N A S A

Experiences with Extra-Vehicular Activities in Response to Critical ISS Contingencies

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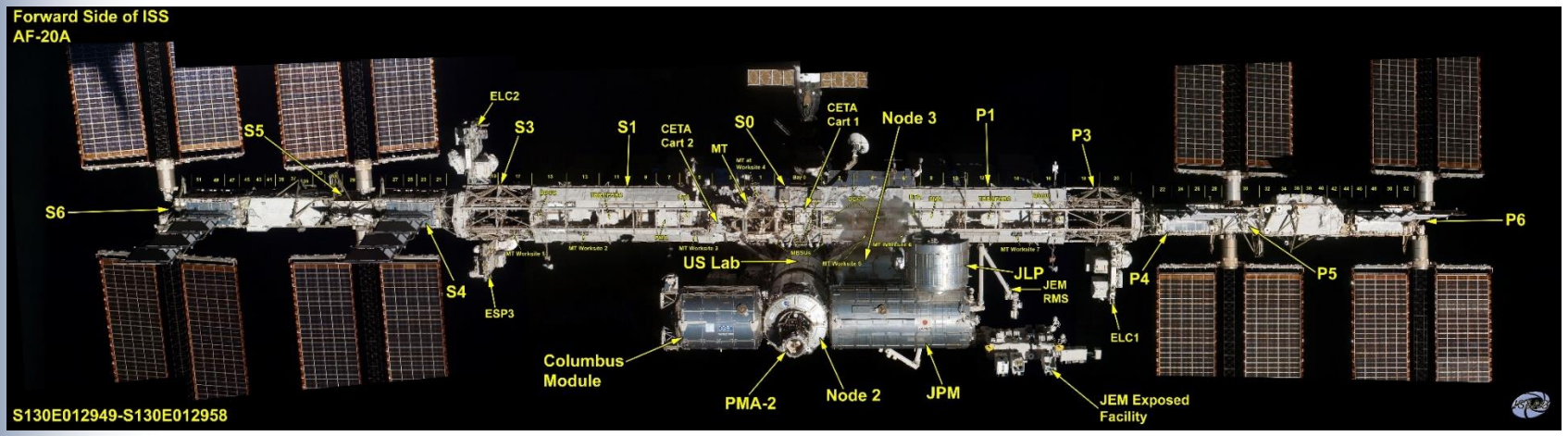
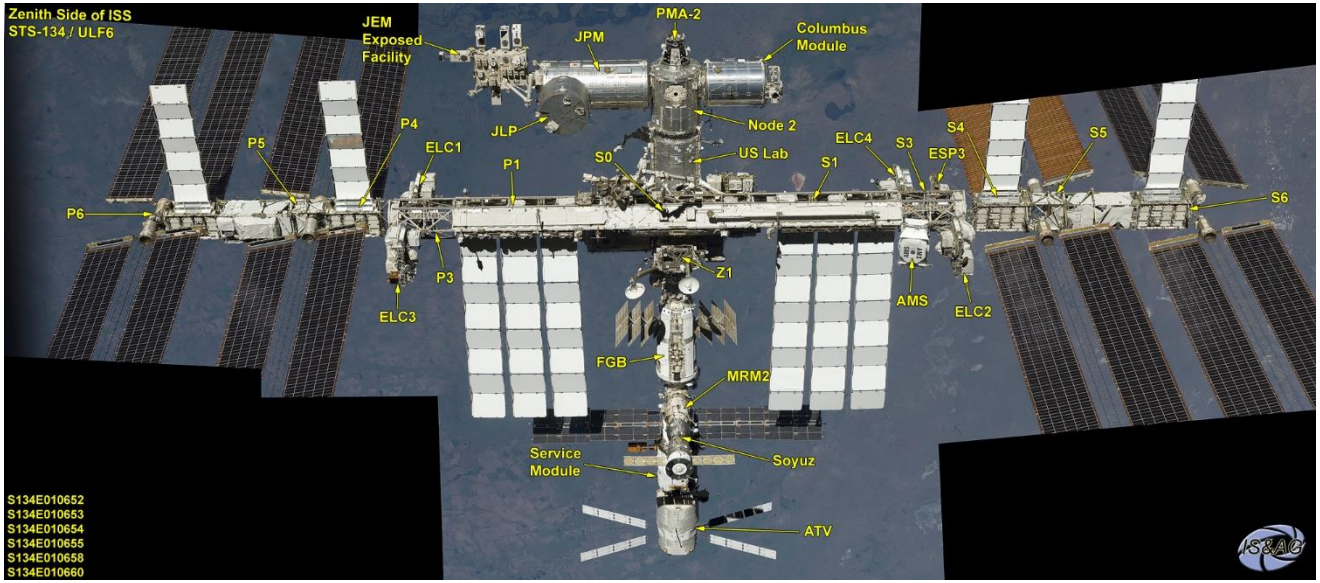




ISS External Infrastructure

- ISS primary utilities (power, thermal) located externally
  - Power routing and conversion
    - Route primary power from solar arrays/batteries to various internal and external loads
    - Convert primary power (~160 VDC) to stable secondary power (~120 VDC)
  - Primary thermal control system
    - Transfer heat from internal loads to external cooling loop via heat exchangers
    - Transfer heat from external loads to external thermal cooling loop via coldplates
    - Reject heat via radiators
  - Command and Data Handling
    - Multiplexer/Demultiplexers (MDMs) controlling external hardware such as cooling loops, solar arrays, robotics

Complications with Infrastructure

- Most hardware located on Integrated Truss Structure facing into velocity vector
  - Potential damage/loss due to Micro-Meteoroid/Orbital Debris (MM/OD)
- Most hardware on the Contingency EVA list has limited or no redundancy
  - Example: Loss of single Pump Module or Flex Hose Rotary Coupler results in loss of 1 of 2 external thermal control loops. Loss of 1 loop requires shutting down half of USOS primary power system due to lack of cooling. USOS becomes zero fault tolerant for survival.
- Maintenance and Supportability of these systems was reduced during ISS design and development
  - In recent years, internal and external jumper cables has led to a somewhat improved redundancy risk posture
- Drove development of “Critical Contingency EVA” List

Critical Contingency EVA List

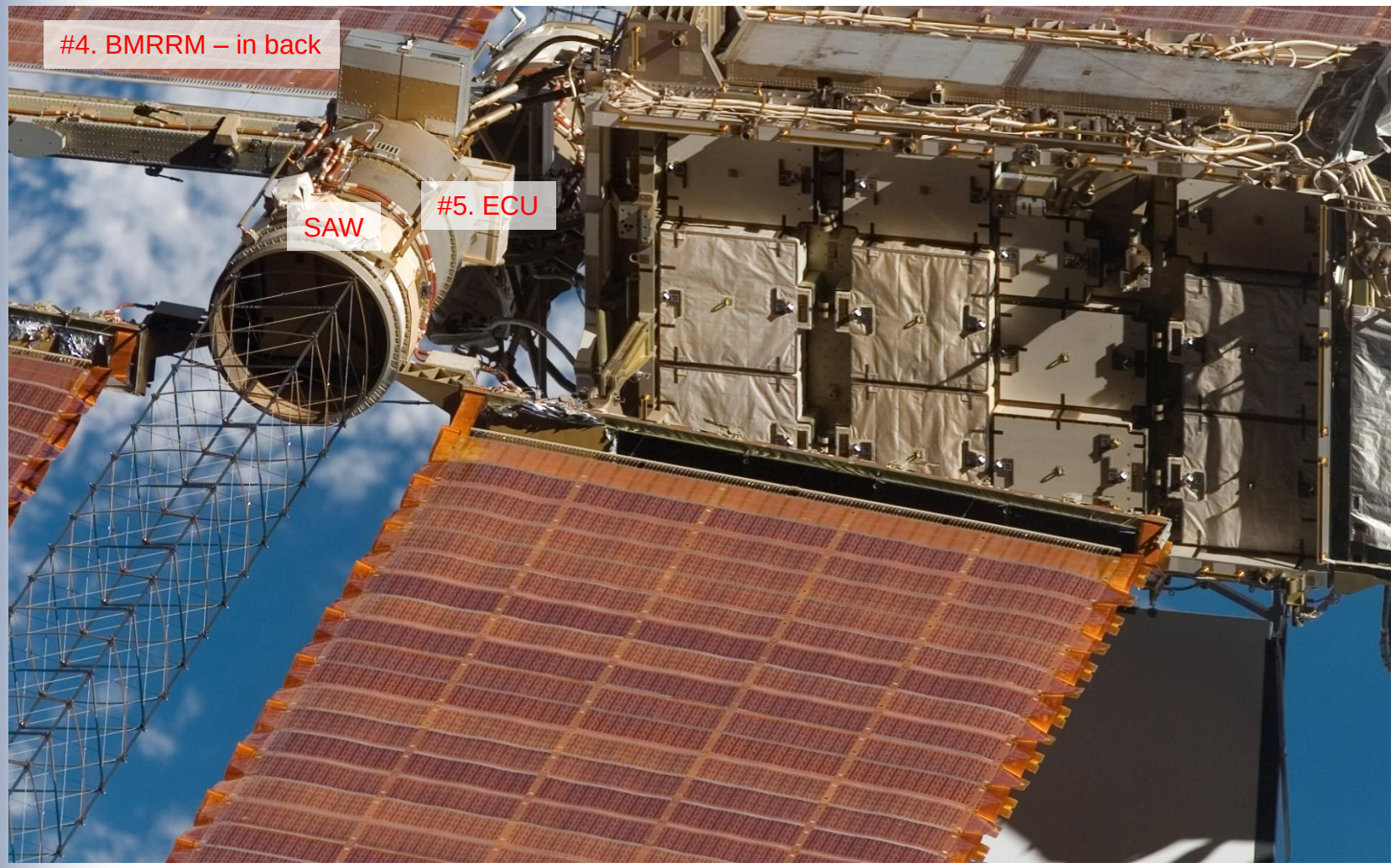
- Started as listing of EVA tasks that, by hardware design or system implementation, would be difficult for EV crew to remove/replace or could impede ISS assembly
- As ISS grew in size, list grew from “Big 8” to “Big 9” to “Big 14” to “Big 11” to now the “Big 13”
  - These are the number of *types* of Orbital Replacement Units (ORUs) – there are generally 2 or more of each type
- First CCE was performed in Fall 2010 to replace a failed external cooling loop pump
  - Quick turnaround EVA response only theory prior to this event
- Lessons learned from those EVAs (3 were required) demonstrated the need for additional pre-failure analysis prior to future contingency EVAs
  - Spawned development of Failure Response Assessment Team (FRAT)

Current CCE List

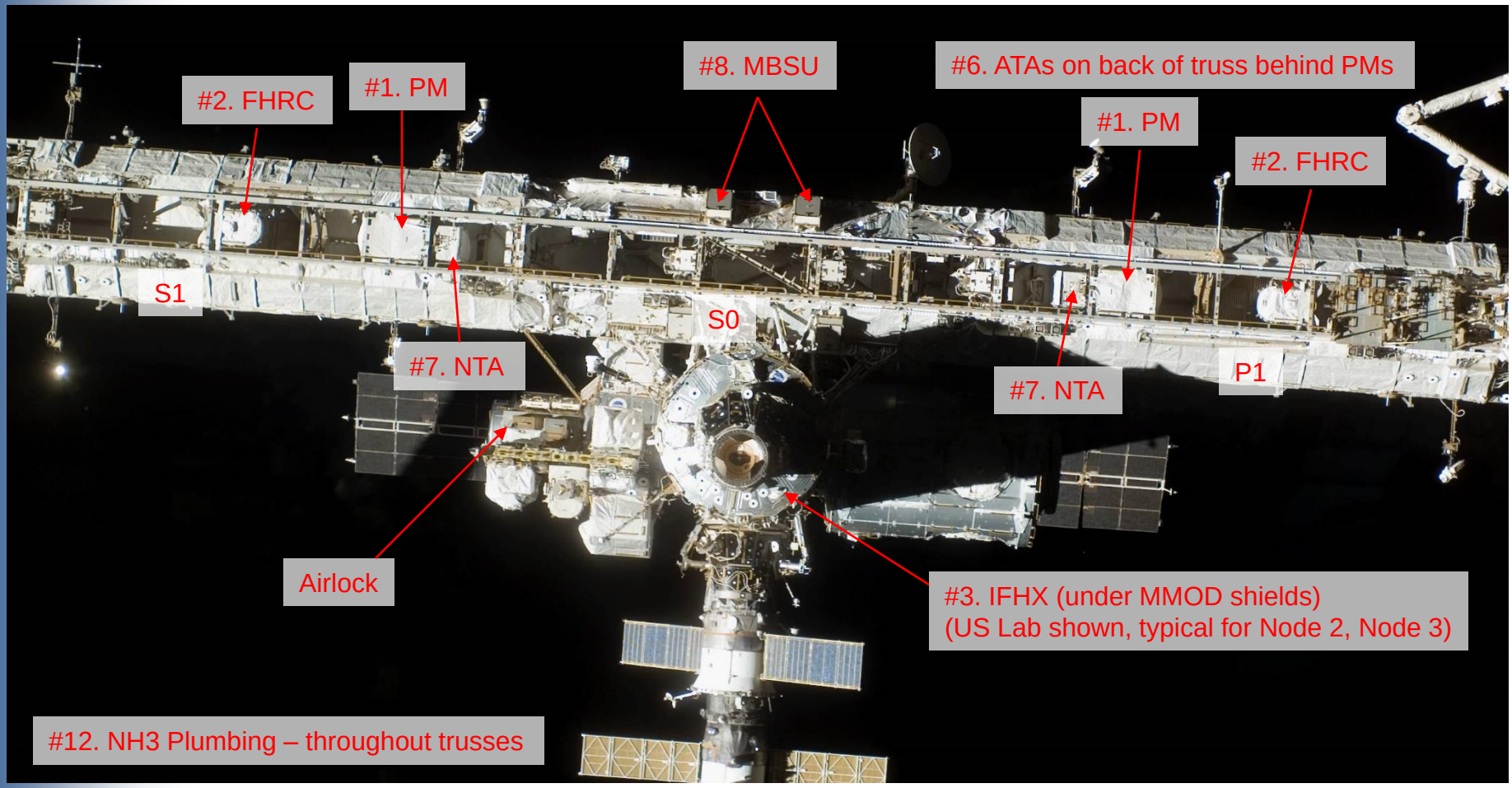
(in order of priority)

1. Pump Module (PM) R&R
2. Flex Hose Rotary Coupler (FHRC) R&R
3. Interface Heat Exchanger (IFHX) R&R
4. Solar Array Wing (SAW) Bearing Motor Roll Ring Module (BMRRM) R&R
5. SAW Electronics Control Unit (ECU) R&R
6. Ammonia Tank Assembly (ATA) R&R
7. Nitrogen Tank Assembly (NTA) R&R
8. Main Bus Switching Unit (MBSU) R&R
9. External (EXT) Multiplexer/Demultiplexer (MDM) R&R
10. DC-to-DC Converter Unit (DDCU) R&R
11. External Remote Power Control Module (RPCM) R&R
12. Ammonia (NH3) Leak Isolation and Recovery
13. Micrometeoroid/Orbital Debris (MMOD) penetration pinpoint and repair

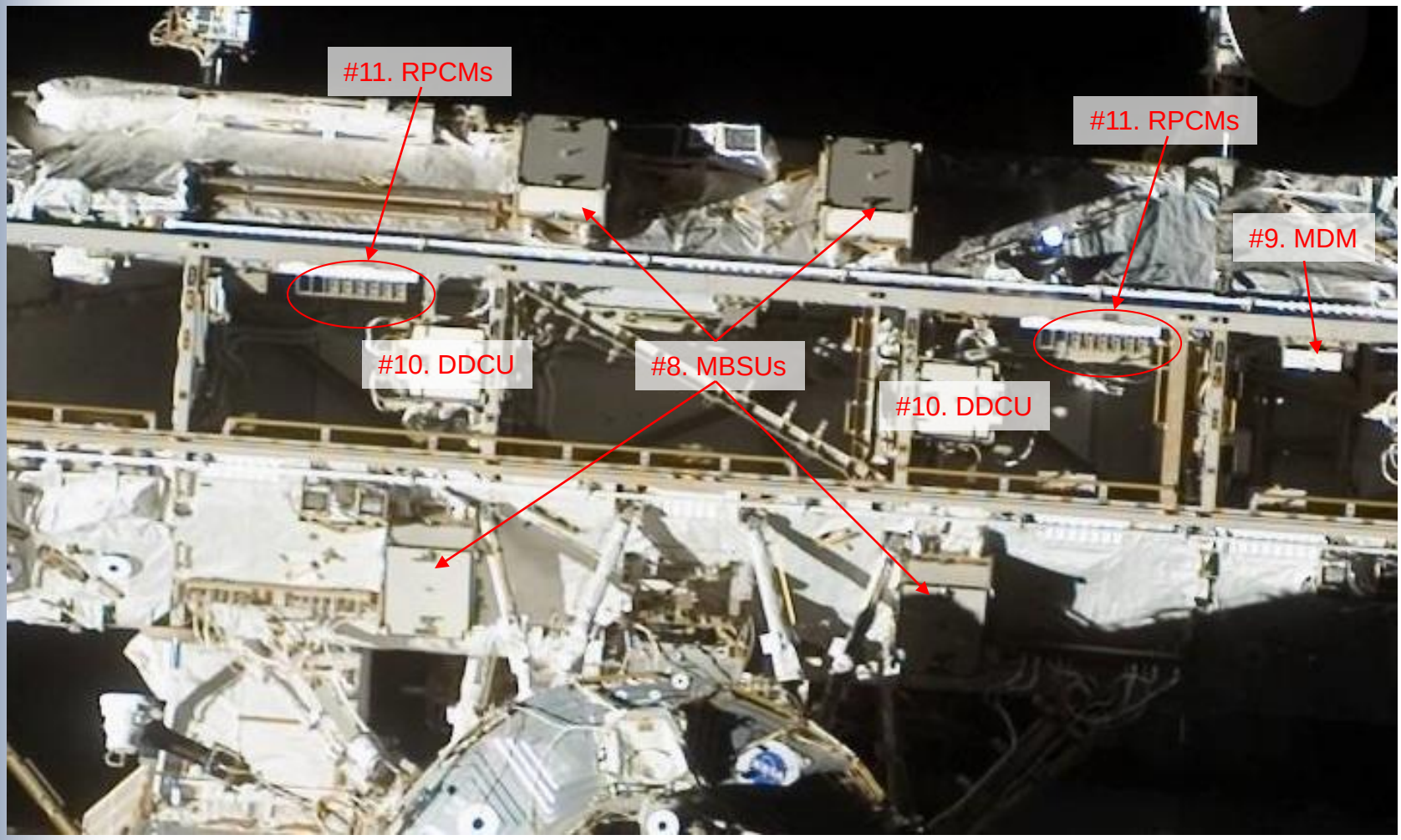
Solar Array CCE ORUs



S1, S0, P1 Truss CCE ORUs

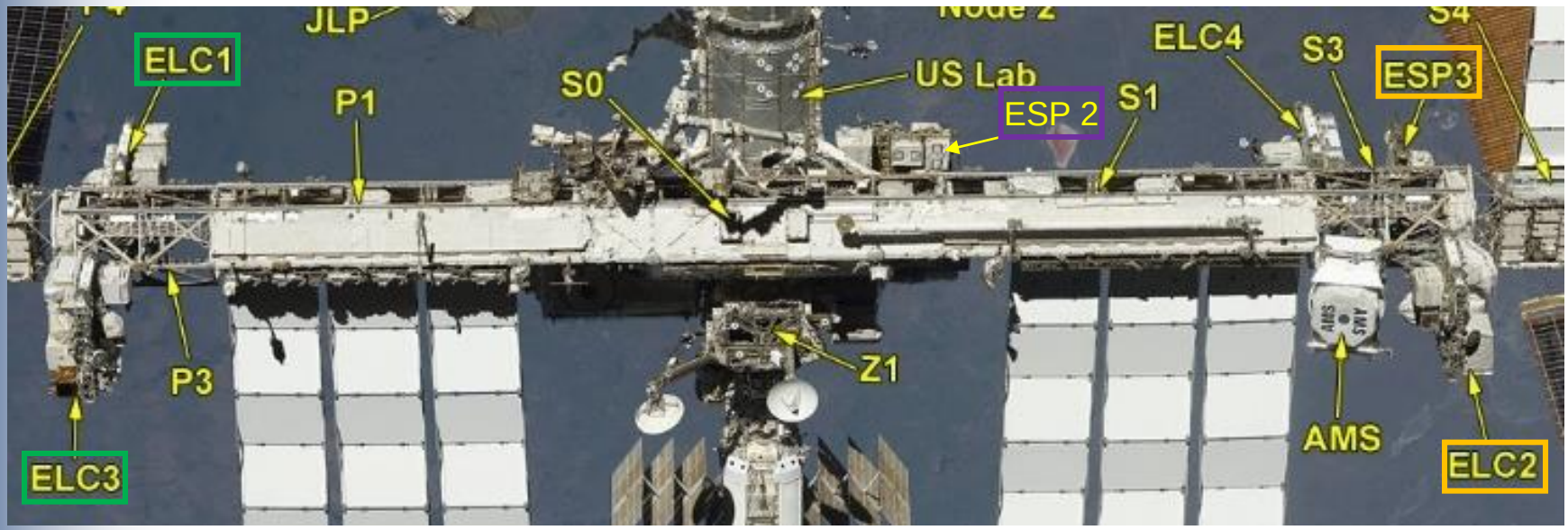


S0 Truss CCE ORUs



Sparing

- Spares for most Contingency EVAs are already externally staged
  - Spare IFHX, DDCU, and BMRRM are internal

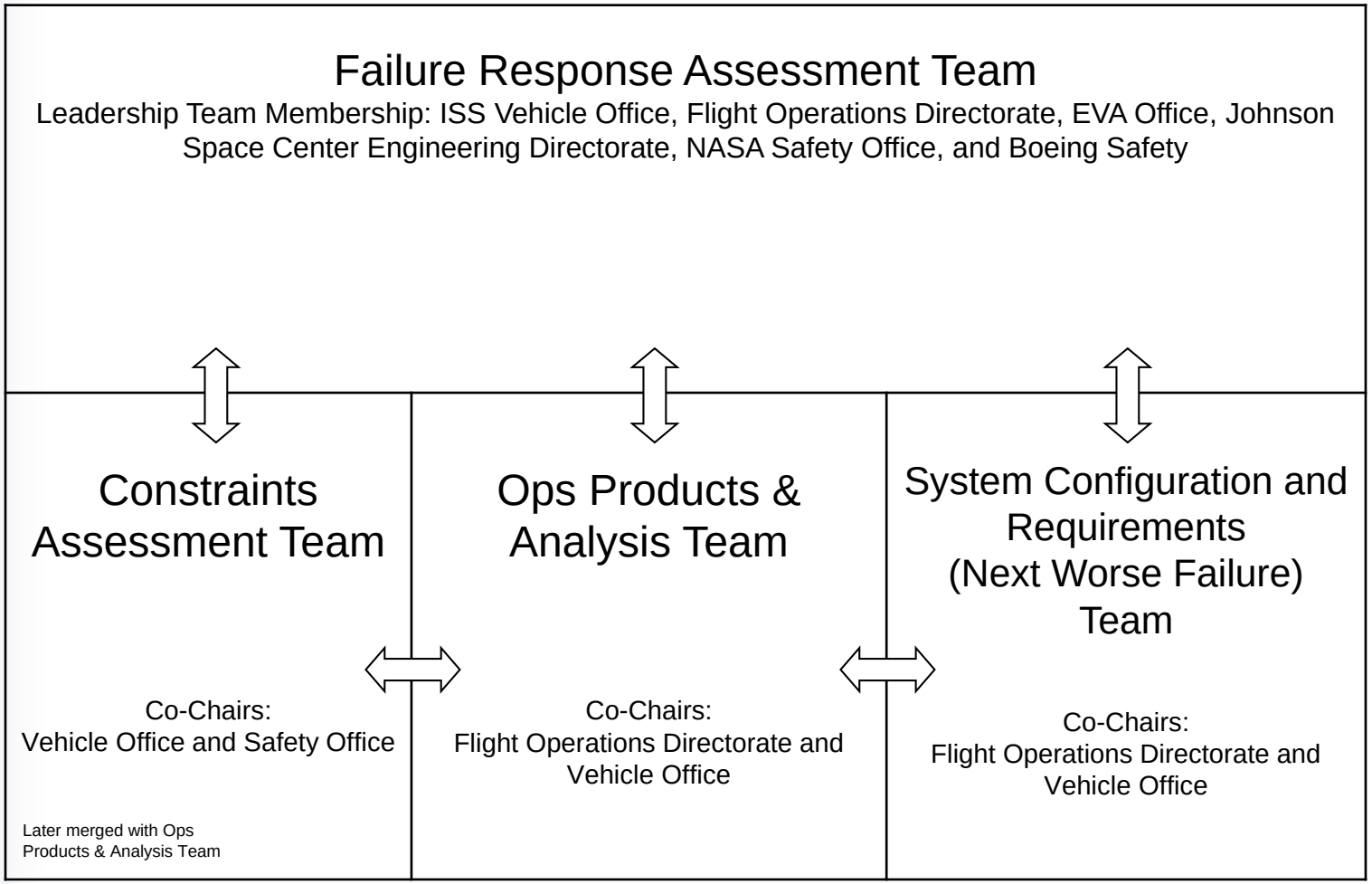


- P3 Truss
  - ELC 1
    - PM, NTA, ATA
  - ELC 3
    - ATA
- ESP 2
  - Forward side of Airlock
    - PM, MBSU (2), FHRC
- S3 Truss
  - ESP 3
    - FHRC
  - ELC 2
    - PM, NTA

Lessons from 2010 PM R&R

- Much of the “Big 14” (2006 – 2008) work was useful in generating EVA response plans and procedures but had not been taken far enough
- Assumptions made pre-failure for procedures and analysis need to be more thoroughly documented, reviewed, and accepted
- As much engineering analysis as possible should be performed pre-failure
  - Trade off between cost/schedule and risk if work is not done
  - Earlier approach only identified needed analysis, did not have funding to perform analysis
- Pre-failure planning must include protections to be put in place after the failure to better posture ISS for the Next Worse Failure (e.g. a failure of the only other functioning coolant loop)

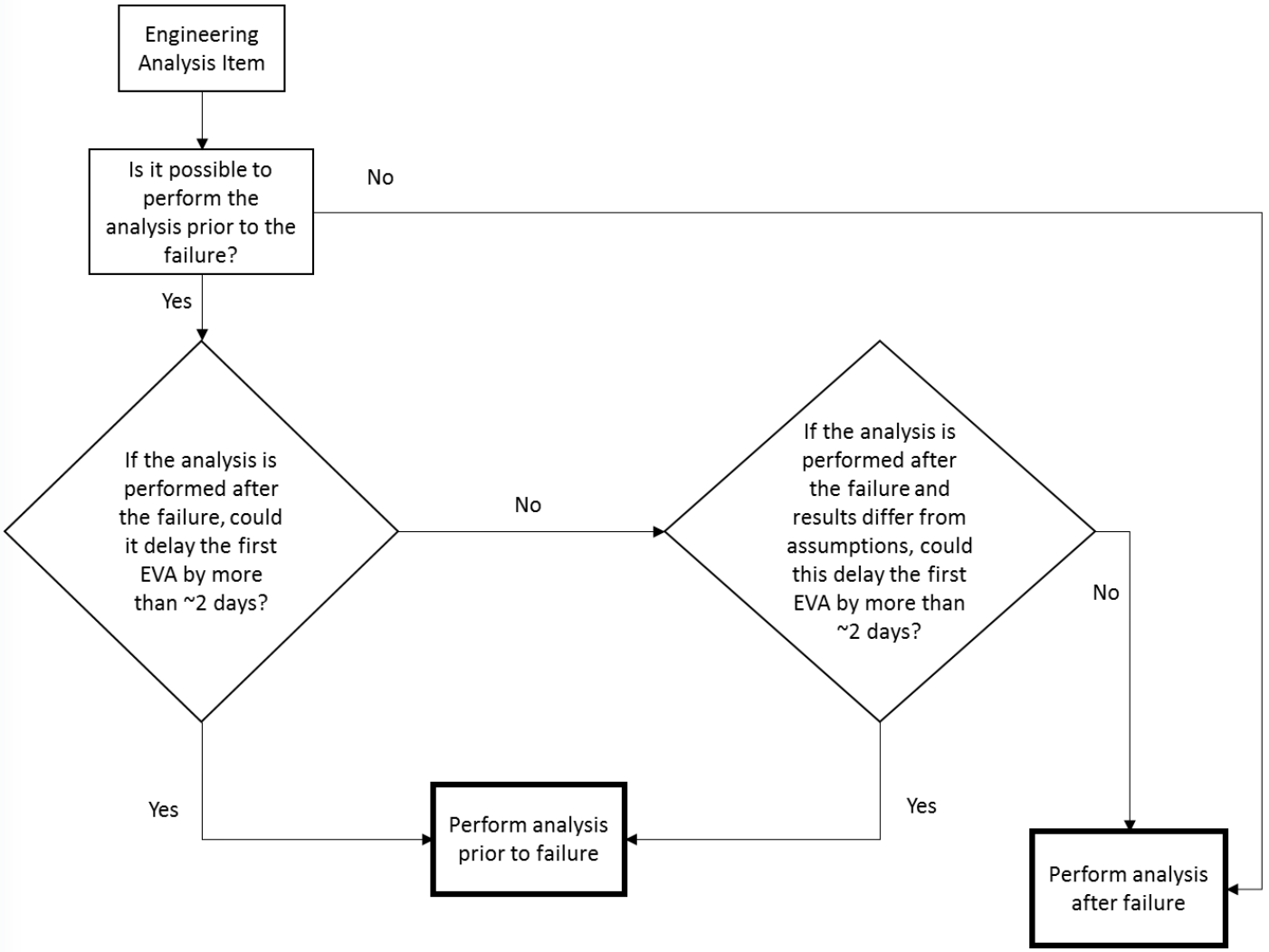
FRAT Organization



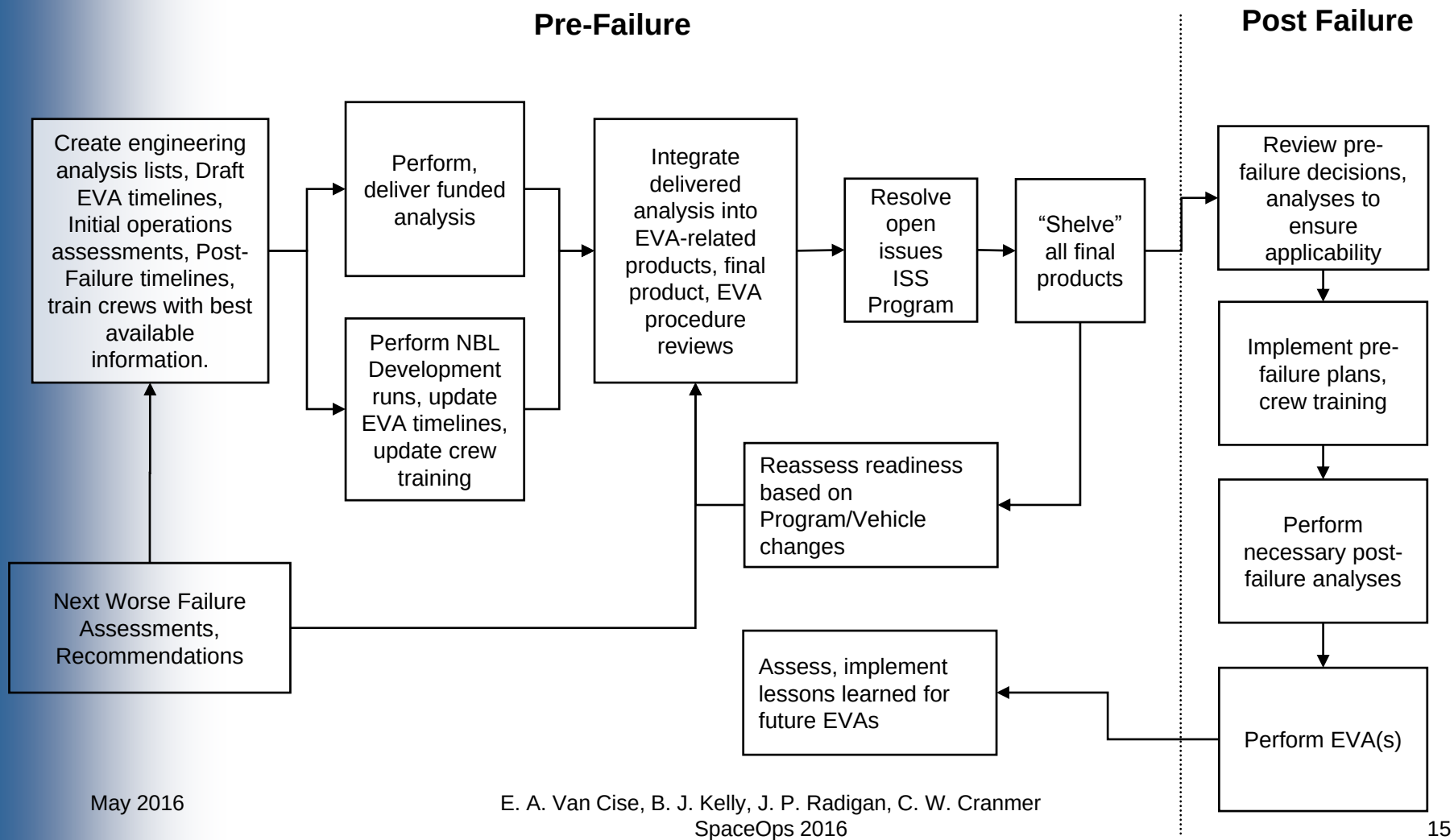
FRAT Products

- Integrated Operations Product Template (IOPT) Process
  - All possible analysis needed for an EVA, notating which *can* be done pre-failure, which *should* be done pre-failure, long (hours) the generic analysis will take if performed pre-failure, and how long the failure-specific analysis would take if performed post-failure
- Pre-failure analysis
  - Subset of IOPT analysis funded and performed in advance of a failure
- Pre-failure planning products
  - Operational procedures, training, post-failure timelines for each ORU created to guide the response from initial failure until execution of the EVA(s)
- Post failure response
  - Briefing to real-time teams to transition from generic FRAT work to post-failure specific work
  - Tailoring of generic pre-failure analysis, assumptions, and decisions to actual situation
  - Finalizing, uplinking, and executing operational products and EVA(s)

Pre- or Post- Failure?



Overall FRAT Project Flow



Summary

- Initial “Big 14” work was put to the test for the first time in 2010. Deficiencies were found in some of the planning and approaches to that work.
- Failure Response Assessment Team created in 2010 to address deficiencies
  - Identify and perform engineering analysis in operations products prior to failure; incorporate results into operations products
  - Identify actions for protecting ISS against a Next Worse Failure after the first failure occurs
  - Better document not only EVA products but also planning products, assumptions, and open actions
- Pre-failure investments against critical failures best postures ISS for swift response and recovery
  - A type of insurance policy
  - Has proven effective in a number of contingency EVA cases since 2010
    - Planning for MBSU R&R in 2012
    - Second PM R&R in 2013
    - EXT MDM R&R in 2014
- Current FRAT schedule projects completion of all analysis in 2018

Backup Data

Acronym List

- BMRRM – Bearing Motor Ring Roll Module
- CCE – Critical Contingency EVA
- DDCU – DC-to-DC Converter Unit
- ECU – Electronics Control Unit
- ELC – External Logistics Carrier
- EMU – Extra-vehicular Mobility Unit
- EPS – Electrical Power System
- ESP – External Stowage Platform
- EV – Extra-Vehicular
- EVA – Extra-Vehicular Activity
- EXT – External
- FHRC – Flex Hose Rotary Coupler
- FOD – Flight Operations Directorate
- FRAT – Failure Response Assessment Team
- GJOP – Generic Joint Operations Panel
- IFHX – Interface Heat Exchanger
- IOPT – Integrated Operations Product Tempalte
- ISS – International Space Station
- ITS – Integrated Truss Segment
- LSAR – Logistics Support Analysis Record
- MBSU – Main Bus Switching Unit
- MDM – Multiplexer/Demultiplexer (similar to computer)
- MHA – Maintenance Hazard Analysis
- MM/OD – Micrometeoroid/Orbital Debris
- NASA – National Aeronautics and Space Administration
- NBL – Neutral Buoyancy Laboratory
- NH3 – chemical formula for Ammonia
- ORU – Orbital Replacement Unit
- PM – Pump Module
- R&R – Remove and Replace
- RPCM – Remote Power Control Module
- SAW – Solar Array Wing
- USOS – United States Orbital Segment
- VDC – Volts, Direct Current

Photo References

- All photos are NASA downlink images
  - S120E008545
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  - S120E009811
  - S120E009847
  - S122E011043