TFAWS Active Thermal Paper Session

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The International Space Station (ISS) Port 1 (P1) External Active Thermal Control System (EATCS) Ammonia Leak

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Thermal & Fluids Analysis Workshop
TFAWS 2019
August 26-30, 2019
NASA Langley Research Center
Hampton, VA

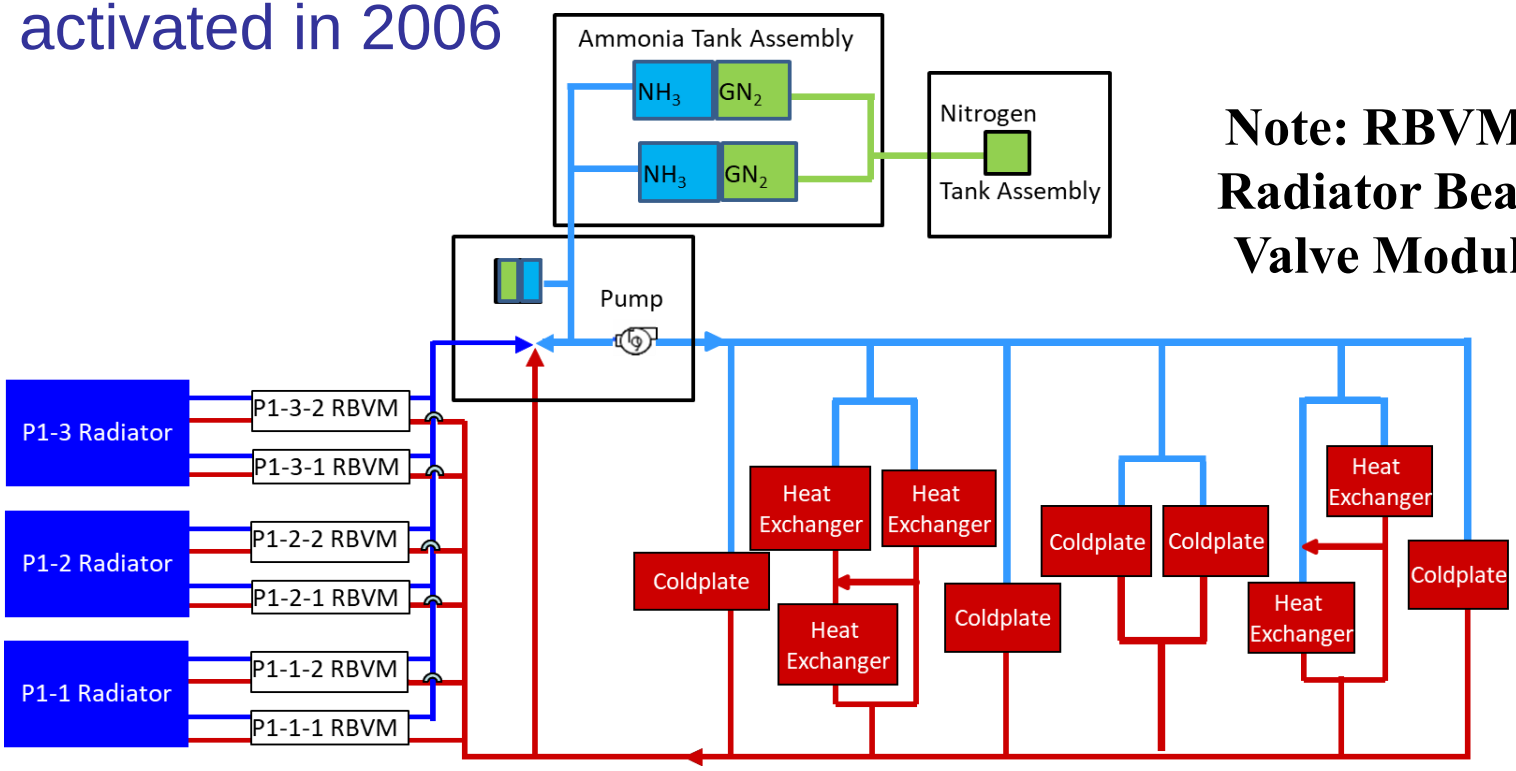
Purpose/Agenda

- **Purpose:** Discuss the ISS P1 EATCS ammonia leak investigation and current findings

- **Agenda:**
  - EATCS 101
  - Houston, We Have A Leak!
  - White Flakes
  - Locating Leaks
  - Root Cause Investigation and TT&E
  - Discussion
  - Conclusion
  - Summary

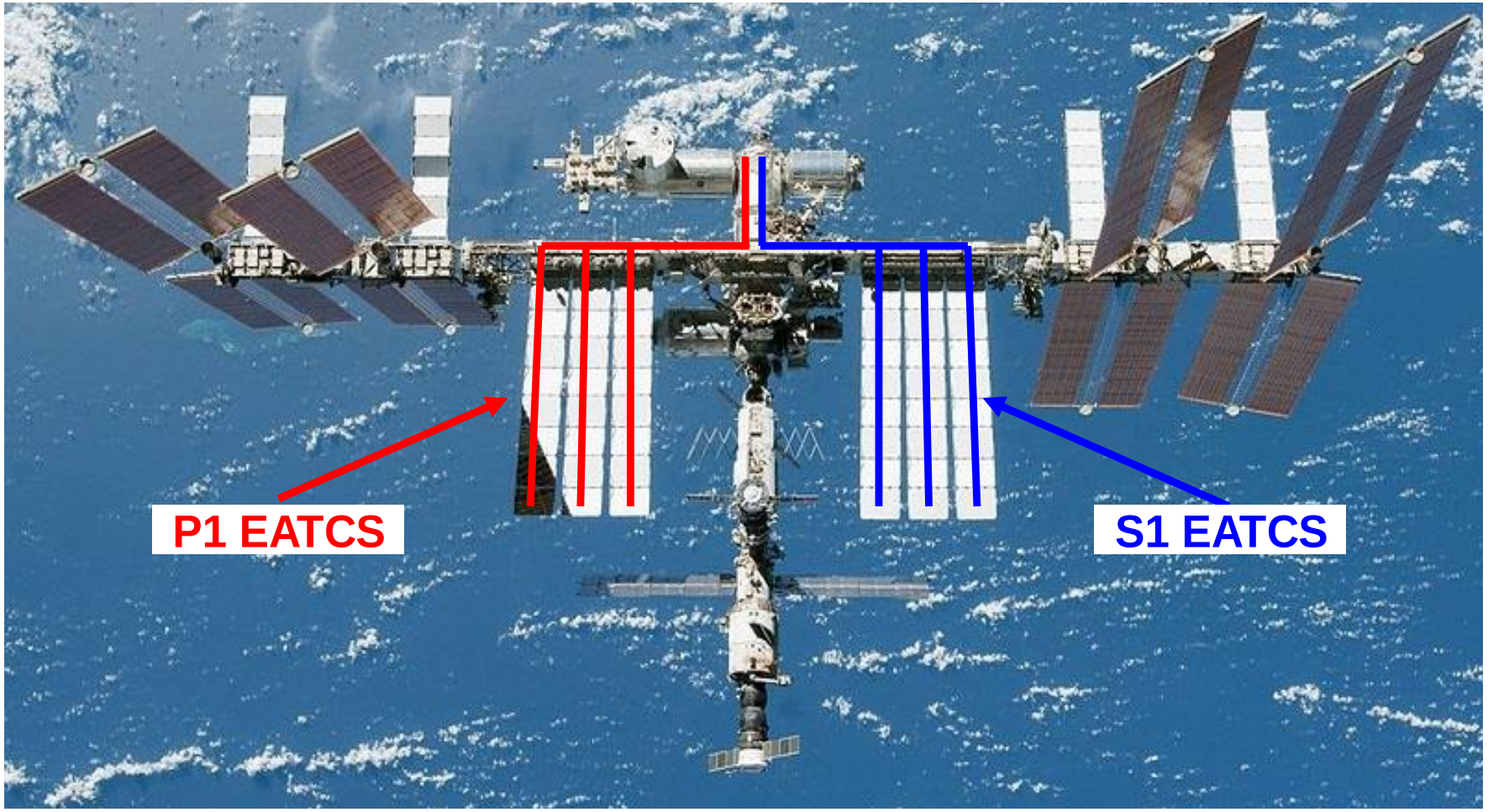
EATCS 101

- EATCS - closed loop single phase system (two redundant loops)
- Mechanically pumps liquid ammonia to cool avionics, payloads and electronic equipment onboard the ISS
- Starboard (S1) and Port (P1) EATCS were launched in 2002, and activated in 2006



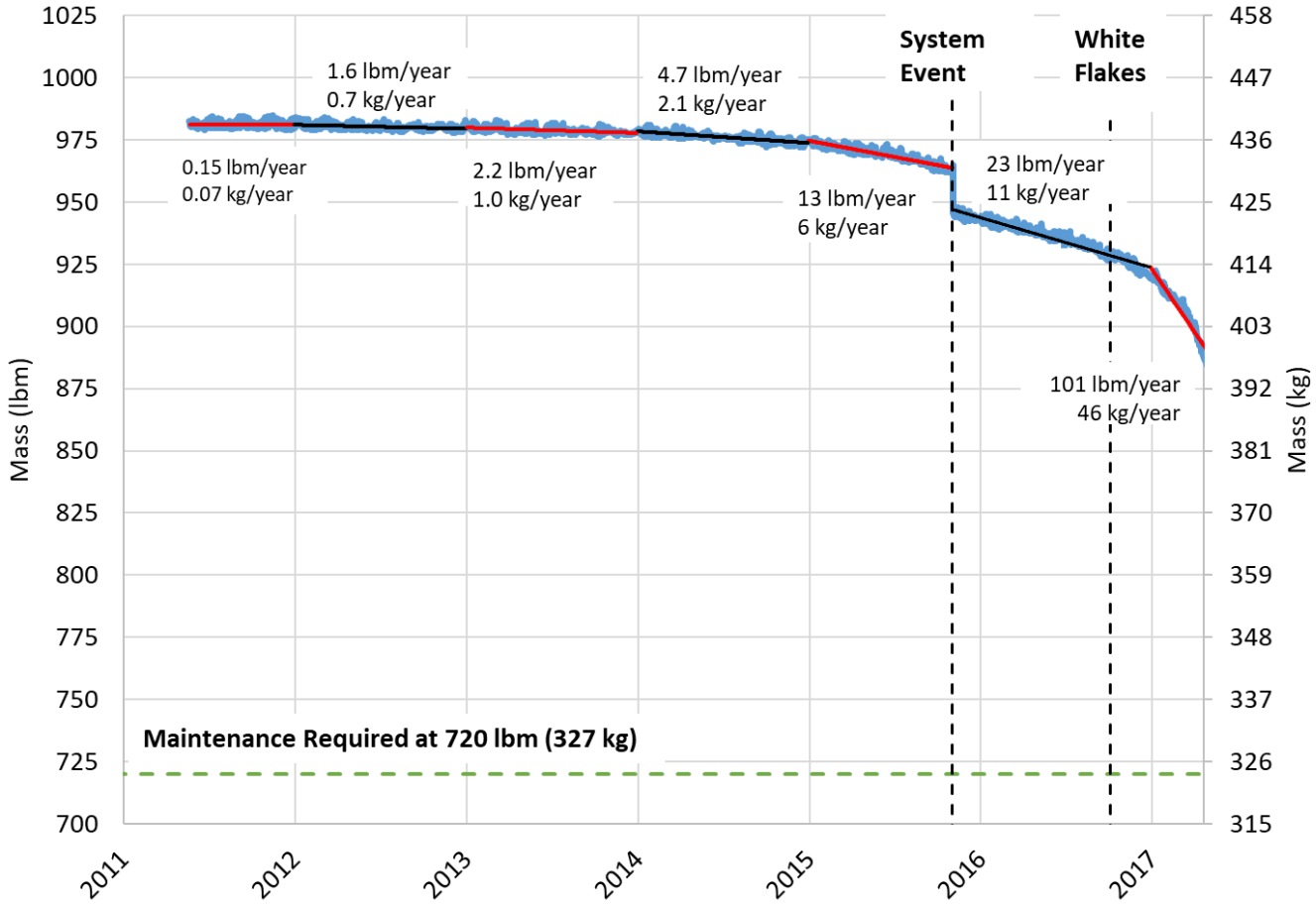
Note: RBVM= Radiator Beam Valve Module

ISS – EATCS Locations



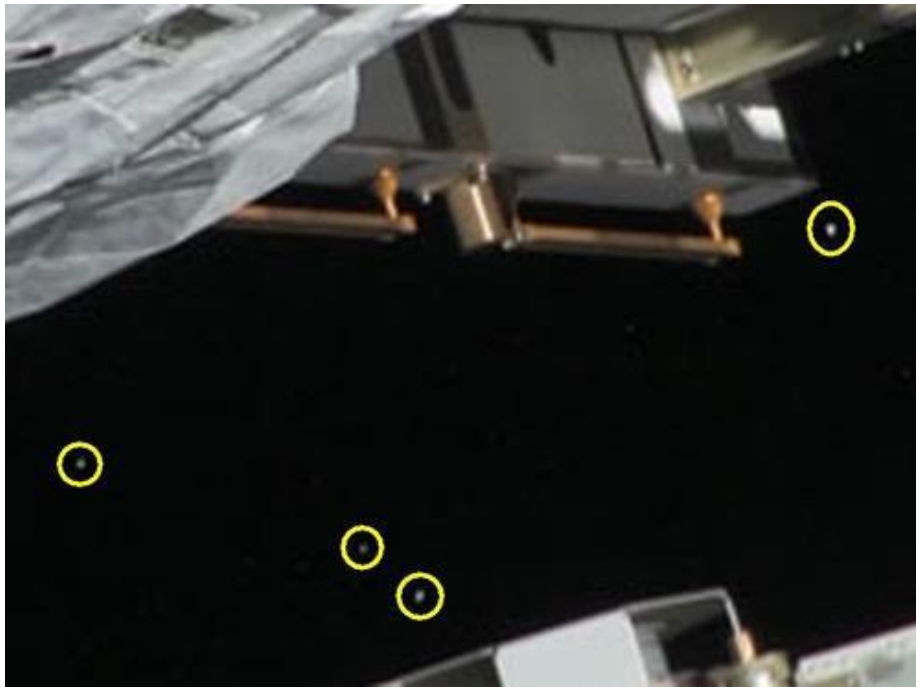
Houston, We Have A Leak!

- The Problem: P1 EATCS -detected a coolant inventory decay in 2012,leak began to accelerate
- Cause/Location: Unknown at the time



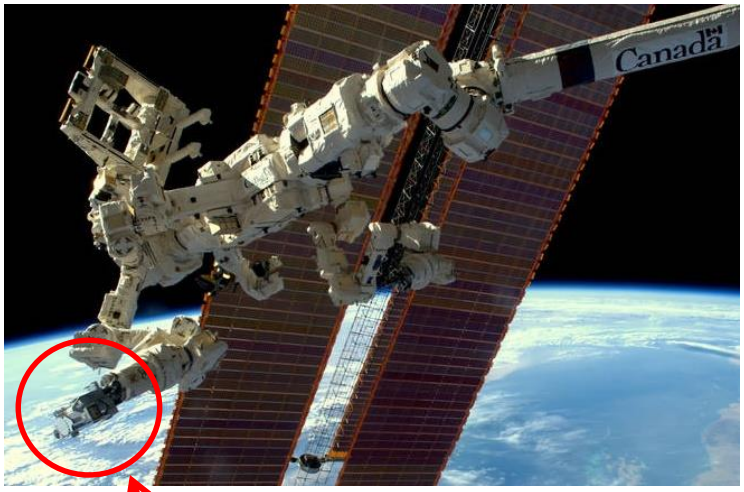
White Flakes

- In early 2016, began observing mysterious “white flakes”, on the P1 external high definition cameras as the leak rate approached 30 lbm/year (13.6 kg/year)
- Uncertain if related to ammonia leak, what else could they be?
- Leaks that produce visible particles or flakes typically thought to be > 50 lbm/day
- Flakes were sporadically seen moving across camera field of view seeming to come from a common location
- Lack of depth perception made it difficult to estimate possible originating locations

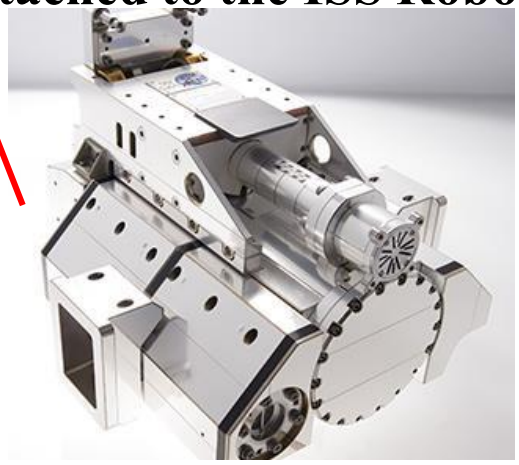


Locating leaks

- Existing techniques to locate a leak was to isolate system into segments and monitor inventory decay
- Cons
  - Shutting down system, time, resources, low chance for success
- Remedy…..the Robotic External Leak Locator (RELL)
- New tool built to work with ISS Robotic Arm
- Remotely detect and ID various gases, and measure their pressures in a vacuum
- Launched in 2015
- Coincidentally, in time to help locate P1 EATCS leak



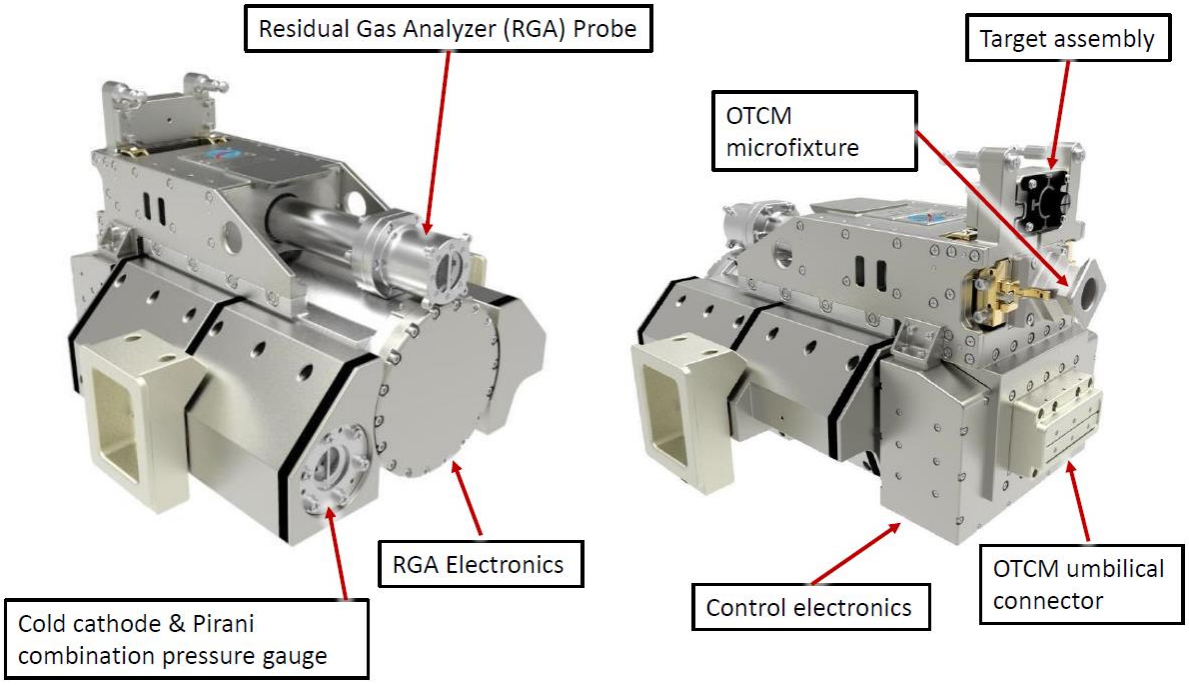
RELL Attached to the ISS Robotic Arm



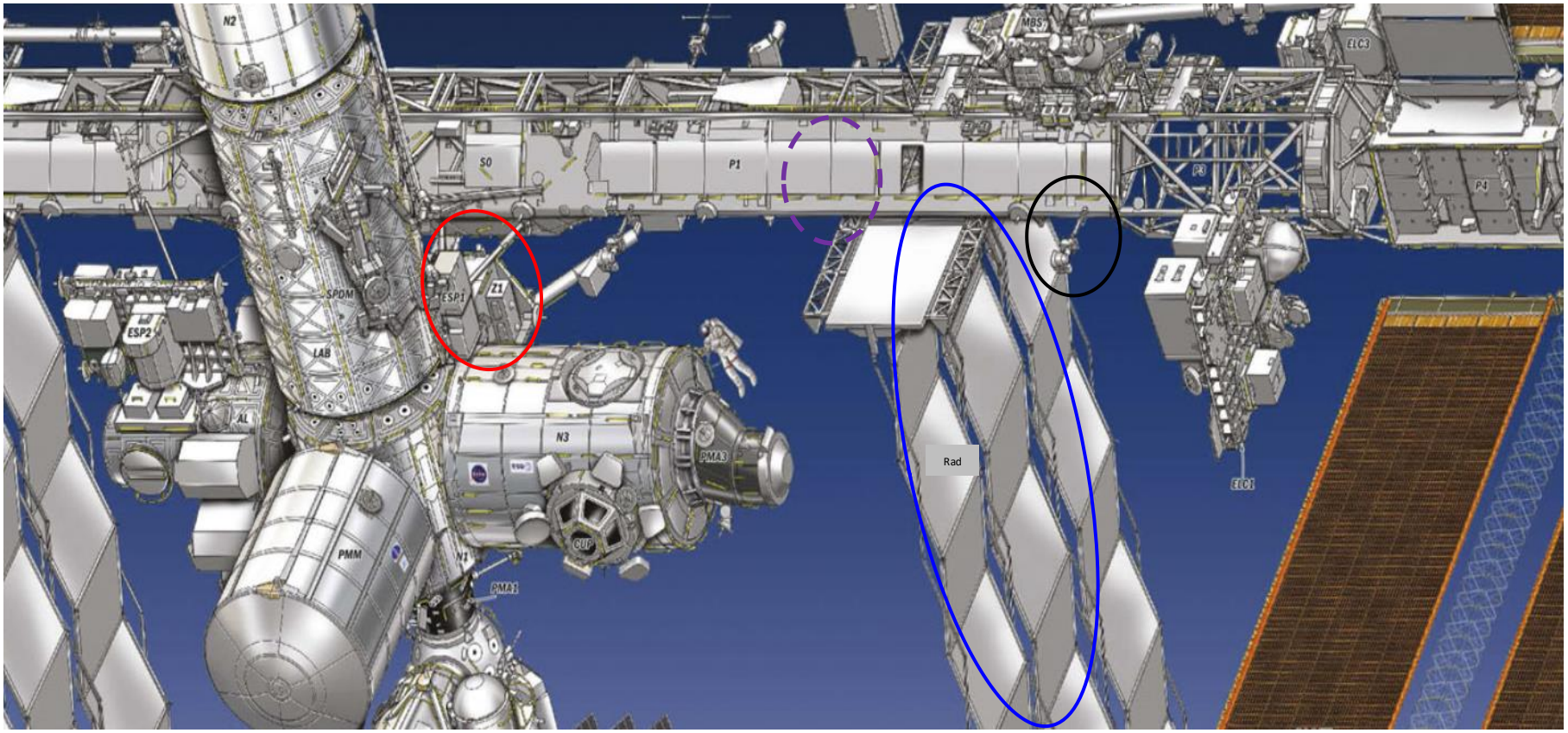
RELL Unit

RELL Capabilities

- Detect molecules up to 100 atomic mass units (amu)
- Measure pressures from standard atmosphere to ~ E^{-12} torr
- Cold Cathode Ion Gauge measures total pressure
- Residual Gas Analyzer (mass spec) measures partial pressure of range of amu
- Pressure measurements are directional in space environment



Possible White Flakes Sources Locations



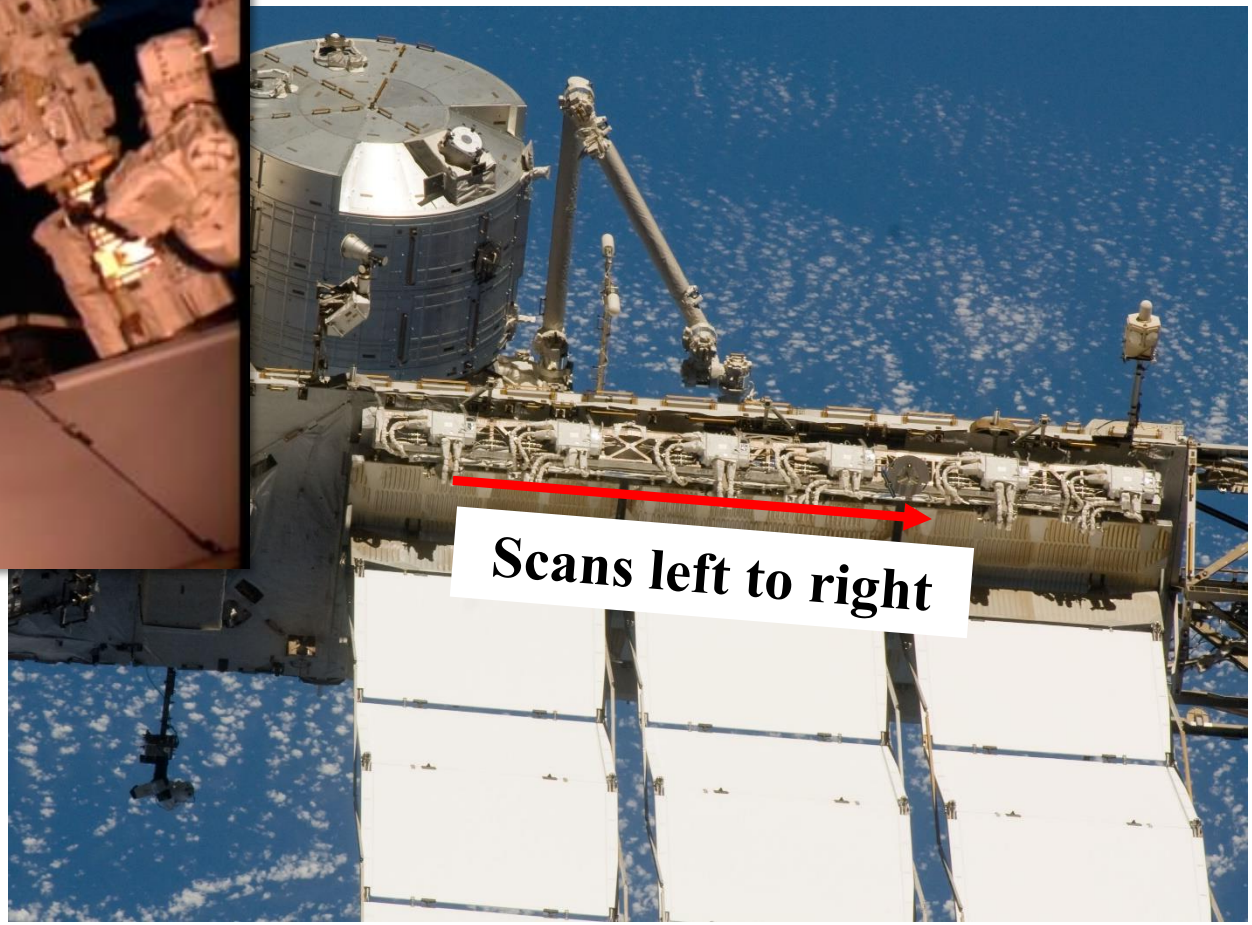
- P1 EATCS Radiators circled in blue, Z1 (decommissioned) and a spare Pump Flow Control Subassembly (PFCS) circled in red, P1 EHDC circled in black, ATA behind structure (dotted purple)

2016 RELL Scans

- Demonstration Scans
  - ISS background (natural atmosphere, ISS vents and outgassing)
    - Pressures measured ~ E-12 to E-8 torr
- P1 EATCS leak and white flake scans
  - Z1, PFCS, ATA
    - No significant ammonia signature present (~ E-8 to E-7 torr)
  - P1 EATCS Radiator Beam Valve Modules (RBVM)
    - Significant ammonia signature pressure

RELL Scan Locations

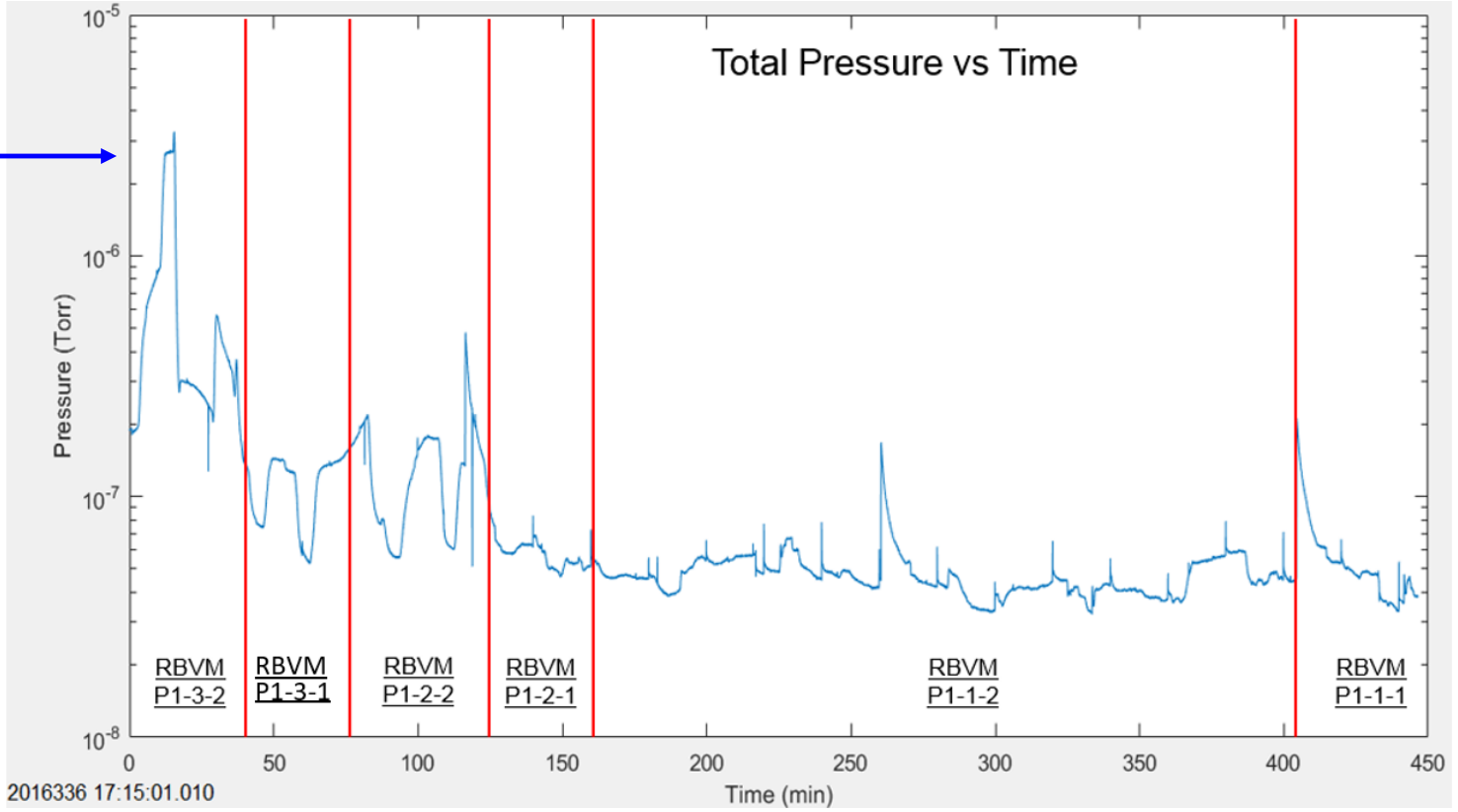
- P1 ISS EATCS Radiator Beam Valve Modules



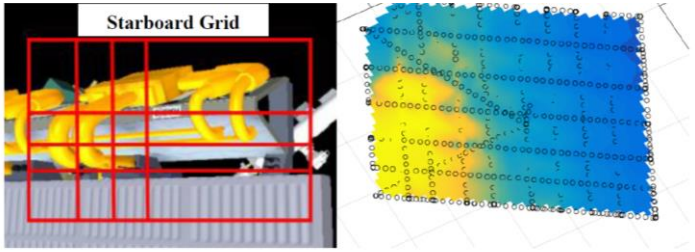
RELL Scans - RBVM

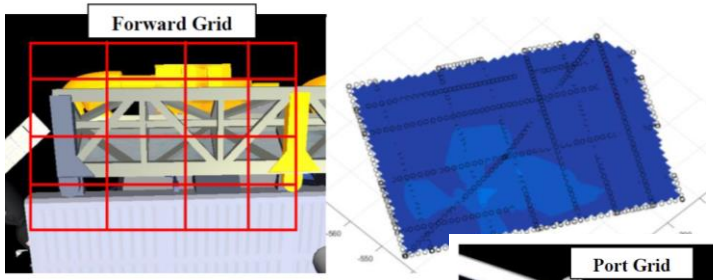
- Noticed total pressure spike at P1-3-2 RBVM on order of ~5E-5 torr
- Low levels of ammonia around other RBVM ~5E-7 torr
- Partial pressure from RGA correlated with ammonia

Scan Direction

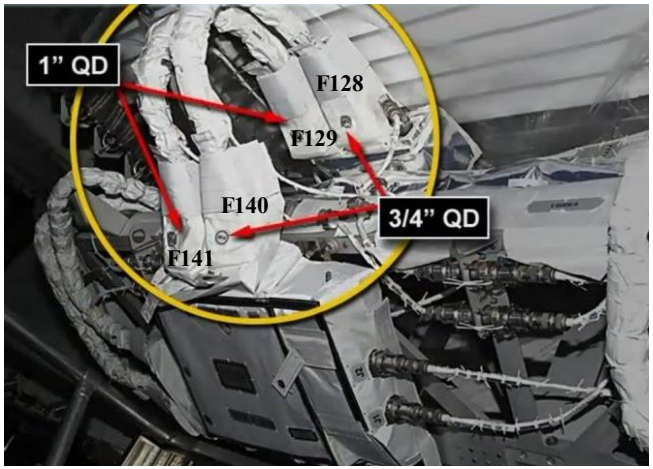


Focused RELL Scans – P1-3-2 RBVM

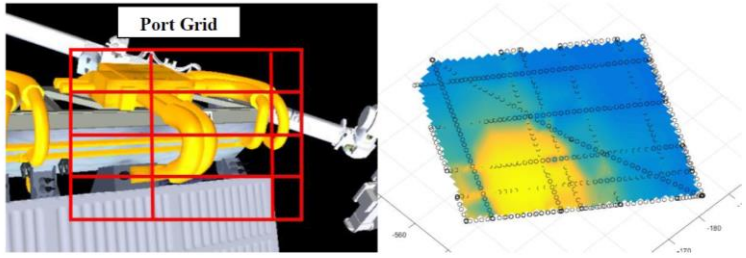


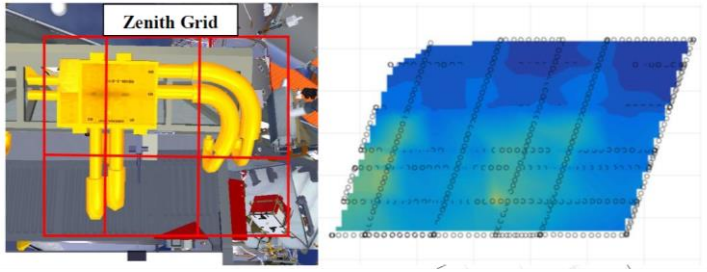


Highest Pressures @ P1-3-2 RBVM to the radiator jumper hoses, and the hard lines underneath



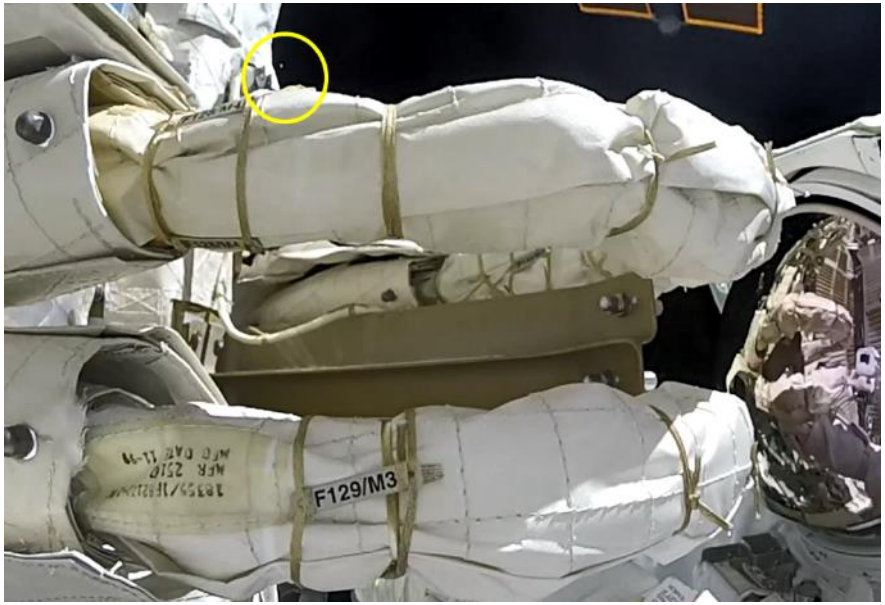
Pressures E-5 torr ~ 50 lbm/year (22.6 kg/year)

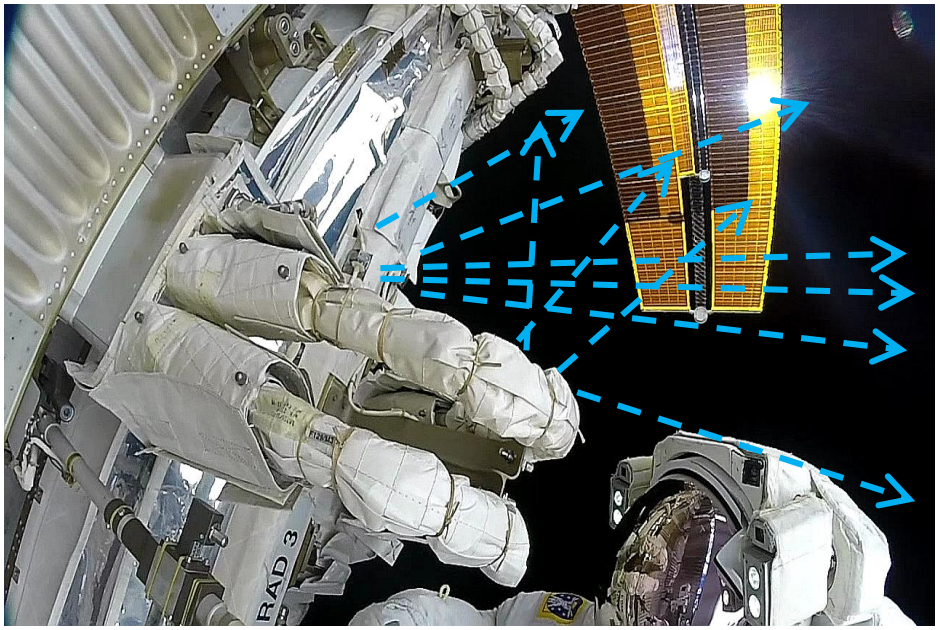




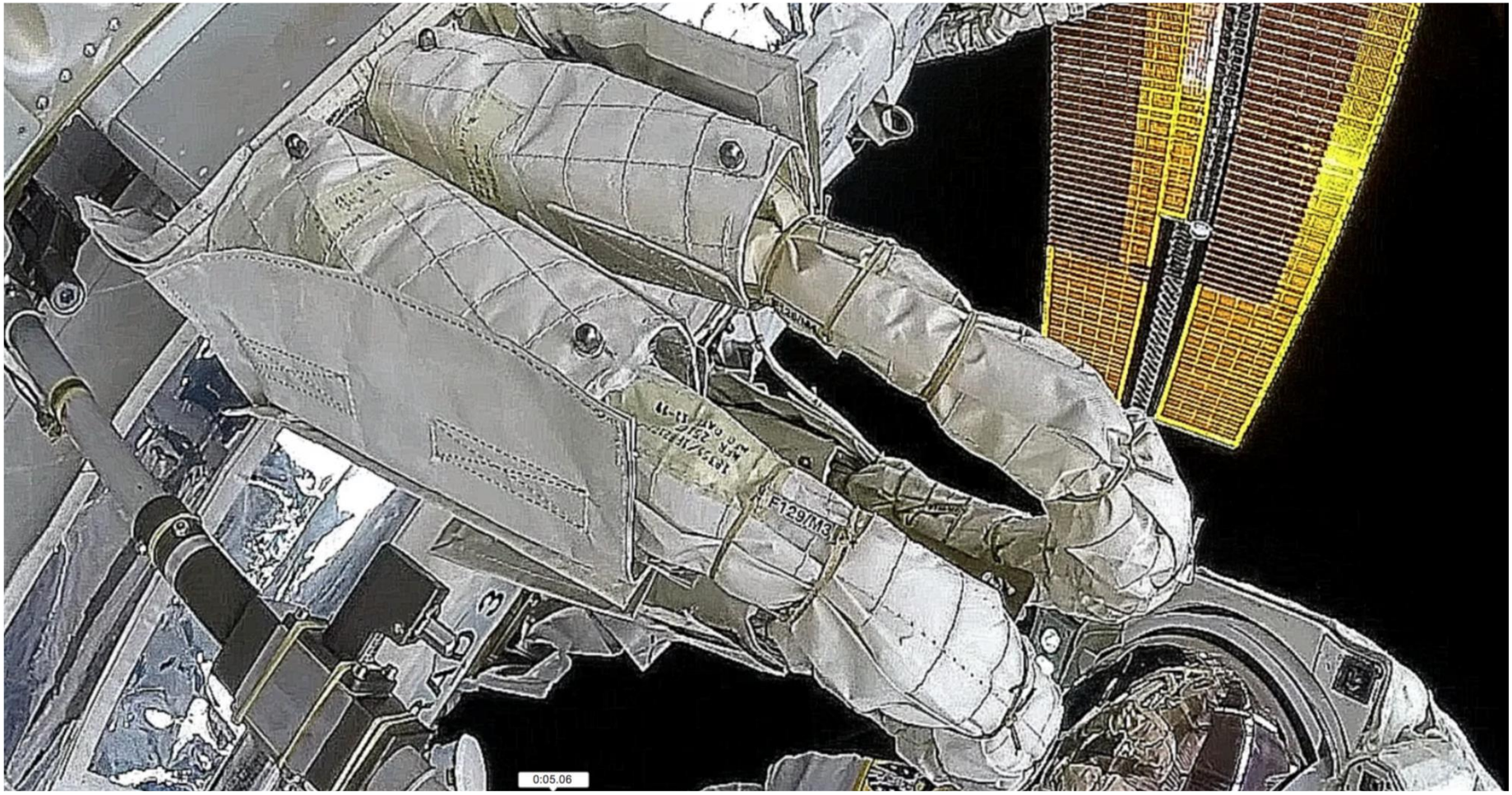
Extravehicular Activity (EVA) Jumper Inspection

- Inspections of the RBVM jumpers hoses and system lines performed during an EVA in March 2017
- Nothing noteworthy observed from the crew
- Post EVA review, multiple white flakes seen from EVA GoPro video

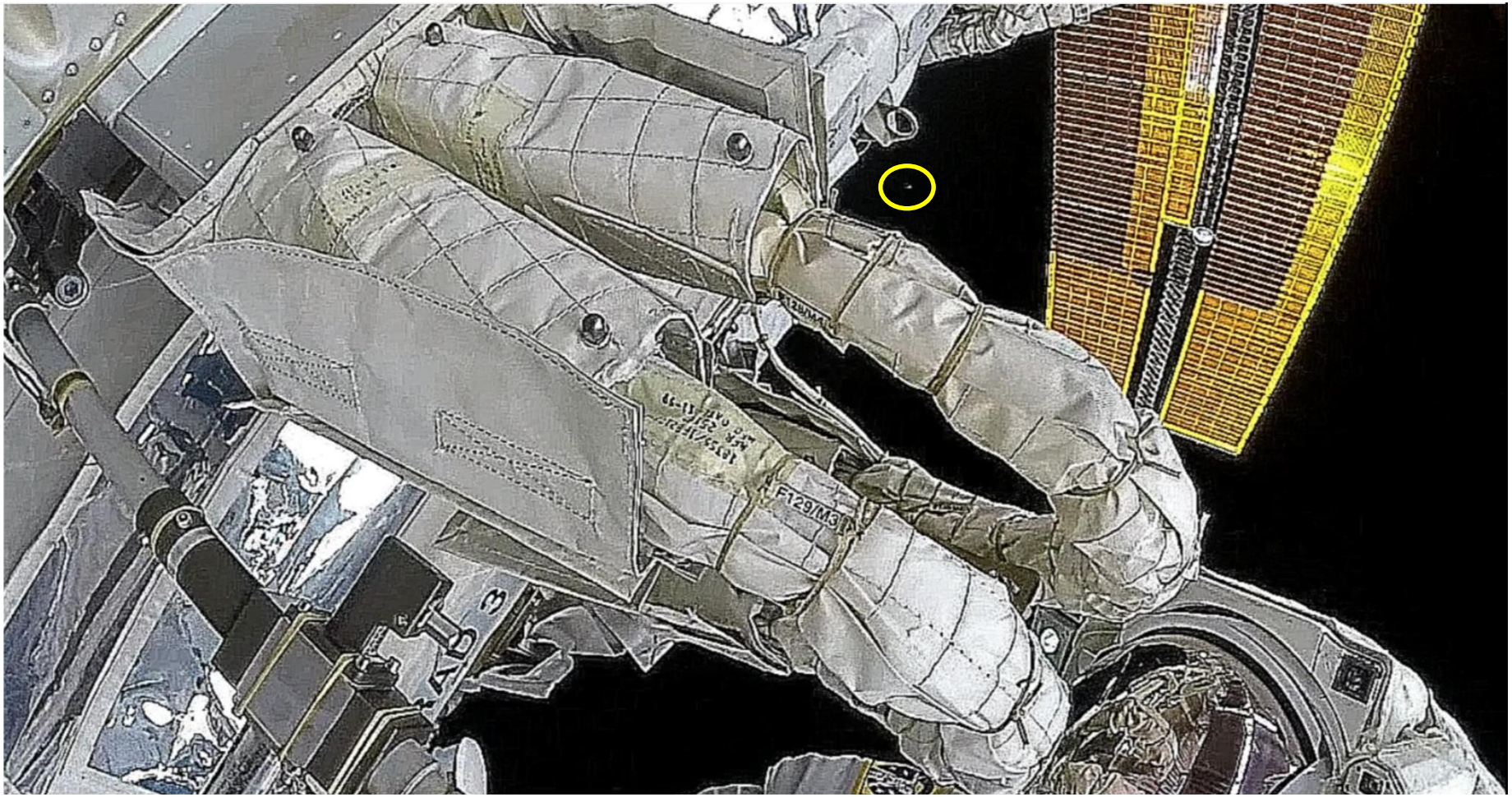




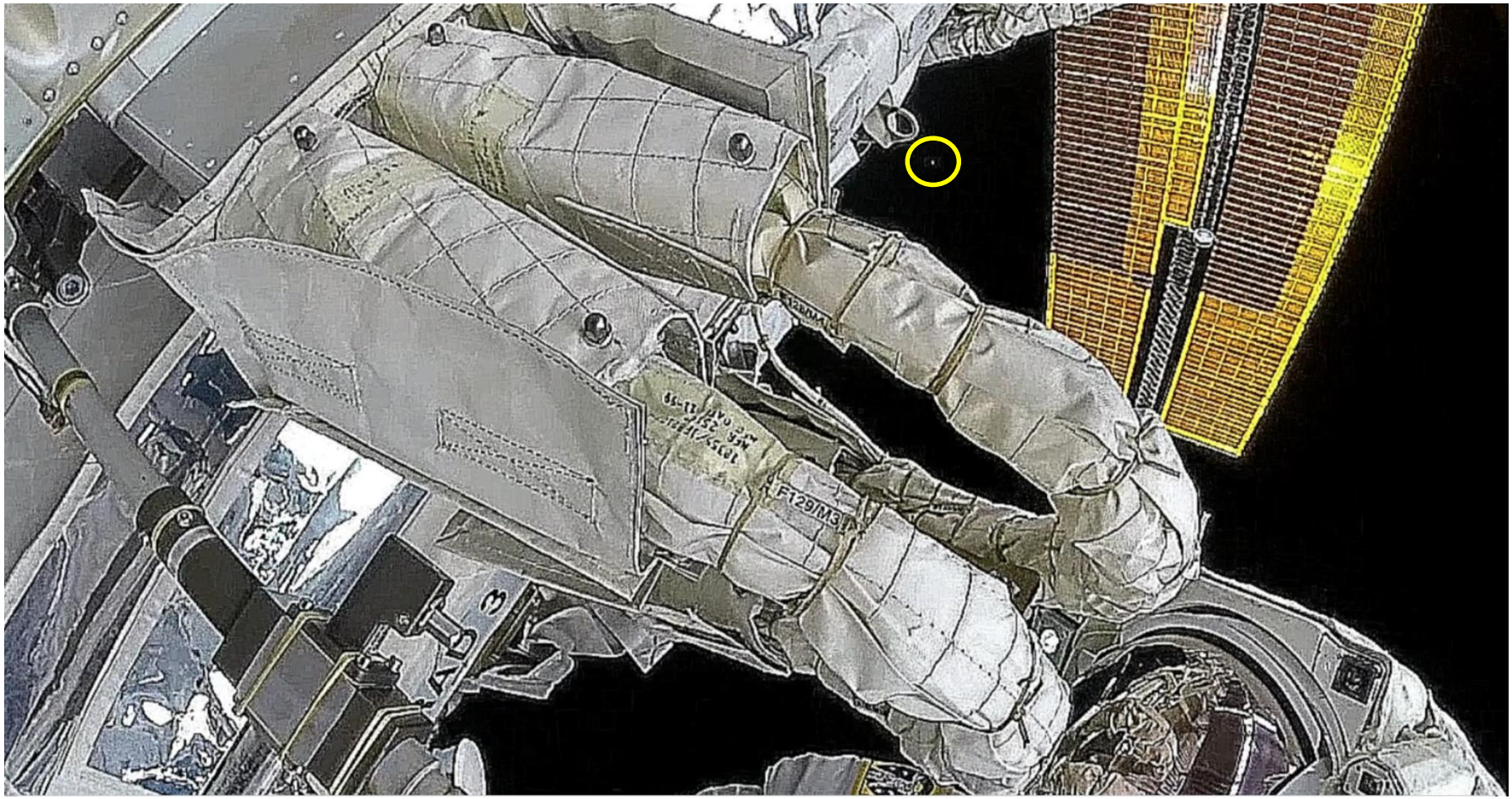
EVA Go Pro Video – Still Image



EVA Go Pro Video – Still Image

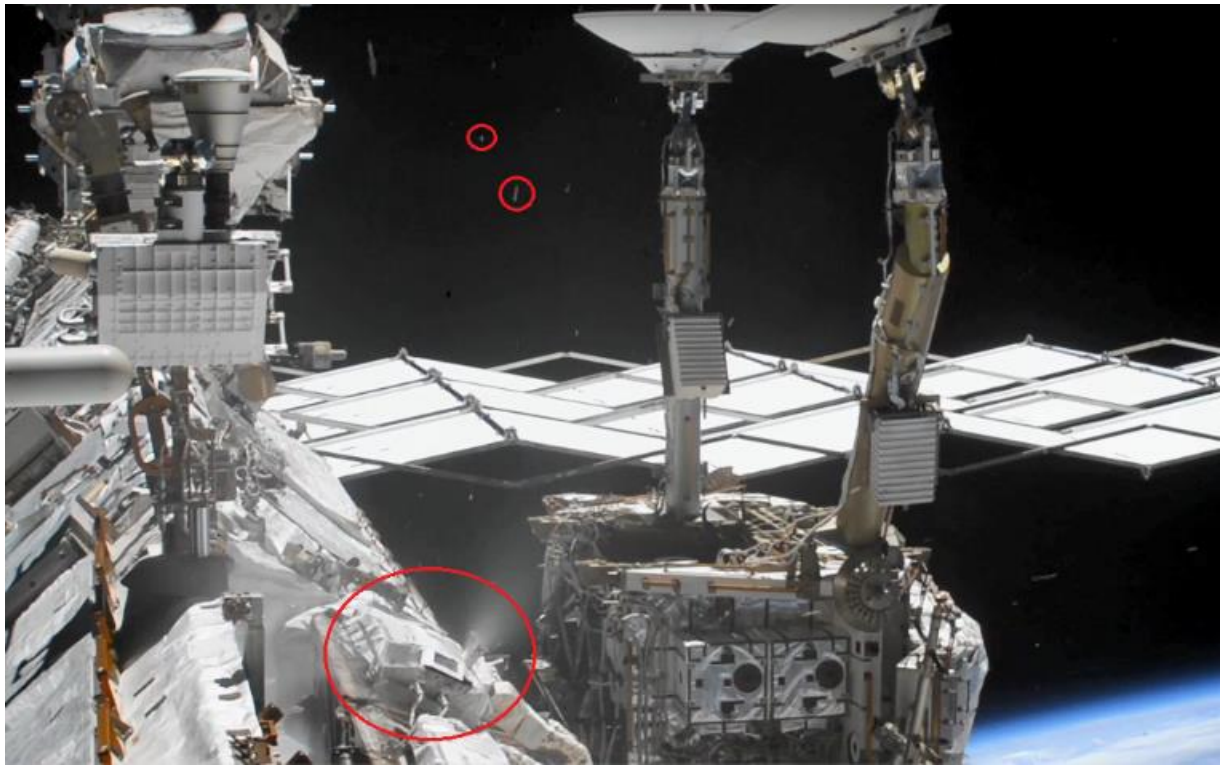


EVA Go Pro Video – Still Image

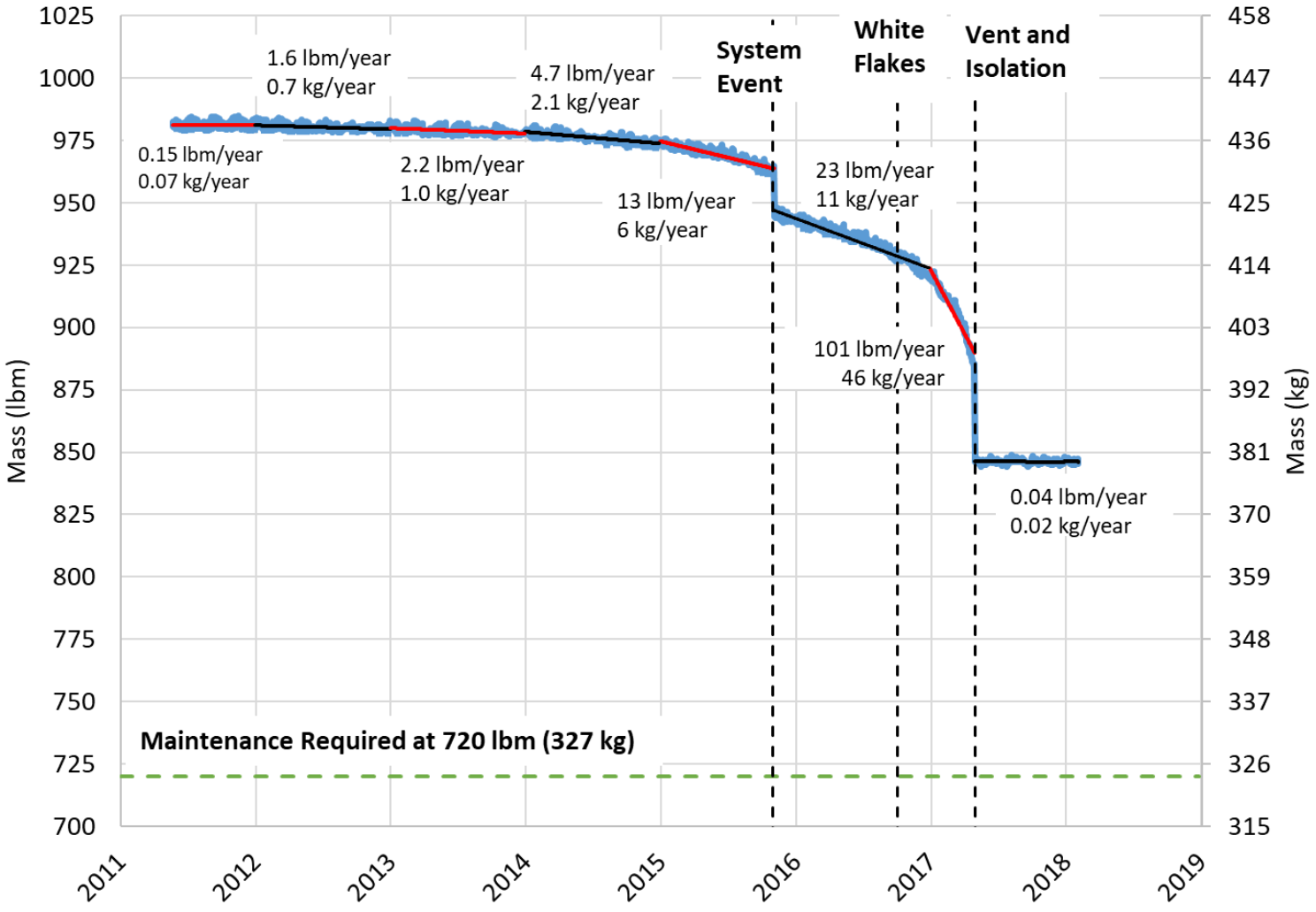


Leak Stopped

- Following the EVA in May 2017, ground command remotely closed the RBVM to the P1-3 radiator; isolating that flow path
- Ammonia was vented to space, stopping the leak
- White flakes have not been observed since and subsequent mass plots show the leak stopped

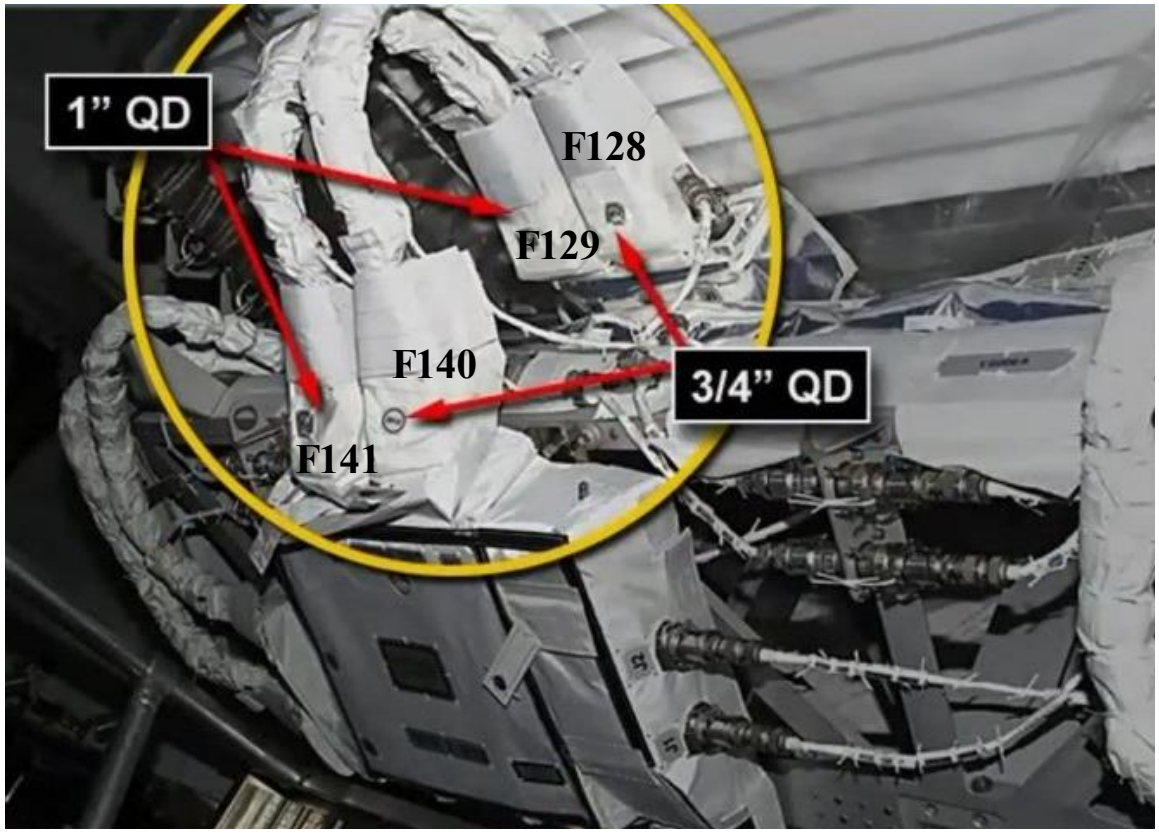


Leak Stopped



Root Cause investigation

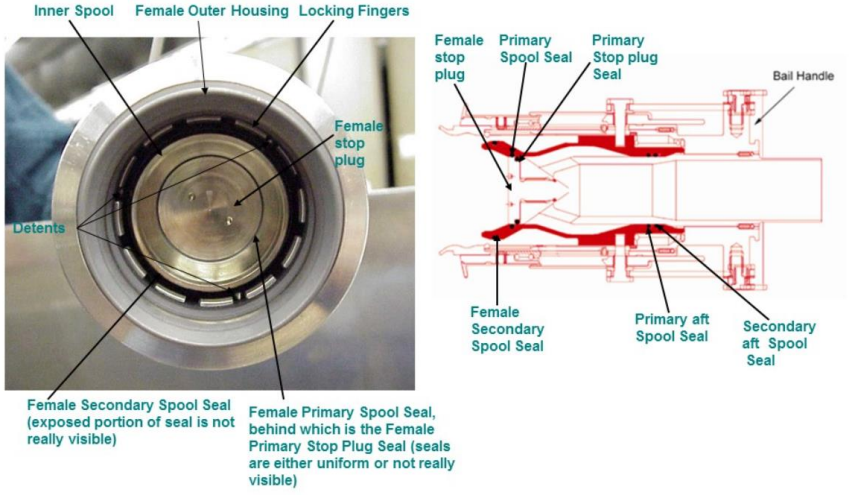
- Most likely leak source - RBVM jumper hoses rather than the hard lines underneath them
- ISS Program agreed to remove the RBVM hoses and returned them to the ground for investigation
- Hoses removed during an EVA in March 2018, and return to the ground in May 2018

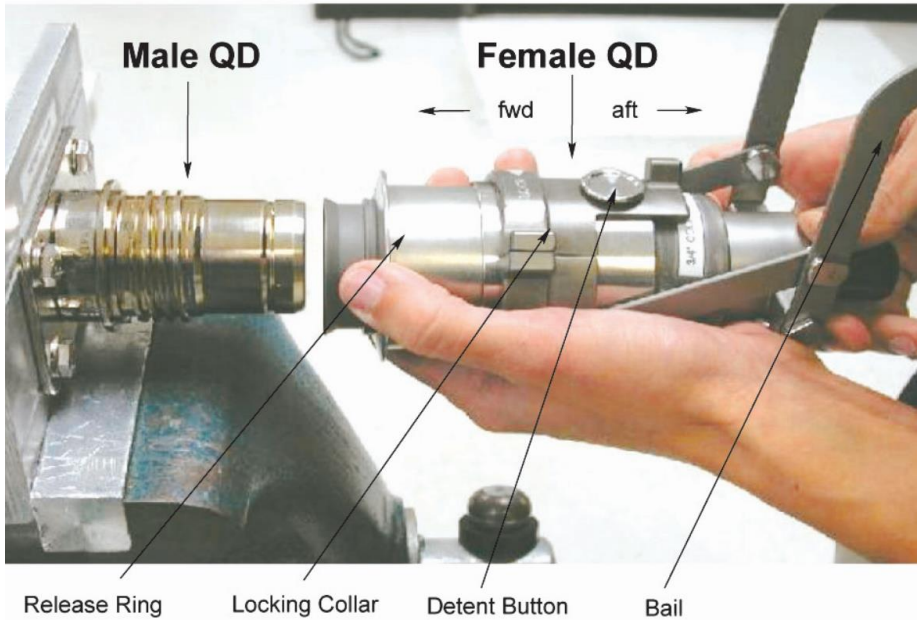


TT&E-Jumper Hose Assembly Overview

- 1” supply and 3/4th return hose
- Each hose contains two female Quick Disconnects (QD)
- Each QD contains multiple seals
- Some seals are not visible without significant QD disassembly

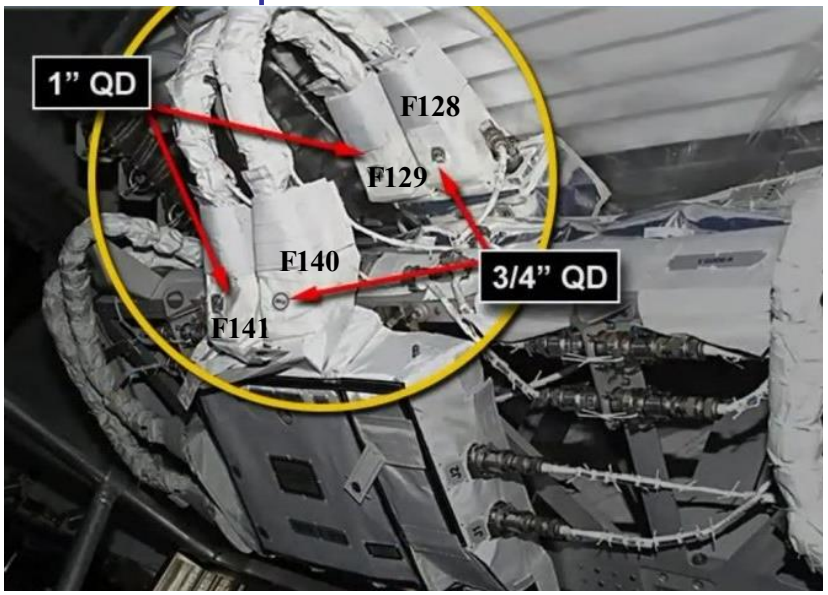
Female QD



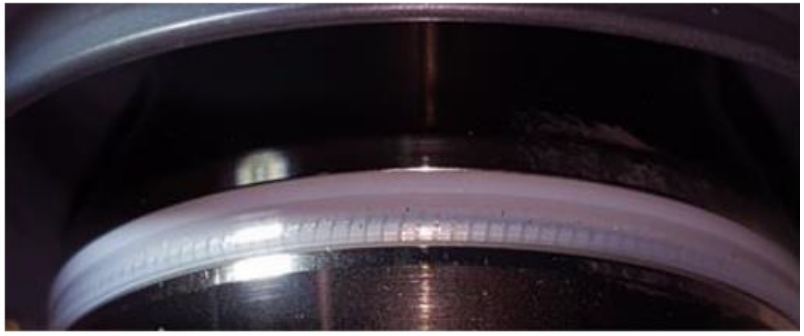


TT&E - 1” Supply Hose

- Inspection shows the 1” supply hose looked good
- Barely failed Leakage requirement of 1 E-4 sccs of Helium at 500 psia (3447 kPa)
- Considered acceptable to be reused “as is”, and returned to the ISS in April 2019



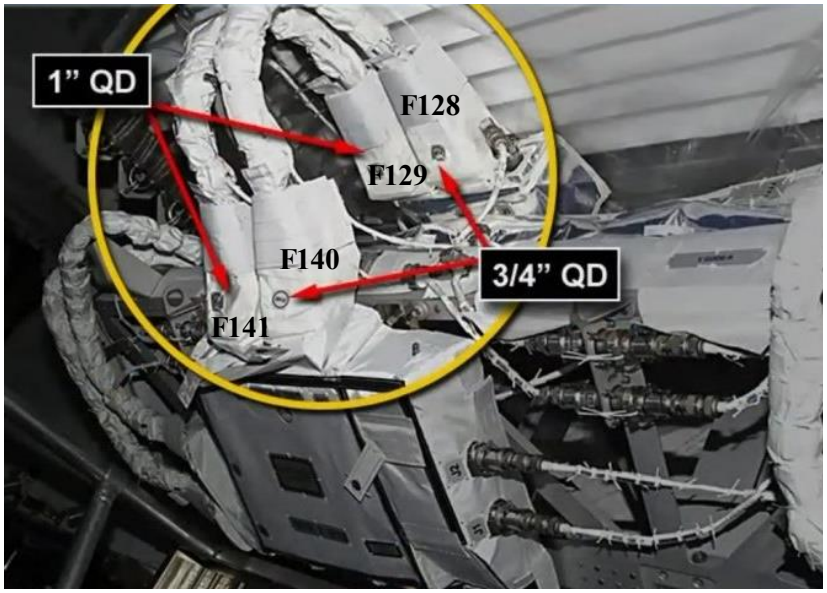
F141 QD secondary seal



F129 QD secondary seal

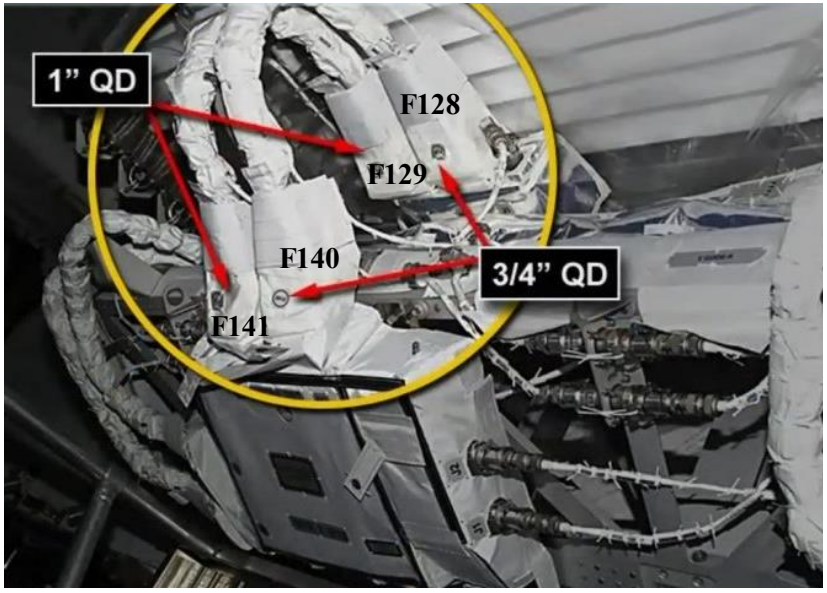
TT&E - 3/4” Return Hose

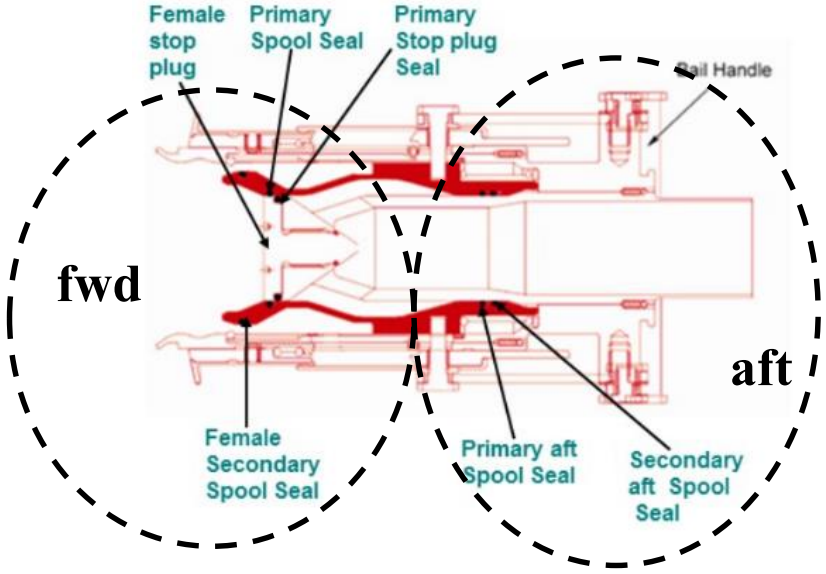
- The 3/4” return hose – not so good
- QD F140 failed the leakage requirement at 2.8E^{-3} sccs of Helium at 500psia (3447 kPa)
- QD F128 failed the leakage requirement at 1.91 sccs of Helium at 500 psia (3447 kPa)



TT&E - 3/4” Supply Hose Additional Leak Test

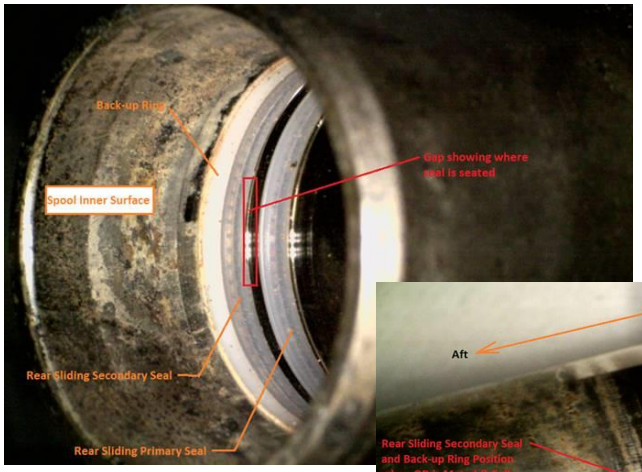
- Forward half QD F128 failed the leakage requirement at 2.2E-1 sccs of Helium at 500 psia (3447 kPa)
- Aft half failed at 0.5 sccs of Helium @ 500 psia (3447 kPa)
- QDs removed for additional TT&E
- New QDs installed, hose assembly launched to the ISS in April 2019



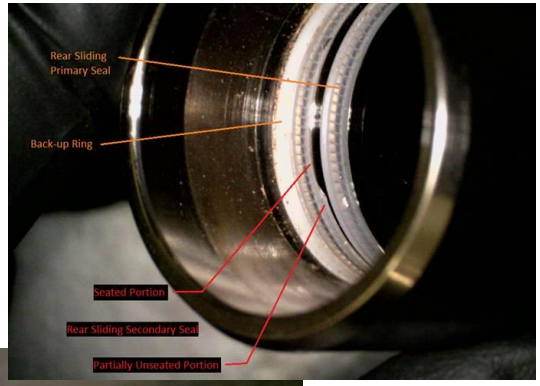


TT&E - QD F128 & F140 Disassembly

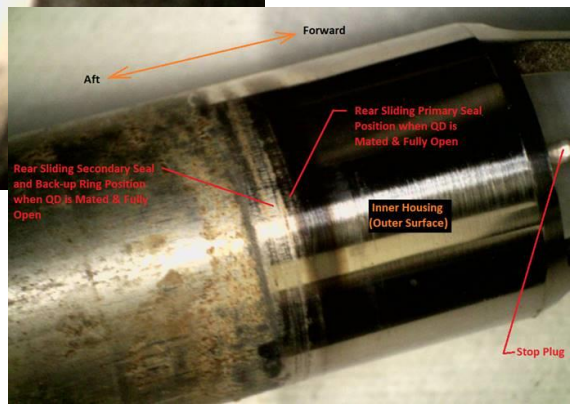
- Appears aft spool seals of QD F128 were responsible for the majority of the P1 EATCS leak
- Further analysis of the deposits and examination of surfaces is planned in the near future



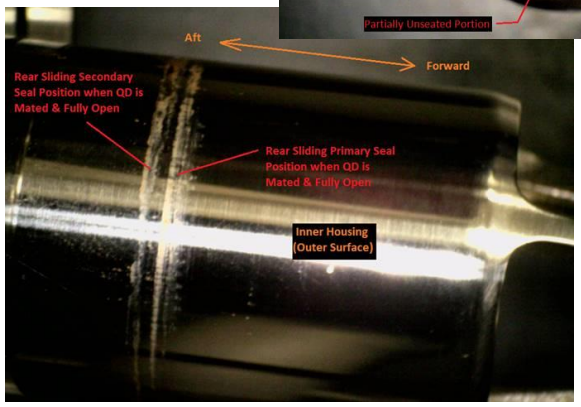
QD F128 Spool



QD F140 Spool

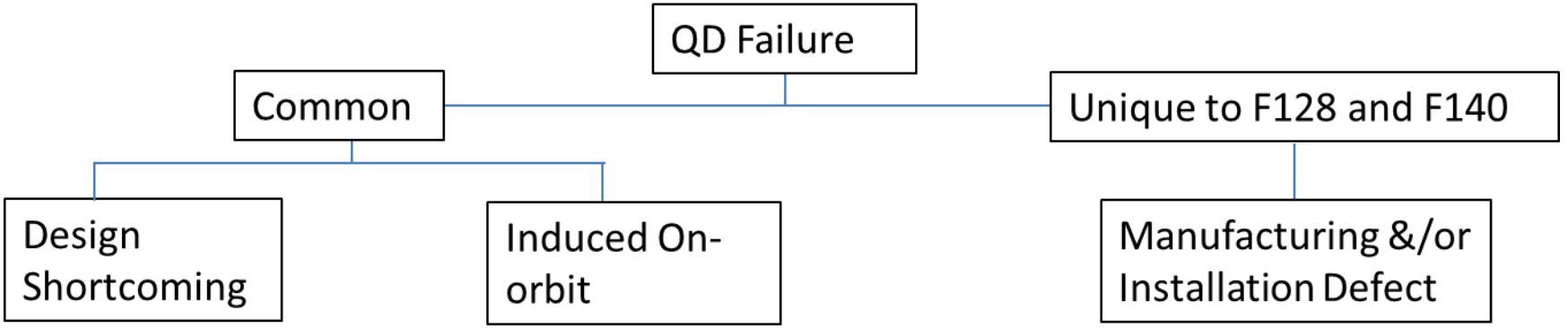


QD F128 Inner Housing



QD F140 Inner Housing

Discussion



- 200 QDs per EATCS, and 36 are the ¾ “ hose
- All RBVM-to-radiator hoses exposed to similar thermal environments
- No other significant leaks observed to date
- GN2 filled radiator flow paths is slowly leaking (5E-3 sccs He) overboard
- All QD seals are made of the same material
- Seals leak worse while exposed to cold temperatures
- F128 QD, leaky QD, failed the leak test on the ground before launch but seals were replaced
- No leaks were detected for 4 years after activation
- EATCS were filled on-orbit, and the ammonia chemistry could not be evaluated

Conclusion

- The results of the QD F128 failure investigation should help address the following:
  - Unique or common failure
  - Male QD counterpart compromised?
  - Possible design changes
  - Sparing posture
  - On-orbit operation changes

Summary

- The ISS P1 EATCS had a slowly increasing ammonia leak, and white flakes were observed from the ISS video cameras
- RELL narrowed down the source of the leak to the P1-3-2 RBVM supply and return jumper hoses
- Hoses and radiator flow paths were isolated, and vented of ammonia; stopping the leak
- White flakes have not been observed since
- Hoses returned to the ground, refurbished and relaunched to ISS
- Leak source – aft seals in QD F128 (radiator end) on the ¾” return hose
- Further evaluation in work