ISS Radiator Face Sheet Anomaly Investigation and Return to Function

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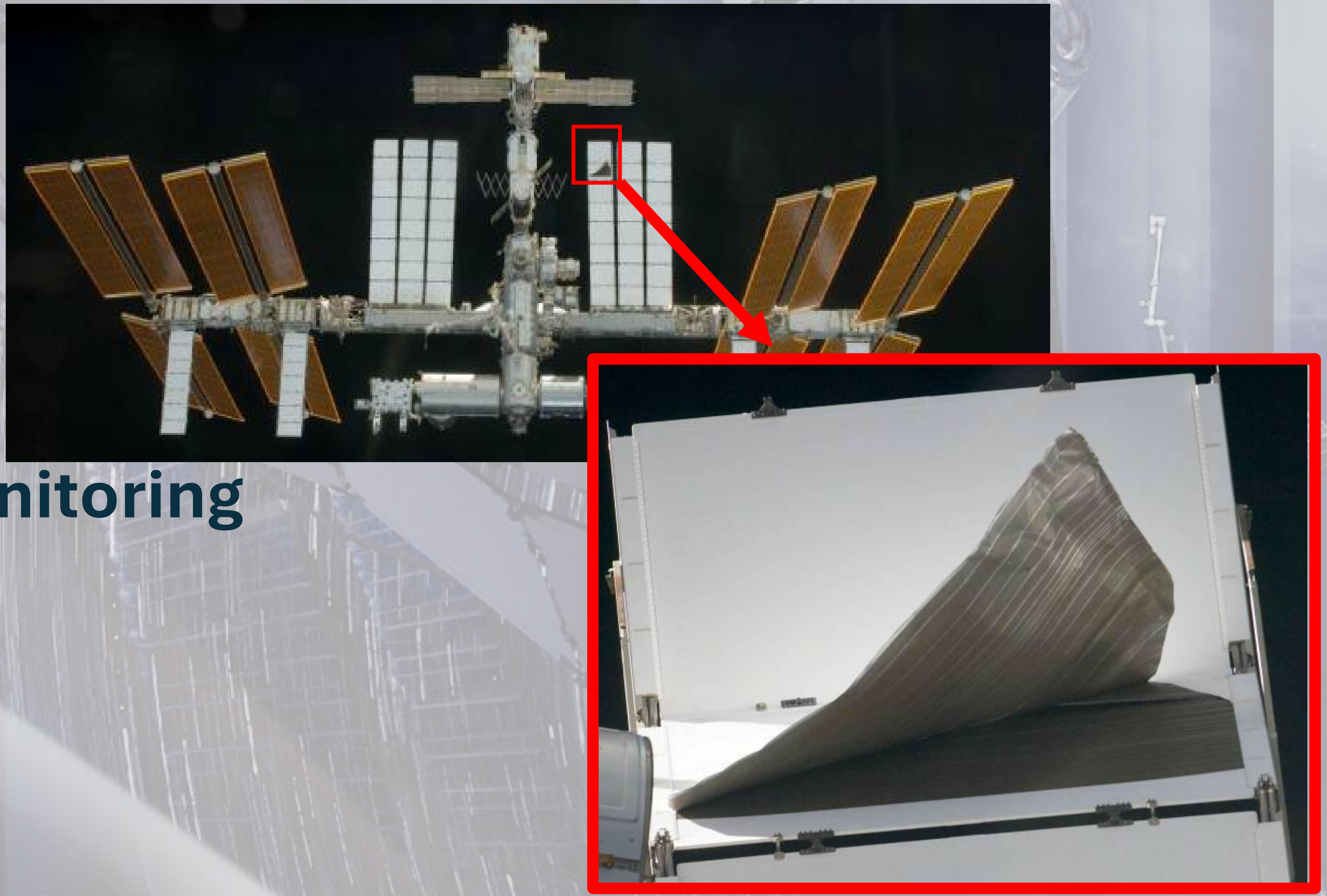
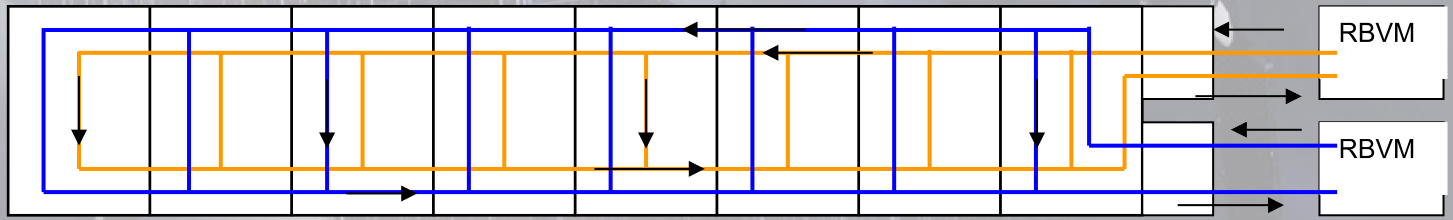
Purpose/Agenda

- **PURPOSE:** Document multi-year investigation, root cause, and rationale to return the radiator to service.
- **AGENDA:**
  - **Overview of ISS EATCS**
  - **Radiator Panel Construction**
  - **Investigation**
  - **System Management and Monitoring**
  - **Use-As-Is Rationale**
  - **Flow Path Fill**
  - **Conclusion**



Overview of ISS EATCS

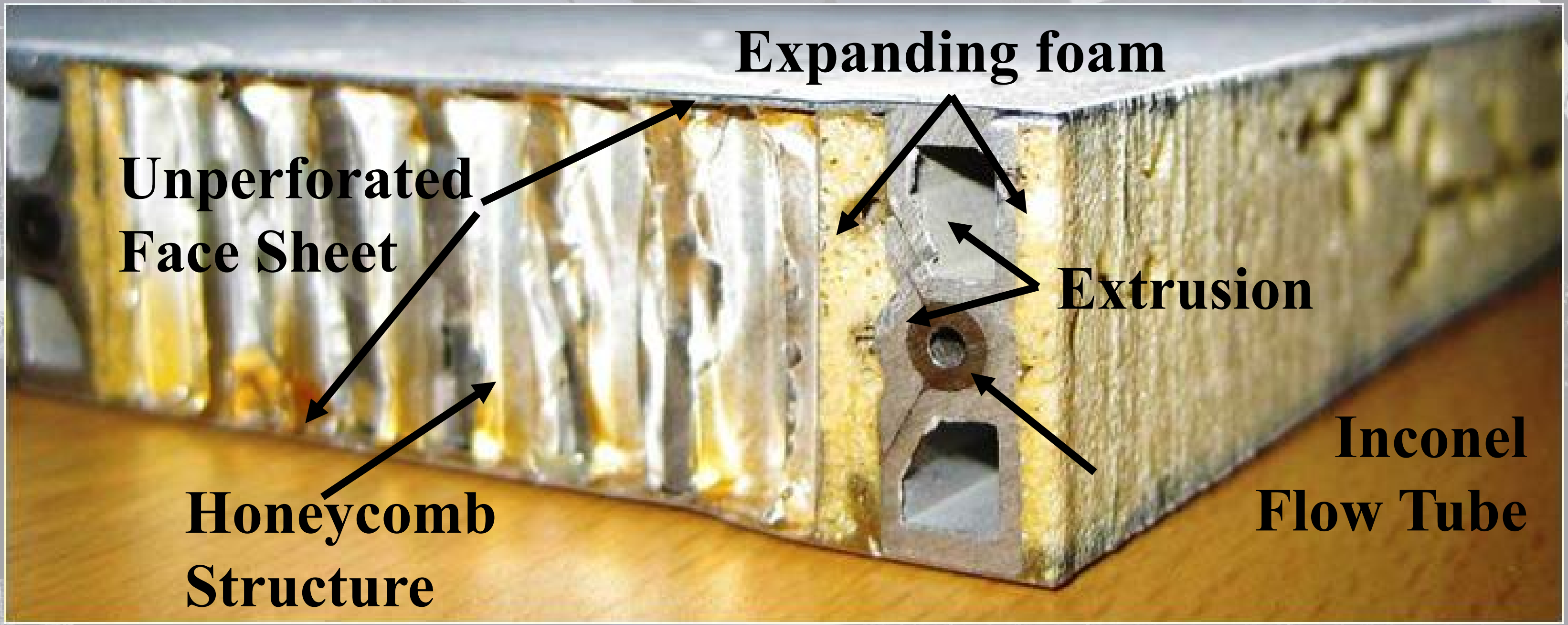
- EATCS rejects heat collected from the ISS Modules to space using radiators.
- Two independent ammonia loops (A-Starboard, B-Port); six radiators total, each with eight panels and two isolated flow paths per radiator.
- Each Loop also contains a pump, accumulator, heat exchangers, a TRRJ for radiator positioning, and RBVM which allows flow paths to be isolate or vented to space.



Simplified Schematic of EATCS Radiator

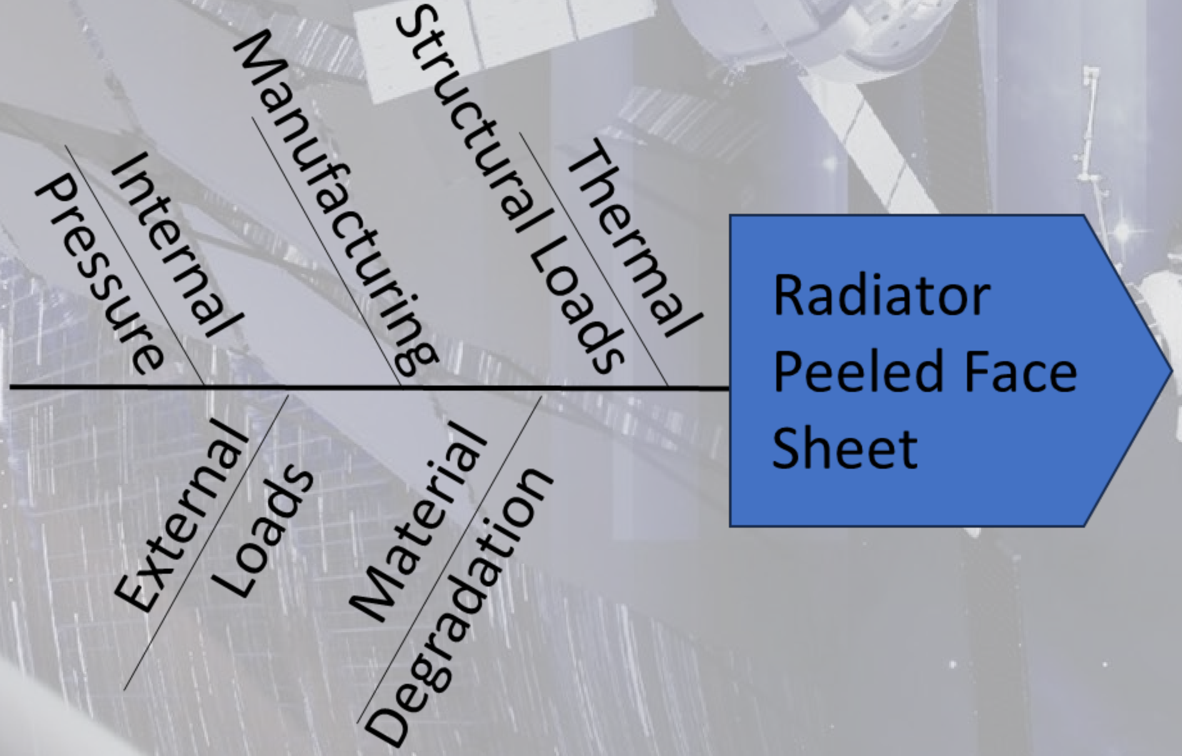
Radiator Panel Construction

- Panel materials: aluminum face sheets + honeycomb core; 22 parallel Inconel flow tubes (11 per path) seated in aluminum extrusions; epoxy/foam bonding; Z93 coating.



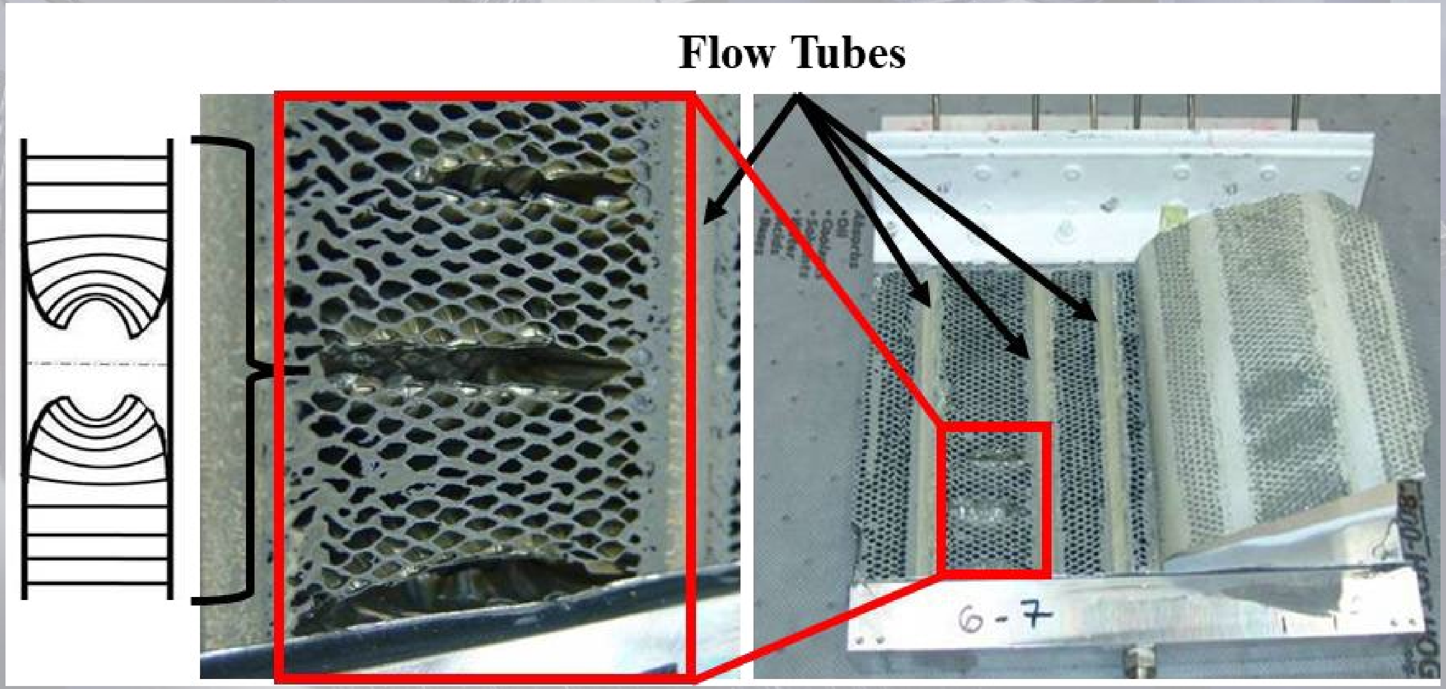
Discovery and Investigation

- Face sheet peel was discovered in 2008 on the Starboard Radiator
- ISS Program decided to vent radiator to prevent additional failures during upcoming dynamic ops
- Cross-disciplinary team developed fault tree and eliminated thermal and external loads as well as material degradation.



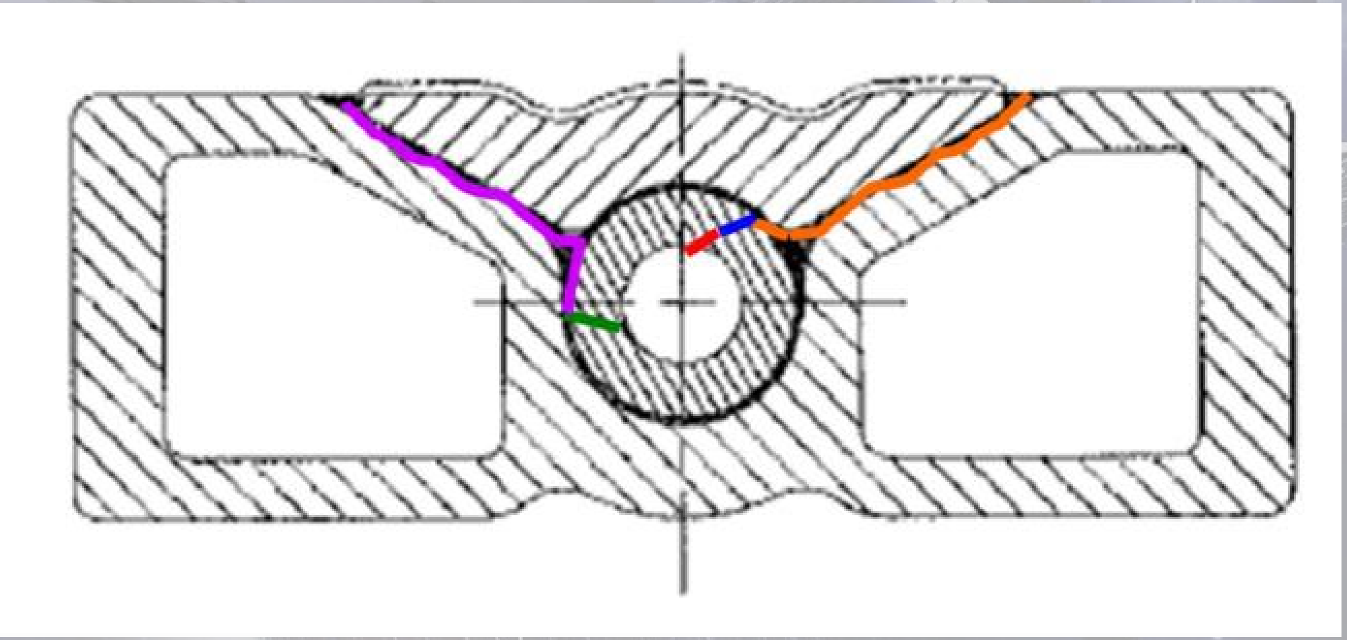
Key Tests

- NDE testing on Qual Radiator- tap-test, x-ray, flash thermography
  - No Delamination
- He leak test on residual tube stock-passed leak test but had small manufacturing flaws in tube wall
  - Extracted tube from Qual radiator also passed leak tests
- Pressurized Panel Section
  - Honeycomb fails before face sheet delaminates



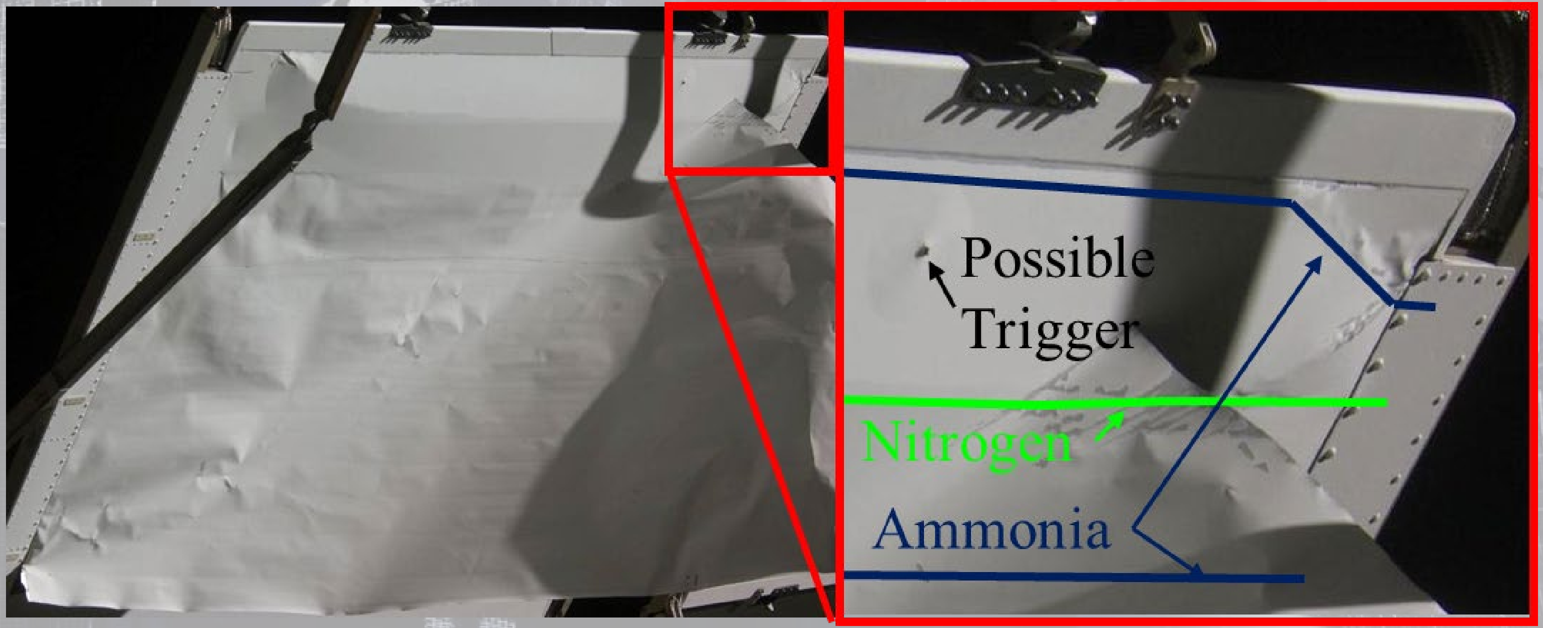
Possible Failure Scenario

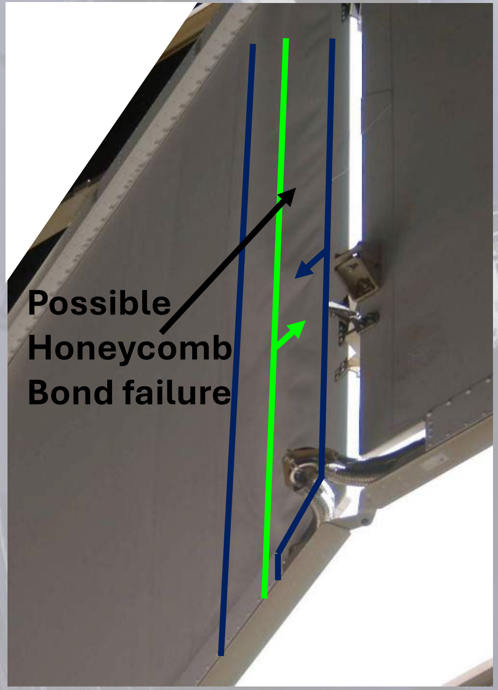
- Leak may have developed from micro-flaw in flow tube which leaked into panel
  - Possible the freeze-thaw cycle exacerbated a flaw
- Radiator had a NH3 and N2 flow path – pressurization could have come from either
- Leak rate too small to be detected by NH3 accumulator
- Only 40% of N2 leaked needed to pressurize panel and cause failure



Triggering the Peel – Two possibilities

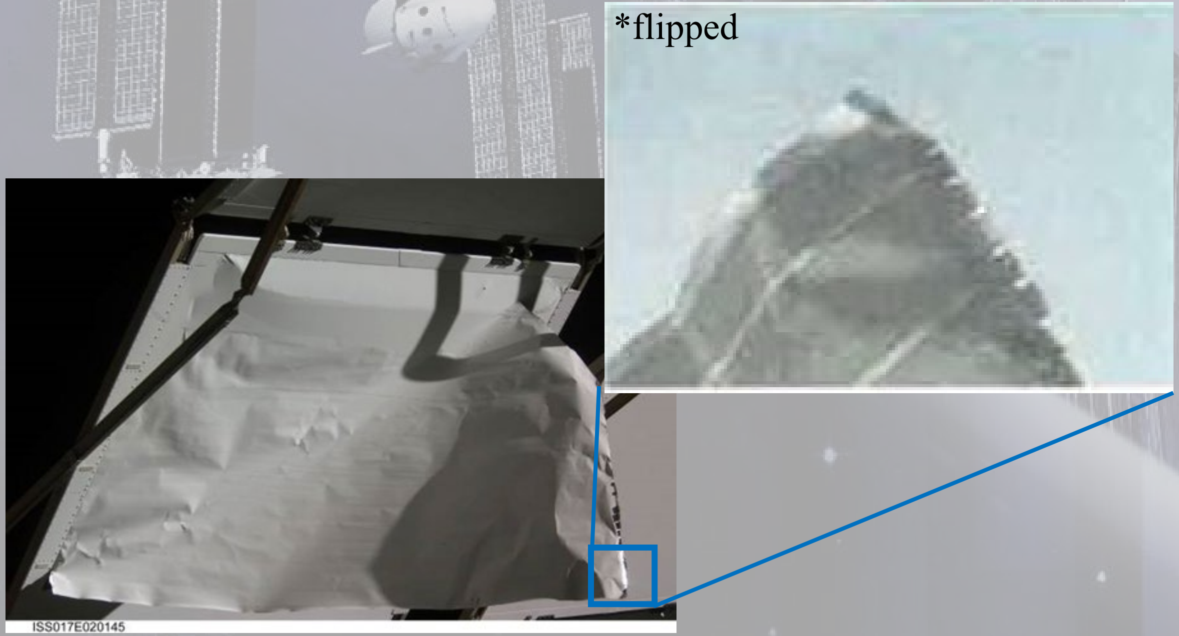
1. MMOD Strike
   - Creates shock in gas pocket
2. Self-Propagating delamination
   - Delamination grows, volume/pressure drops, leak adds gas, pressure rises again

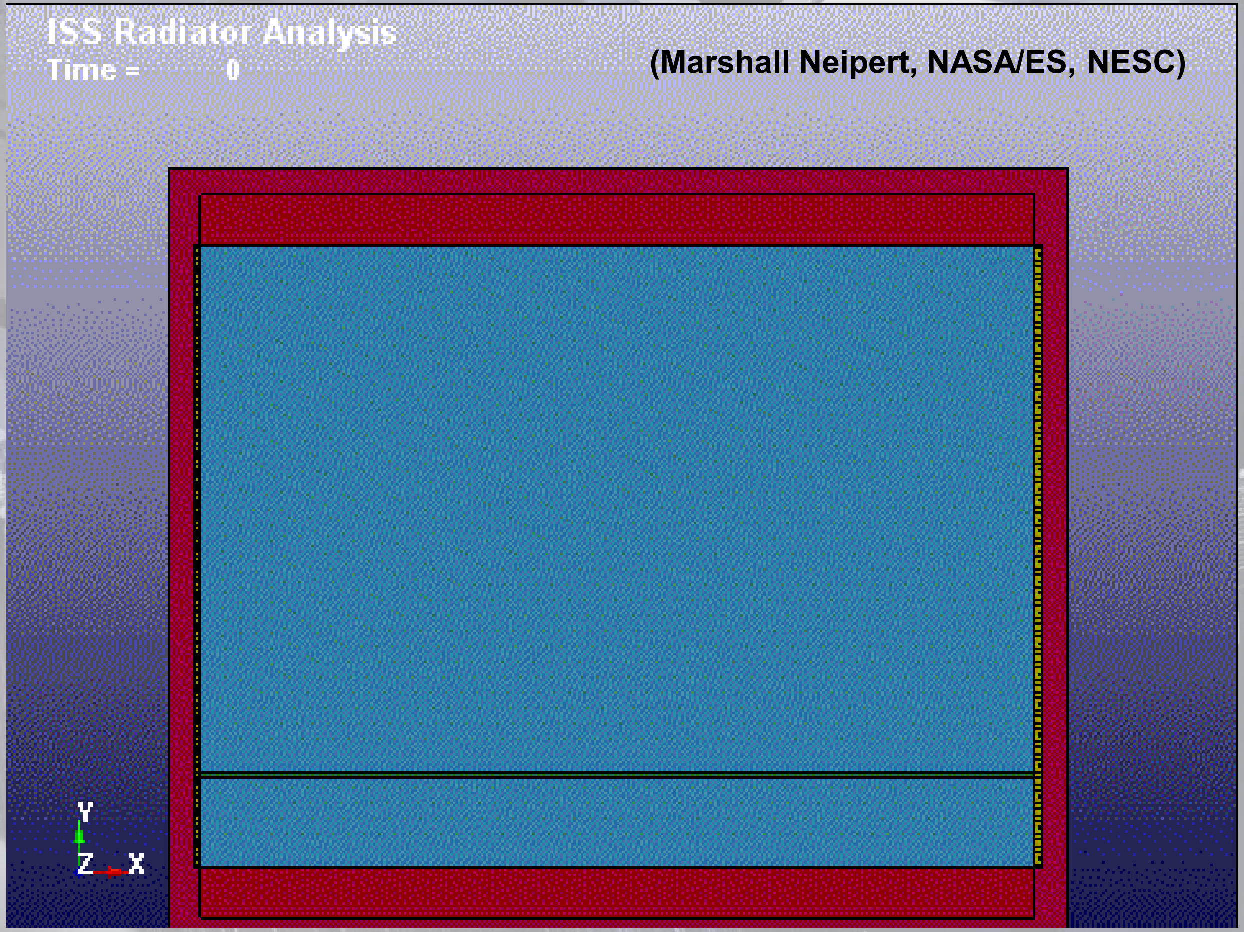




LS-DYNA Correlation (Performed by NESC)

- Dynamic FEA reproduced blow-out, crinkled face sheet, and tearing at the manifold fasteners



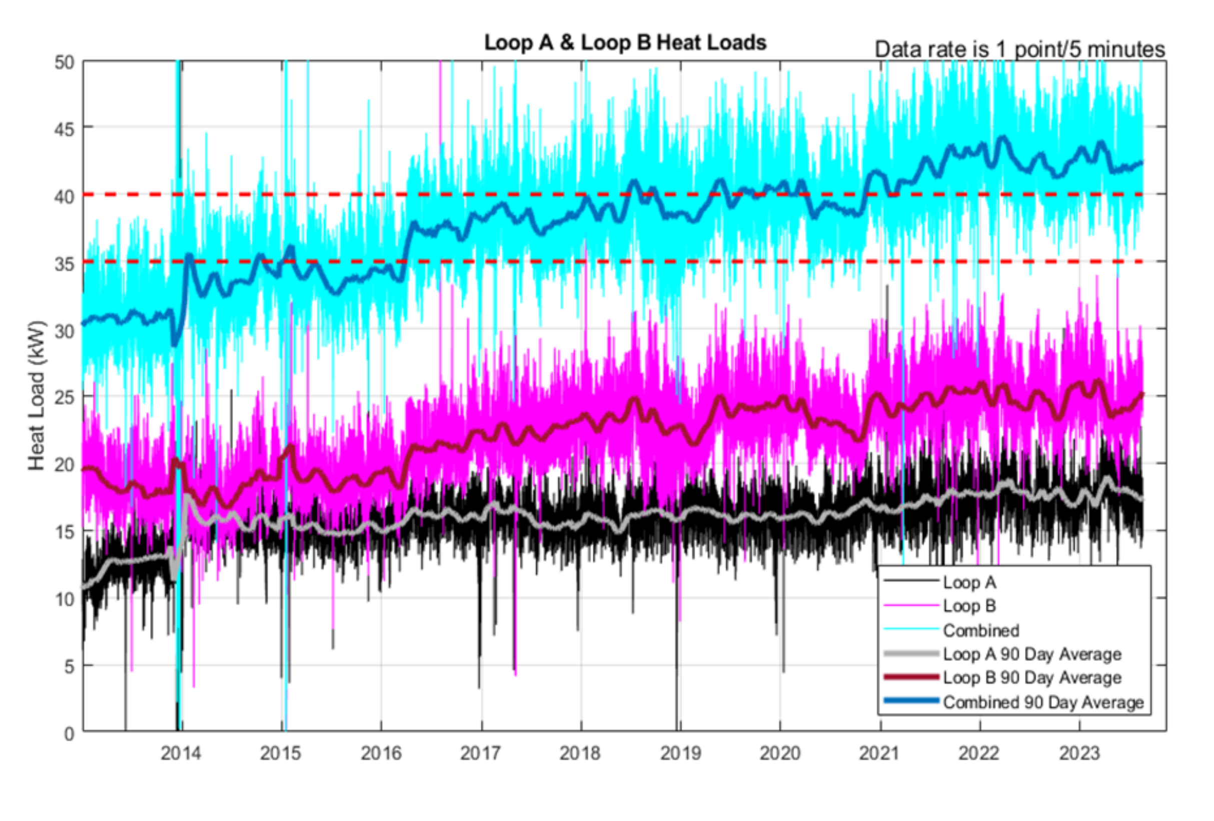


Risk Management and Monitoring (2009-2024)

- Decided to keep radiator deployed as analysis showed radiator would not break and retraction could cause more damage and create debris
- Software was updated to reduce NH_3 loss in the event of a large leak
- Perform periodic imagery of peeled face sheet and showed no change in 15 years
- Trending shows continued small leak in N_2 flow path and a small NH_3 leak INTO the vented flow path through the RBVM

Increasing Heat Rejection Demand

- Since 2010, heat loads have increased
  - Increased number of payloads and new efficiencies to increase utilization
- The loss of this flow path and another on the Port side due to a QD leak left little to no margin
  - Flight Controllers were forced to actively transfer loads from one loop to another or Autotrack the TRRJ
  - Loss of a single loop would force steep cuts to payloads and impact science operations



Use-as-is Rationale

- Radiator, by analysis and inspection, is structurally sound
- No large leak to space in the radiator as shown by a small pressure increase in the NH3 flow path from the leaking RBVM
- Performance impact is minor as only 1 of the 8 panels was affected
- MMOD strikes to panel provide venting of other gas pockets
- Understanding the capability is useful for future planning- is this radiator a viable ORU

2025 Flow Path Refill

- ISS approved filling 1 flow path on each loop including the vented flow path on the damaged radiator to restore full redundancy
- Prior to fill, EATCS Loop was repressurized so that NH3 remained liquid phase after the flow path was re-integrated
- Had to spin down the pump to avoid cavitation during filling but kept the controller energized to minimize risk of damaging controller during start up
- Fill was completed without anomalies and shown good performance since
    - Imagery shows no structural change and operational overhead has decreased

Lessons Learned and Conclusion

- Preventative options:
  1. Perform He leak checks at the tube stock level(~5 miles) to catch micro-leaks
  2. Use perforated honeycomb panels to prevent any pressurization in the panels
- EATCS robustness allowed Loop A to operate at 50% capability for 16 years while investigation took place
- Added flow paths allow for full redundancy of operations and reduces flight-ops burden

Acknowledgements and References

- NASA JSC PTCS, M&P, S&M, ISAG, Boeing ATCS, PTCS, M&P and S&M, NESC, Lockheed Martin.

- Cowan, D., and T. Bond, "Coolant Leak from ISS External Active Thermal Control System (EATCS) – An Examination of Most Probable," (ICES 2022)