Emerging Science and Technology to Address Naval Undersea Medicine Needs:

: Lessons Learned from Analog Contexts and Lunar Mission Planning

Robert Sanders, MD, FACEP, FUHM
Flight Surgeon, Program Medical Officer,
EVA & Human Surface Mobility Program,
National Aeronautics and Space Administration (NASA)

NASA & Submarine Medicine

- **Background:**
  - Similarities and challenges of lunar mission planning parallel that of submarine operation
  - Looking to Industry for initial solutions
  - Some can leverage terrestrial analogs/models
  - Others must be solved by NASA directly

Lunar EVA Requirements

- **Artemis Mission: Astronaut into the field**
  - Return to the lunar surface for science an exploration
  - Initially lander-based operations (Artemis 3+)
  - Pressurized rover ops (Artemis 7+)

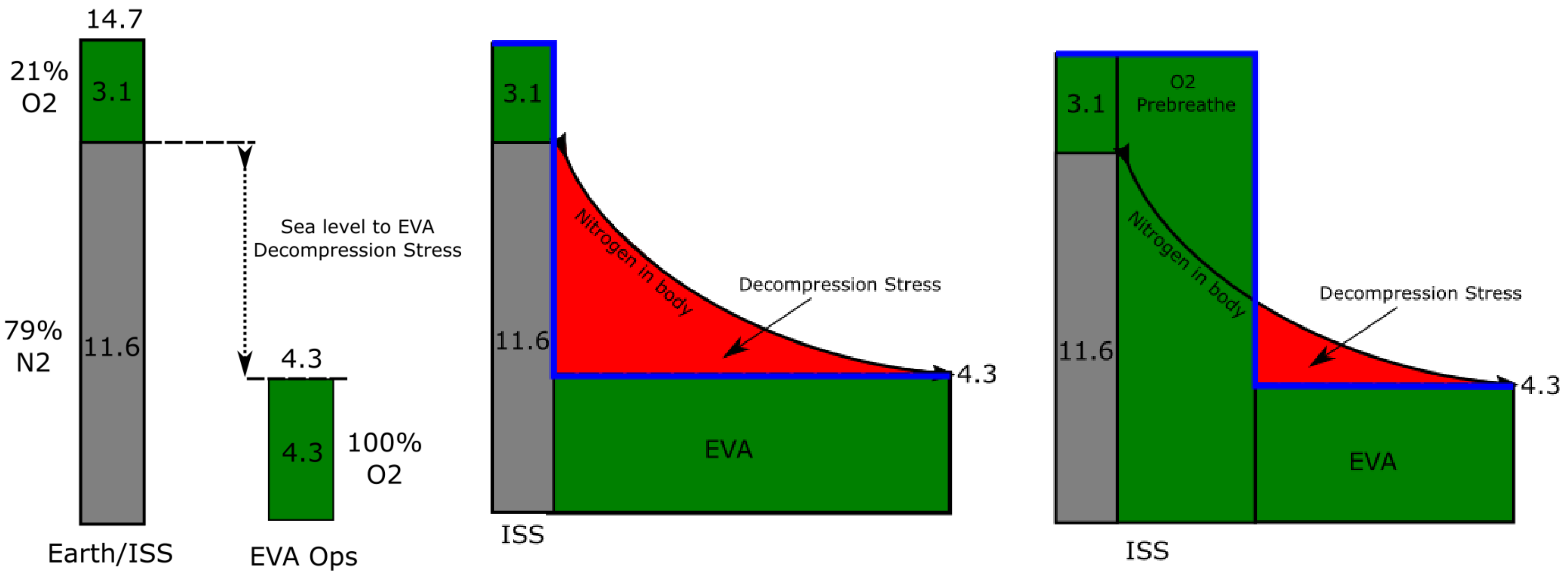
  - Rapid deployment EVA (spacewalks)
    - ISS model not efficient enough
    - Solution space:
      - Habitation & suit pressure
      - Gas mixes

EVA: extravehicular activity;

Conditions for DCS (ISS operations)

- Decrease in Pressure
- Change in Phase State

- Supersaturation must be present
  - Tissue pN2 > Ambient Pressure



ISS operational mitigation: oxygen prebreathe
Prebreathe time based on risk acceptance

ISS: International Space Station

Risk Definition

- DCS risk (human health)
  - ≤ 15% Type I DCS and Cutis Marmorata with 95% confidence interval
  - ≤ 20% grade IV VGE (95% confidence interval)
  - NO Type II DCS

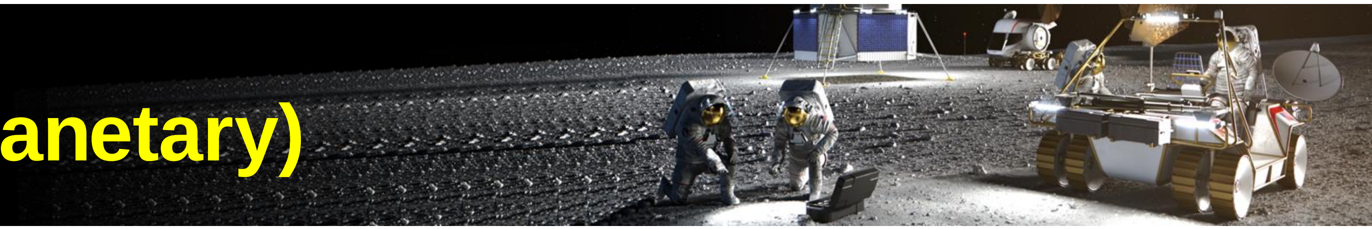
- Lesson learned:
  - If risk acceptance is high enough, adverse medical outcomes may not be "contingencies" or failures, and *must* be planned for:
  - i.e. DCS is a statistical likelihood and not a failure

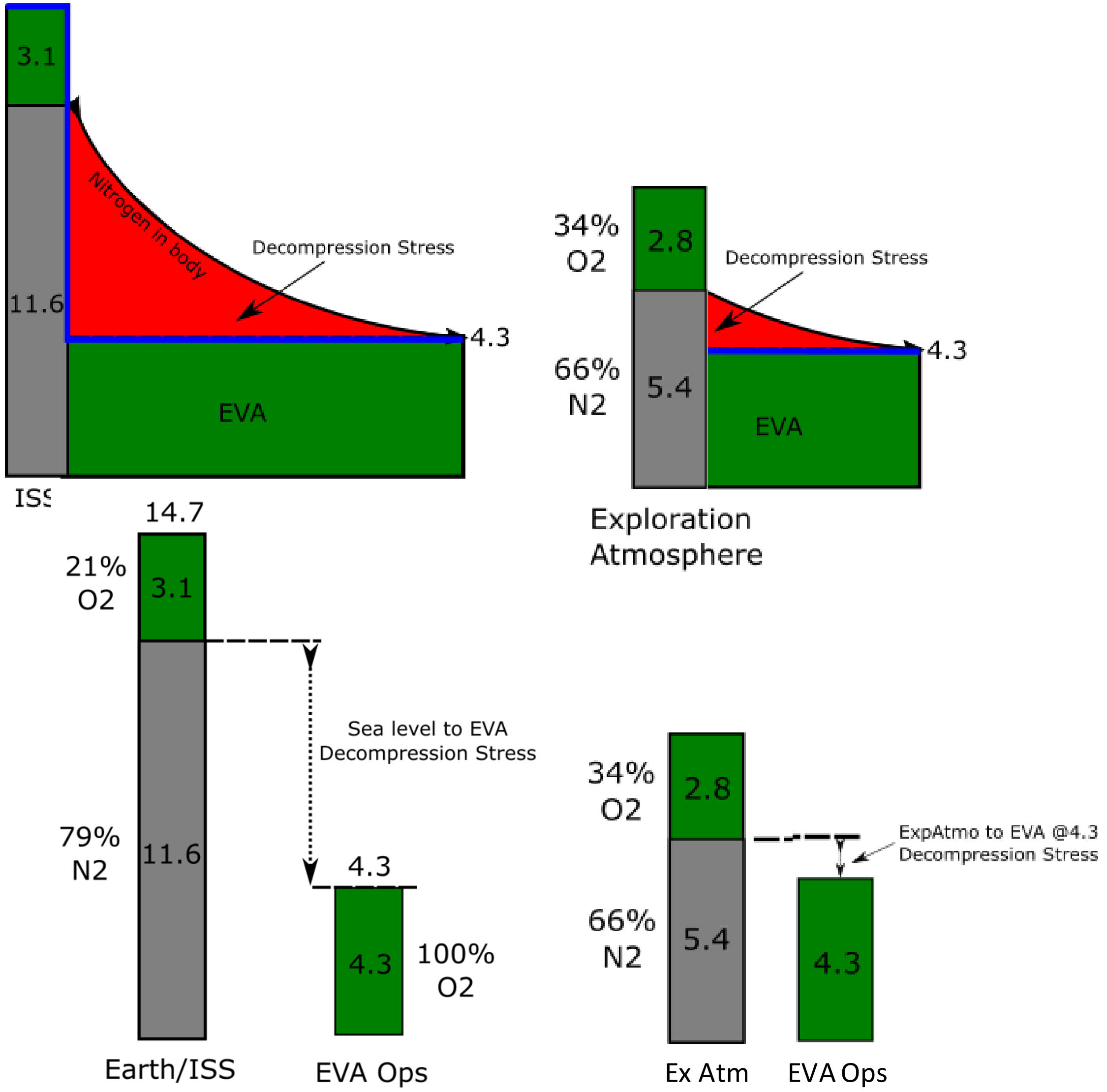
Contingency Planning: Medical

- **Must plan for, and train for contingencies well in advance**
  - Risk is a fact, not a concept and should be discussed *in advance*
    - Modeling is a tool NASA has traditionally used: (Integrated Medical Model (IMM) for ISS operations, and IMPACT for lunar operations, Tissue Bubble Dynamics Model for DCS)
  - Health Risk vs. Operational Risk
    - DCS will result in loss of mission objectives
    - 15% Type I per person per EVA ok from a health standpoint, but
    - Loss of EVA may not be acceptable from a mission standpoint
  - Lesson learned: modelling and discussing human health risk and operational risk as independent entities is critical to mission planning

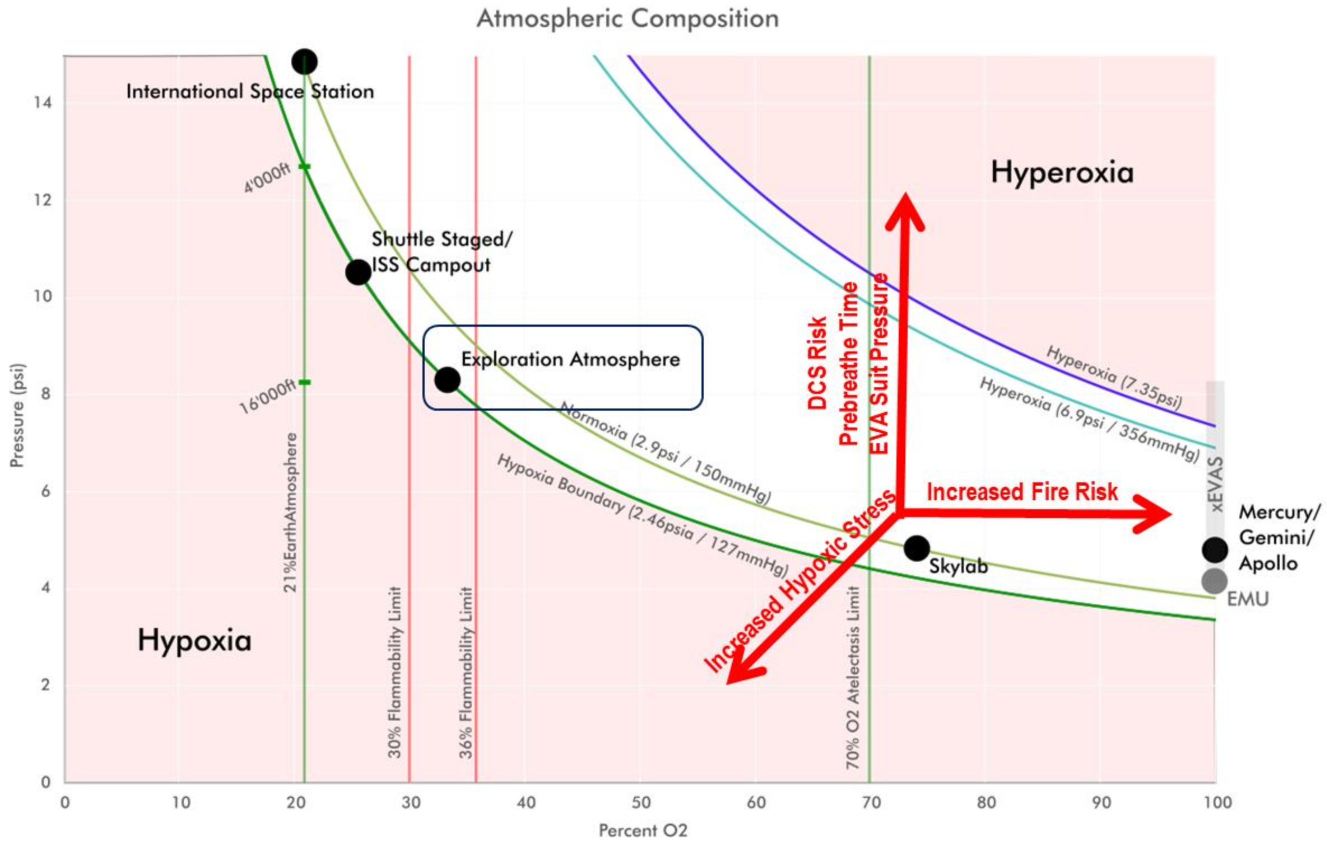
DCS: Decompression Sickness

Conditions for DCS (ISS vs. Planetary)





- Decrease in Pressure
- Change in Phase State
- Tissue pN2 > Ambient Pressure



Lunar - Primary operational mitigation: environmental control

Programmatic Risk: DCS Mitigation

- To ↓DCS risk efficiently:

- Engineering solutions such as a low N_2 atmosphere & variable pressure suits required
  - Requires cooperation & discourse between vendors
  - Proprietary info, competition, fixed price contracts, etc make such discussions a challenge

- Lesson Learned: Facilitating communication and cooperative controls between vendors is critical to effective solutions

Planetary Prebreathe Protocol Testing and Validation at NASA

What is "Exploration Atmospheres"?

- Study to validate lunar prebreathe (denitrogenation) options
- 12-day study with subjects "living" in a 3-story 20' diameter chamber at about 15,000' altitude
- 5 simulated EVAs, to determine a minimal acceptable duration
- Lesson Learned: a clear and reasonable written DCS disposition policy helps dispel the angst (and effects) of reporting

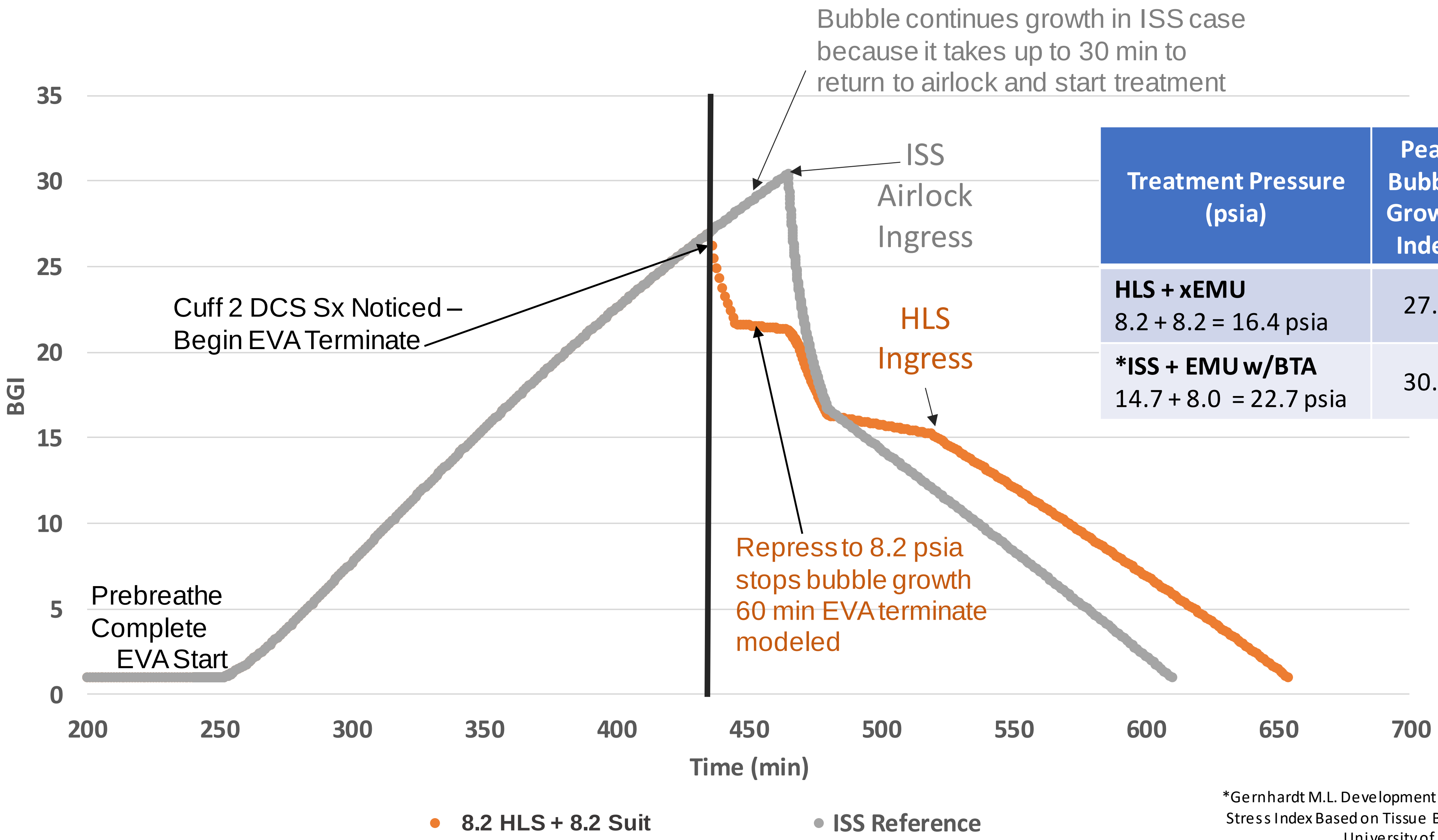
Creative Solutions: Suit as Chamber

- **Treatment: chamber vs. suit**
  - Remain in suit
  - Recognition and exam (training *and* reporting)
  - Specialized neuro (to allow for in-suit diagnosis)
  - For lunar: potential comm delays require autonomy

- **Pressure relationships:**
  - Terrestrial (Diving DCS & Treatment):
    - Symptoms occur at 14.7 psi
    - Treatment pressure is 41 - 88 psi (60-165 fsw)
    - 2.8 - 6x *increase* in pressure
  - On Orbit (Lunar DCS & Treatment):
    - Symptoms occur at 4.3 psi
    - Treatment pressure is up to 18.4 psia
    - 4.3x *increase* in pressure
    - Unknown/untested efficacy but >14.7 psia / GLO

GLO: ground level oxygen

Bubble Dynamics* Comparison ISS vs Exploration Capabilities

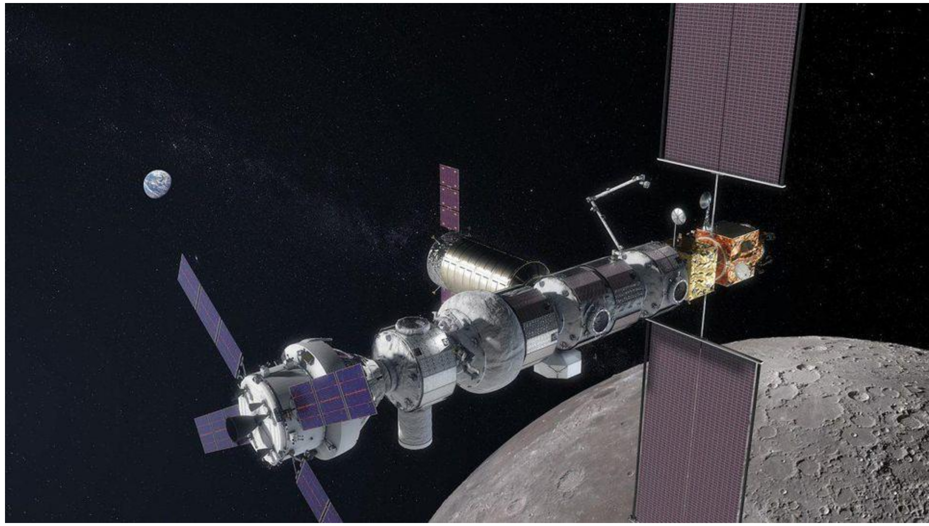


Treatment Pressure (psia)	Peak Bubble Growth Index	Time to Bubble Resolution from symptom onset (h:mm)
HLS + xEMU 8.2 + 8.2 = 16.4 psia	27.0	3:49 (60 min) 3:18 (30 min)
***ISS + EMU w/BTA** 14.7 + 8.0 = 22.7 psia	30.4	2:55

*Gernhardt M.L. Development and Evaluation of a Decompression Stress Index Based on Tissue Bubble Dynamics. Ph.D dissertation, University of Pennsylvania, UMI #9211935, 1991.

Conclusions

- **We can and will learn from each other**
  - Government/industry collaboration
- **Our missions may be different**
  - But people are the same
  - Risks and constraints are the same
- **We all need to work together and with industry to answer all the questions discussed today**




"How wonderful it is that nobody need wait a single moment before starting to improve the world." Anne Frank
Thank You
robert.w.sanders@nasa.gov

Backup Slides

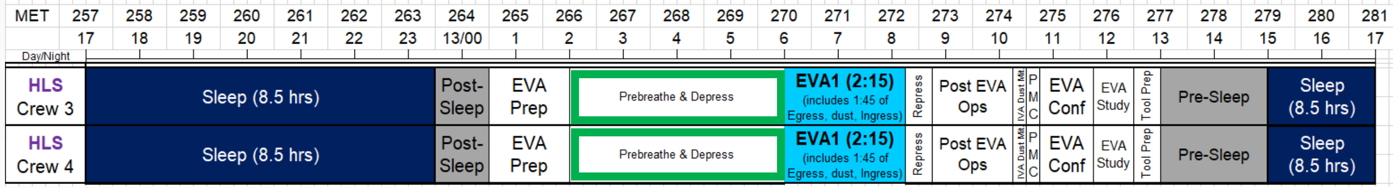
Artemis Mission Impacts to Prevent DCS

*Assumes 6hr EVA @ 4.3 psia and approximately equal DCS risk level

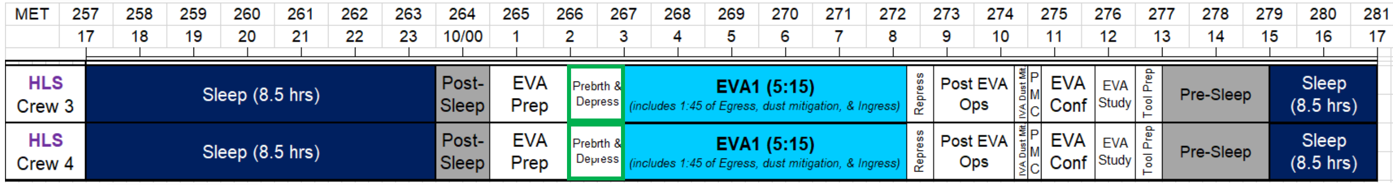
Saturation Atmosphere	Planetary Prebreathe*
14.7 psi, 21% O2	6:30-7:00 [2]
10.2 psi, 26.5% O2	3:00-3:30 [3]
8.2 psi, 34% O2	**0:20** [4,5]
5.0 psi, 100% O2 (Apollo, Gemini)	0:00

Unvalidated estimates (i.e., not yet available for flight)

Validated 2023



Notional Timeline with 10.2 psi / 26.5% O2 Atmosphere and 3h 30 min Prebreathe



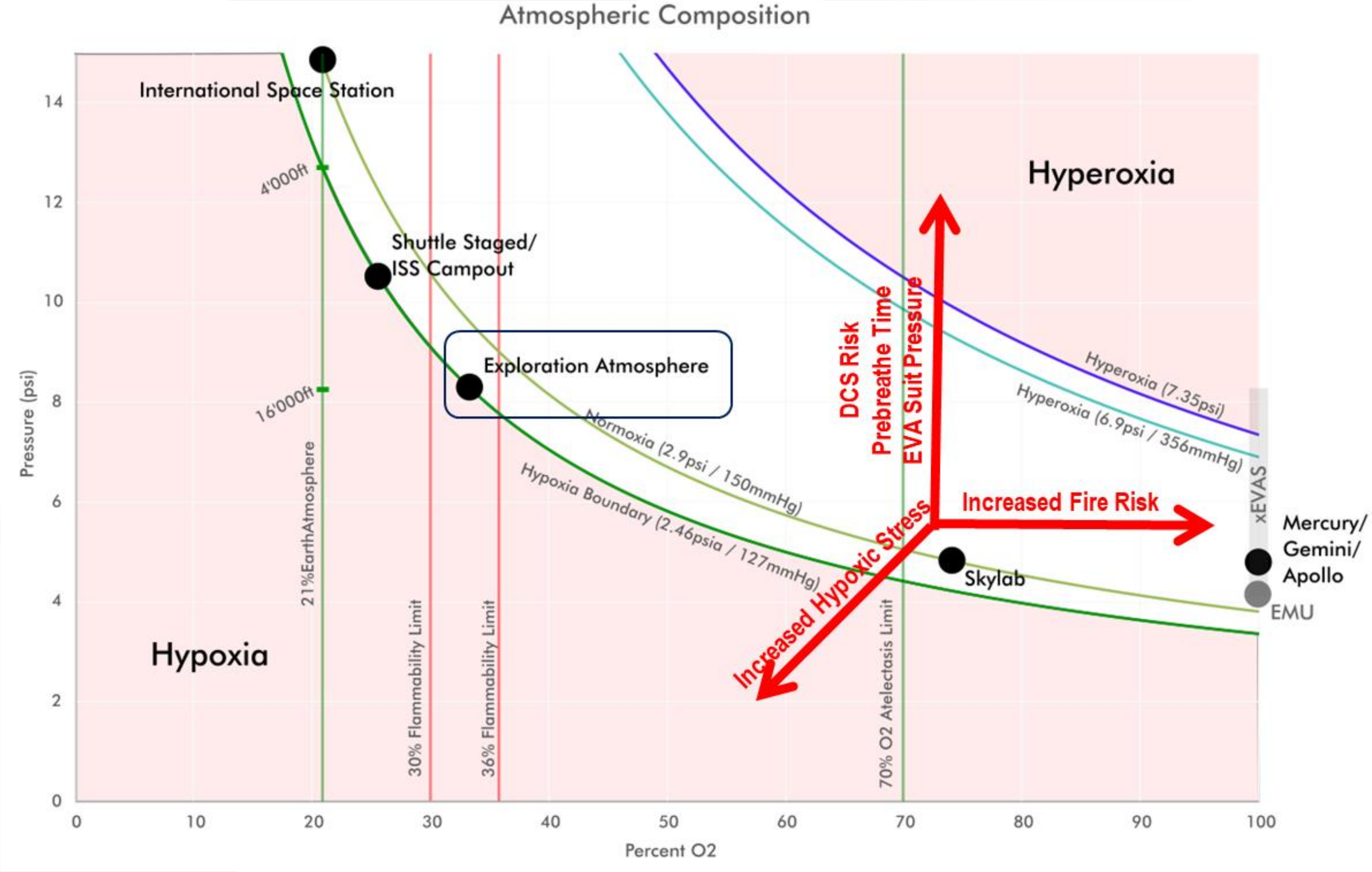
Notional Timeline with Exploration Atmosphere (8.2 psi / 34% O2), 30 min Prebreathe

Notes:

- *Notional timelines to demonstrate the impact of a longer prebreathe on EVA duration*
- *Suit Pressure remains 4.3 psi throughout*
- *Utilizes NASA-STD-3001 "<15% DCS @95% confidence" per person per EVA and verified by test*

[2] Abercromby et al. *Suited Ground Vacuum Chamber Testing Decompression Sickness Tiger Team Report,* (2019) NASA Technical Report. NASA/TP-2019–220343
[3] Abercromby et al. *Using the Shuttle Staged Prebreathe Atmosphere and Variable Pressure Spacesuits for Exploration Extravehicular Activity*, (2018) AsMA.
[4] Abercromby et al. *Modeling Oxygen Prebreathe Protocols for Exploration EVA Using Variable Pressure Suits,* (2017) AsMA.
[5] Abercromby et al. *Modeling a 15-min extravehicular activity prebreathe protocol using NASA's exploration atmosphere (56.5 kPa/34% O2)*. Acta Astronautica, 109 (2015), pp.76-87.

Artemis DCS Mitigation Process: *Start with Engineering Solutions*



- Low ppN_2 Atmosphere
  - 8.2 psia/34% O_2 for surface operations
  - Bounded by hypoxia and flammability (already optimized)
  - Flammable materials require Materials Usage Agreements (MUA)

- Variable Pressure Spacesuit
  - Capabilities required to enable Artemis missions
  - Government reference design has 4.3, 5.0, 6.2 and 8.2 psid