Open Atmospheres Forum
Exploration Atmospheres Validation Study

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Executive Summary

- The *Exploration Atmosphere Prebreathe Validation Studies* will validate prebreathe plans for Artemis to reduce decompression sickness (DCS) risk to acceptable levels*
  - Lunar EVA (walking) is significantly more provocative for DCS than microgravity EVA (floating) [1]
  - Shuttle & ISS protocols are therefore applicable to microgravity only
  - Apollo had 100% O2 cabin and zero EVA prebreathe; unacceptable flammability risk for Artemis
  - Artemis habitat and suit atmospheric parameters have not been finalized
- 20’ Hypobaric Chamber in B7 at JSC has been outfitted to support multi-day human testing
- Initial prebreathe validation studies have crew living at 8.2 psi, 34% O_2, 66% N_2 (aka “Exploration Atmosphere”)
- During simulated EVAs, chamber operates at 4.3 psi with subjects on O_2 masks
  - No pressurized suits will be used during the simulated EVAs
- Funded by EVA Program; multiple participating organizations
- **A 3-day hypobaric chamber evaluation with 6 subjects and 2 in-chamber technicians took place in May 2022**
- **An 11-day hypobaric chamber test with 6 subjects and 2 in-chamber technicians took place in June 2022**

- **DCS is a potential outcome of this testing**
  - Type I DCS is also a potential outcome during flight implementation per NASA STD-3001:
    ≤ 15% Type I DCS @ 95% statistical confidence; No Type II DCS
    ≤ 20% VGE (bubbles)
- **Purpose of test series is to ensure *acceptably low incidence* of Type I DCS, not zero DCS**

[1] Conkin et al. “Venous gas emboli and ambulation at 4.3 psia” Aerosp Med Hum Perform. 2017; 88(4):370–376.

Decompression Sickness (DCS)

- Decreasing ambient pressure causes release of nitrogen dissolved in tissues, which may result in DCS
  - **Grade IV VGE:** Venous Gas Emboli "Silent bubbles" (no symptoms or clinical findings) can be detected by Doppler; Grade IV is the most severe form, and is correlated with risk of DCS
  - **Type I DCS:** Joint pain; single extremity tingling or numbness; mild skin symptoms
  - **Type II DCS:** Central neurological or cardiopulmonary symptoms; can be life-threatening
- Pre-EVA denitrogenation via oxygen prebreathe *reduces* DCS risk during EVA

Flight prebreathe protocols must be validated via human ground testing prior to operational implementation

Why Exploration Atmosphere?

- Significantly increased frequency of EVAs is expected during planetary ops vs. ISS
  - Up to 24 hrs / person / week
- DCS risk is increased by ambulation and physical activity vs microgravity[1]

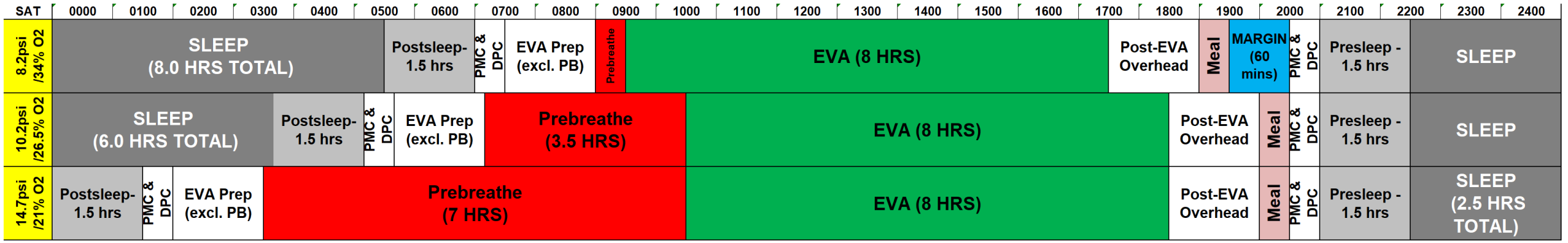
Current ISS prebreathe protocols would add significant timeline overhead and are NOT validated for planetary EVA

– Shuttle & ISS protocols are applicable to microgravity only

Apollo had 100% O_2 cabin and zero EVA prebreathe

[1]Conkin J, et al. Venous gas emboli and ambulation at 4.3 psia. Aerosp Med Hum Perform. 2017; 88(4):370–376.

Timeline Implications



- Timelines are notional and for purposes of comparison only
- All prebreathe durations are model-based estimates [2-4]
- Detailed depress profiles being worked with CX3

Exploration conops are incompatible with multi-hour prebreathe durations

[2] Abercromby et al. *"Suited Ground Vacuum Chamber Testing Decompression Sickness Tiger Team Report"*, 2018 NASA Technical Report
[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.

Rationale for Exploration Atmosphere

Saturation Atmosphere	Microgravity Prebreathe* (h:mm)	Planetary Prebreathe*
14.7 psi, 21% O2	4:00 (resting)	6:30-7:00 [2]
10.2 psi, 26.5% O2	0:40	3:00-3:30 [3]
8.2 psi, 34% O2	**0:00-0:15**	**0:00-0:30** [4,5]
5.0 psi, 100% O2 (Apollo, Gemini)	0:00	0:00

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

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

[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.

Research Goals

Primary Research Goal

1. **Prebreathe Validation (H3PO)**

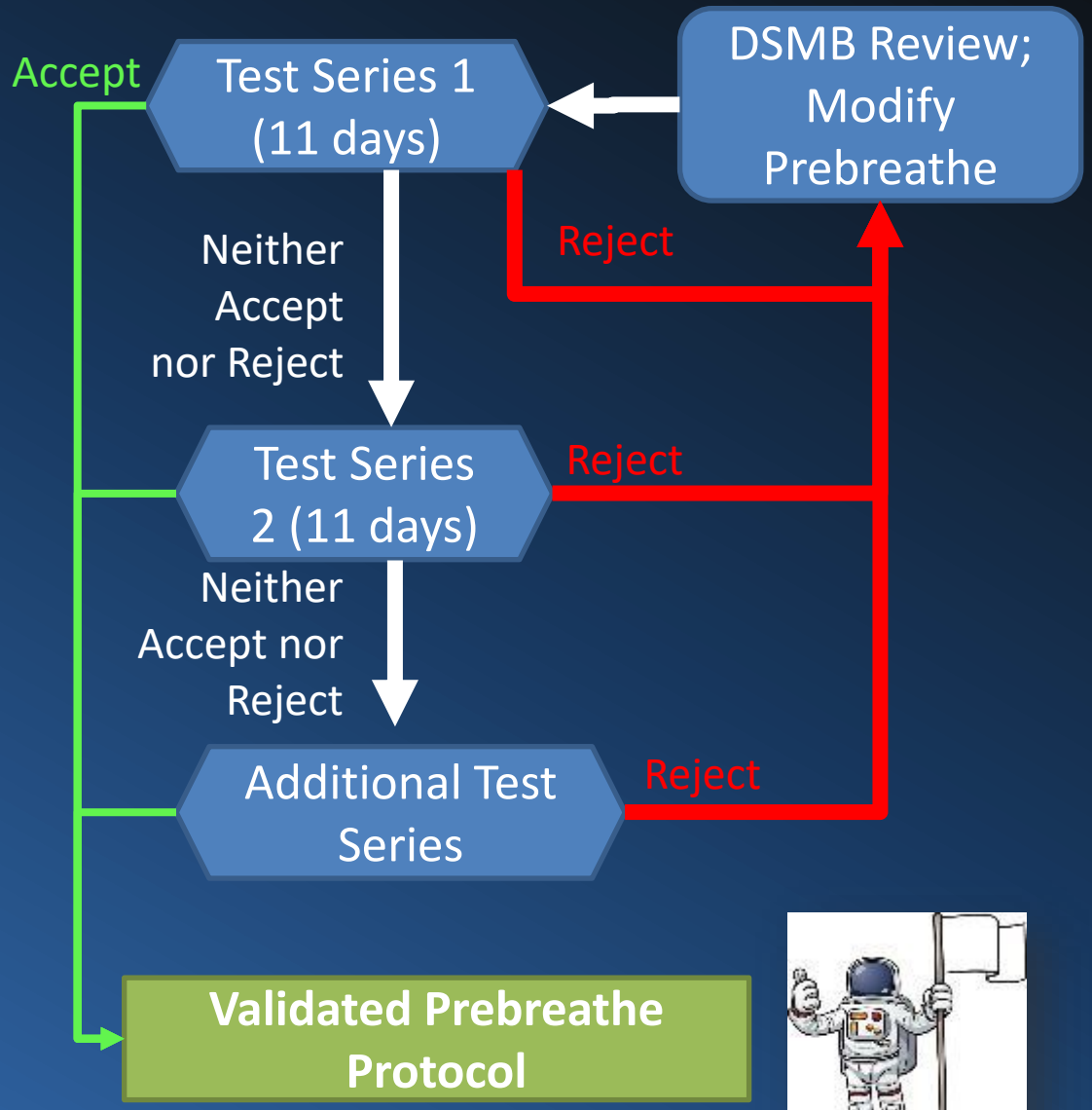
Secondary Research Goals

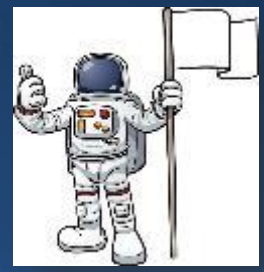
2. Response/Recovery from Mild Exercise (H3PO)
3. Visual Acuity and Contrast (H3PO)
4. Acute Mountain Sickness Symptoms (H3PO)
5. Performance during EVA Simulations (H3PO)
6. Physiological Reponses of Hypobaric Hyperoxic Environment (Cardiovascular and Vision Lab)
7. Hematology/Immunology/Inflammatory Response (Immunology Lab)
8. Oxidative Damage (Nutritional Biochemistry Lab)
9. Appetite and Food Intake Impacts (Space Food Systems Lab)
10. Sleep Quality and Duration Impacts (Behavioral Health and Performance Lab)
11. Neurocognitive and Functional Responses (Behavioral Health and Performance Lab)
12. Habitability Acceptability (HFEL/CDSA)

Exploration Atmosphere Validation

- Accept Criteria (per NASA-STD-3001):
  - ≤ 15% incidence of Type I DCS (@95% CL)
  - ≤ 20% incidence of Grade IV VGE (@95% CL)
  - No Type II DCS
- Reject Criteria
  - > 15% incidence of Type I DCS (@70% CL)
  - > 20% incidence of Grade IV VGE (@70% CL)
  - Any Type II DCS
- Neither
  - Requires review and additional data

- We can accept the protocol with:
  - *no* DCS in 19 exposures
  - 1 DCS in 30 exposures



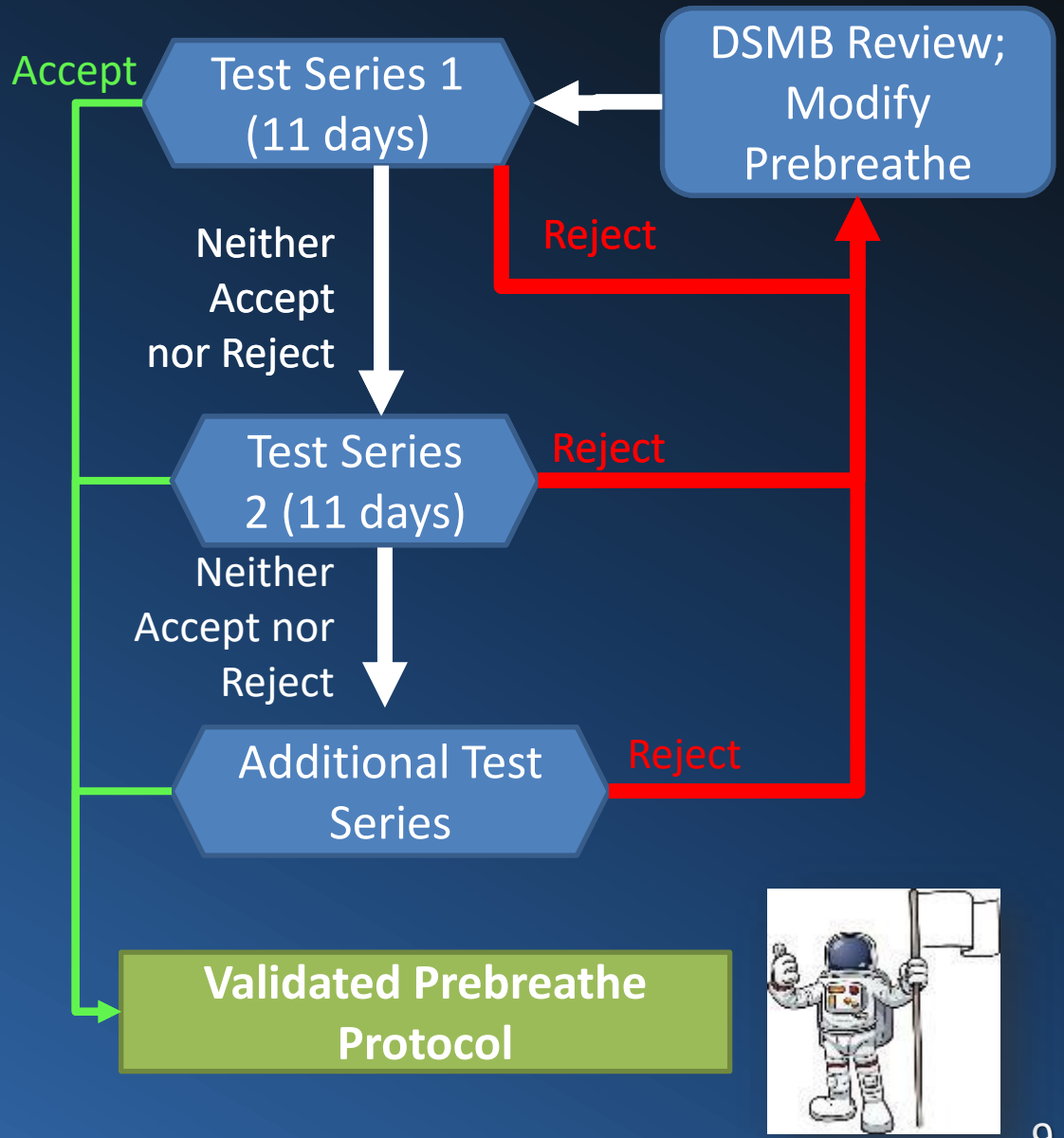


DSMB: Data Safety Monitoring Board

Expected Results

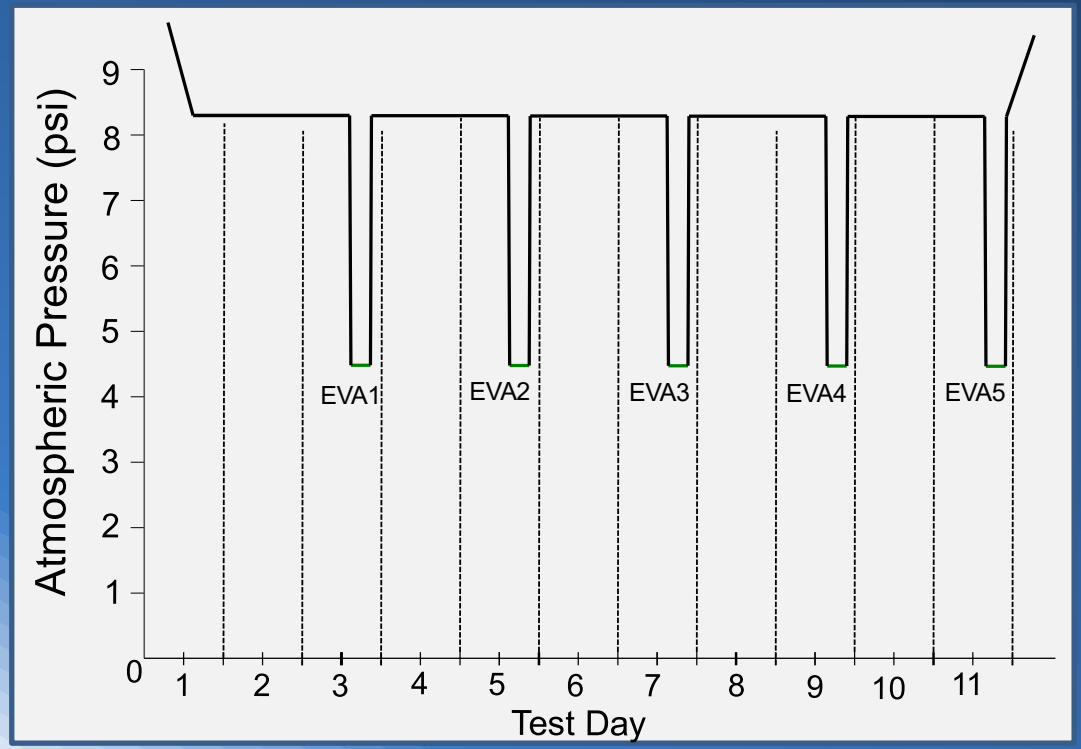
- **DCS is a potential outcome of this testing**
  - 24/7 medical coverage, and dual coverage w/ docs in-person during EVAs
  - Portable hyperbaric (treatment) chamber will be located inside B7 to enable immediate DCS treatment if required
  - Protocol is IRB approved
  - External Data Safety Monitoring Board providing additional oversight

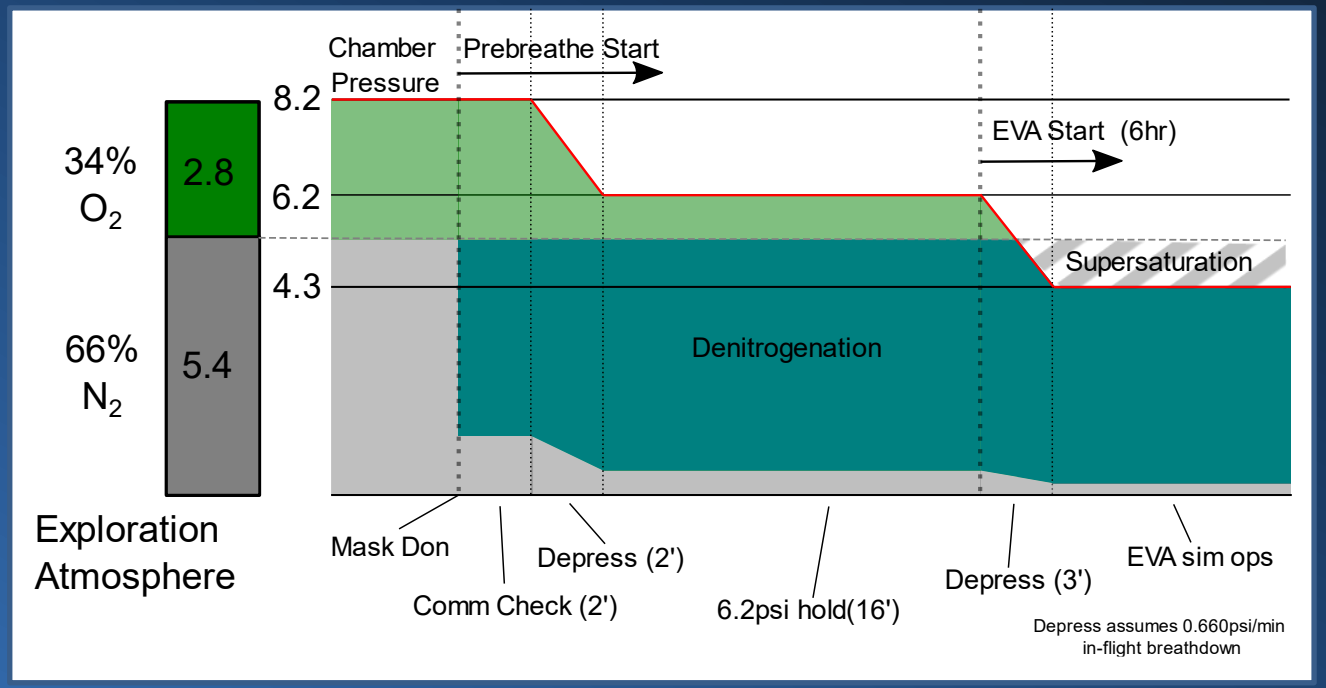
- **Approach is based on (and consistent with) Shuttle & ISS prebreathe protocol validation testing**



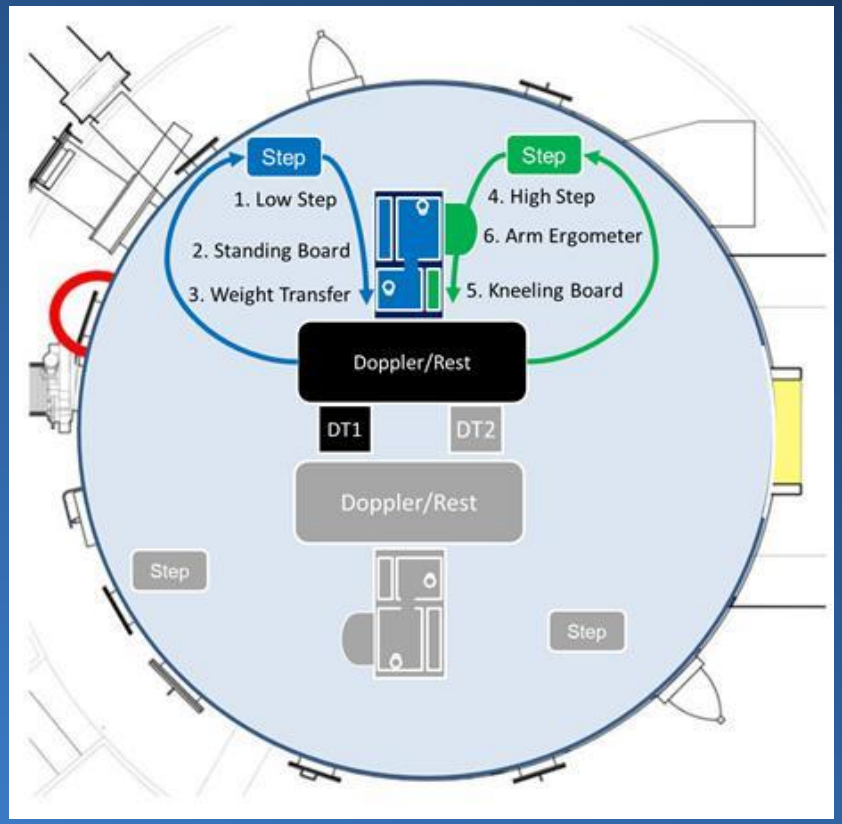
Prebreathe Validation Approach

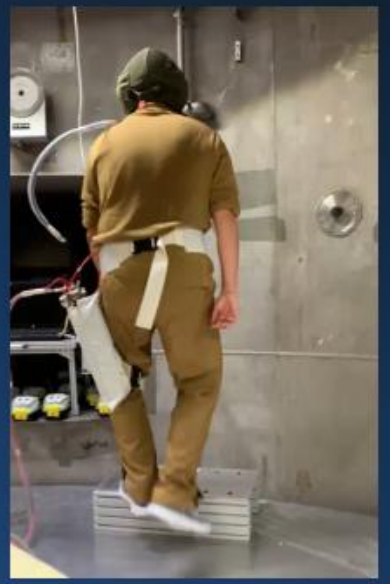
- What prebreathe is sufficient to meet NASA-STD-3001 standards in a Lunar/Mars environment?
  - Equilibrate to Exploration Atmosphere: 8.2psi/34% O_2 for 48 hrs
  - Minimum prebreathe duration: 20 min ≥ 6.2psi
  - Simulated EVA: 4.3psi/85% O_2
  - Simulate EVA workload: 6 tasks for 6hrs across workload ranges





EVA Simulation





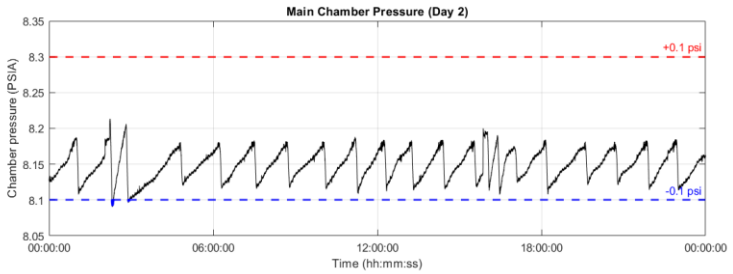
Characterize Adaption to Exploration Atmosphere

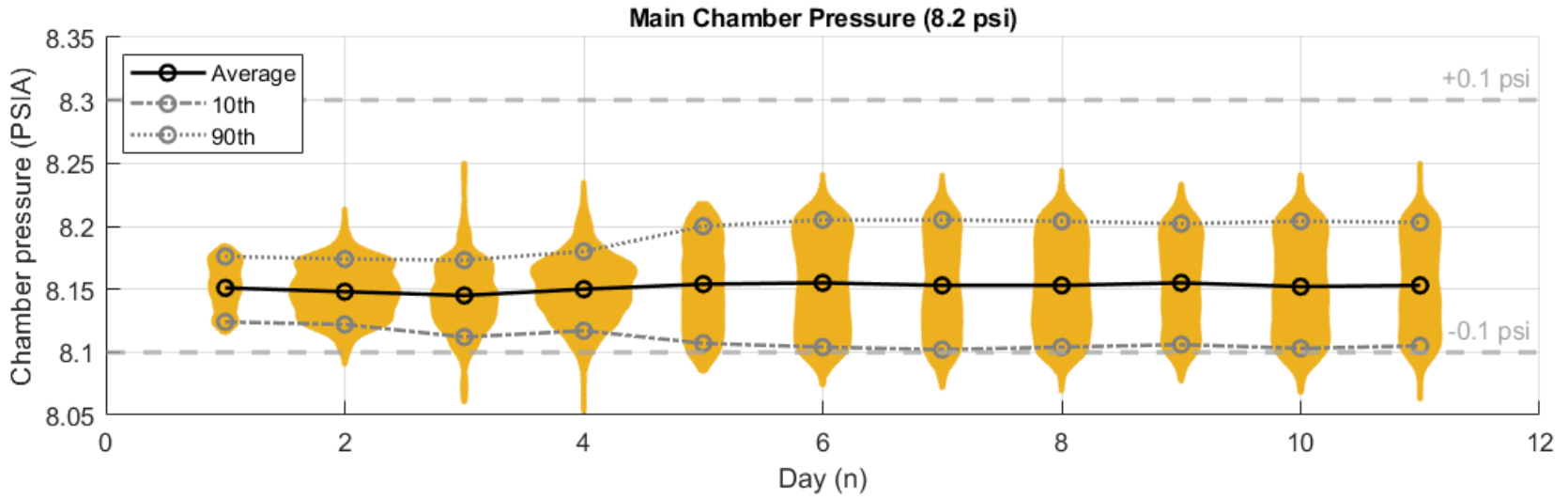
- Hypoxic stress:
  - PiO_2 = 128mmHg
    - Equivalent Air Altitude: 4000ft
  - PCO_2 < 3mmHg
- Early look at potential Artemis concerns:
  - Materials/Flammability mitigation
  - Food system
  - Procedures

OUTCOMES

11-day Study Chamber Pressure

- Average Habitat pressure: 8.15psi (target 8.2psia +/- 0.1)
  - Time outside limits: 0-103 min/day (goal ≤2 hrs/day) **Within Goals**
    - Longest excursion: 15min



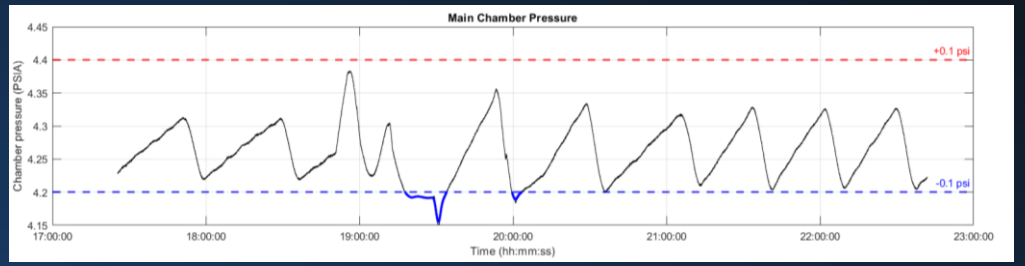


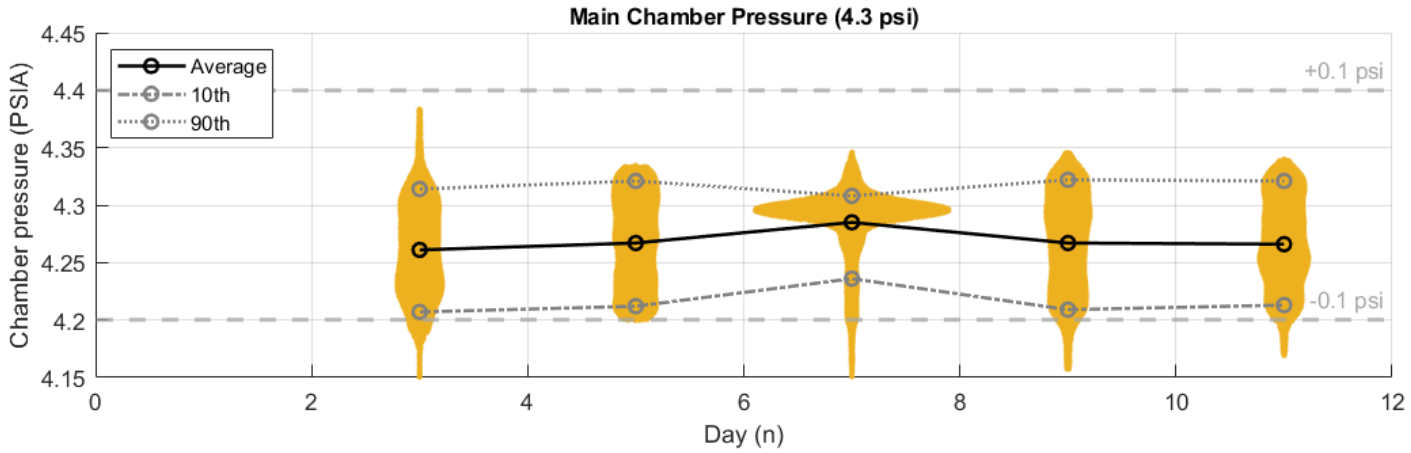
	1	2	3	4	5	6	7	8	9	10	11
Average (PSIA)	8.1510	8.1480	8.1450	8.1500	8.1540	8.1550	8.1530	8.1530	8.1550	8.1520	8.1530
10th (PSIA)	8.1240	8.1220	8.1120	8.1170	8.1070	8.1040	8.1020	8.1040	8.1060	8.1030	8.1050
90th (PSIA)	8.1760	8.1740	8.1730	8.1800	8.2000	8.2050	8.2050	8.2040	8.2020	8.2040	8.2030
Max (PSIA)	8.1900	8.2130	8.2500	8.2350	8.2180	8.2410	8.2400	8.2440	8.2330	8.2400	8.2500
Min (PSIA)	8.1090	8.0910	8.0610	8.0530	8.0850	8.0740	8.0720	8.0700	8.0770	8.0680	8.0630

11-day Study Chamber Pressure – EVA Sims

- Average EVA pressure: 4.27psi (target 4.3psia +/- 0.1)
  - Time outside limits: 0-20min/EVA (goal ≤2 min/EVA)
    - Longest excursion 16min

Within Goals

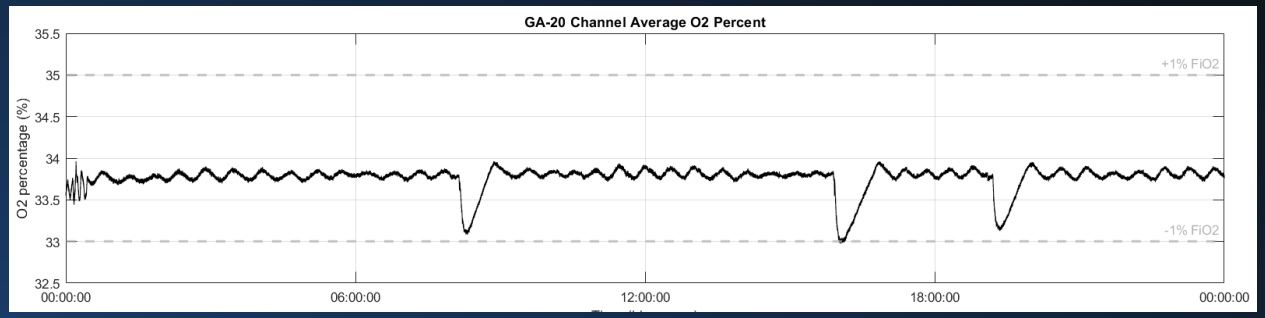




	3	5	7	9	11
Average (PSIA)	4.2610	4.2670	4.2850	4.2670	4.2660
10th (PSIA)	4.2070	4.2120	4.2360	4.2090	4.2130
90th (PSIA)	4.3140	4.3210	4.3080	4.3220	4.3210
Max (PSIA)	4.3830	4.3350	4.3460	4.3460	4.3400
Min (PSIA)	4.1470	4.1990	4.1280	4.1570	4.1690

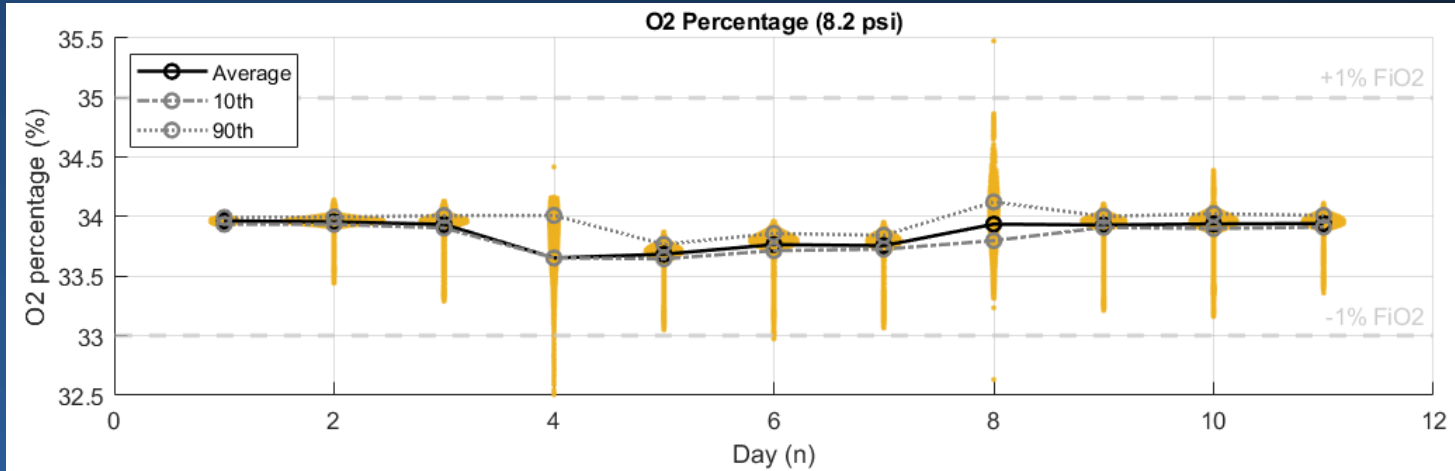
11-day Study Chamber Oxygen

- Average Chamber O2: 33.96% (target 34% +/-1%)
  - 10th-90th percentile: 33.78-34.17%
  - Allowed excursion: 30min/day (chamber average)
    - Longest excursion: 26 min
- ***Oxigraf calibration still being characterized***
  - **Single** gas grab sample 30.25% (Gas Lab)
  - If chamber was ***actually*** at 8.15psi, 30.25% FiO2:
  - EAA: 4000 ft -> 6500 ft
  - P(DCS): 2.7% -> 3.9% per exposure



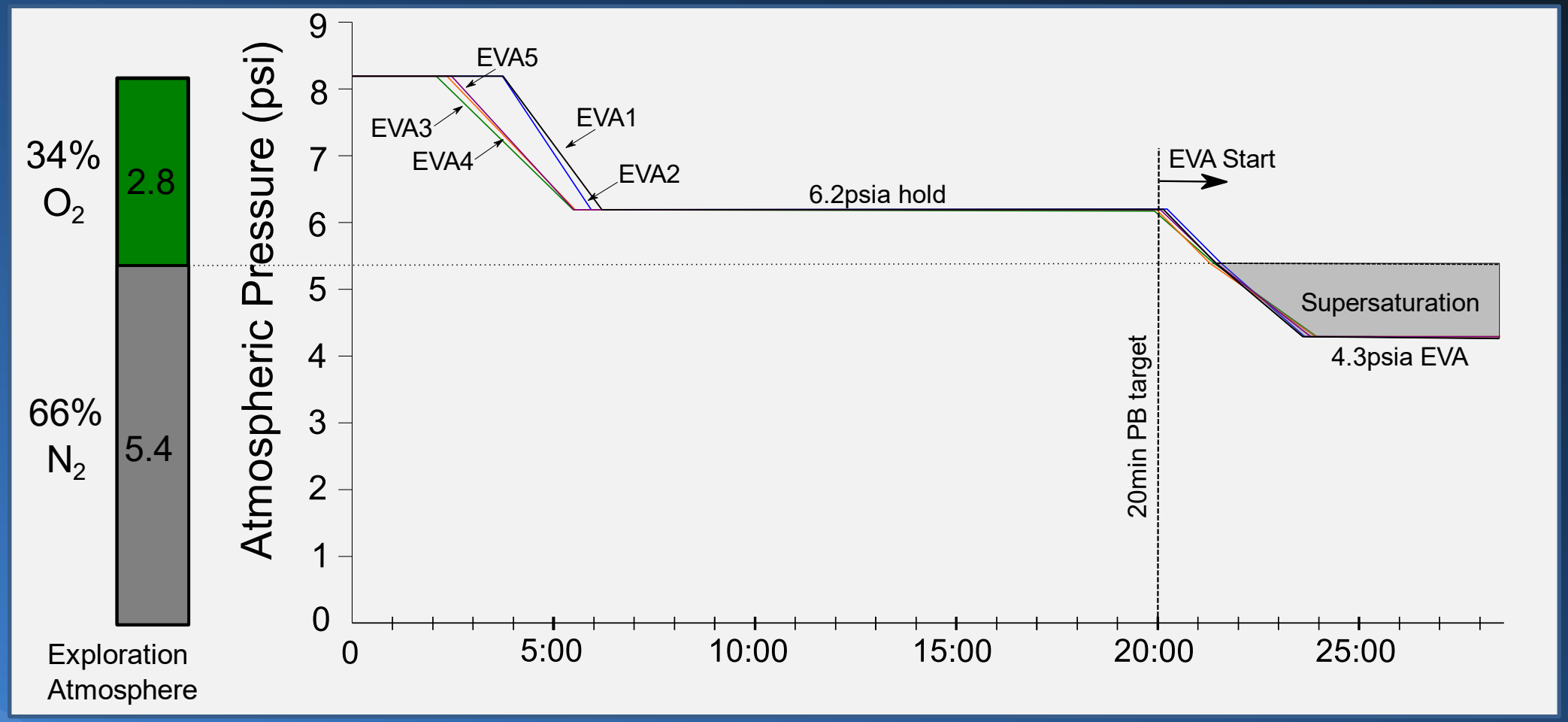
Even if O_2 levels were lower than intended, results are still applicable to Exploration Atmosphere; flight atmosphere would be more protective

Forward work:
EC4-EHP FY23 ITA being developed to understand & resolve O2 measurement/ monitoring methods



	1	2	3	4	5	6	7	8	9	10	11
Average (%)	33.9649	33.9572	33.9360	33.6538	33.6855	33.7660	33.7575	33.9376	33.9307	33.9398	33.9432
10th (%)	33.9362	33.9361	33.9054	33.6542	33.6465	33.7150	33.7276	33.7993	33.9102	33.9007	33.9128
90th (%)	33.9939	33.9978	34.0093	34.0111	33.7680	33.8603	33.8438	34.1242	34.0031	34.0254	34.0108
Max (%)	34.0409	34.1430	34.1314	36.0516	33.8733	33.9640	33.9540	47.6383	34.1085	34.3898	34.1133
Min (%)	33.8884	33.4401	33.2897	24.1942	33.0508	32.9748	31.4106	22.0968	33.2129	33.1615	33.3588

Was the prebreathe within parameters?



Prebreathe Times:
EVA1: 20min 14 sec
EVA2: 20min 21 sec
EVA3: 20min 01 sec
EVA4: 20min 04 sec
EVA5: 20min 10 sec

*Transition from 6.2 psi to 5.4 psi (supersateration point) added ~80-90 sec

EVA Summary: Preliminary DCS Data

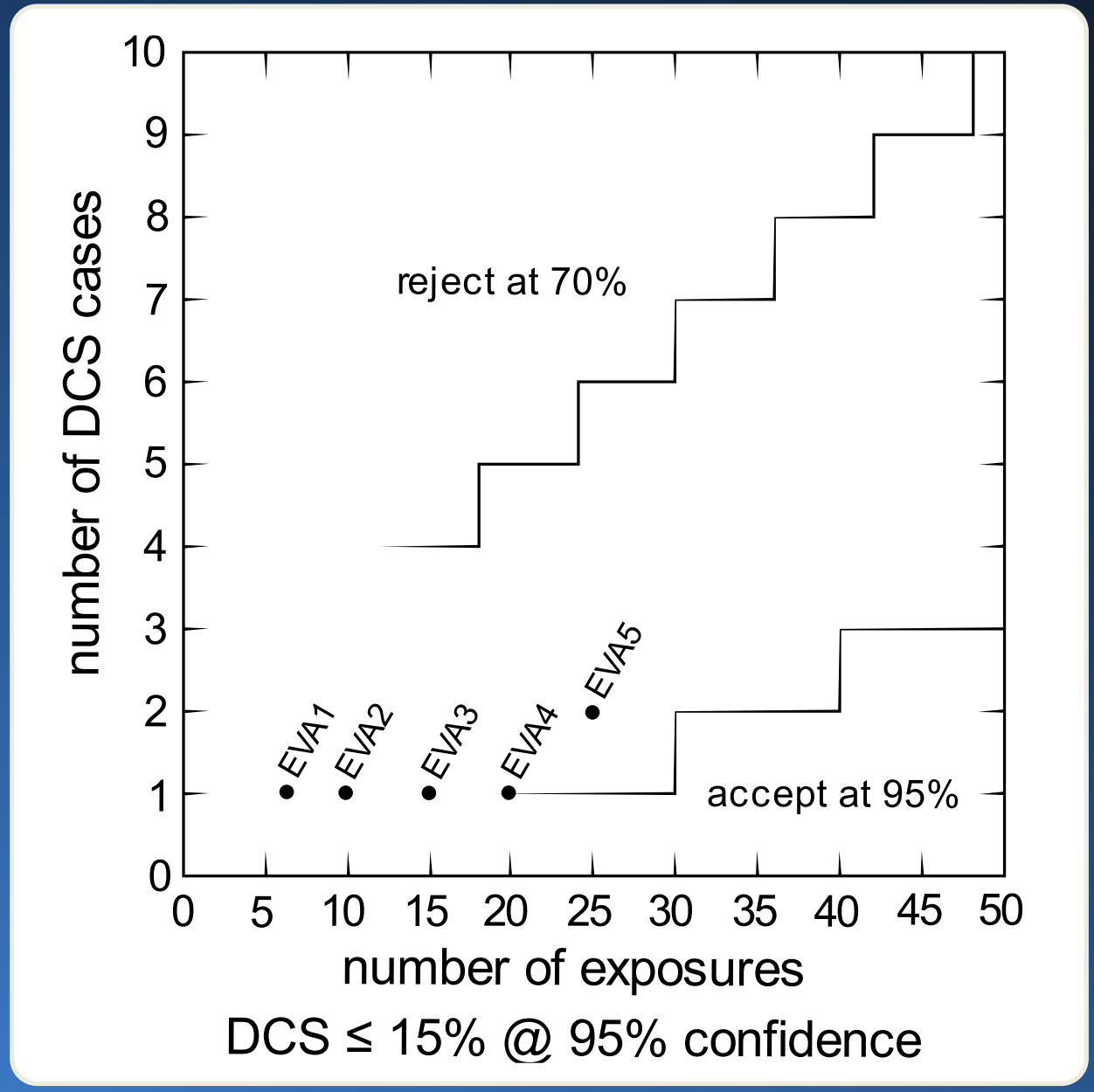
DCS Incidence rate during 11-day study:

- **EVA 1**: 6 subjects participated, 1 DCS case
- **EVA 2**: 4 subjects participated, no DCS*
  - 1 subject sat out EVA per protocol on ground level oxygen due to DCS on EVA1
  - 1 subject sat out EVA due to mask fit issues
- **EVA 3**: 5 subjects participated, no DCS
  - 1 subject sat out EVA due to mask fit issues
- **EVA 4**: 5 subjects participated, no DCS
  - 1 subject sat out EVA due to musculoskeletal issues
- **EVA 5**: 6 subjects participated, 1 DCS case
  - 1 subject excluded due to musculoskeletal issues

Summary: 2 DCS cases out of 25 total simulated EVAs during the 11-day study (8% DCS)

* DCS case in Doppler Technician – not a study subject

EVA Summary: Preliminary DCS Data



DCS ≤ 15% @ 95% confidence

EVA Summary: Preliminary Venous Gas Emboli Data

Venous Gas Emboli (VGE) ≥ Grade IV incidence rate during 11-day study:

- **EVA 1**: 6 subjects participated, 0 VGE IV
- **EVA 2**: 4 subjects participated, 0 VGE IV
- **EVA 3**: 5 subjects participated, 0 VGE IV
- **EVA 4**: 5 subjects participated, 0 VGE IV
- **EVA 5**: 5 subjects participated, 0 VGE IV

Grade IV VGE: Venous Gas Emboli "Silent bubbles" (no symptoms or clinical findings) can be detected by Doppler; Grade IV is the most severe form, and is correlated with risk of DCS

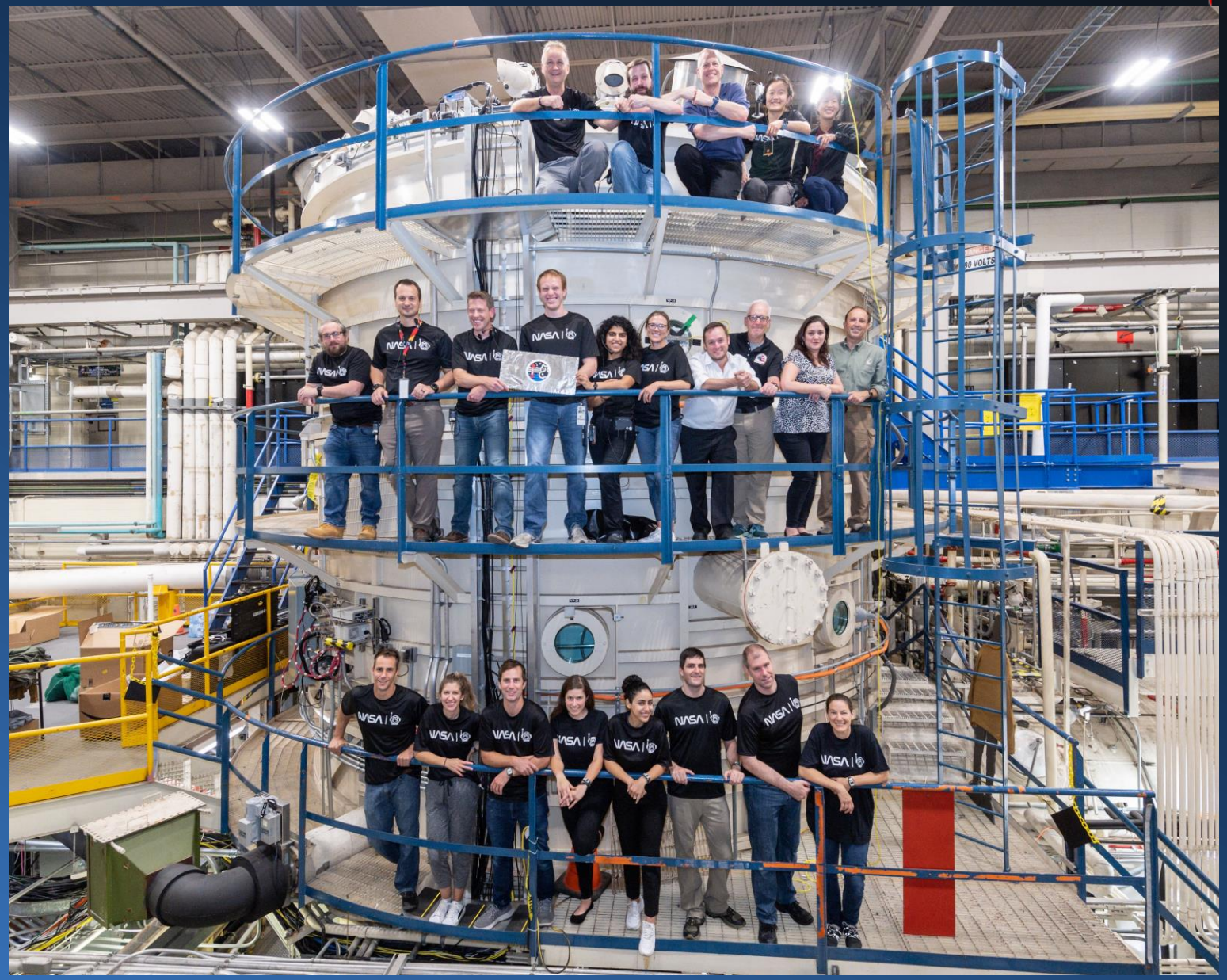
Conclusion

- Successfully carried out 11-day test
  - Chamber pressure parameters within goal
  - Chamber oxygen parameter within control band, but reviewing sensor calibration
  - Prebreathe duration within seconds of target duration
  - No DCS Type II
  - Two DCS Type I cases; symptoms fully resolved
  - Excellent cross-organization teamwork and integration of test support teams
- Lessons Learned
  - 1-day and 3-day tests extremely valuable for test team, subjects, and protocol verification
  - Several subjects with mask fit problems
  - Sleep timing and accommodations borderline – implemented schedule fixes, but forward work on bunks
  - Various habitability tweaks to implement on future runs (hygiene system, etc)
  - Importance of backup subjects/critical test team members realized due to COVID surge

Next Steps

- Finalize post-11-day test:
  - Resolve O2 sensor issues
  - Review pressure control mechanism
    - Possible to adjust control logic to oscillate 8.15-8.25psi instead of 8.10-8.20?
    - Consider tweaking low bias on 4.3psi set point
  - Maintain proficiency of all test personnel
    - Consider short test to review sensors and maintain proficiency
  - Complete data analysis for secondary measures
    - Will we need further 'hypoxia characterization' testing?
- Provide study debrief and 'data quick look' at multiple forums ('roadshow')
- Determine objectives and schedule for next chamber tests
  - Aiming for ~two 11-day chamber tests per year
- Establish and kick-off 'Open Atmospheres' research forum to cross-pollinate across DCS research groups

Thank you!



Thank you!

LINK to WALKAROUND VIDEO

BACKUP SLIDES

VGE grading

- VGE IV audio clip
- ?E-B grades videos?

Protocol: EVA Simulations

- Odd Days: EVA Simulations (N_{EVA} = 5)
  - Subjects don masks and breathe 85% O_2 during 15 min depress to 4.3 psia.
    - DTs prebreathe 100% O_2 for 30min prior to depress
  - Complete 6 hrs of prescribed simulated EVA activities
  - Rest + noninvasive Doppler bubble monitoring every 15 min during the EVA simulation
  - 15-min repressurization to return all subjects and DTs back to 8.2 psia

Day 1	3hr PB @ 100% O2, 14.7 psia; Depress to 8.2 psia, equilibrate
Day 2	Equilibrate + Hypoxia Characterization
Day 3	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 4	
Day 5	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 6	
Day 7	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 8	
Day 9	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 10	
Day 11	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2

Protocol: Hypoxia Characterization

- Even Days:

  Rest + Hypoxia Characterization

  – Various physiologic and cognitive measurements will be taken to characterize the effects of hypobaric hypoxia in the exploration atmosphere.

Day 1	3hr PB @ 100% O2, 14.7 psia; Depress to 8.2 psia, equilibrate
Day 2	Equilibrate + Hypoxia Characterization
Day 3	
Day 4	Hypoxia Characterization
Day 5	
Day 6	Hypoxia Characterization
Day 7	
Day 8	Hypoxia Characterization
Day 9	
Day 10	Hypoxia Characterization
Day 11	

Requirements

Day	Pressure c	Average	10th	90th	Max	Min	# excursions	Excursion total time (minutes)	Longest individual excursion (min)
Day1	8.2	8.151468	8.123692	8.176414	8.189722	8.109277	0	0	0
Day2	8.2	8.148438	8.122054	8.174355	8.213481	8.0905	2	5	3
Day3	8.2	8.144571	8.112355	8.173159	8.249884	8.060608	5	30	15
Day4	8.2	8.149828	8.116983	8.179824	8.234517	8.053345	10	26	5
Day5	8.2	8.153581	8.106864	8.200306	8.217888	8.08492	26	44	3
Day6	8.2	8.154723	8.103963	8.204823	8.240783	8.07396	42	86	4
Day7	8.2	8.152825	8.102258	8.205355	8.24034	8.0721	31	75	5
Day8	8.2	8.153376	8.104406	8.203672	8.244127	8.069531	40	81	7
Day9	8.2	8.155236	8.106487	8.202011	8.23321	8.07717	22	37	4
Day10	8.2	8.152311	8.1029	8.203606	8.240473	8.068313	40	103	7
Day11	8.2	8.153388	8.104926	8.202986	8.249773	8.062888	27	51	7
Day3	4.3	4.26148	4.207428	4.31369	4.383462	4.146558	2	20	16
Day5	4.3	4.267084	4.211723	4.3214	4.334703	4.199368	0	0	0
Day7	4.3	4.284709	4.23575	4.308487	4.346351	4.127626	3	9	4
Day9	4.3	4.266711	4.208845	4.321883	4.345642	4.157009	3	14	9
Day11	4.3	4.266467	4.212786	4.320842	4.340239	4.168789	1	6	6

3.16 Pressurization & Control

3.16.1 Maintain 8.2 psia

The 20-foot Facility shall maintain the internal atmosphere at 8.2 psia + / - 0.1 psia. Fluctuations of 0.1 psia above and below the nominal range of 8.2 psia + / - 0.1 psia are allowed for a cumulative time not to exceed 2 hours per day.

Justification: Needed to simulate expected spacecraft performance.

3.16.2 Maintain 6.2 psia

The 20-foot Facility shall maintain the internal atmosphere at 6.2 psia + / - 0.1 psia. Fluctuations of 0.2 psia above and below the nominal range of 6.2 psia + / - 0.1 psia are allowed for no more than 2 minutes.

Justification: Needed to simulate expected spacecraft and space suit performance.

3.16.3 Maintain 4.3 psia

The 20-foot Facility shall maintain the internal atmosphere at 4.3 psia + / - 0.1 psia. Fluctuations of 0.1 psia above and below the nominal range of 4.3 psia + / - 0.1 psia are allowed for no more than 2 minutes.

Justification: Needed to simulate expected space suit performance.

3.16.4 Maintain Nitrogen (N2) / Oxygen (O2) Concentration at 8.2 psia

The 20-foot Facility shall maintain the internal atmosphere at 34% O2 / 66% N2 (+ / - 1% each) during 8.2 psia operations. Fluctuations of 1% above and below the nominal range of 34% O2 / 66% N2 (+ / - 1% each) are allowed for a cumulative time not to exceed 30 minutes per day.

Justification: Needed to simulate expected spacecraft performance.

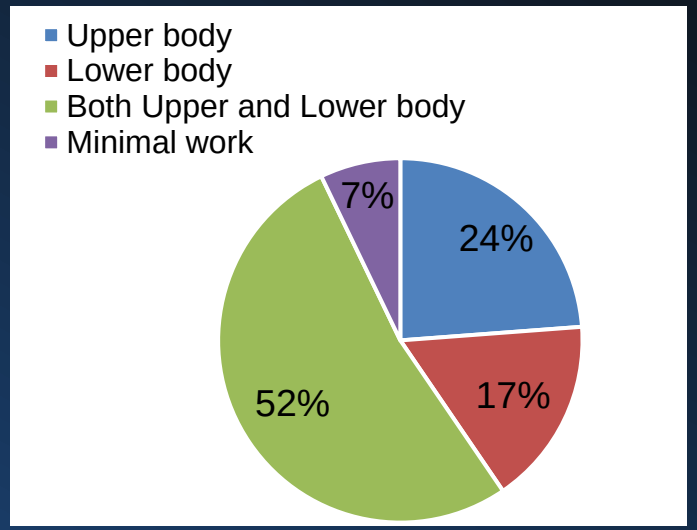
3.16.5 Set Nitrogen (N2) / Oxygen (O2) Concentration at 8.2 psia

The 20-foot Facility shall be capable of stabilizing the internal atmosphere at 34% O2 / 66% N2 (+ / - 1% each) within 15 minutes once a stable pressure of 8.2 psia is obtained.

Justification: Needed to simulate expected spacecraft performance.

EVA Simulation – Rationale for Tasks

- 61 exploration EVA tasks[2] were decomposed into 126 subtasks then characterized by functional requirements of each subtask
- **Categories:**
  - **Body Positioning:** Seated, Kneeling, Standing, Mobile, etc.
  - **Muscle Groups:** Whole/Both, Upper, Lower
  - **Ambulation:** None, Walking, Walking (terrain), Walking (slopes), Crawling, Climbing
  - **Loading Bearing:** None, Carrying, Pushing/Pulling, Attached to Suit
  - **Loads:** None, Minimal (<5 lbs), Variable, Heavy (>30 lbs)
  - **Upper Body Reach (Workspace):** None, Standard, Extended
  - **Hand Usage:** None, Fine Motor Skills, Grip Strength, Vibration, Shock, Other/Combination
  - **Task Occurrence:** Rare (<10% of EVAs), Some (~30%), Many (~50%), Most (~75%), Nearly All (>90%)
  - **Task Duration (expected)**
  - **Task Frequency:** 1-2 times per EVA, Every 2 hours during EVA, Every hour during EVA, 1-30 minutes during EVA



Parent Task Title	Children of the Parent Task	Load Bearing Type	Upper Body Loads	Upper Body Reach	Fine Motor / Grip	Task Occurrence	Task Duration	Task Frequency
Offload Equipment from Landers	mobile, upper and lower body work	Carrying Load	Variable Load (minimal to heavy)	Extended Workspace	Grip Strength	Rarely Occurs in any EVA (<10%)	5-15 minutes	Every 1-30 minutes during EVA
Offload Equipment from Landers	mobile, upper and lower body work	Pushing / Pulling Load	Heavy Load (> 30 lbs.)	Extended Workspace	Grip Strength	Rarely Occurs in any EVA (<10%)	5-15 minutes	Every 1-30 minutes during EVA
Load Equipment onto Rovers	mobile, upper and lower body work	Carrying Load	Variable Load (minimal to heavy)	Extended Workspace	Grip Strength	Occurs in many EVAs (~50%)	5-15 minutes	Every ~1 hr during EVA
Clean Equipment	stationary, upper body work while kneeling	No Load	No Significant Loading	Extended Workspace	Fine Motor	Occurs in some EVAs (~30%)	15-60 minutes	Total of 1-2 times during EVA
Clean Equipment	stationary, upper body work while standing	No Load	No Significant Loading	Extended Workspace	Fine Motor	Occurs in most EVAs (~75%)	15-60 minutes	Total of 1-2 times during EVA
Conduct Visual Inspection / Examine Surroundings	mobile, ambulation	No Load	No Significant Loading	None	Fine Motor	Occurs in nearly all EVAs (90-100%)	1-5 minutes	Every 1-30 minutes during EVA
Conduct Visual Inspection / Examine Surroundings	seated	No Load	No Significant Loading	None	None	Occurs in nearly all EVAs (90-100%)	1-5 minutes	Every ~1 hr during EVA
Conduct Photo Documentation	stationary, upper body work while kneeling	Other / Unknown	Minimal Load (less than 5 lbs.)	Standard Workspace	Fine Motor	Occurs in nearly all EVAs (90-100%)	1-5 minutes	Every 1-30 minutes during EVA
Conduct Photo Documentation	stationary, upper body work while standing	Other / Unknown	Minimal Load (less than 5 lbs.)	Standard Workspace	Fine Motor	Occurs in nearly all EVAs (90-100%)	1-5 minutes	Every 1-30 minutes during EVA

[2]Coan D. Exploration EVA System Concept of Operations. NASA TR, EVA-EXP-0042 RevB. 2020

EVA Simulation – Final Task Circuit

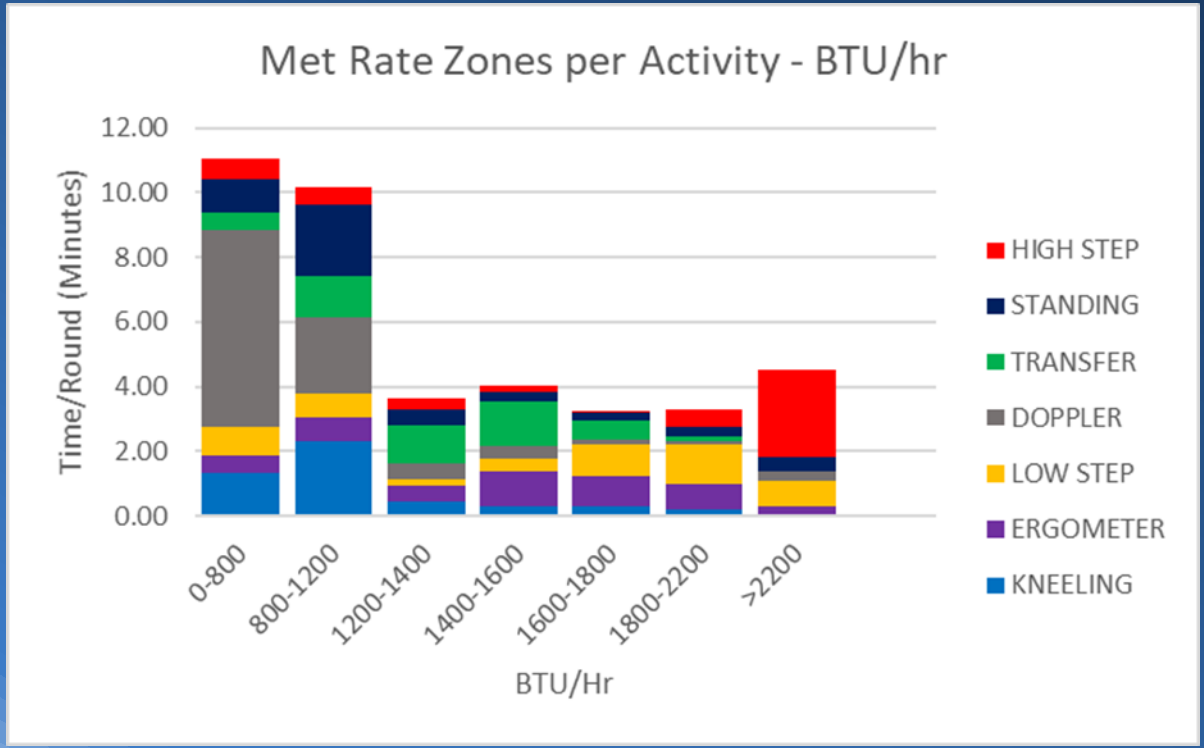
- Navigate, ascend/descend, and traverse terrain
  - Step-ups (low and high): lower/full body task, no powered equipment required, can alter workload with step size and cadence
- Retrieve, transport, and stow equipment/tools
  - Weight transfer: mobile whole-body task
- Collect samples, conduct repairs, or install connectors
  - Kneeling task board: stationary task, mild cognitive engagement
  - Standing task board: stationary task, mild cognitive engagement
- Deploy/operate experimental package
  - Arm ergometer: stationary upper body task, can standardize workload with rpm and resistance
- Target: Maintain an average of 30-40% VO_2max[3-5]
  - High-step included a fast 2-min period (70%), as high levels of activity have been shown to highly correlate with DCS risk[6]

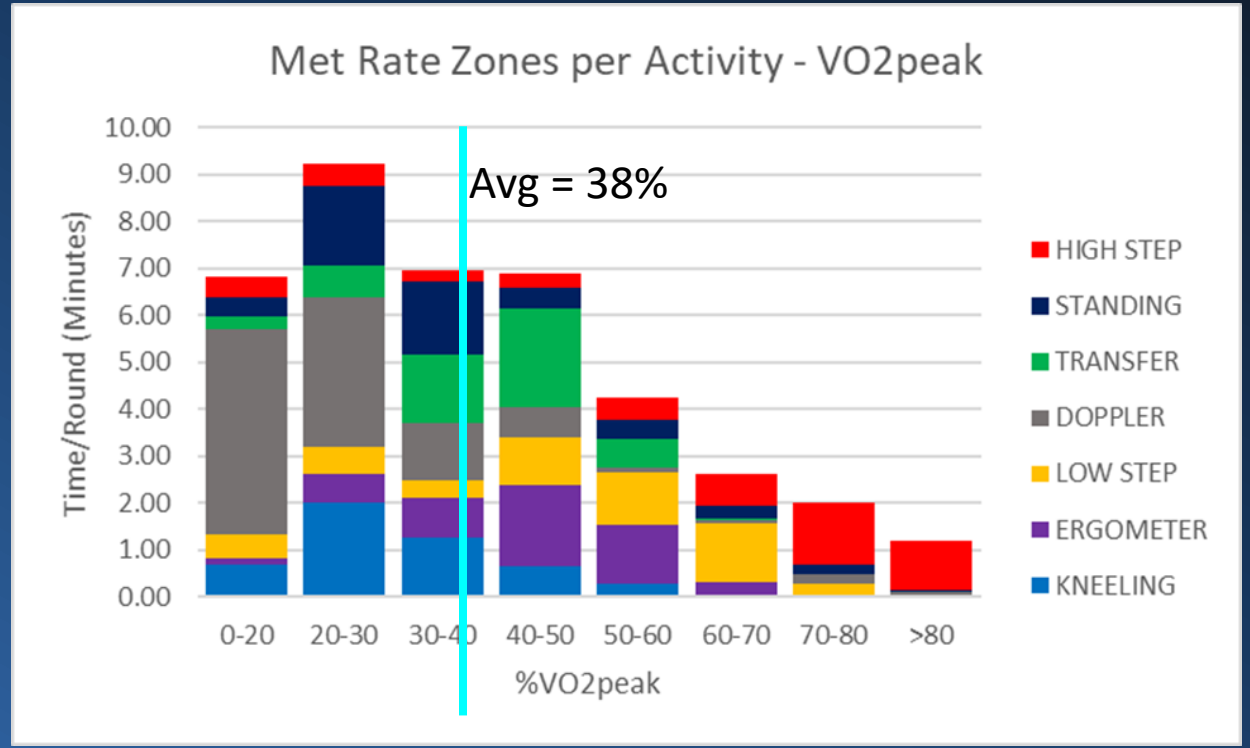
	Task	ConOps	Workload Rx
1	***High Steps***	Ambulation on Uneven Terrain	Step Height at 12 inch Cadence to target 50-70% VO2peak
2	***Standing Task Board***	Maintenance R&R and Procedures	---
3	***Weight Transfer***	Transport Equipment/Tools	Number of transfers (15 or 25lb weights)
DOP	***Doppler / Rest***	Rest	---
4	***Low Steps***	Ambulation on Flat Terrain	Step Height at 6-inch Cadence to target 50% VO2peak
5	***Arm Ergometer***	Deploy Experiments and Use Sampling Tools	Resistance at 30W Cadence to target 30%VO2peak
6	***Kneeling Task Board***	Kneeling, Fine Motor, Upper Body	---
DOP	***Doppler / Rest***	Rest	---

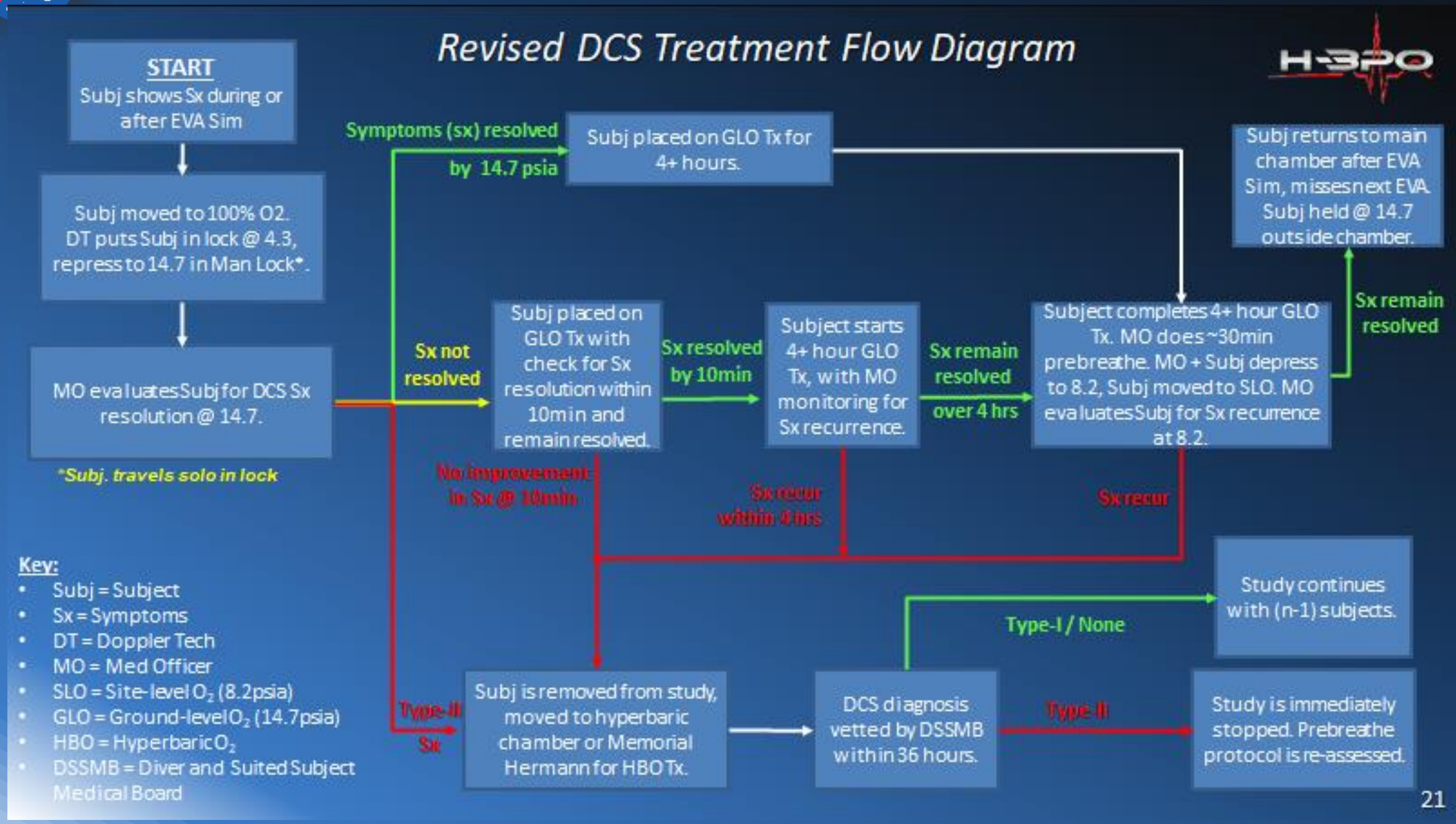
[3]Astrand I. Degree of strain during building work as related to individual aerobic work capacity. Ergonomics. 1967;10(3):293-303.
[4]Jørgensen K. Permissible loads based on energy expenditure measurements. Ergonomics. 1985;28(1):365-9.
[5]Epstein Y, Rosenblum J, Burstein R, Sawka MN. External load can alter the energy cost of prolonged exercise. Eur J Appl Physiol Occup Physiol. 1988;57(2):243-7.
[6]Webb J, Krock L, Gernhardt M. Oxygen consumption at altitude as a risk factor for altitude decompression sickness. 2010; 81(11): 987-992.

Pilot Data - Results

- The average %VO_2peak across all tasks was ~38% (1274 BTU/hr).






Revised DCS Treatment Flow Diagram
START
Subj shows Sx during or after EVA Sim
Subj moved to 100% O2. DT puts Subj in lock @ 4.3, repress to 14.7 in Man Lock*.
MO evaluates Subj for DCS Sx resolution @ 14.7.
*Subj. travels solo in lock
Symptoms (sx) resolved by 14.7 psia
Subj placed on GLO Tx for 4+ hours.
Subj returns to main chamber after EVA Sim, misses next EVA. Subj held @ 14.7 outside chamber.
Sx not resolved
Subj placed on GLO Tx with check for Sx resolution within 10min and remain resolved.
Sx resolved by 10min
Subject starts 4+ hour GLO Tx, with MO monitoring for Sx recurrence.
Sx remain resolved over 4 hrs
Subject completes 4+ hour GLO Tx. MO does ~30min prebreathe. MO + Subj depress to 8.2, Subj moved to SLO. MO evaluates Subj for Sx recurrence at 8.2.
Sx remain resolved
No improvement in Sx @ 10min
Sx recur within 4 hrs
Sx recur
Key:
Subj = Subject
Sx = Symptoms
DT = Doppler Tech
MO = Med Officer
SLO = Site-level O2 (8.2psia)
GLO = Ground-level O2 (14.7psia)
HBO = Hyperbaric O2
DSSMB = Diver and Suited Subject Medical Board
Type-II Sx
Subj is removed from study, moved to hyperbaric chamber or Memorial Hermann for HBO Tx.
DCS diagnosis vetted by DSSMB within 36 hours.
Type-I / None
Study continues with (n-1) subjects.
Type-II
Study is immediately stopped. Prebreathe protocol is re-assessed.
21

Test Summaries

- Testing history:
  - Nov 2021: Overnight test @ 14.7 psi / 21% O2 (n=8)
  - Feb 2022: 1-day test @ 8.2 psi / 4.3psi O2 (n=2)
  - May2022: 3-day test @ 8.2 psi / 34% O2 (n=8)
  - June 2022: 11-day test @ 8.2 psi / 34% O2 (n=8)
- Future Goal:
  - Multiple 11-day tests/year and 3-day ‘training’ runs

Study Acceptability Survey

- EVA Simulation (e.g. prebreathe, mask fit, exercises, discomfort)
- Chamber (e.g. comms, noise, transfer ops, etc.)
- Sleep (e.g. timing, interruptions, noise, lighting, comfort, temperature)
- Clothing (e.g. comfort, fit, hygiene)
- Waste management system and hygiene (e.g. toilets, personal care items, etc.)
- Food (e.g. quantity, type, quality)
- Science block (e.g duration, level of effort, timing functionality)

Exploration Atmospheres Study Acceptability Status

Acceptability Scale

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements in concept necessary and/or No deficiencies		Minor improvements in concept desired and/or Minor deficiencies		Improvements in concept warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Instructions for Rating the Habitat Questionnaires

Participants are asked to provide their ratings and associated comments regarding the acceptability of various study elements during the simulation.

Definitions

Borderline – Deficiencies which – if uncorrected – may affect ability to complete the test/mission
Unacceptable – Deficiencies which – if uncorrected – will likely affect ability to complete the test/mission
Totally unacceptable - Deficiencies which – if uncorrected – will preclude completion of the test/mission

Acceptability Ratings

Reflect on the overall habitability and human factors of the chamber, including the food system, and indicate the extent to which improvements, if any, are desired, warranted, or required using the Acceptability Scale. Please provide descriptions of any improvements or deficiencies.

Acceptability

- Acceptability questionnaire:
  - No subjects withdrew
  - Added additional sleep in last 3 days of study (timeline change)
- EVA Simulation (e.g. Prebreathe, mask fit, exercises, discomfort)
  - 9: mask fit
- Chamber (e.g. Comms, Noise, transfer ops, etc.)
  - 6: toilet transfer ops without 'bucket'
- Sleep (e.g. timing, interruptions, noise, lighting, comfort, temperature)
  - 9: Mattress
- Clothing (e.g. comfort, fit, hygiene)
  - 6: PBI clothing fit
- WMS and Hygiene (e.g. toilets, personal care items, etc.)
  - 7: Transfers, use of urine jugs (additional in study)
- Food (e.g. quantity, type, quality)
  - 6: Hard to keep weight on with cold food, would like snacks during day
- Science block (e.g duration, level of effort, timing functionality)
  - 6: Blood draws/early morning timing

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements in concept necessary and/or No deficiencies		Minor improvements in concept desired and/or Minor deficiencies		Improvements in concept warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

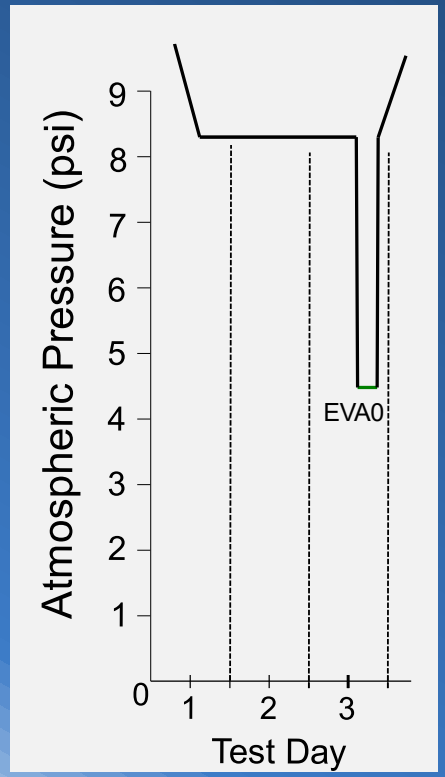
Lessons Learned

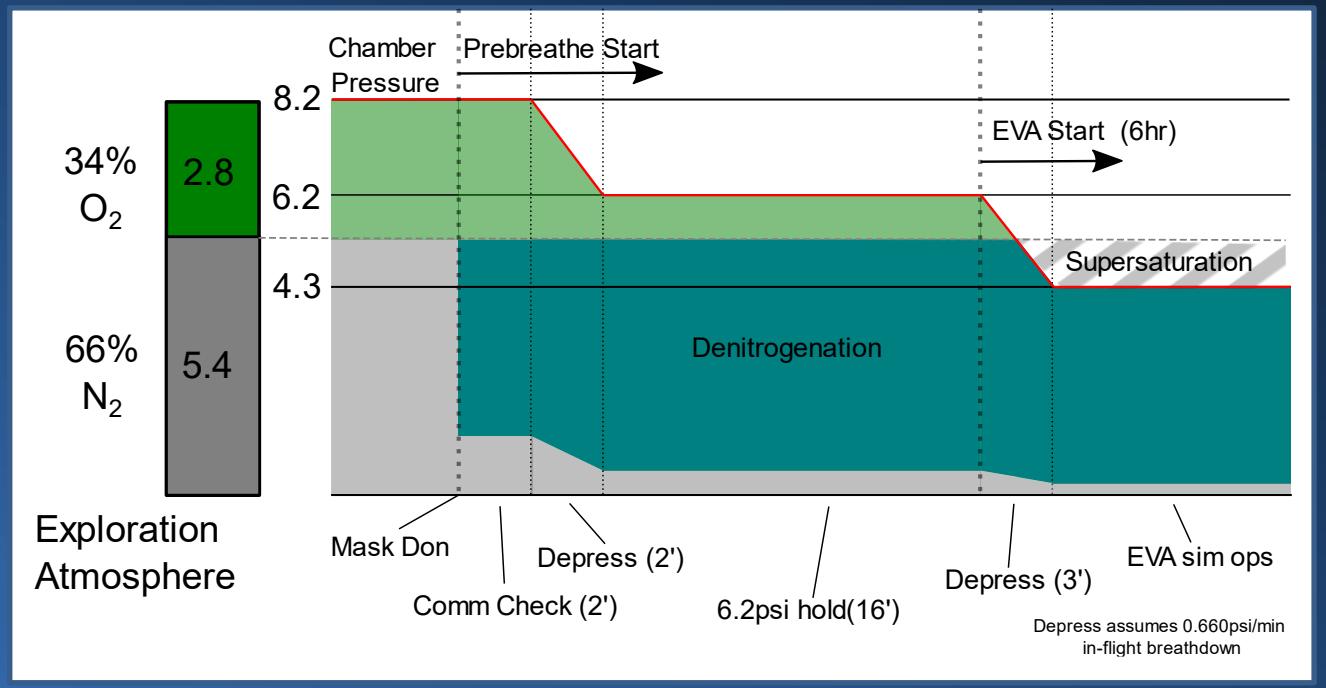
- Overall were able to conduct both a 3-day and 11-day test successfully
  - Significant concern from management on provoking DCS
  - Mitigated, but not totally resolved by 11-day study
- 3-day test was *critical* from both a team readiness and subject training perspective
  - Unanimous recommendation by subjects to do such a test – even at 14.7psi
- Single science block/procedures training much preferred
  - Vs single/ '1-off' trainings by each 'department'
  - Integrates well with a 3-day (or even 1.5 day)
  - Less 'pre/post' data collections, or add more days to 'study' (not just chamber days)
- Sleep:
  - Biggest concern in both of timing (acceptably 'fixed') and comfort (still far from 'fixed')
- Limit individual duty hours for support/science team

3 DAY TEST

Prebreathe Validation Approach

- What prebreathe is sufficient to meet NASA-STD-3001 standards in a Lunar/Mars environment?
  - Equilibrate to Exploration Atmosphere: 8.2psi/34% O_2 for 48 hrs
  - Minimum prebreathe duration: 20 min ≥ 6.2psi
  - Simulated EVA: 4.3psi/85% O_2
  - Simulate EVA workload: 6 tasks for 6hrs across workload ranges





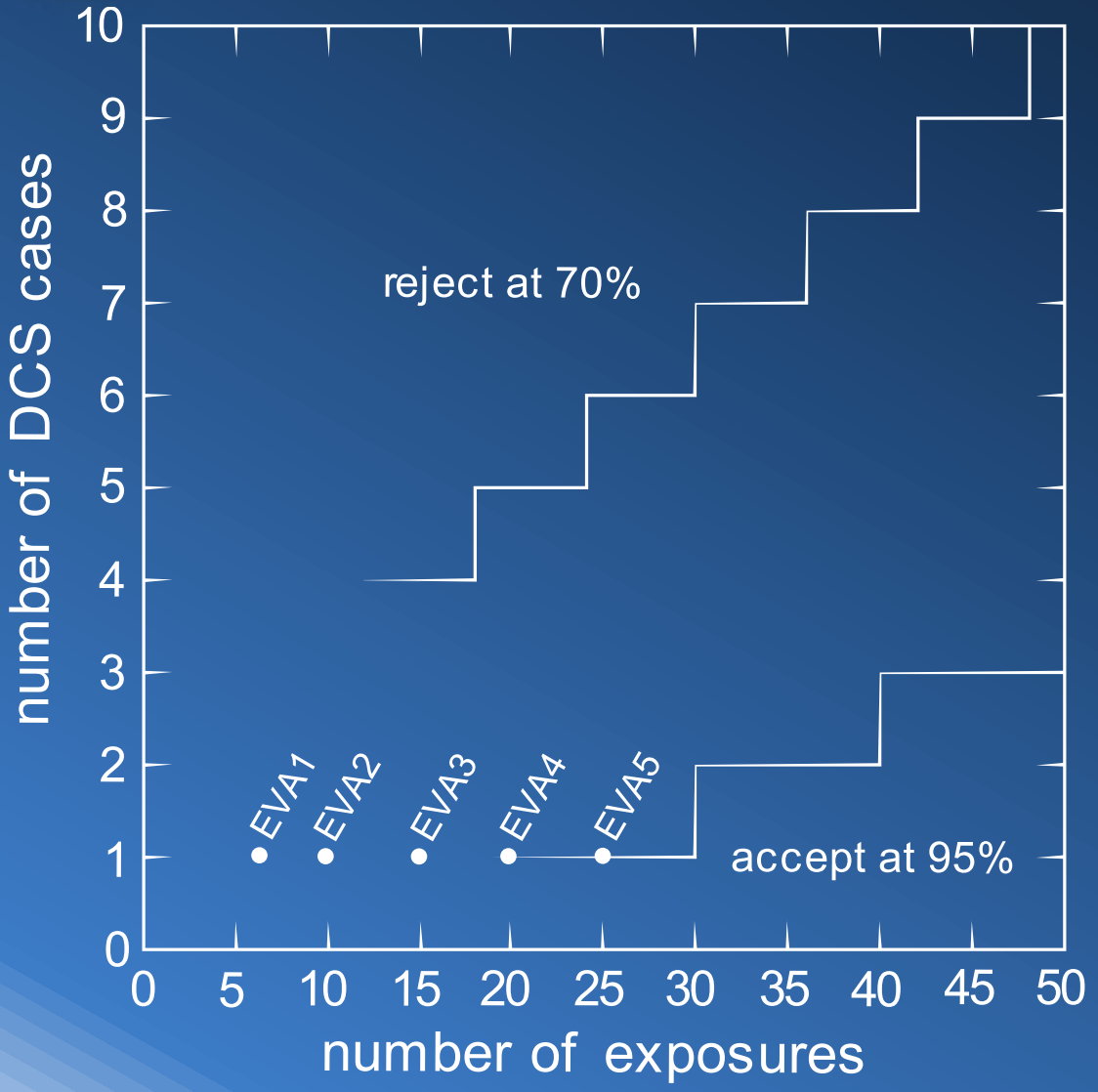
Preliminary EVA Summary : DCS

- 3 day:
  - Meets study criteria?
  - 6 exposures, 0 DCS
- 11 day:
  - EVA1: 6 exposures, 1 DCS
  - EVA2: 4 exposures, 0 DCS (1 GLO, 1 mask fit)
    - (*1 DCS in DT)
  - EVA3: 5 exposures, 0 DCS (1 mask fit) (DT in GLO)
  - EVA4: 5 exposures, 0 DCS (1 MSK)
  - EVA5: 5 exposures, _ DCS

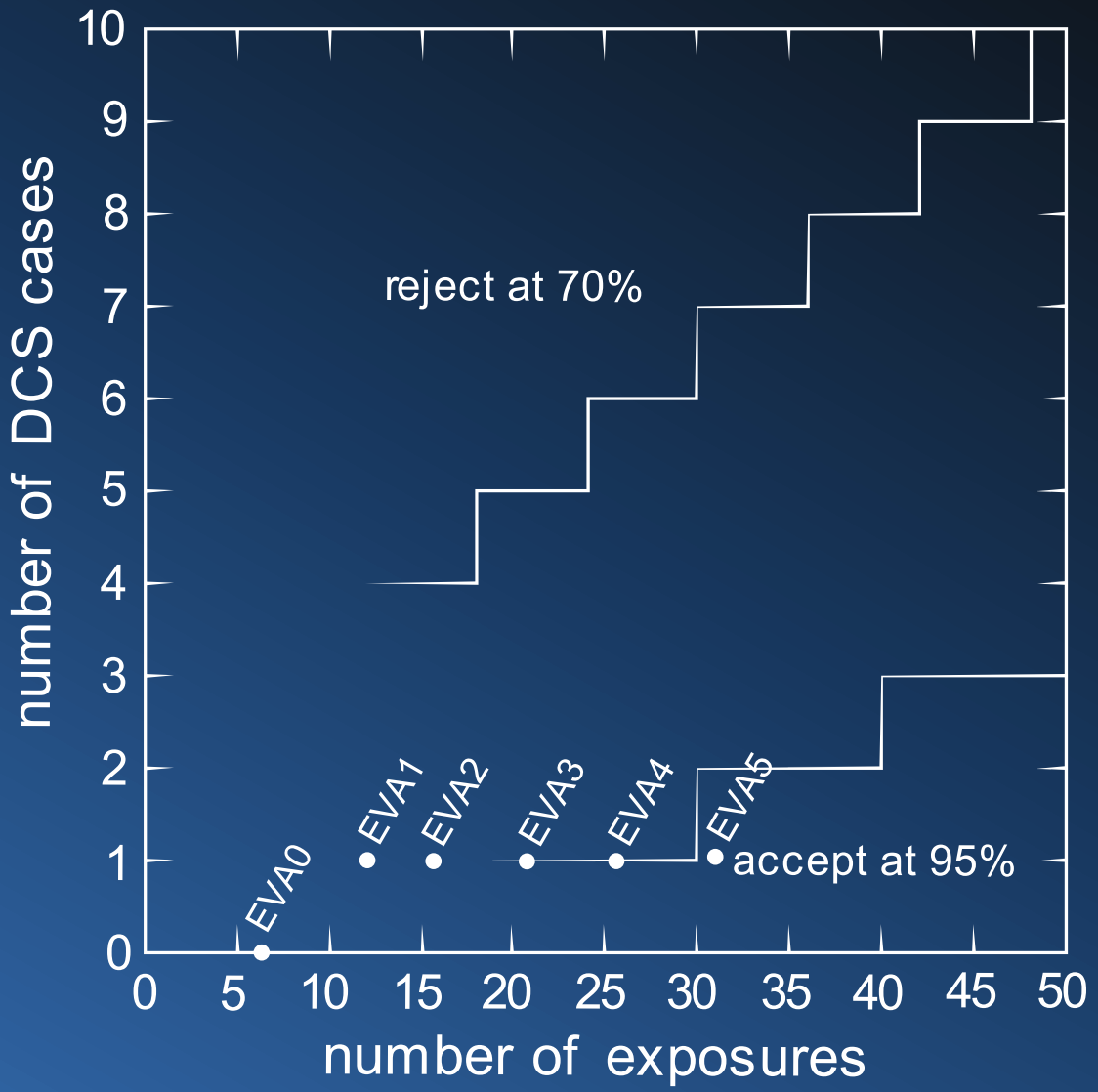
- 11-day
  - EVA1 1/6
  - EVA2 1/10
  - EVA3 1/15
  - EVA4 1/20
  - EVA5 _/25

- 11 + 3 day:
  - EVA0 0/6
  - EVA1 1/12
  - EVA2 1/16
  - EVA3 1/21
  - EVA4 1/26
  - EVA5 _/31

EVA Summary (Preliminary DCS)



DCS ≤ 15% @ 95% confidence



DCS ≤ 15% @ 95% confidence

EVA Summary (Preliminary VGE)

- 3 day:
  - Meets study criteria?
  - 6 exposures, _ VGE IV
- 11 day:
  - EVA1: 6 exposures, _ VGE IV
  - EVA2: 5 exposures, _ VGE IV
  - EVA3: 5 exposures, _ VGE IV
  - EVA4: 5 exposures, _ VGE IV
  - EVA5: _ exposures, _ VGE IV