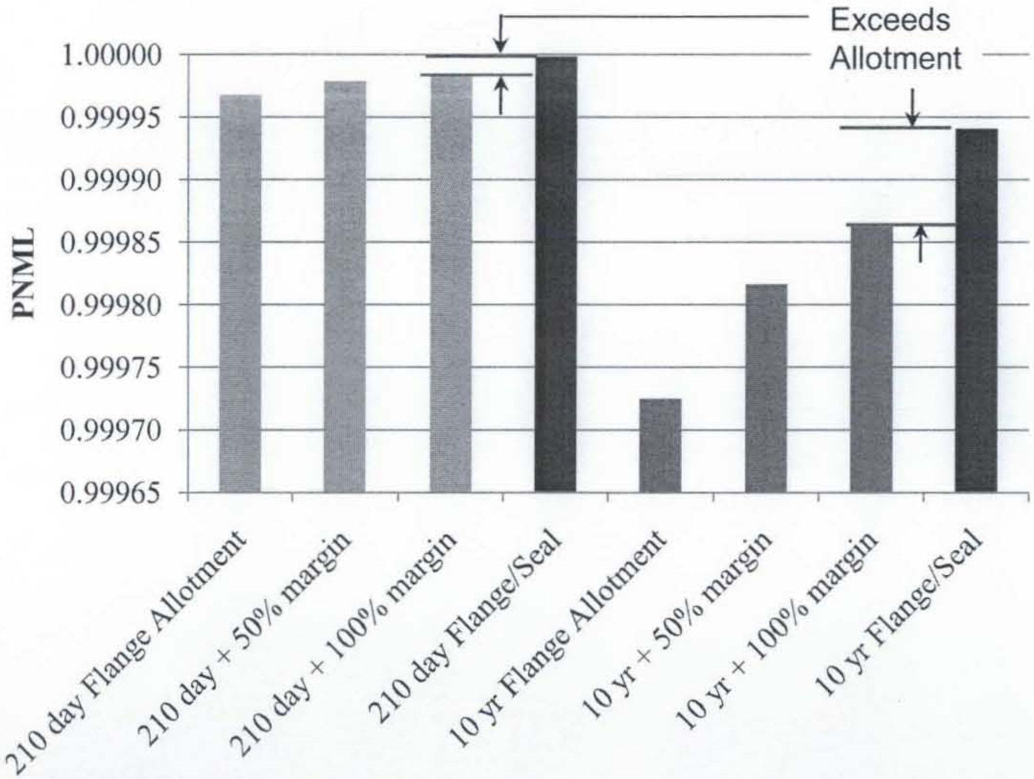
For LIDS Seal only: Probability of No Mission Loss due to seal failure caused by MMOD threats to the 2.5 mm wide LIDS seal during the 4 days after launch and before docking with ISS.



Seal PNML (4 day exposure) greatly exceeds sub-allotment PNML + Margin

ISS Flange/Seal System PNML Compared to Allotment

Risk allotment for 210 days of exposure and added margins of safety compared to Seal PNML found through BUMPER simulations and seal/flange testing. 10 years of service is simulated by 5 years of ram exposure.



Seal +Flange PNML higher than sub-allotment PNML + margin for either time mission case

Summary

- The primary design parameters for the seal bulb are it's height, width, and hardness
  - MMOD durability is most sensitive to seal width
  - A wider seal is less vulnerable to MMOD damage, however, adhesion and clamping load increase as width is increased
- MMOD risks to the LIDS seal/flange system are dominated by risks to the <u>flange</u> since the flange is exposed for a much longer time (10 yrs) than the seals.
- LIDS seal MMOD risk requirements are exceeded at least <u>by a factor of 2</u> (i.e. including a 100% margin) for the <u>ISS mission</u> for a LIDS seal bulb 2.5 mm wide.
  - Greater margins were found for the Lunar Sortie, and Lunar Outpost missions.
- Since other factors, both known, (e.g. higher temperature) and unknown, (e.g. a change in risk allotment), might undermine the seal's relative reliability compared to safety requirements, it is recommended that the seal be made as wide as clamping loads will allow.

Acknowledgements

- The authors sincerely thank:
  - MMOD Analyses group including Eric Christiansen , William Bohl, Kevin Deighton, and Michael Bjorkman
  - Donald Henderson and Karen Rodriguez and team at White Sands Test Facility who conducted all of the hypervelocity impacts used in this work.
  - Chris Gallo and Henry Nahra for their support running the BUMPER computer simulations to assess MMOD threats
- We acknowledge the collaboration and contributions of
  - Richard Rauser and Donald Roth for helpful CT work and
  - Richard Tashjian for his technical assistance with the experimental hardware.

Appendix

Ongoing Work

- Several aspects of MMOD related threats to the seals and flange are still being examined by Glenn through a very limited number of hypervelocity impacts at WSTF:
  - Examining 4" seals (vs. rings cut from sheet material)
  - Impacts at LIDS seal maximum temperature (125 ^{o}C);
  - Impacts from particles of low density (near 1 g/cc);
  - Oblique impacts (75^{o})

- Plan to accommodate findings from above:
  - If results warrant, re-check MMOD analyses using methodology and check relative to margins used herein
  - Use slightly wider seal (~0.12" based on upcoming sub-scale load tests) for:
    - Additional MMOD margin and
    - Reduce seal leakage rates to lowest level possible while still staying within load limits.

Relevant Supporting References

(1) "Meteoroid and Debris Threats to NASA's Docking Seals," H.C. de Groh III, C.A. Gallo, and H.K. Nahra, AIAA-2009-3524, Presented and published at the 1st AIAA Atmospheric and Space Environments Conf., On-Orbit Spacecraft-Environment Interactions session, June 22, 2009, San Antonio TX.

(2) "Effects of Hypervelocity Impacts on Silicone Elastomer Seals," H.C. de Groh III and B. Steinetz, AIAA-2009-5249, Presented at the AIAA Joint Propulsion Conf., Advanced Seals Session, Denver CO, Aug. 8, 2009.