Lessons Learned Conducting Spacewalks from the International Space Station

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Disclosure Information

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We have no financial relationships to disclose.

We will not discuss off-label use and/or investigational use in our presentation

Introduction

- From the International Space Station (ISS) Flight Surgeon and ISS Biomedical Flight controller perspective:
  - Review Extravehicular Activity (EVA) mission control support, denitrogenation (prebreathe) protocols and flight rules
  - Assess ISS breaks in prebreathe protocols experienced
  - Helmet water intrusion event
  - Highlight lessons learned performing prebreathe protocols and EVAs

Methods

- Mission records for US segment EVAs in the Extravehicular Mobility Unit (EMU) from the ISS Quest Airlock
- Analyzed from July 2001 to March 2017
- Total of 122 two-person EVAs (244 astronaut excursions)
- 797 hours total EVA time
- Average 6.5 hours per EVA
- Typical EVA length 5 – 7 hours

Space Medicine Console Support for EVA

- Mission Control Center (MCC) Front room:
  - Biomedical Flight Controller
  - Flight Surgeon
- MCC Multi-Purpose Support Room:
  - Crew Health Care Systems [CHeCS BioMedical Engineer (BME)] Flight Controller
  - ECG support tech/Nurse
- Increment Management Center:
  - Flight Surgeon
- On-Call:
  - EVA Prebreathe Subject Matter Experts (Integrated Product Team)


NASA

Prebreathe Protocols Used on ISS

- 4-Hour In-Suit (1 use, 2 crew exposures)
- Cycle Ergometer with Vibration Isolation and Stabilization (CEVIS) Exercise
  (21 uses, 42 crew exposures)
- Campout (73 uses, 146 crew exposures)
- In-Suit Light Exercise (ISLE) (26 uses, 52 crew exposures)

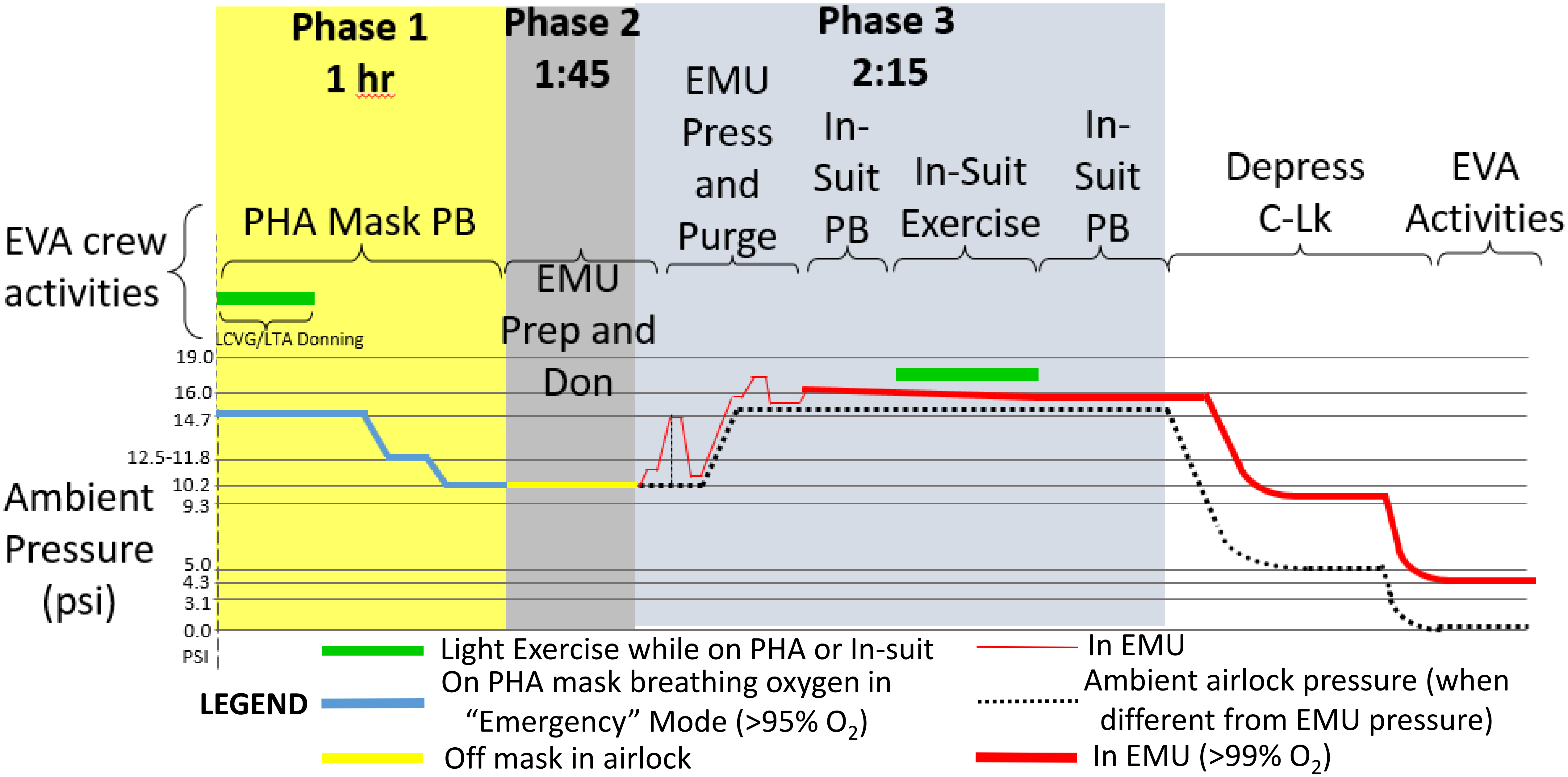
Equipment Lock

Crew Lock

CEVIS Exercise Protocol and First Use of Quest Airlock

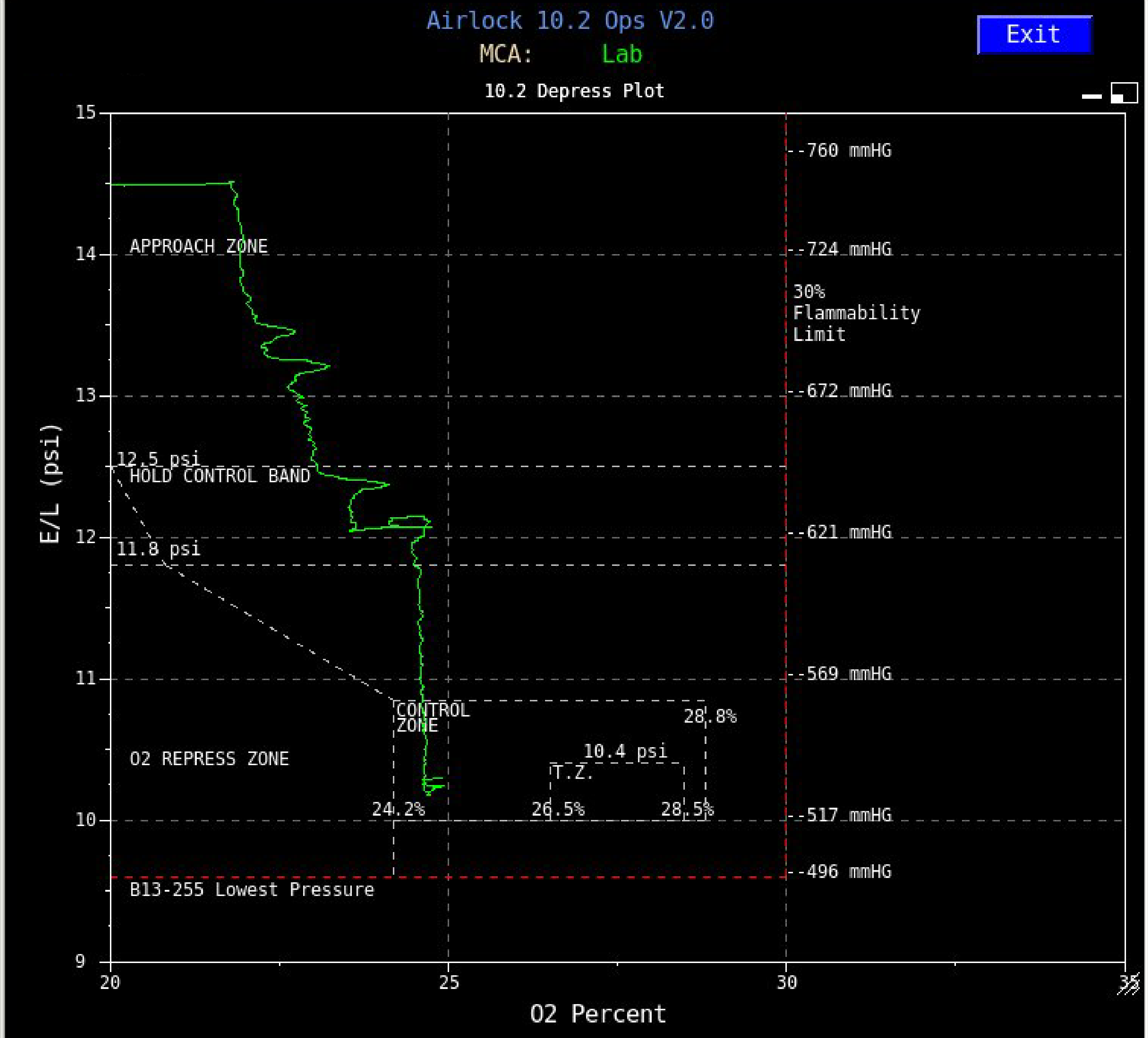
Not to Scale

ISLE Protocol: Pressure Profile



Monitoring

- Prebreathe
  - O2 concentration
  - O2 consumption
  - Airlock pressures
- During EVA
  - Metabolic Rate
  - ECG
  - CO2



Flight Rules

- Flight rules document pre-coordinated plans and decisions
- Goal is to minimize the amount of real-time discussion required to make decisions

B13-260 **EMU IN-SUIT LIGHT EXERCISE PREBREATHE PROTOCOL [HC] [RI] [E] [J] (CONTINUED)**

A. THE INITIAL 60-MINUTE MASK PREBREATHE MUST BE ON PHA IN EMERGENCY MODE WITH > 95 PERCENT O_2, AT LEAST 45 MINUTES OF WHICH MUST BE ACCOMPLISHED PRIOR TO DEPRESS BELOW 11.8 PSI/610 MMHG. THE INITIAL PREBREATHE WILL NOT BE TERMINATED UNTIL THE HABITABLE ELEMENT PRESSURE REACHES THE CONTROL ZONE. THE CONTROL ZONE IS DEFINED AS A MINIMUM OXYGEN CONCENTRATION OF 24.2 PERCENT, WHERE 26.5 PERCENT OXYGEN IS OPTIMAL, AT A SUSTAINED PRESSURE BETWEEN 10.84 PSI/561 MMHG AND 10.0 PSI/517 MMHG. ®[081811-00392A]

EV CREW WILL PERFORM DONNING OF THE LIQUID COOLING AND VENTILATION GARMENT (LCVG), BIOMED, AND LOWER TORSO ASSEMBLY (LTA) OR EQUIVALENT WORKLOAD DURING THE 60-MINUTE MASK PREBREATHE.

In order to reach an optimal O2 concentration, the depress to 10.2 psi/527 mmHg will nominally be initiated when 30 minutes remain in the mask prebreathe clock. This amount of time protects for the upper O2 limit for flammability constraints and should allow crew to doff masks when their required prebreathe time has expired. Historically, it takes an estimated 26-30 minutes to perform the depress from 14.7 psi/760 mmHg to the control zone, per the following: 3 minutes for hatch closure + 8 minutes to depress from 14.7 psi to 12.5 psi (760 mmHg to 646 mmHg) + 2-3 minutes hold between 12.5 psi/646 mmHg and 11.8 psi/610 mmHg + 11 minutes to depress from 12.5/11.8 psi (646 mmHg/610 mmHg) to the control zone + 2-4 minutes for O2 stabilization and readings.

From a physiological standpoint, 10.2 psi/527 mmHg is the optimal pressure, and 23 percent is the actual minimum acceptable oxygen concentration in the control zone. The lower oxygen limit was raised to 24.2 percent to account for the CSA-O2's error band of ±1.2% O2 (±6 mmHg) and the additional total pressure correction factor. CSA-O2's have since been replaced onboard ISS with Portable O2 Monitors. The Portable O2 Monitor's measurement range is 14-32% O2 with an accuracy of ±0.8% O2 (±4 mmHg). The minimum control zone O2 concentration will remain as 24.2 percent instead of 23.8 percent for additional physiological margin and operational purposes. The Portable O2 Monitor has an alternate engineering name of ISS Portable Oxygen Monitor (IPOM) (P/N SEG52102597-301). ®[100614-01054]

The donning of the LCVG, LTA, and Biomed must be initiated while on mask because the protocol was designed based on the metabolic rate generated while donning these items. The donning of these 3 items is considered part of the light exercise that makes up the protocol. If not achieved, crew can substitute light exercise that approximates the donning of the LCVG, Biomed, and LTA to match the intent of the protocol. ®[081811-00392A]

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Flight Rules

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FLIGHT RULES

B13-260 EMU IN-SUIT LIGHT EXERCISE PREBREATHE PROTOCOL [HC] [RI] [E] [J] (CONTINUED)

TABLE B13-260-I – LIGHT IN-SUIT EXERCISE PREBREATHE PAYBACK CHART (CONTINUED)

PREBREATHE ACTIVITY PORTION	POINT OF INTERRUPTION	TIME ELEMENT	REQUIRED ACTION	REQUIRED PROFILE
PHASE THREE				
100 MINUTE IN-SUIT PREBREATHE [6]	WITHIN CONTROL ZONE	≤ 10-MINUTE INTERRUPTION (SINGLE OR CUMULATIVE)	MAKE UP O_2 TIME IN SUIT OR PHA. [1] [2] [5] [7] [8] [9]	MAKEUP RATIO: 2:1
	WITHIN CONTROL ZONE	> 10-MINUTE INTERRUPTION (SINGLE OR CUMULATIVE)	REPEAT 50-MINUTES OF RESTING IN-SUIT PREBREATHE AND ANY REMAINING EXERCISE CYCLES. [3] [7] [8] [9]	ON MCC CALL
	PRESSURE BETWEEN CONTROL ZONE AND 14.7 PSI/760 MMHG	≤ 10-MINUTE INTERRUPTION (SINGLE OR CUMULATIVE)	MAKE UP O_2 TIME IN SUIT. [1] [5] [7] [9]	MAKEUP RATIO: 2:1
	PRESSURE BETWEEN CONTROL ZONE AND 14.7 PSI/760 MMHG	> 10-MINUTE INTERRUPTION (SINGLE OR CUMULATIVE)	REPEAT IN-SUIT LIGHT EXERCISE PREBREATHE PROTOCOL OR CONSIDER ALTERNATE PREBREATHE PROTOCOL. [4] [7] CREW SCHEDULING CONSTRAINTS MAY NECESSITATE SHORTENING OR RESCHEDULING THE EVA.	ON MCC CALL
	EXERCISE ONLY	1 EXERCISE CYCLE MISSED	NO MOD REQUIRED [10] [11]	N/A
	EXERCISE ONLY	> 1 EXERCISE CYCLE MISSED	PERFORM REMAINING EXERCISE TO COMPLETE 10 EXERCISE CYCLES [10] [11]	PAUSE

®[081811-00392A]

Flight Rules

	(SINGLE OR CUMULATIVE)	REMAINING EXERCISE CYCLES. [3] [7] [8] [9]	
PRESSURE BETWEEN CONTROL ZONE AND 14.7 PSI/760 MMHG	≤ 10-MINUTE INTERRUPTION (SINGLE OR CUMULATIVE)	MAKE UP O_2 TIME IN SUIT. [1] [5] [7] [9]	MAKEUP RATIO: 2:1
PRESSURE BETWEEN	> 10-MINUTE	REPEAT IN-SUIT LIGHT EXERCISE	ON MCC CALL

- Last phase = Most common time to have a break

Breaks in Prebreathe

- Campout:
  - Exp 14 - Feb 2007: regulator came off of prebreathe mask during depress entering overnight campout (break of 2 min, 2:1 payback)
  - STS-124 – June 2008: communications cap cable not fully connected, helmet removed to reconnect (break of 3:05, 2:1 payback)
  - STS-128 – Sept 2009: communication cap chin strap came undone, helmet removed to fix (break of 3:30, 2:1 payback)


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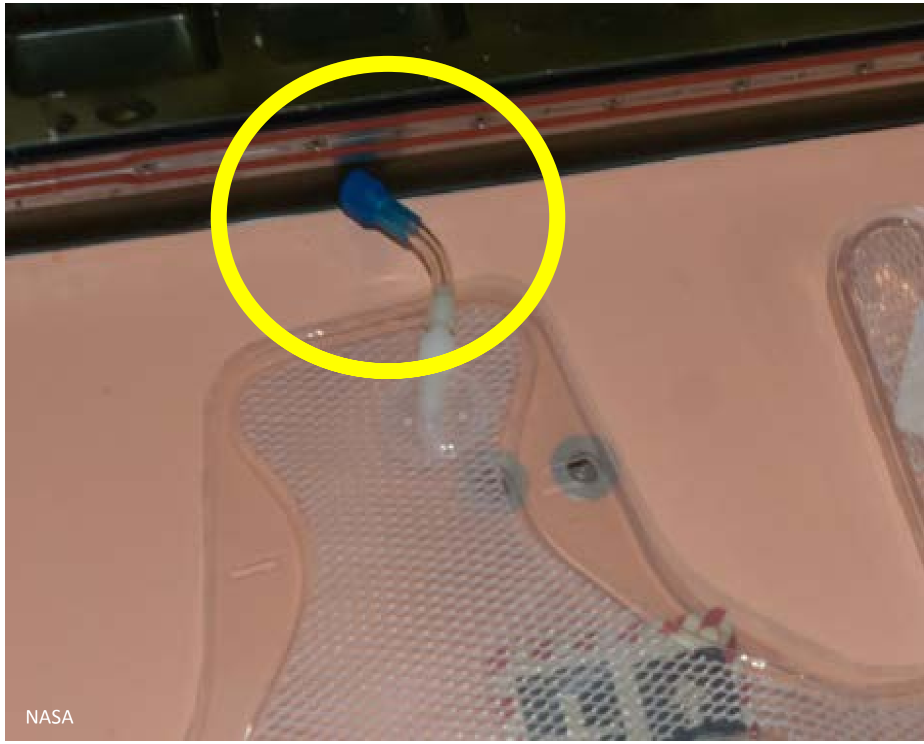
Breaks in Prebreathe (Cont.)

- Campout:
  - STS-129 EVA 2 – Nov 2009: False Russian Segment Rapid Depress caution during overnight campout early in sleep period. Automated response caused airlock to repressurize. Changed to CEVIS Exercise protocol next day.
  - STS-129 EVA 3 – Nov 2009: Bite valve came off drink bag shortly after repress to 14.7 psi. Depress Airlock down to 10.2 psi to replace drink bag to allow unlimited time to address issue (no payback required due to depress back to 10.2 psi, ~1 hr timeline hit)



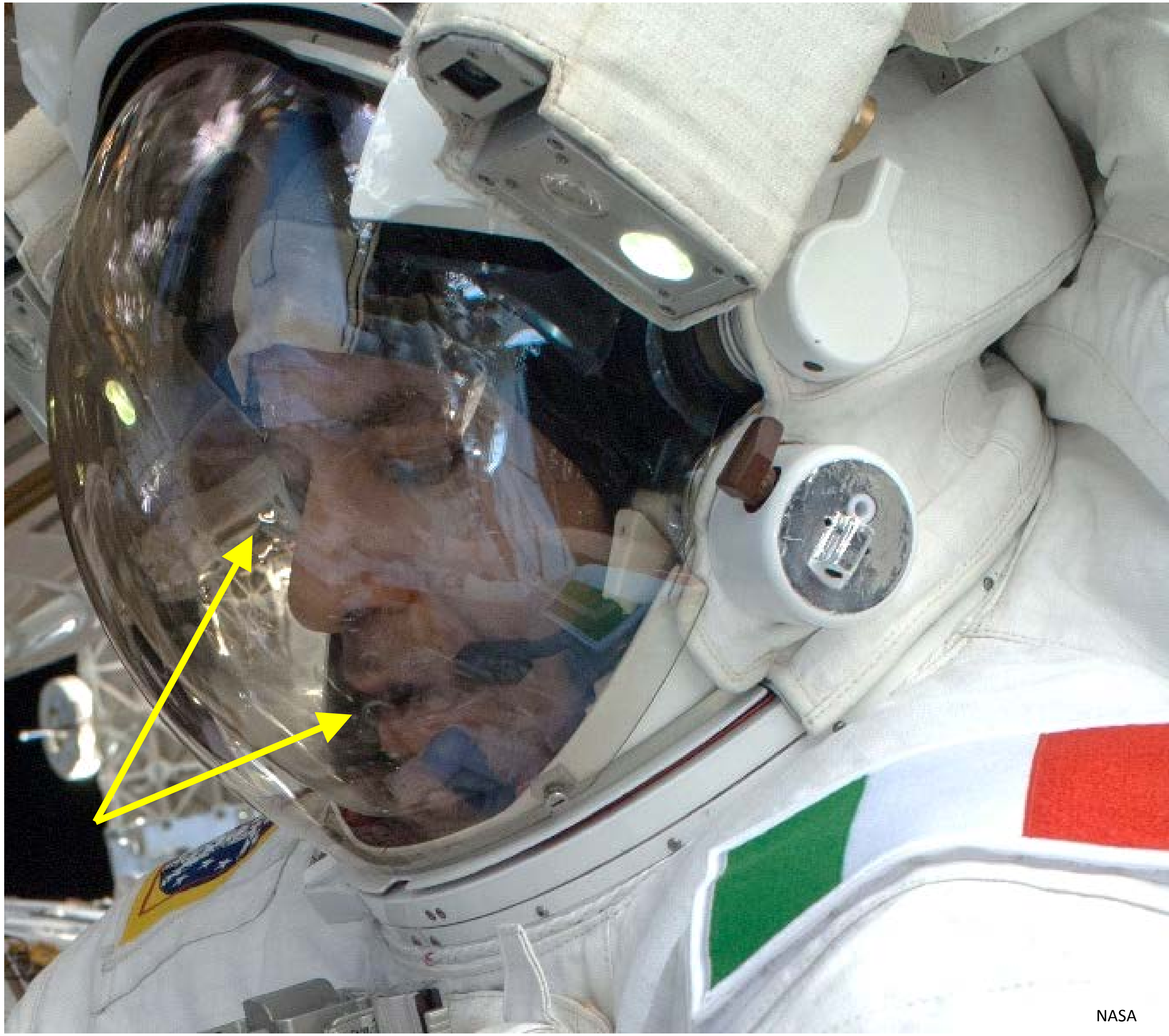
Breaks in Prebreathe (Cont.)

- ISLE
  - Exp 50 – Jan 2017: EMU CO_2 removal cartridge (CCC) replaced while EMU suit fan was on. The CCC is replaced before crew begins EVA to allow full CO_2 removal for EVA (break of 4:00, 2:1 payback)

Lessons Learned from Breaks in Prebreathe

- Develop a common language/terminology between communities/flight controllers
- Develop rules for anticipated anomalies/breaks
- Continue to perform simulations to refine prebreathe protocol procedures

Water in the Helmet



Water in the Helmet

- July 16, 2013, ESA’s Luca Parmitano and NASA’s Chris Cassidy exited the ISS airlock to begin US EVA 23.
- Roughly 44 minutes into the EVA, Parmitano noticed that the back of his head felt wet. The amount of water in the helmet subsequently increased and began to collect on his face.
- Water began to cover his eyes, nose, ears, and communications cap. Luca experienced impaired breathing, vision, communication and hearing impeding communication. Over 1.5 liters accumulated in the helmet.
- The EVA was emergently terminated and the crew made their way back to the airlock.
- Though ultimately Parmitano fared well, aspiration of water could have required his crewmates to perform an emergency resuscitation.

Mishap Board Findings

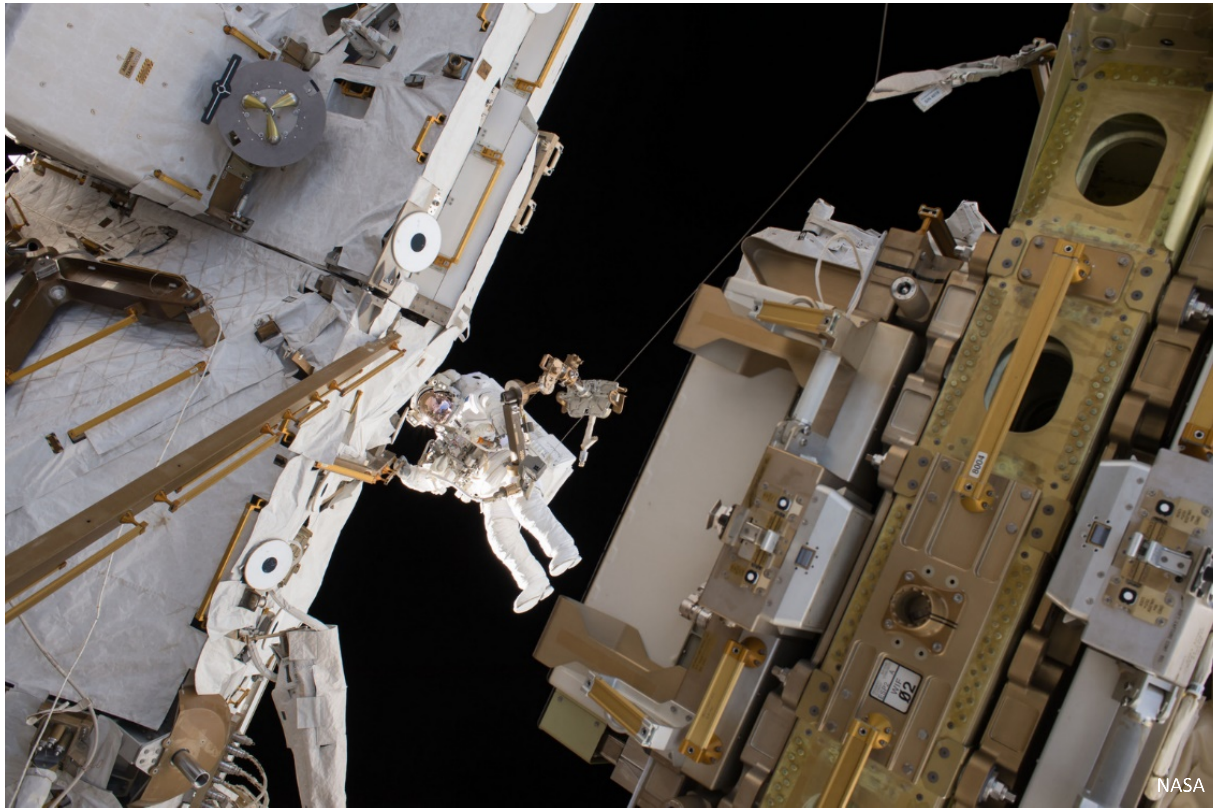
- Inorganic materials caused blockage of the drum holes in the EMU (Extravehicular Mobility Unit) water separator resulting in water spilling into the vent loop that feeds into the helmet.
- NASA team had a lack of knowledge regarding this particular failure mode.
- Similar suit failure misdiagnosis when it initially occurred on a previous EVA.

Lessons Learned from Water in Helmet

- Complex systems carry unknown/ unrealized hazards
- Creative Solutions to mitigate risks
  - Helmet Absorption Pad (HAP)
  - Procedure Updates
  - Hand Signals
  - Snorkel

Summary

- Best plans and training for complex operations should also include contingency situations.
- Continual evaluation of complex operations is required in order to improve safety, procedures and other products required for execution.



Questions?