



# Risks from Small Orbital Debris

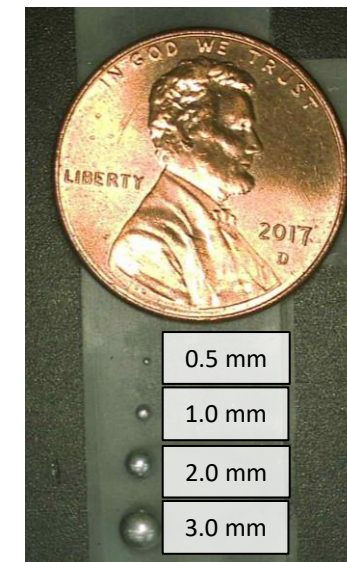
## “small things that carry a big punch”

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# What this talk is about

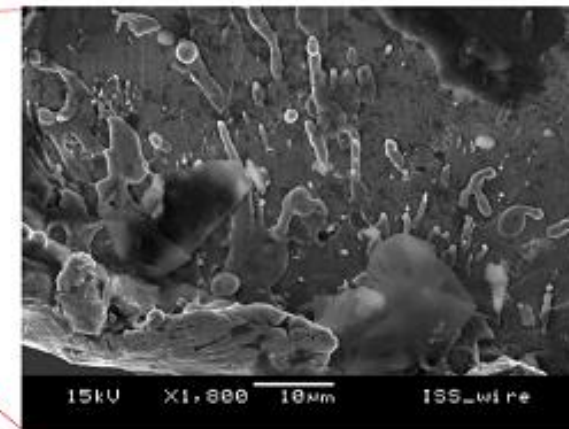
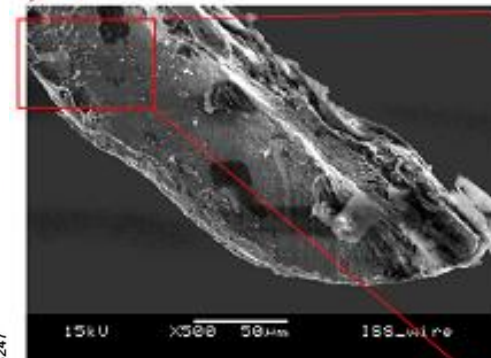
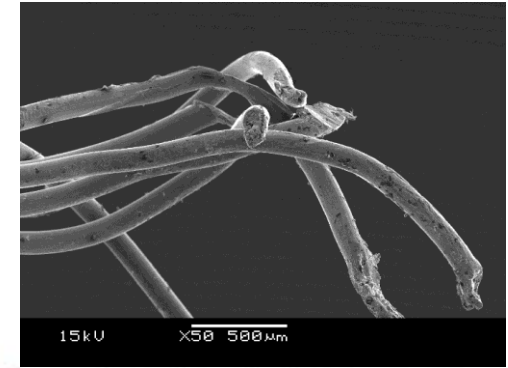
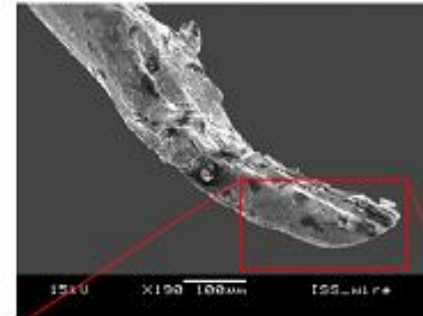
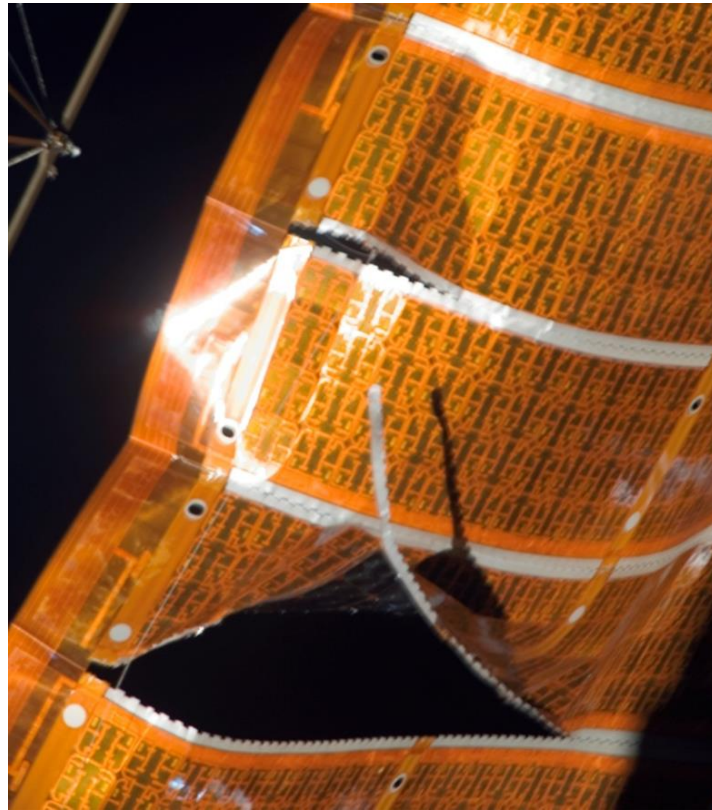
- **Small orbital debris, < 1cm diameter but more typically in 1mm to 3mm diameter size range, are risk drivers for many spacecraft**
  - Referred to as “millimeter sized debris”, impacts from small debris can lead to hardware failures & loss-of-mission for crewed and non-crewed satellites
    - Some failures can even lead to satellite breakup
  - This talk provides evidence that the threat to mission success from millimeter sized debris is a legitimate concern by considering **(1) on-orbit impact data**, **(2) hypervelocity tests** on spacecraft systems, **(3) risk assessments** for ISS and satellites.



# On-orbit evidence



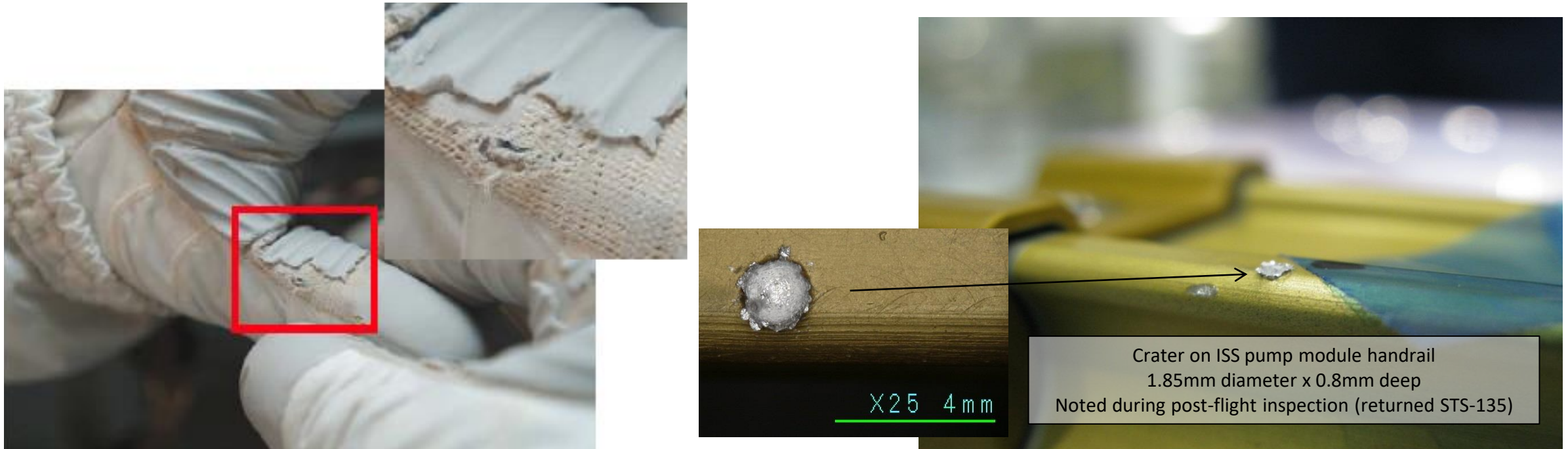
- **ISS has experienced impact damage from small MMOD with real consequences: repair & replacement, crew time, loss of capabilities, etc.**
  - **Example 1:** During STS-120 two solar array wings were removed from Z1 truss and relocated to P6 location. During re-deployment, the 4B solar array wing was torn in two places, due to a snagged guide wire. The guide wire was removed and “cuff-links” added to stabilize the array.



# On-orbit evidence (continued)



- **Example 2:** An EVA was terminated early on STS-118 due to glove cuts caused by sharp edges created by a small MMOD strike to a handrail.
  - Source of glove damage found to be a small crater on an airlock handrail (where the crew exits for EVAs)
  - Tape was initially used to cover the crater, but later a clam-shell device was placed around the crater. In addition, the EMU gloves were modified (toughened) with Kevlar to reduce cut glove potential. Inspections of handrails for craters performed now from ISS photos.



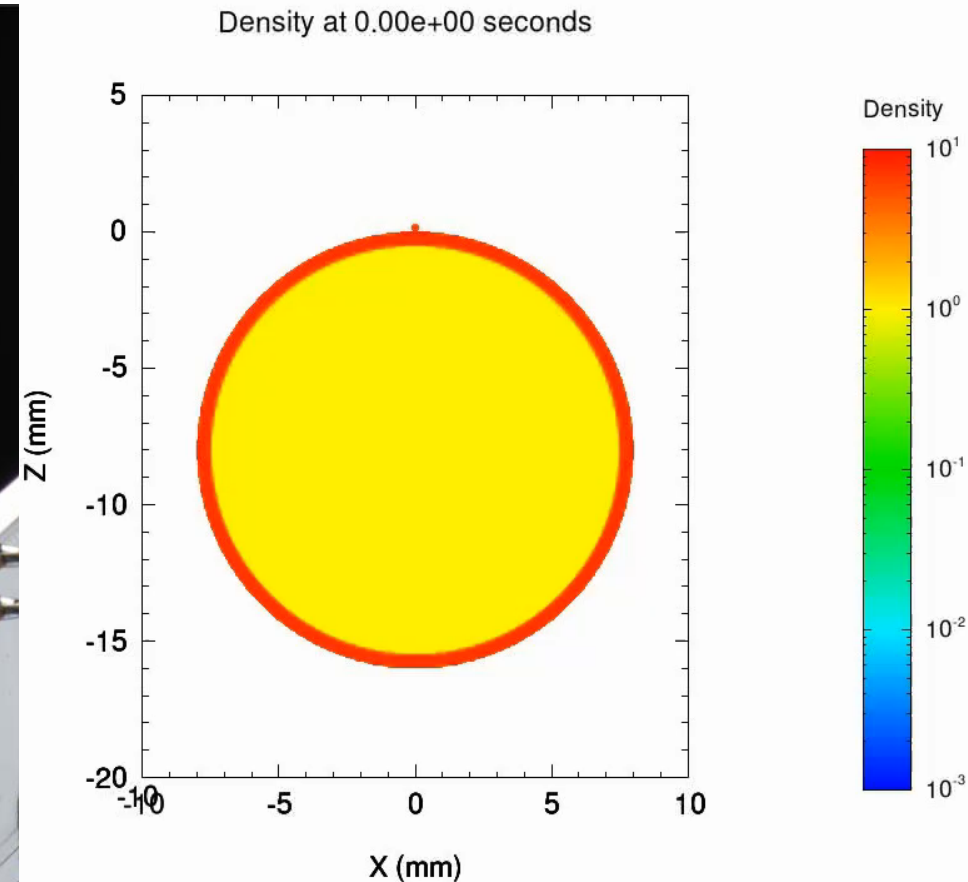
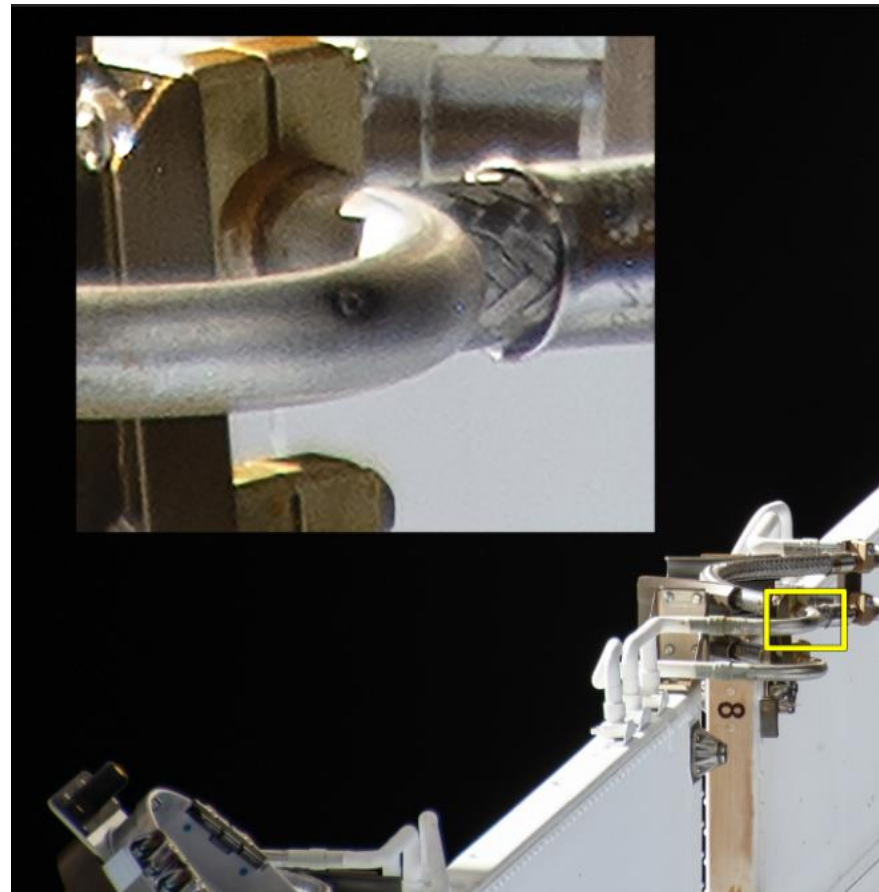
# On-orbit evidence (continued)



- **Example 3: Russian module radiator leak that occurred in Oct. 2023**
  - Leak of radiator interconnect line on the Multipurpose Laboratory Module (MLM) could be due to small MMOD particle: 0.36mm diameter steel projectile at 10 km/s results in observed 1.3mm diameter hole in the radiator line



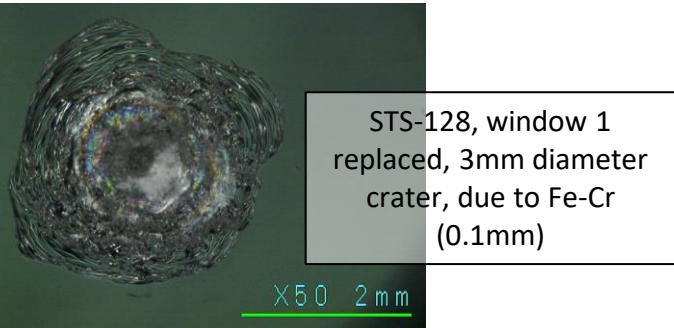
Iss070e006528: MLM Radiator Line Leak Location



# On-orbit evidence (continued)

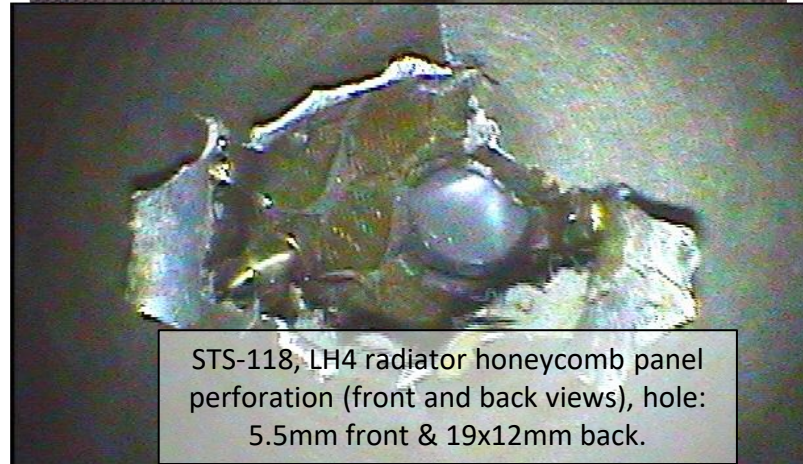
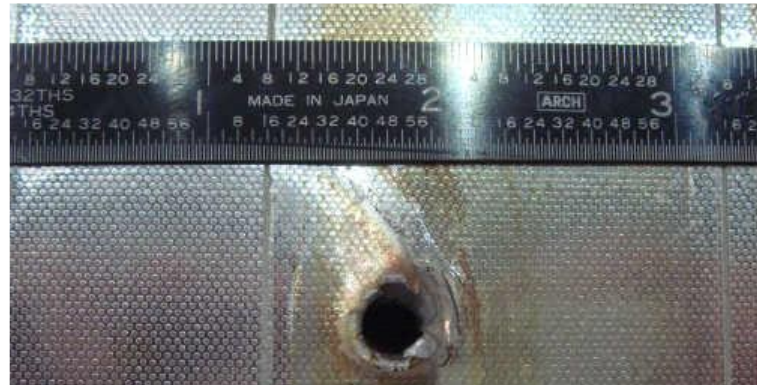


- Example 4:** The Space Shuttle Program augmented radiators and wing leading edge (WLE), modified ISS dock attitude and performed on-orbit inspections to reduce risk from small debris and meteoroid impacts.
  - Numerous MMOD damages observed on radiators, windows and WLE post-flight justified these vehicle design and operational changes.

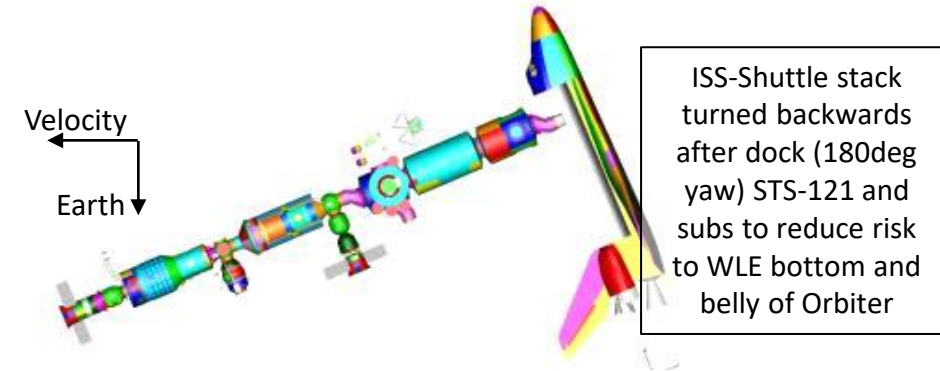


STS-128, window 1 replaced, 3mm diameter crater, due to Fe-Cr (0.1mm)

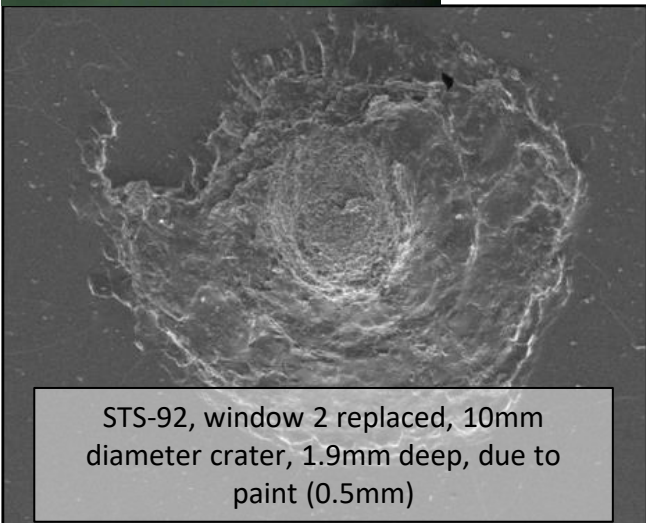
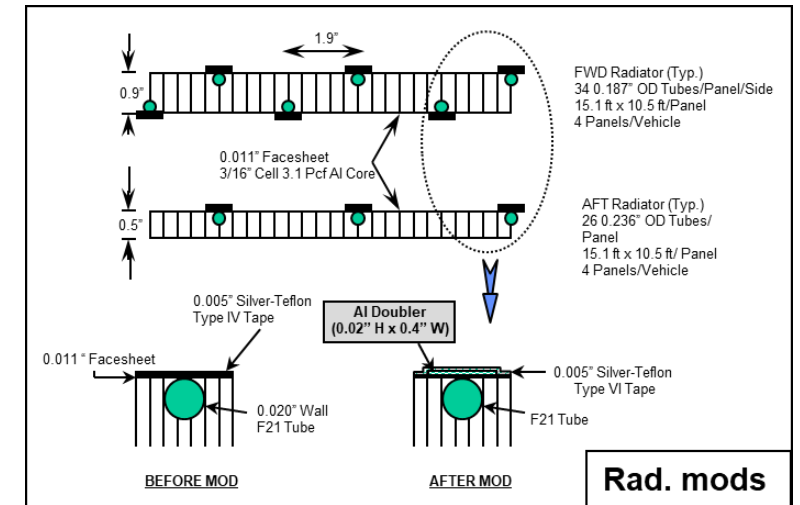
X50 2mm



STS-118, LH4 radiator honeycomb panel perforation (front and back views), hole: 5.5mm front & 19x12mm back.



ISS-Shuttle stack turned backwards after dock (180deg yaw) STS-121 and subs to reduce risk to WLE bottom and belly of Orbiter



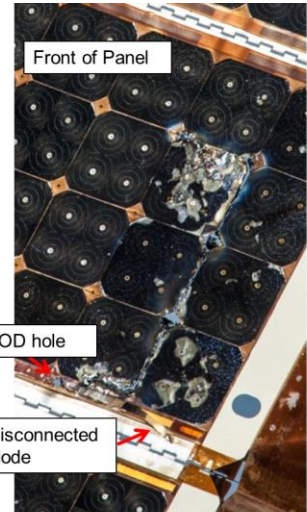
STS-92, window 2 replaced, 10mm diameter crater, 1.9mm deep, due to paint (0.5mm)

# On-orbit evidence (continued)



**Others:** Many other examples of small MMOD causing issues or representing close-call to operating spacecraft.

- ISS solar array power degradation due to disconnected bypass diode (several burned out solar array strings, loss of 400 cells per string)
- ISS P4 PV radiator through perforation with 13cm exit hole: likely due to 4mm-5mm diameter MMOD particle
- ISS Service Module window #7 damage that resulted in the window shutter permanently closed and inner pressure cover installed
- ISS Ku-Band antenna gimbal hole identified on STS-126 causing alignment control issues
- STS128 impact on flow tube that had been augmented with doubler (would have resulted in radiator leak without doubler and early end of mission)
- STS86 near perforation of radiator interconnect line



iss040e064550



ISS P4 Photovoltaic Radiator exit hole



Service Module window #7, damage 3mm to 5mm

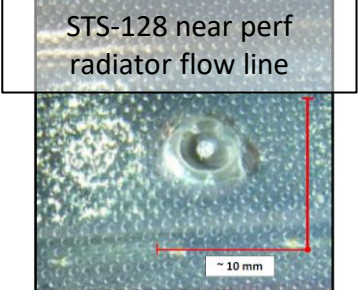
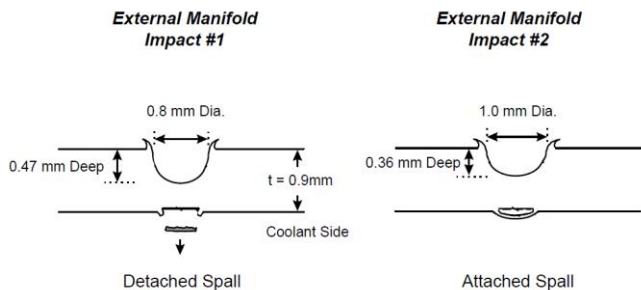
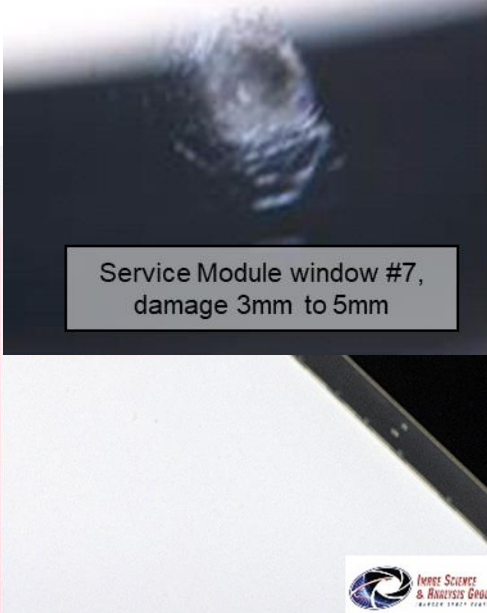
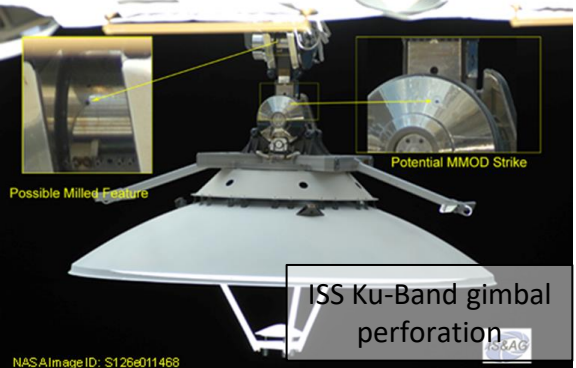


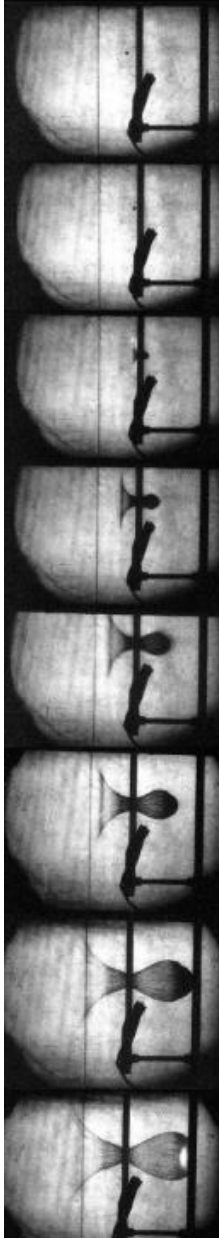
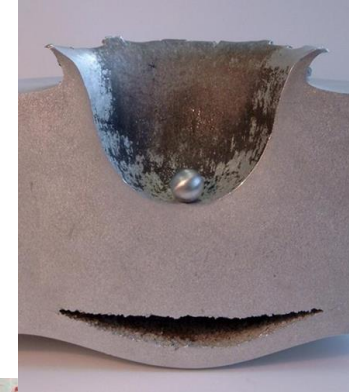
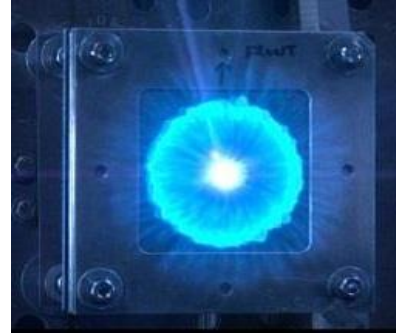
Figure 1. Impact crater on the radiator located on the interior of the Shuttle payload bay doors. The impact was on an aluminum "doubler" directly over the tube carrying Freon coolant used to cool electronic equipment and avionics in the Shuttle.



# Hypervelocity impact test results anchor small debris analysis



- JSC-XI5 Hypervelocity Impact Technology (HVIT) group plans and coordinates 300-400 impact tests per year: many of these tests are on spacecraft components that fail from small debris (i.e., 1mm-3mm projectile diameters)
  - White Sands Test Facility (WSTF) two-stage light gas-guns up to 8 km/s
  - University of Dayton Research Institute (UDRI) 3-stage launcher to 10 km/s
- Data used to develop and verify ballistic limit equations used in Bumper code on range of different spacecraft components and subsystems

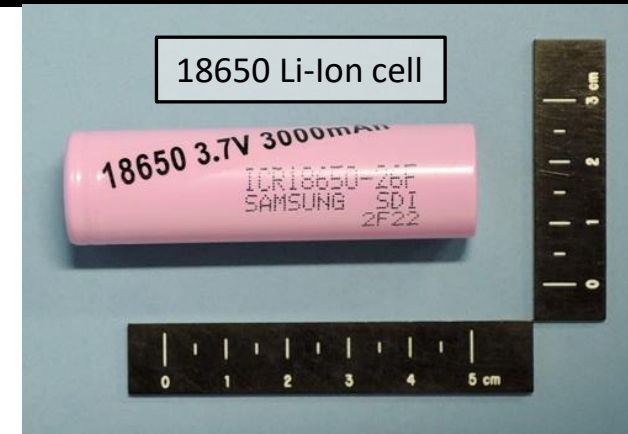


# Hypervelocity Impact Test Results

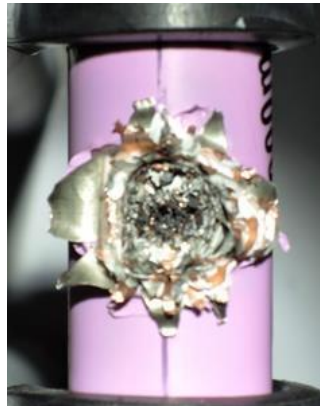


- **Example 1: Batteries are potential source of orbital debris & satellite failure/breakup**

- Li-Ion failure modes: internal shorts without cell perforation, cell perforation, thermal runaway (propagation concern)
- Ni-H2 failure modes: leak/depress



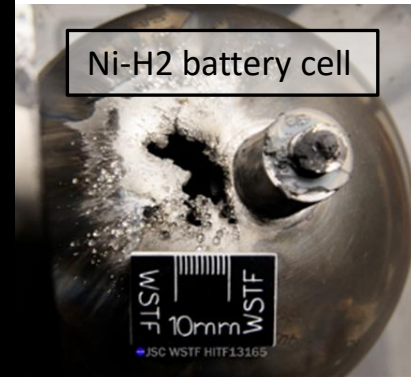
HITF17049  
1.0mm Al @  
6.95 km/s



HITF17050  
2.0mm Al @ 6.89 km/s



Ni-H2 battery cell



# Lithium-Ion Battery Tests



Test: HITF-12143, 1cm diameter Al @ 6.86 km/s

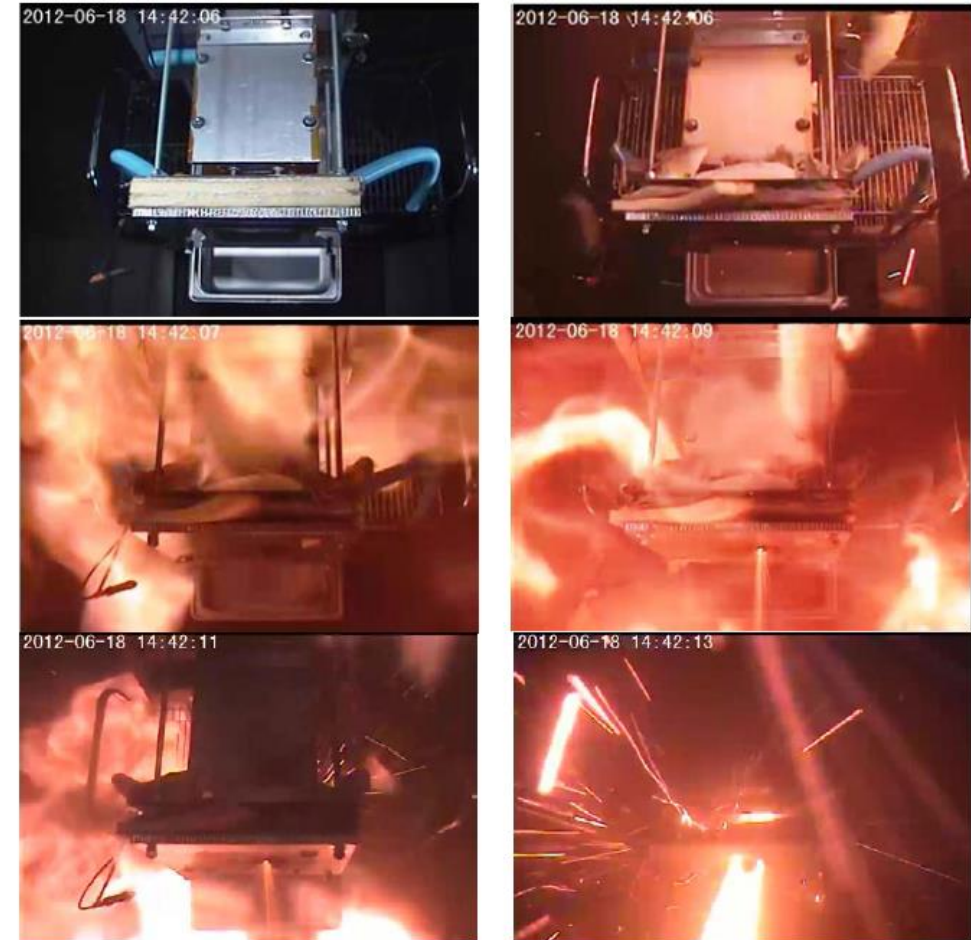
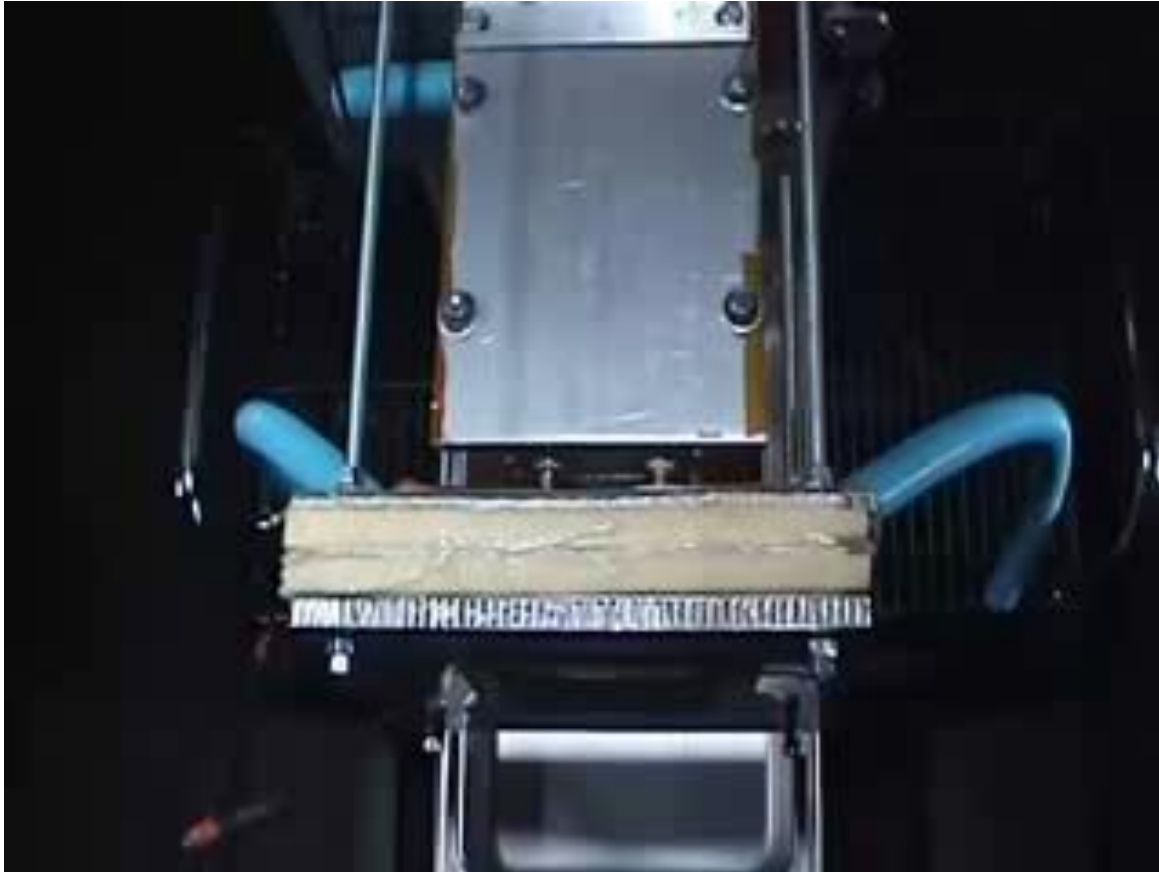


Figure 1.2-1. HITF12143 visible video frames at 1s-2s intervals after impact.

# Lithium-Ion Battery Tests



**Energetic response to hypervelocity impact: cell did not rupture, but internal contents were ejected from cell and littered chamber floor**

Post-test photos from HITF-12143, 1cm diameter Al @ 6.86 km/s



Post-test photos of test chamber floor after test HITF-12143

Each of the blocks (white/black checker board) in L-shaped ruler on right are 1 cm long



*Figure 1.2-2. After test imagery of HITF12143 a) shield with 9.5cm diameter through-hole, and b) cell close-up with impacted cell on right showing molten material from cell interior that was ejected and deposited on exterior of cell.*

# Hypervelocity Impact Test Results



- **Example 2:** Pressure vessels can leak or rupture due to MMOD damage, leading to loss-of-mission and possible spacecraft loss of control due to venting from leaks, or breakup from secondary failures after rupture.
- **Composite overwound pressure vessels (COPVs) used in upper stages and spacecraft tested to determine leak and burst thresholds.**
  1. Len x Dia: 50.8cm x 16.8cm, test pressure: 286 Atm (0.59 of burst)
  2. Len x Dia: 88.6cm x 42.5cm, test pressure: 300 Atm (0.65 of burst)

Leak failure mode (tank type 1)  
1.7mm Al @ 7.23 km/s, 45deg

Burst failure mode (tank type 1)  
1.7mm Al @ 7.01 km/s, 0deg



Debris from COPV burst test (largest debris) represents secondary impact hazard to other spacecraft hardware

# Composite Overwound Pressure Vessel (COPV) Testing



## Consequences from burst test of larger COPV

Before Test HITF17078  
(similar setup as HITF17552)



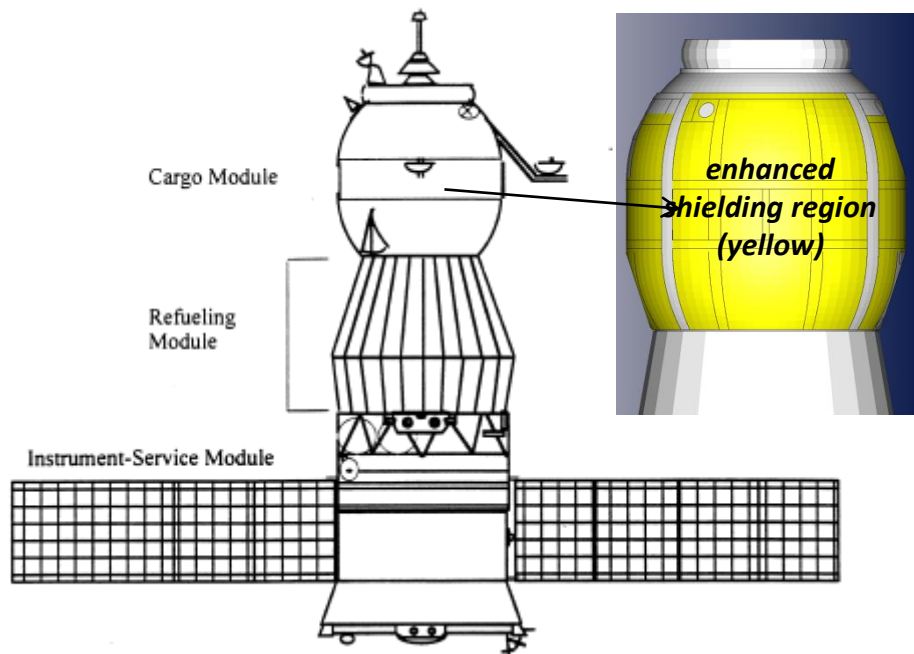
After Test HITF17552



HVIT17552: 5.0mm Al @ 6.82 km/s, 0deg  
(note: buckling of 5/8" thick steel plate under the test article)

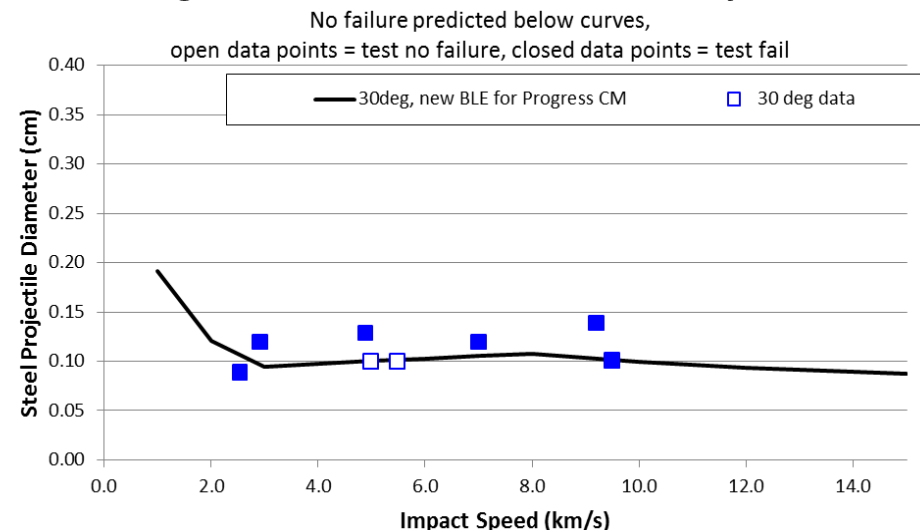
# Hypervelocity Impact Test Results

- **Example 3: Soyuz/Progress vehicle shielding**
- Originally, the pressure shell of the Soyuz Orbital Module and Progress Cargo Module were covered by a thermal blanket and were vulnerable to perforation by 1mm diameter aluminum debris particles impacting at typical ISS impact conditions (10 km/s)
- In 2012-2015, RSC-Energia added an aluminum bumper with standoffs to these vehicles, and the outer thermal blanket also augmented with additional materials and added over the bumper which improved protection to 2mm diameter aluminum debris...which decreased MMOD risk by 3-5 times depending on vehicle location.



Bumper shield and Standoffs being added to outside of Soyuz Orbital Module and Progress Cargo Module.

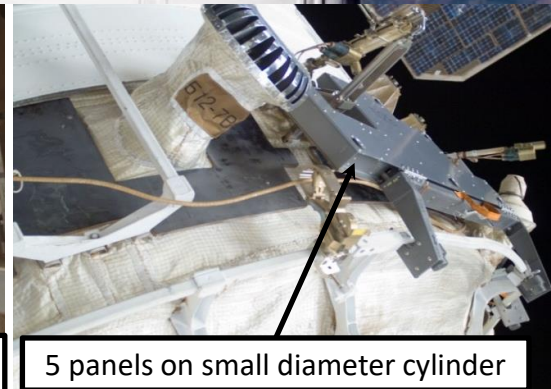
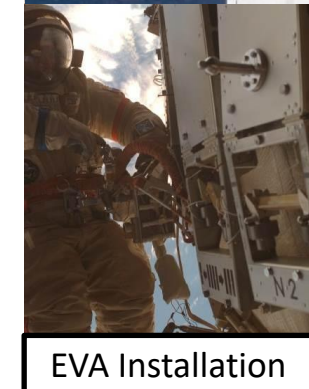
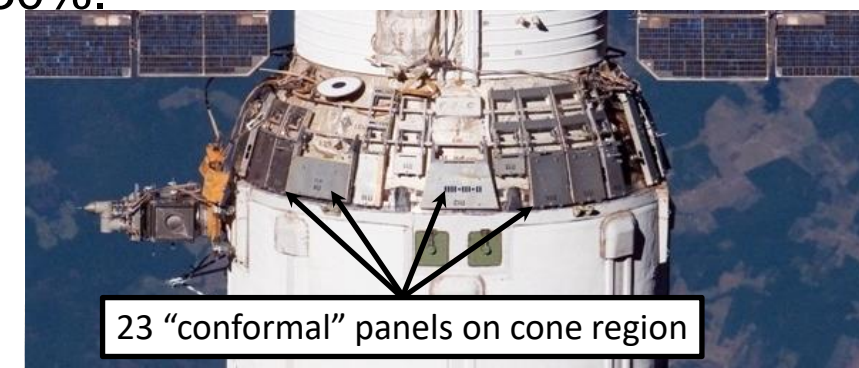
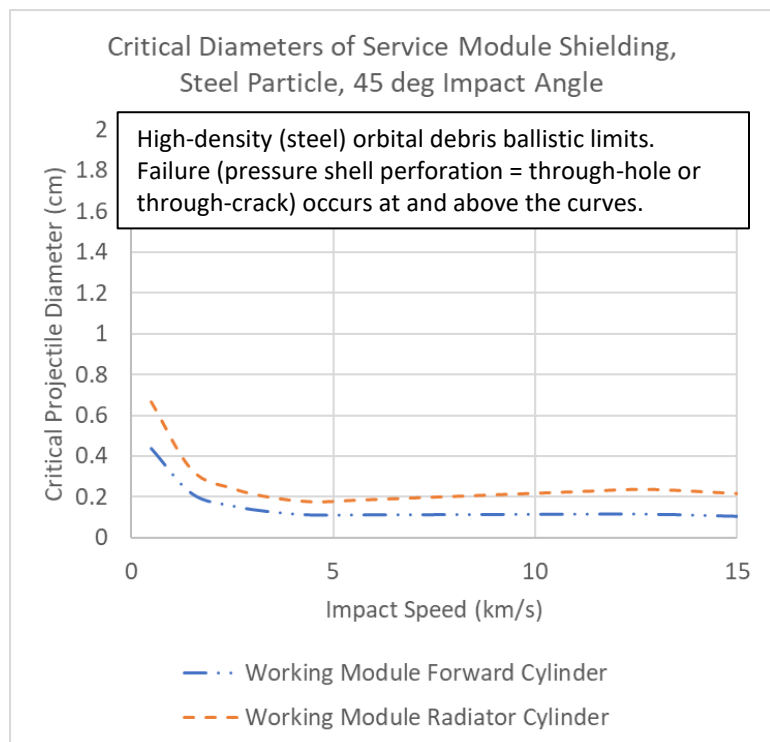
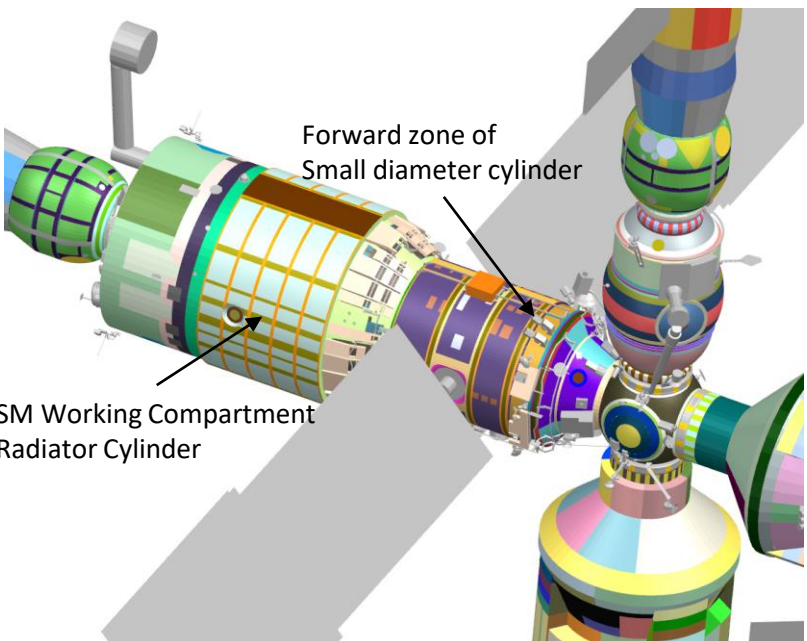
## Progress CM ballistic limits for Steel Projectiles



# Hypervelocity Impact Test Results

- **Example 4: ISS “Zvezda” Service Module shielding**

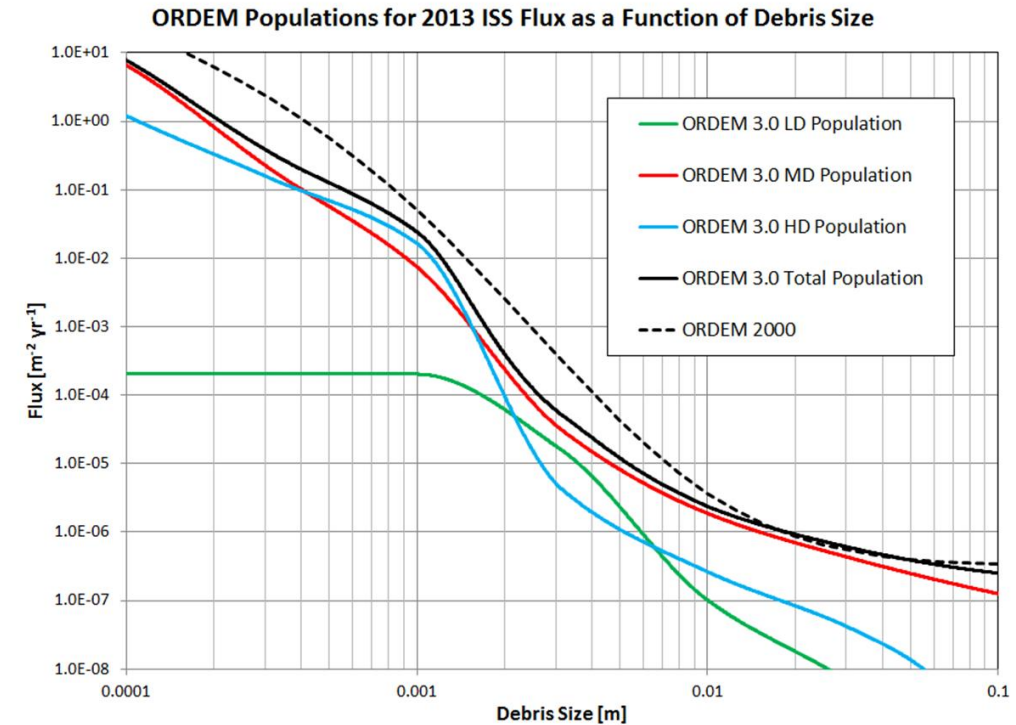
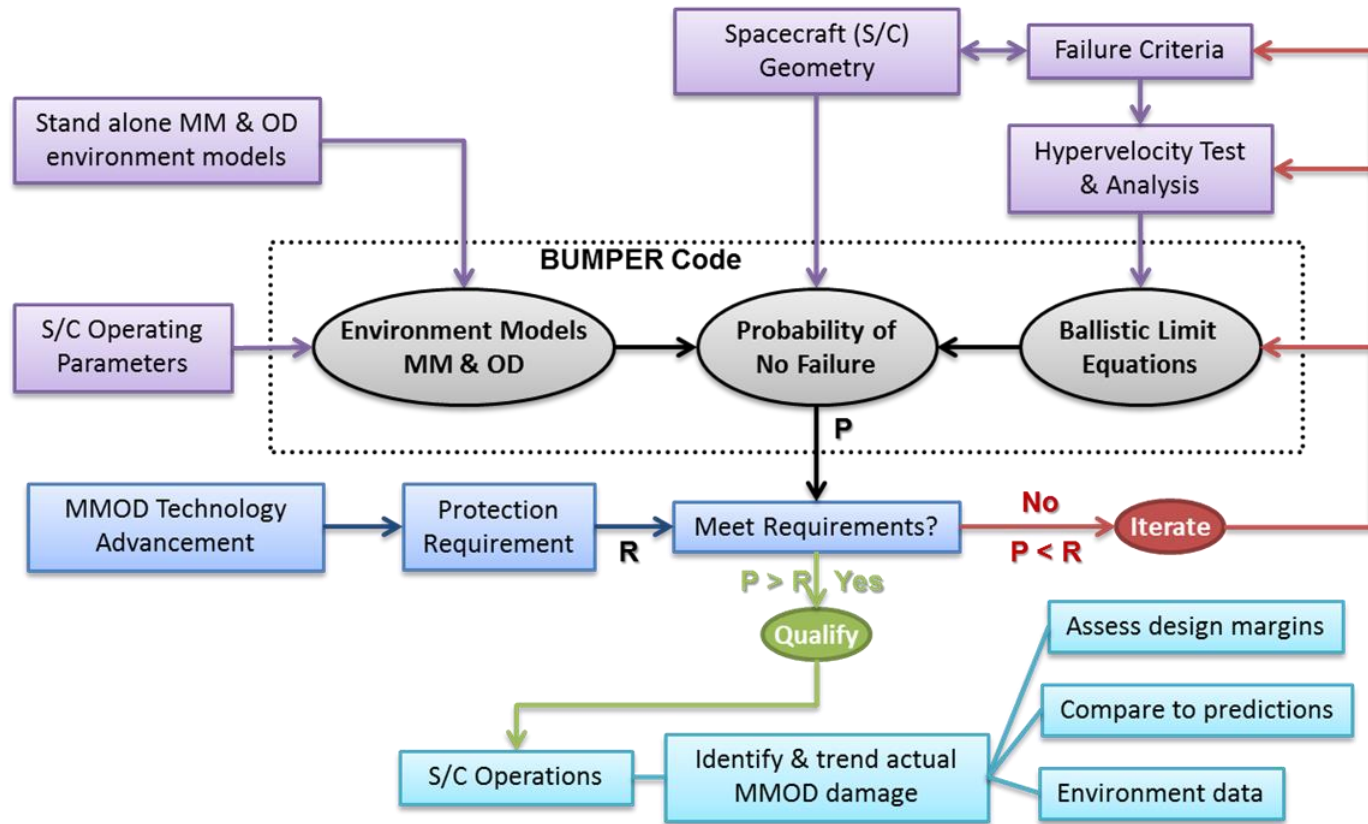
- Areas of the Zvezda Service Module are protected by body mounted radiators with short (2 cm) standoff between the outer radiator bumper and the pressure shell of the module.
  - Perforation of the pressure shell will occur with projectiles larger than 1-2mm steel debris and 2-4mm aluminum debris.
- In 3 missions between 2002 and 2012, a total of 28 augmentation shield panels were added by EVA to exterior areas of the Service Module to reduce MMOD risk by 30%.



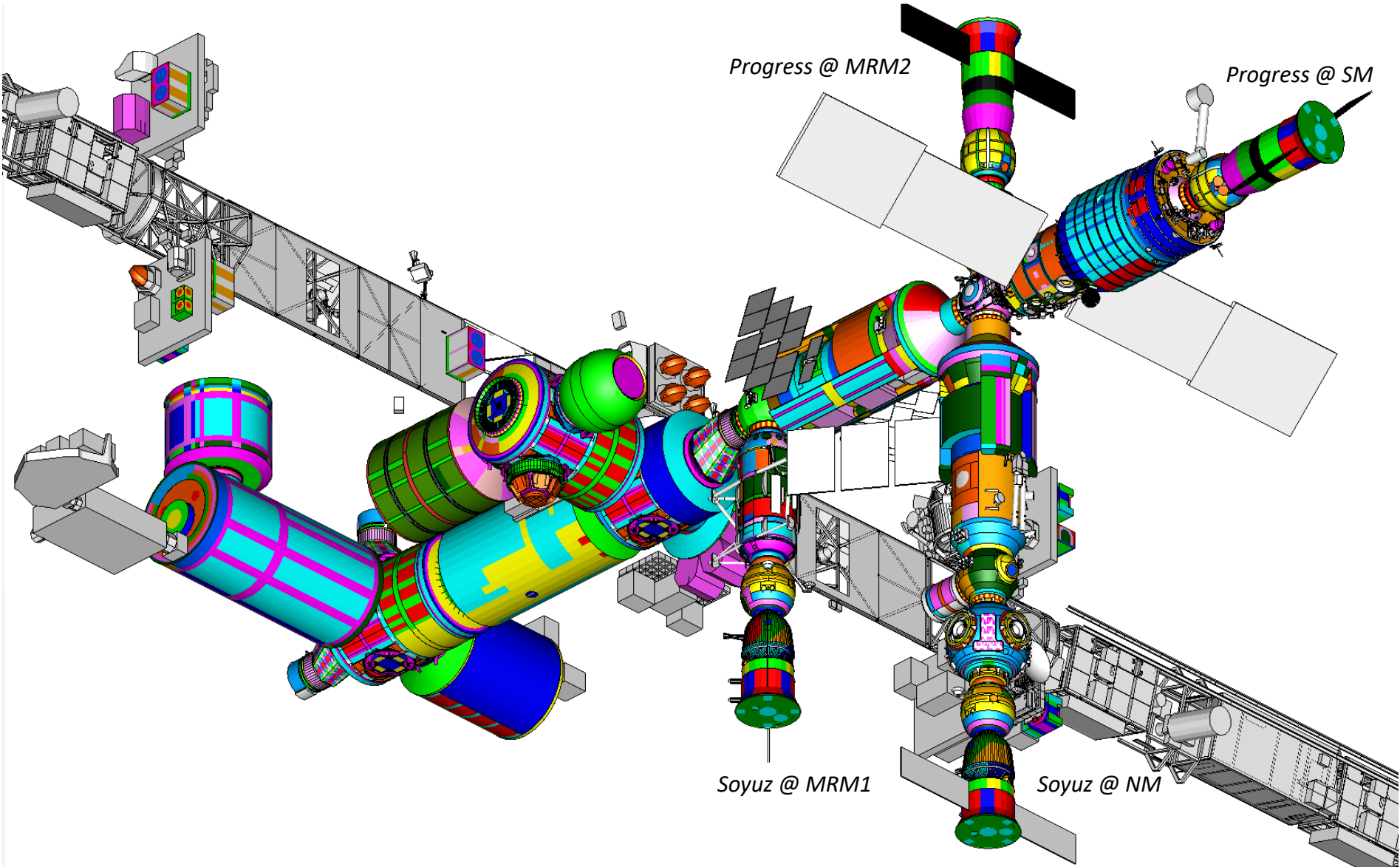
# Meteoroid and Orbital Debris (MMOD) Risk Assessments



- HVIT uses results of MMOD risk assessments to identify MMOD risk drivers, evaluate risk mitigation options, optimize MMOD shielding, verify compliance with protection requirements.



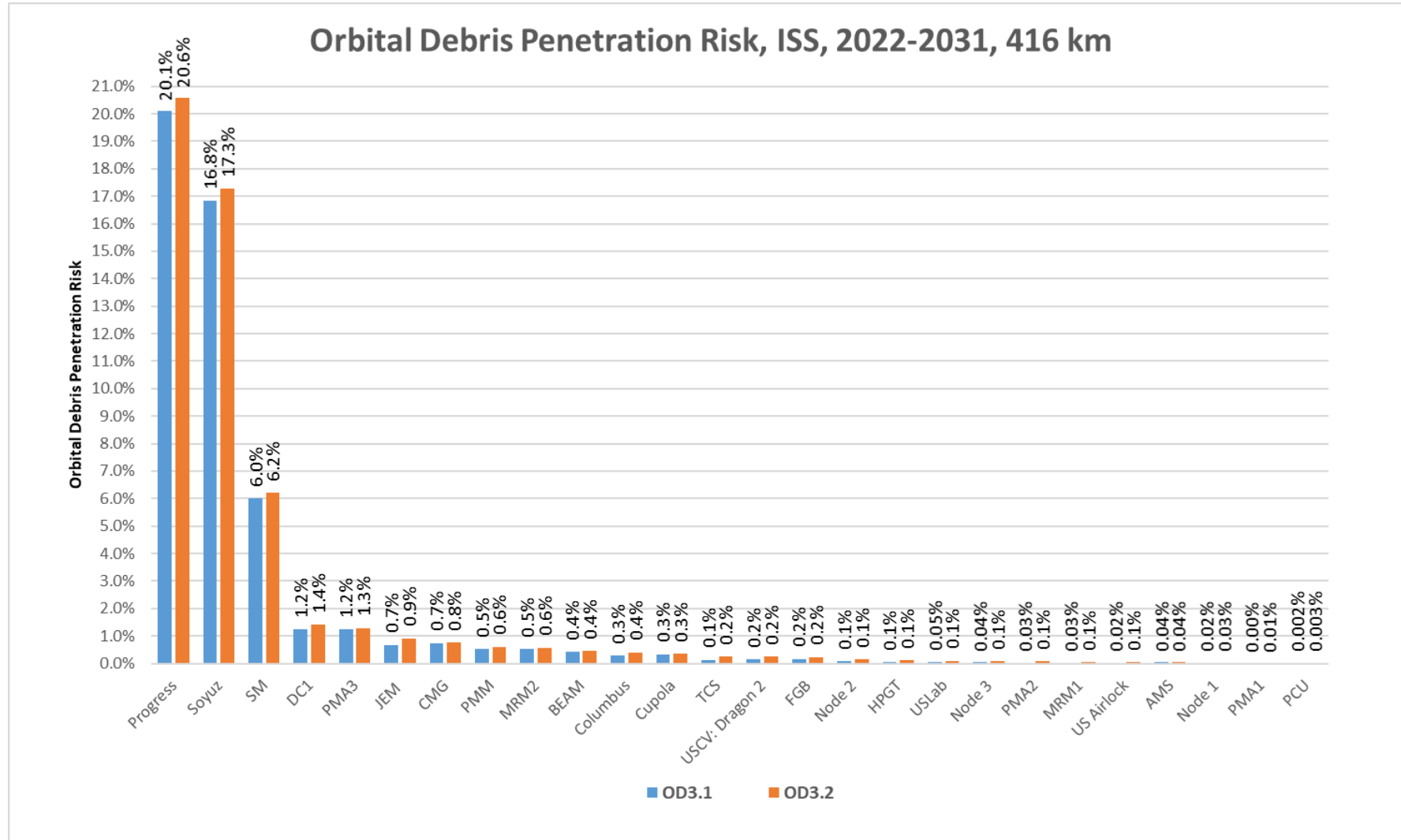
# ISS Finite Element Model for MMOD risk assessment using Bumper-code



# Meteoroid and Orbital Debris (MMOD) Risk Assessments



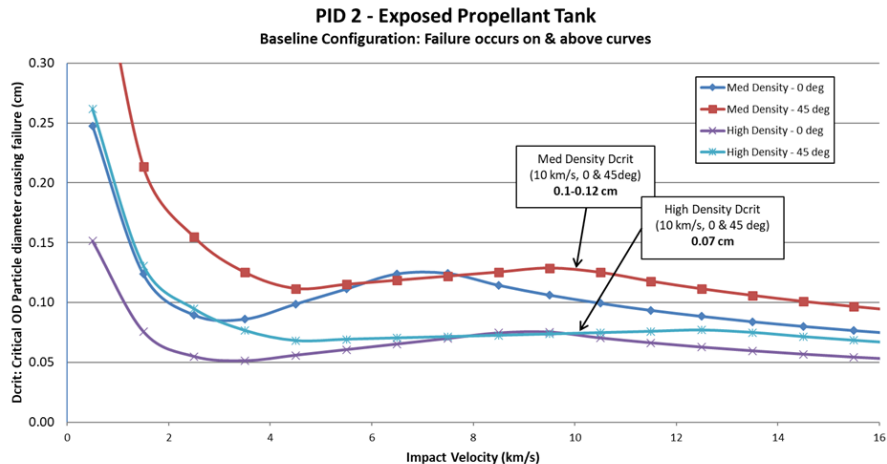
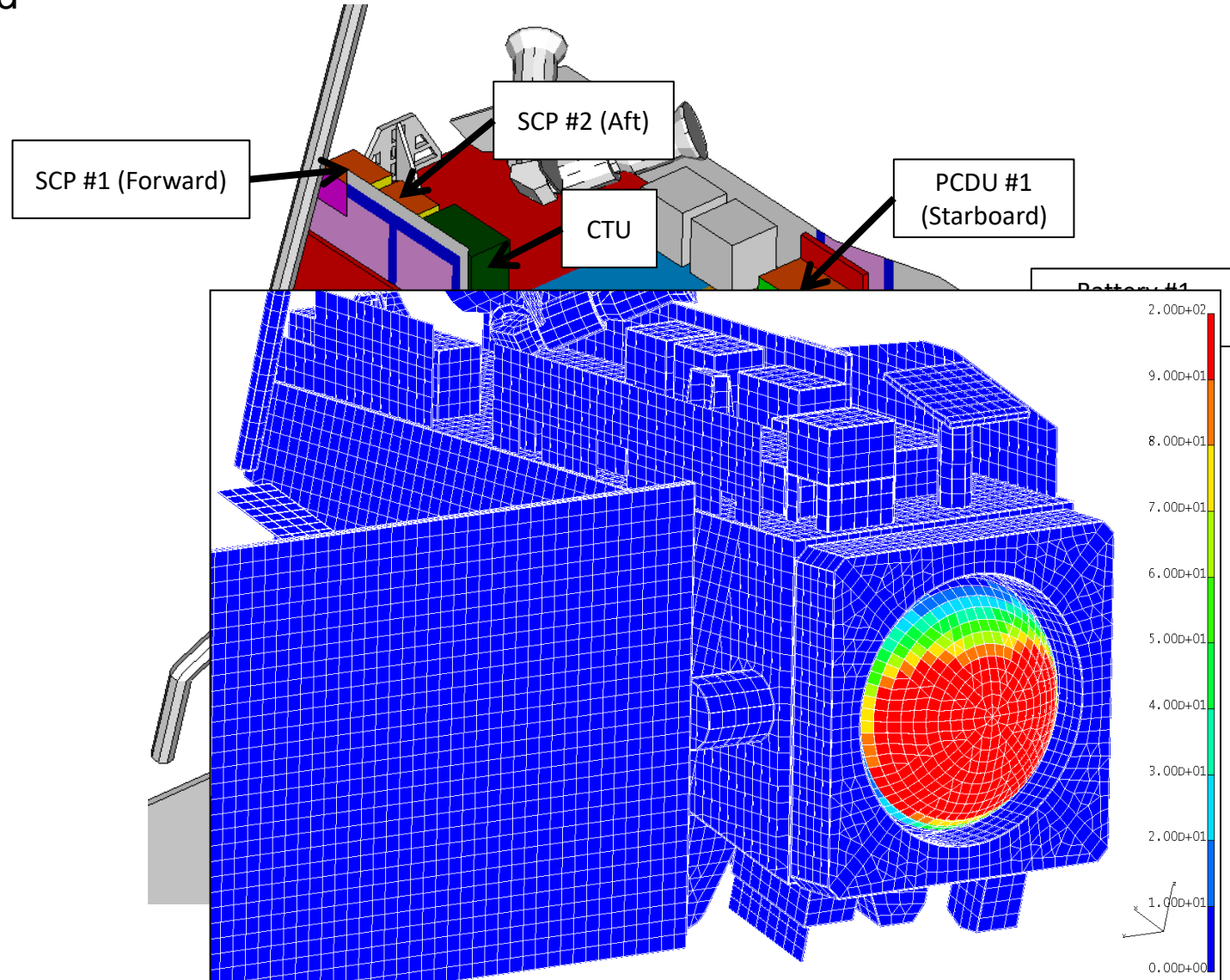
- ISS MMOD risk is driven by lightly shielded items that are vulnerable to 1mm-3mm orbital debris: Soyuz, Progress, Service Module



# Non-crewed spacecraft MMOD risk assessments



- Satellite MMOD risk is driven by lightly shielded items that are vulnerable to 1mm orbital debris
- Example: Orbital debris risk for the JPSS-1 satellite was initially driven by a non-shielded area of the propulsion tank at aft-end of the spacecraft
- The ballistic limit curves below illustrates this region is vulnerable to 1mm-1.2mm medium density orbital debris at 10 km/s, and 0.75mm high-density orbital debris at same speed
- This vulnerable area was augmented with a cover for JPSS-1 and JPSS-2



# Concluding Remarks



- Risk assessments indicated that small orbital debris, typically 1mm-2mm in diameter, is a risk driver for spacecraft, ranging from large crewed spacecraft (ISS) to non-crewed satellites.
  - This is demonstrated by hypervelocity impact tests on the ground of critical spacecraft systems, and evidence from failures and “close-calls” that we have seen with operational spacecraft such as ISS, Shuttle and crew and cargo vehicles.
- It is an important objective of the ODPO to obtain data on the amount of small debris in orbit via ground sensors, evaluation of damage identified on returned hardware and from on-orbit experiments such as MACS.