



Validation of Decompression Sickness Risk Mitigation Protocols for Planetary Spaceflight

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Disclosures



- No conflicts of interest/disclosures



Objective



- Describe the need for a multi-year strategic roadmap for the management of DCS risk for future human missions to the moon and Mars
- Describe the key components on the strategic roadmap and introduce two subsequent presentations, which will provide more detailed statuses on progress to date





SPACE POLICY DIRECTIVE – 1

Reinvigorating America's Human Space Exploration Program



“Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities.

Beginning with missions beyond low-Earth orbit, **the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.**”



Exploration Prebreathe



- Significantly more frequent EVA expected during planetary ops vs. ISS
 - Up to 24 hrs / person / week
- NASA Standard requires < 15% risk of Type I DCS at 95% confidence
 - No Type II observed during previous ground trials that meet this criteria
- No validated protocols exist for planetary EVA
 - Shuttle & ISS protocols are applicable to microgravity only ¹

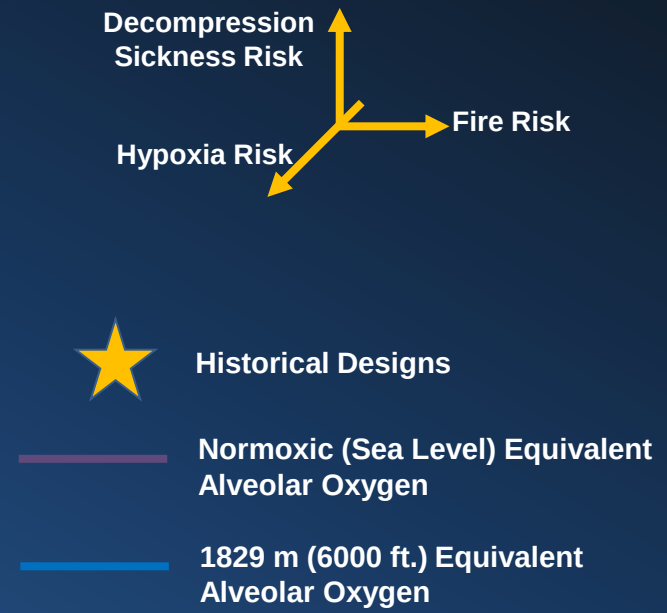
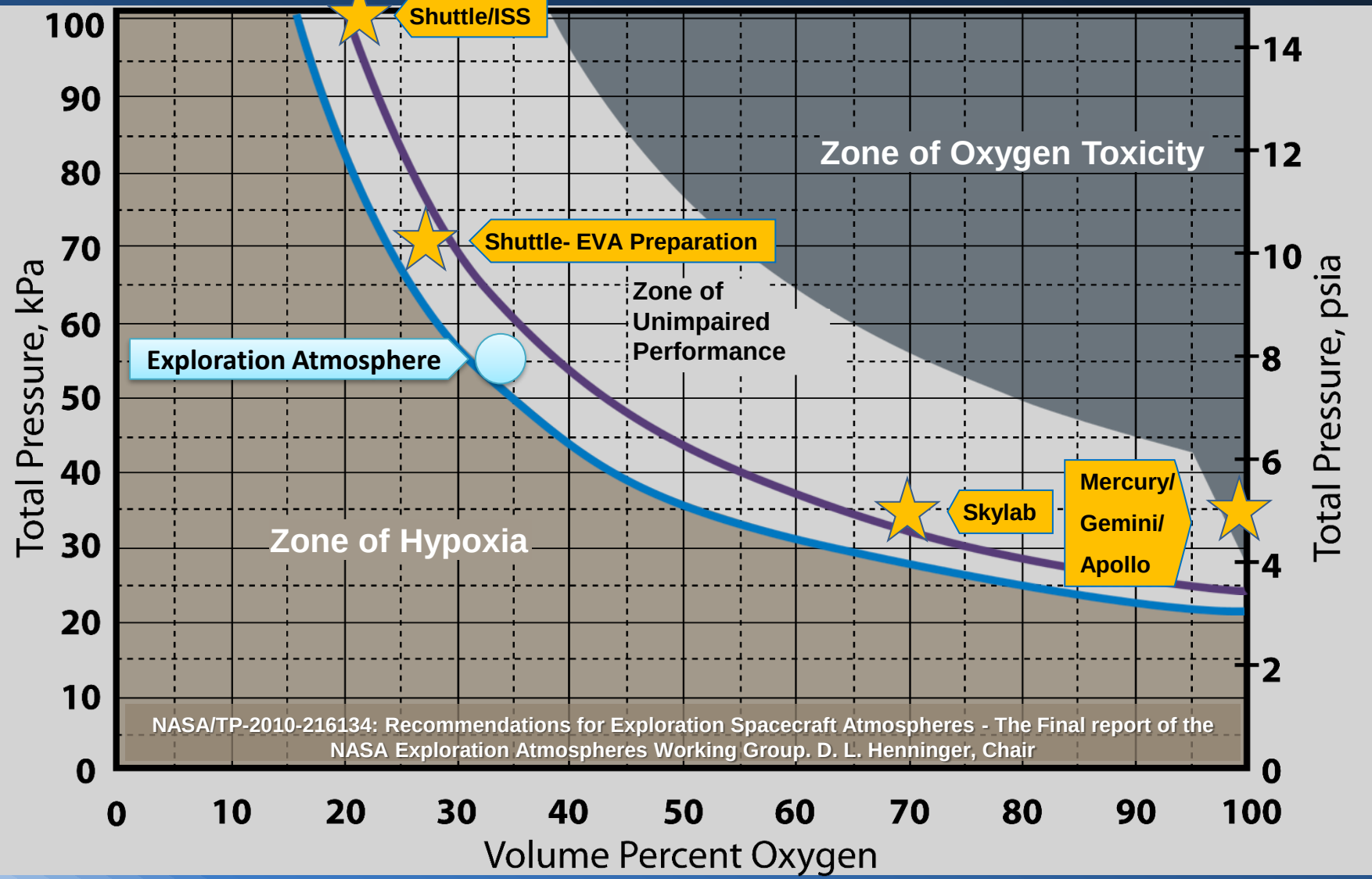


Apollo had 100% O₂ cabin
and zero EVA prebreathe

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



Habitable Atmospheres Employed in the Past





Rationale for Exploration Atmosphere



- Multidisciplinary EAWG recommendation to adopt 8.2 psia / 34% O₂ as a capability for future missions
 - Compromise balancing prebreathe duration, hypoxia, and flammability risk. Assumed a 29.6 kPa (4.3 psi) spacesuit.

Saturation Atmosphere	Microgravity Prebreathe* (h:mm)	Estimated Planetary Prebreathe*
14.7 psi, 21% O2	4:00	6:30-7:00 ²
10.2 psi, 26.5% O2	~2:40 (ISLE)	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

*Assume 6hr EVA @ 4.3 psia

Un-validated (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.



DRAFT Lunar Prebreathe Table



	Scenario 1	Scenario 2	Recommended Scenario 3	Scenario 4	Scenario 5
Gateway Atmosphere *	14.7, 21% O ₂	10.2 psi, 26.5% O ₂	10.2 psi, 26.5% O ₂	14.7 psi, 21% O ₂	14.7 psi, 21% O ₂
Lander *** Atmosphere	10.2 psi, 26.5% O ₂	10.2 psi, 26.5% O ₂	8.2 psi, 34% O ₂	14.7 psi, 21% O ₂	8.2 psi, 34% O ₂
Prebreathe prior to and/or during descent?	1+ hours TBR (on mask, or in-suit)	None required	None required	None	3+ hours TBR (on mask, or in-suit)
Minimum time in Lander prior to EVA	Longer prebreathe if EVA prior to 36 hours	No constraint	No constraint after 24 hours Small PB penalty if earlier than 24hrs	None	Longer prebreathe if EVA prior to 36 hours
Estimated O ₂ prebreathe prior to EVA **	Estimate 3-3.5 hours TBR	Estimate 3-3.5 hours TBR	Estimate 0 -30 mins TBR	Estimate 6.5-7 hours TBR	Estimate 0 -30 mins TBR

* Assume 36+ hours at atmosphere prior to lander undocking; balance N2 in all atmospheres

** Estimated prebreathe times are approximations and not validated; assume 6 hour EVA @ 4.3 psia.

*** Assumed Conops requires use of a reduced pressure, O₂ enriched environment to provide staged denitrogenation. Scenario 4 is provided for reference, but would probably not facilitate the assumed Conops

Assumed Conops***	
Orion transit to Gateway	TBD days
Orion docked to Gateway	5 days
Lander undock, transit to lunar surface (12 hrs)	Lunar Day 1
Post landing safe-ing & reconfig (~4 hrs)	
Crew Sleep (8 hrs)	
EVA 1	Lunar Day 2
EVA 2	Lunar Day 3
No EVA	Lunar Day 4
EVA 3	Lunar Day 5
EVA 4	Lunar Day 6
Lander ascent, return to Gateway	Lunar Day 7



DRAFT Lunar Prebreathe Table



	Scenario 1	Scenario 2	Recommended Scenario 3	Scenario 4	Scenario 5	Assumed Conops***	
Gateway Atmosphere *	14.7, 21% O ₂	10.2 psi, 26.5% O ₂	10.2 psi, 26.5% O ₂	14.7 psi, 21% O ₂	14.7 psi, 21% O ₂	Orion transit to Gateway	TBD days
Lander *** Atmosphere	10.2 psi, 26.5% O ₂	10.2 psi, 26.5% O ₂	8.2 psi, 34% O ₂	14.7 psi, 21% O ₂	8.2 psi, 34% O ₂	Orion docked to Gateway	5 days
						Lander undock, transit to lunar surface (12 hrs)	Lunar Day 1
Prebreathe prior to and/or during descent?	8.2 psia / 34% O ₂ / 66% N ₂ is recommended but not required 4.3 psia spacesuit operating pressure is also not required					Post landing safe-ing & reconfig (~4 hrs)	
Minimum time in Lander prior to EVA	Longer prebreathe if EVA prior to 36 hours	No constraint	NO constraint after 24 hours Small PB penalty if earlier than 24hrs	None	Longer prebreathe if EVA prior to 36 hours	Crew Sleep (8 hrs)	
<u>Estimated</u> O ₂ prebreathe prior to EVA **	Estimate 3-3.5 hours TBR	Estimate 3-3.5 hours TBR	Estimate 0 -30 mins TBR	Estimate 6.5-7 hours TBR	Estimate 0 -30 mins TBR	EVA 1	Lunar Day 2
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						No EVA	Lunar Day 4
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						Lander ascent, return to Gateway	Lunar Day 7

* Assume 36+ hours at atmosphere prior to lander undocking; balance N₂ in all atmospheres

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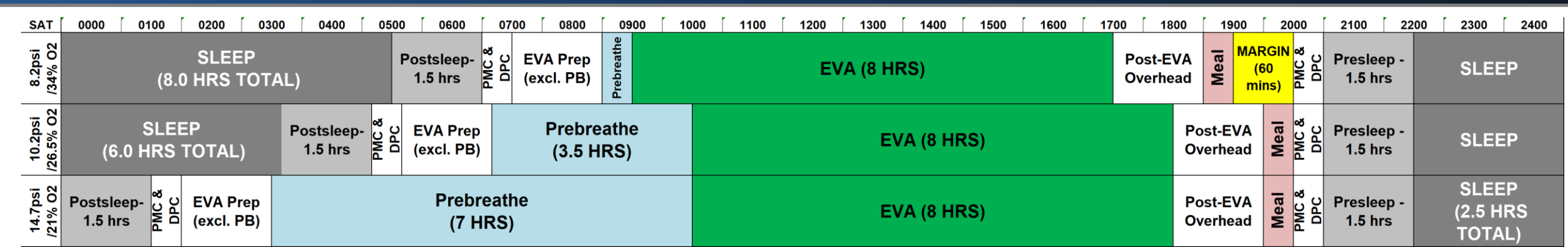
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Timeline Analysis



Assuming 8 hr EVAs 3x/week, by how much must crew sleep time be reduced?



Assumptions

- 1 DPCs are for system status checks and any general Q&A for crew
- 2 PMCs are for pre/post EVA medical status checks
- 3 Sleep period = 8 hrs, immediately following Presleep activity (no sleep shifting for crew during surface ops)
- 4 Post/presleep include routine system/HAB cks, hygiene and meal
- 5 EVA Prep includes pre-EVA conference with MCC

- 60 mins timeline margin for 30 min prebreathe case
- 3.5 hr and 7 hr prebreathe will likely violate crew duty day constraints
- Routine sleep deprivation very unlikely to be acceptable



The Challenge: One Size May Not Fit All



- Commercial providers and international partners expected to provide landers, pressurized rovers, habitats, and spacesuits
- 56.5 kPa (8.2 psia), 34% O₂, 66% N₂ ***recommended*** by NASA for vehicles supporting high frequency EVA
- **Specific pressure set points not required by NASA for vehicles or spacesuits**
 - Intent is to give commercial providers maximum flexibility
 - Other requirements (e.g. on crew time) expected to drive designs towards reduced prebreathe solutions



Multiple different combinations of vehicle and spacesuit atmospheres are possible

- However, **existing models are insufficient** to accurately inform design decisions and approve flight protocols
 - Wide range of model predictions & opinions on effect of metabolic rates in particular
 - Affects operations, consumables, hardware, and human risk





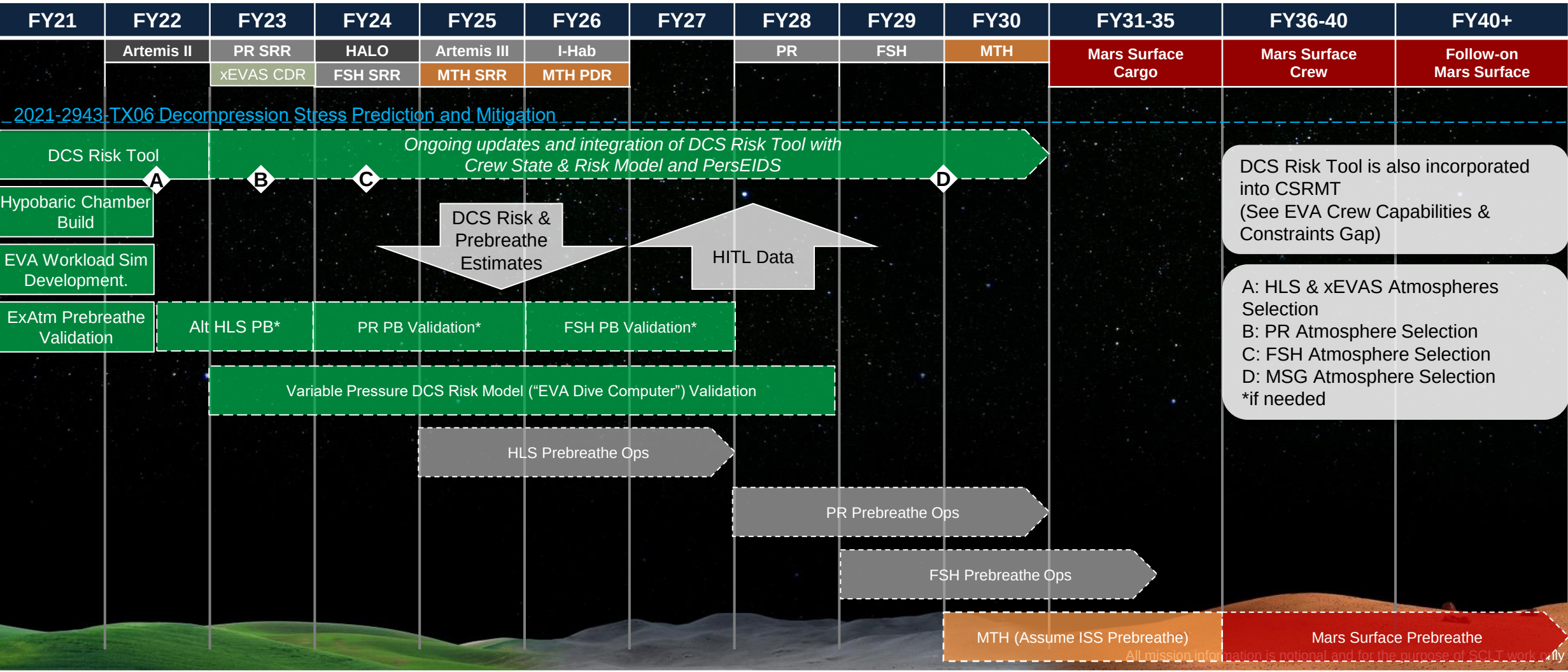
The Approach: Plan for (and enable) Multiple Solutions



ID	Description	Status
1	Establish hypobaric chamber facility capable of supporting 8-person EVA prebreathe validation tests at saturation atmospheres up to 36% O ₂ .	Complete (Alex Garbino presentation).
2	Validate an EVA physical workload simulation for use during prebreathe validation testing.	Complete (Patrick Estep presentation)
3	Validate the recommended “exploration atmosphere” prebreathe protocol.	Scheduled (Summer-Fall 2022)
4	Validate prebreathe protocols for additional atmospheric combinations that bound the most likely potential operating ranges of future vehicles and spacesuits.	Planning underway. Targeting draft study design Fall 2022.
5	Update DCS risk estimation models based on results of prebreathe validation studies.	Python software tool created; updates to be made based on results of #4 and #5



DCS Prediction & Mitigation Roadmap

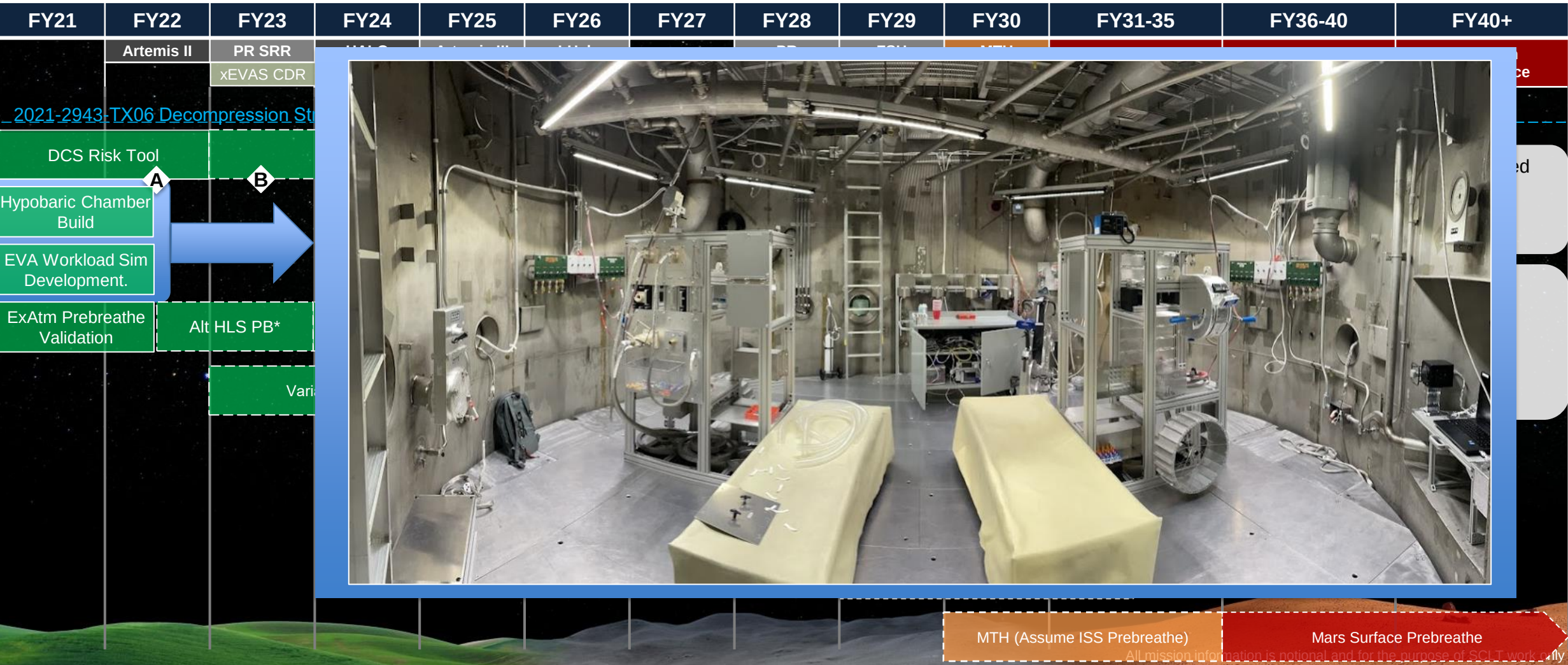


Ground
ISS / LEO
Lunar surface
Mars transit
Lunar orbit
Mars surface

Events/milestones
Decision point

Assumed that Shuttle/ISS prebreathe protocols will be applicable to Gateway and MTH; these protocols are already validated for microgravity but not for planetary EVA

DCS Prediction & Mitigation Roadmap



- Ground

ISS / LEO

Lunar orbit
- Lunar surface

Mars transit

Mars surface
- Events/milestones

◆ Decision point

See acronyms list at front of document

Assumed that Shuttle/ISS prebreathe protocols will be applicable to Gateway and MTH; these protocols are already validated for microgravity but not for planetary EVA



Conclusions



1. Development and validation of new DCS risk management tools and protocols is required for humans to return to the moon
2. NASA has invested significantly in hypobaric research facilities and methods over the past 4 years in preparation for ground testing
3. Testing will begin with validation of the Exploration Atmosphere prebreathe protocol
4. Identification and prioritization of subsequent ground tests will be based on the combination of known suit and vehicle atmospheres where available, and the longer-term goal of a validated model encompassing the future vehicle-suit atmospheric trade space
5. Results will be published and collaboration opportunities will be pursued



National Aeronautics and Space Administration

A full-page background image showing an astronaut in a white spacesuit standing at the bottom of a deep, rocky crater. A series of concentric, glowing circular openings lead from the crater floor up towards the center of the image, where a bright view of Earth is visible. The scene is dramatically lit, with the astronaut's reflection on the ground and lens flare effects from the light at the end of the tunnel.

Questions?

www.nasa.gov