HUMAN PHYSIOLOGY, PERFORMANCE, PROTECTION & OPERATIONS

Panel:
NASA's Exploration Atmospheres & EVA Strategies

May 2022
Aerospace Medicine Association

Alejandro Garbino
MD, PhD, MPH, FAsMA

Panel Structure

- Panel 1: NASA's Exploration Atmospheres & EVA Strategies
  - VALIDATION OF DECOMPRESSION SICKNESS RISK MITIGATION PROTOCOLS FOR PLANETARY SPACEFLIGHT (Abercromby)
  - REDUCTION OF DECOMPRESSION SICKNESS USING SUITPORTS AND INTERMITTENT RECOMPRESSION (Gernhardt)
  - NITRIC OXIDE SUPPLEMENTATION (Sanders)
  - DEVELOPMENT OF AN EXTRAVEHICULAR ACTIVITY PHYSICAL WORKLOAD SIMULATION FOR USE IN GROUND VALIDATION OF EXPLORATION PREBREATHE PROTOCOLS (Estep)
  - DEVELOPMENT AND TESTING OF A FACILITY TO STUDY SPACECRAFT AND SPACESUIT ATMOSPHERES AND DECOMPRESSION PROTOCOLS (Garbino)
- Panel 2: Management of DCS and Crew Injury During Exploration EVA
  - DCS TREATMENT FOR EXPLORATION ATMOSPHERE STUDY (Sanders)
  - EVALUATION OF DCS TREATMENT CAPABILITIES WHEN PERFORMING EVA FROM REDUCED PRESSURE ENVIRONMENTS (Dervay)
  - REVIEW OF TYPE 1 DECOMPRESSION SICKNESS DISPOSITION POLICIES FROM 18 ORGANIZATIONS (Zamarron)
  - ANALYSIS OF MILD TYPE I DECOMPRESSION SICKNESS RETURN TO ALTERNOBARIC OPERATIONS FOR SHORT DURATION LUNAR MISSIONS (Harman)
  - BOOTS ON THE MOON: INCAPACITATED CREW RESCUE (ICR) AND ACUTE INJURY (Walton)

Panel Structure

- Panel 1: NASA's Exploration Atmospheres & EVA Strategies
  - VALIDATION OF DECOMPRESSION SICKNESS RISK MITIGATION PROTOCOLS FOR PLANETARY SPACEFLIGHT
    - DCS risk has been mitigated by high % oxygen atmospheres (Apollo) or extended prebreathe times (Shuttle/ISS)
    - For Moon/Mars exploration, new protocols are needed that balance the two
    - Presented by: Andrew Abercromby
  - REDUCTION OF DECOMPRESSION SICKNESS USING SUITPORTS AND INTERMITTENT RECOMPRESSION
    - (Gernhardt)
  - NITRIC OXIDE SUPPLEMENTATION
    - (Sanders)
  - DEVELOPMENT OF AN EXTRAVEHICULAR ACTIVITY PHYSICAL WORKLOAD SIMULATION FOR USE IN GROUND VALIDATION OF EXPLORATION PREBREATHE PROTOCOLS
    - (Estep)
  - DEVELOPMENT AND TESTING OF A FACILITY TO STUDY SPACECRAFT AND SPACESUIT ATMOSPHERES AND DECOMPRESSION PROTOCOLS
    - NASA-JSC rebuilt the 20ft chamber to be able to support 11-day tests for decompression stress
    - Infrastructure allows Doppler and Ultrasound monitoring and can provide a range of atmospheres 14.7-8.2psi, 21-34% O2
    - Presented by: Alejandro Garbino

HUMAN PHYSIOLOGY, PERFORMANCE, PROTECTION & OPERATIONS

DEVELOPMENT AND TESTING OF A FACILITY TO STUDY SPACECRAFT AND SPACESUIT ATMOSPHERES AND DECOMPRESSION PROTOCOLS

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Disclosures

- No conflicts of interest/disclosures.

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Panel 1:

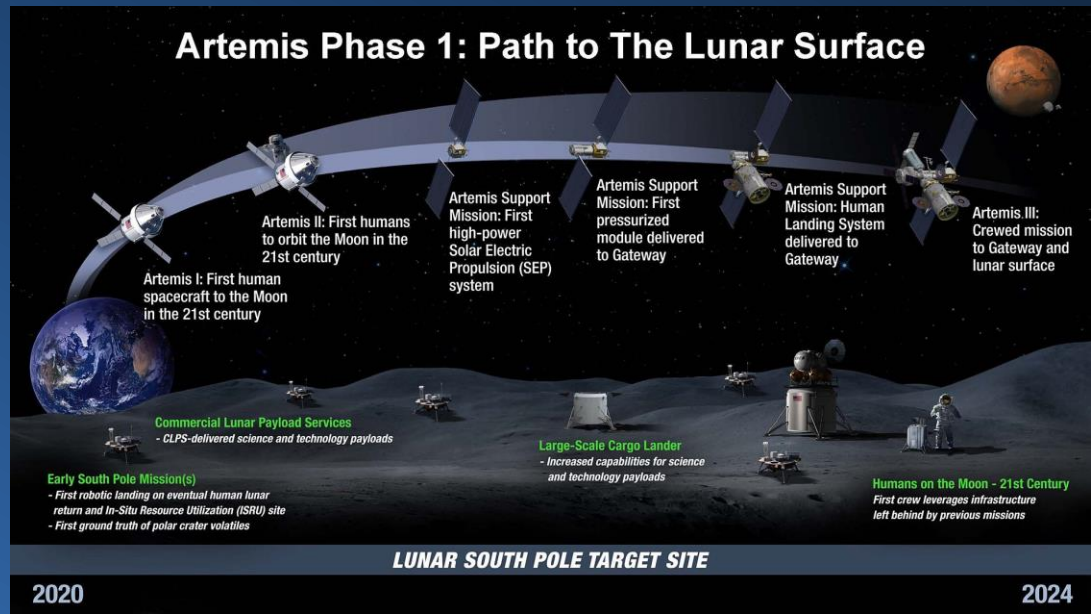
NASA's Exploration Atmospheres & EVA Strategies

Panel 2:

Management of DCS and Crew Injury During Exploration EVA

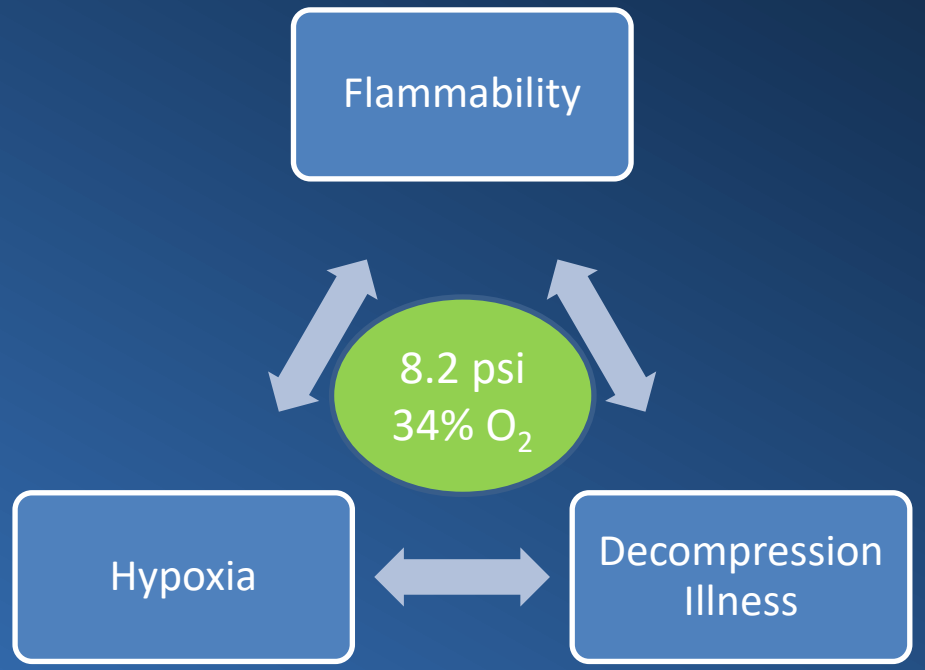
Artemis Program

- Dec 2017 – Space Policy Directive 1:
  - Lunar landings
  - Eventual Lunar Outpost
  - Develop tech for Mars
- Very high EVA tempo
  - Potential bouts of daily, multi-hour EVA
    - Up to 24hrs/crew/week



Exploration Atmosphere Recap

- Exploration Atmospheres Working Group (2005) and subsequent work proposed a saturation environment that minimizes prebreathe time, and balances risk

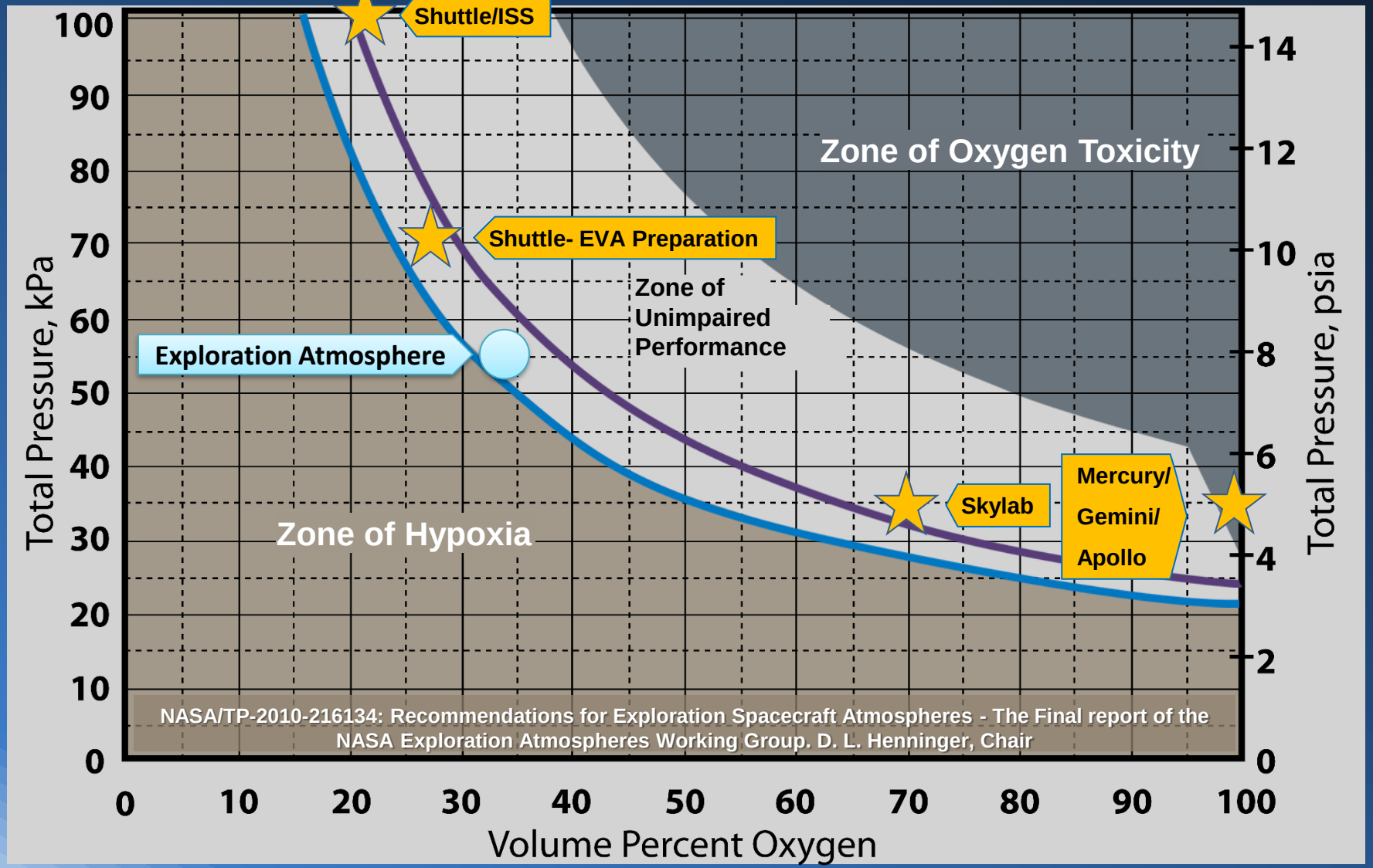


- Now we need a facility to test in!

Exploration Atmosphere Recap

EA slides from previous (export-approved) panel

Habitable Atmospheres Employed in the Past



Historical Designs

Normoxic (Sea Level) Equivalent Alveolar Oxygen

1829 m (6000 ft.) Equivalent Alveolar Oxygen

20ft chamber history

- Built in the 1960s to support Gemini/Apollo program
- 6.1 m diameter x 8.4 m high (20.0 ft x 27.5 ft)
- 229 m3 (8,090 ft3) volume
- Vacuum of 1 x 10-2 torr (1 Pa) (equivalent to 76,200 m or 250,000 ft altitude)
- Access:
  - Top loading chamber
  - loading outerlock 1.2 m x 1.5 m (4.0 ft x 5.0 ft)
  - door to rapid decompression chamber

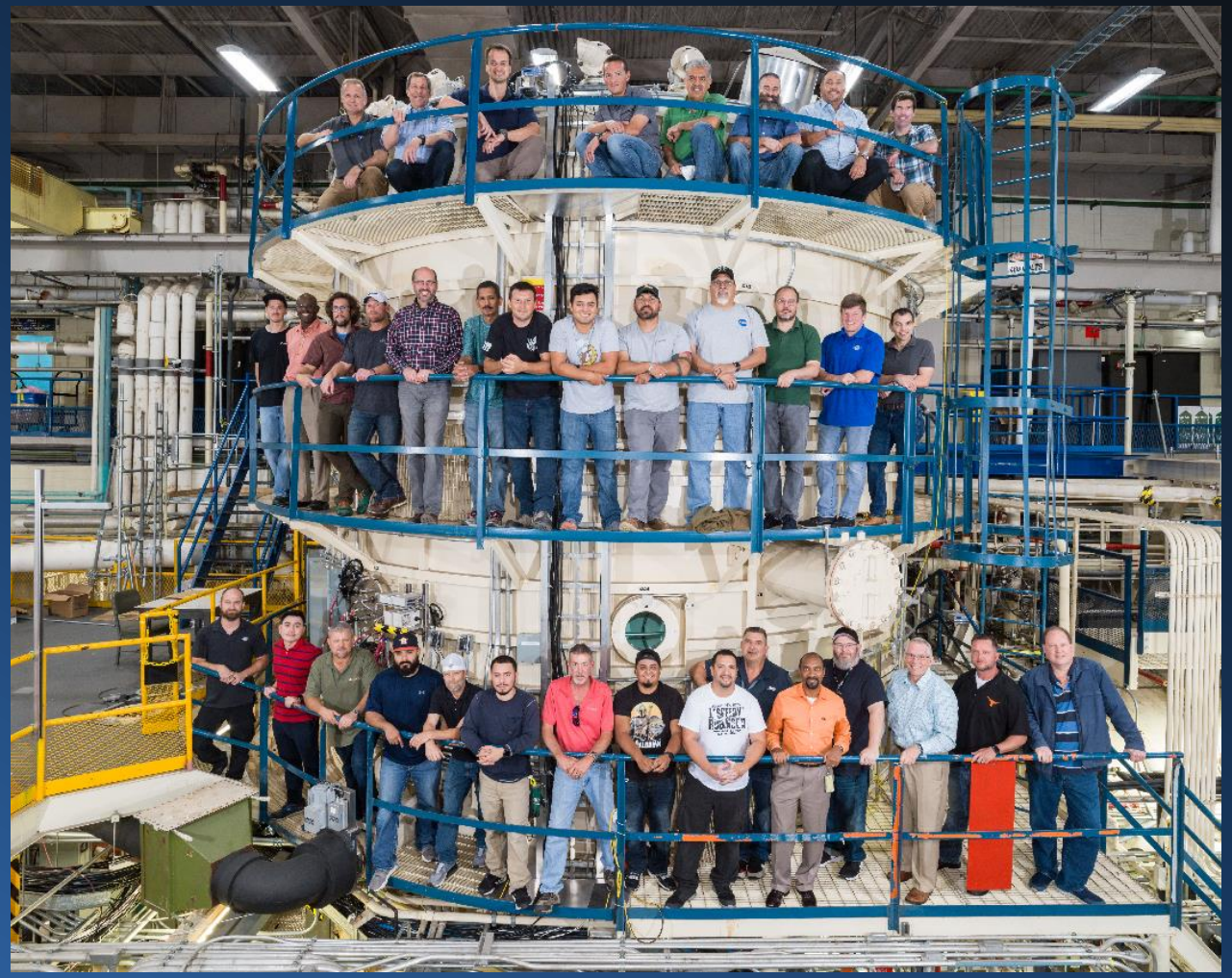
20ft chamber history

- 1971 : SMEAT
  - Skylab Medical Experiments Altitude Test
  - 56 day test – baseline for Skylab missions
    - 5psi (34.5kPa), 70% O_2
- 1995-7 : Space Station and Advanced Environmental Control and Life Support System tests (ambient pressure)
- 2016 : CO_2 cognitive study (ambient pressure)

Objective: Validate the exploration atmosphere prebreathe protocol via HITL ground testing

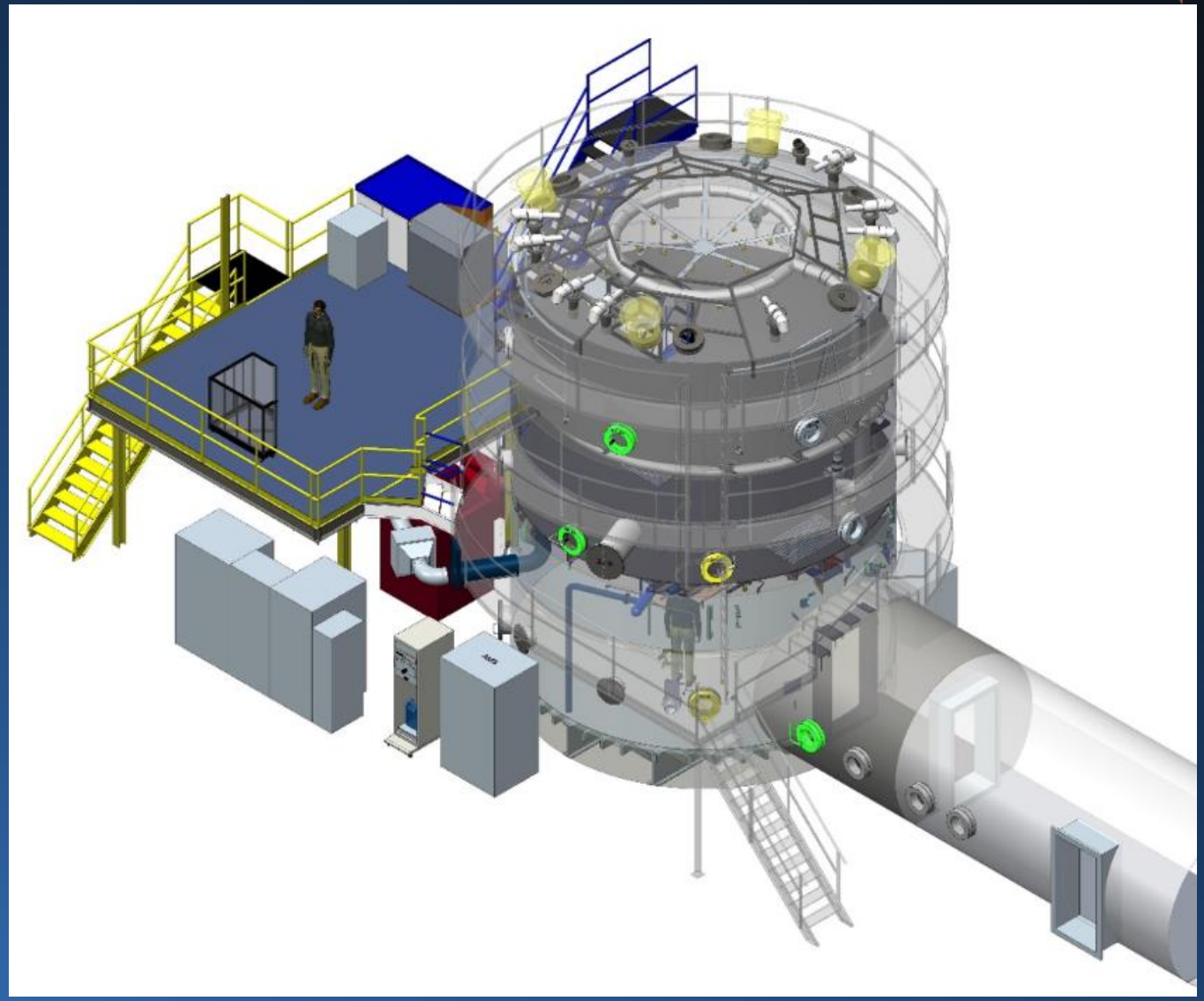
Project Team

- Complex, multi-disciplinary test
- Funded by xEVA in preparation for the Artemis Moon walks
- Combination of:
  - Aerospace doctors/physiologists
  - Hyperbaric/dive medicine doctors/physiologists
  - Decompression experts
  - Space habitation specialists
  - Materials and Flammability engineers
  - Chamber/facility experts
  - Test safety officers
  - Space nutrition experts
  - Project manager/integrators
  - Statisticians
  - Hardware subject matter experts
  - Ultrasonographers
  - Phlebotomists
  - Lighting environment engineers
  - Audio and video engineers
  - Immunologists
- Data Safety and Monitoring Board (External)



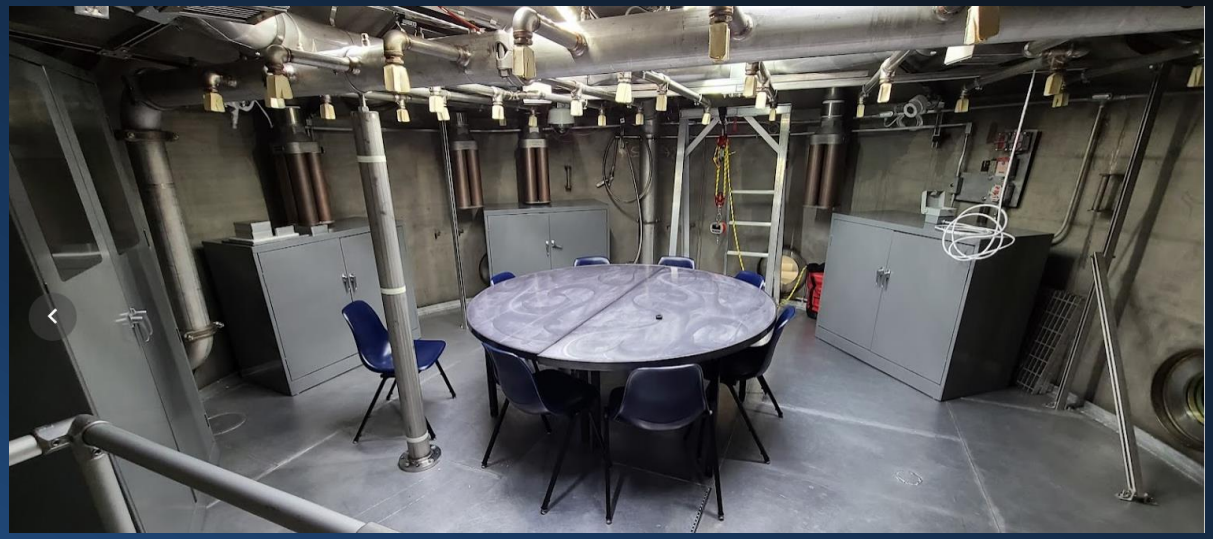
20ft Chamber Modernization

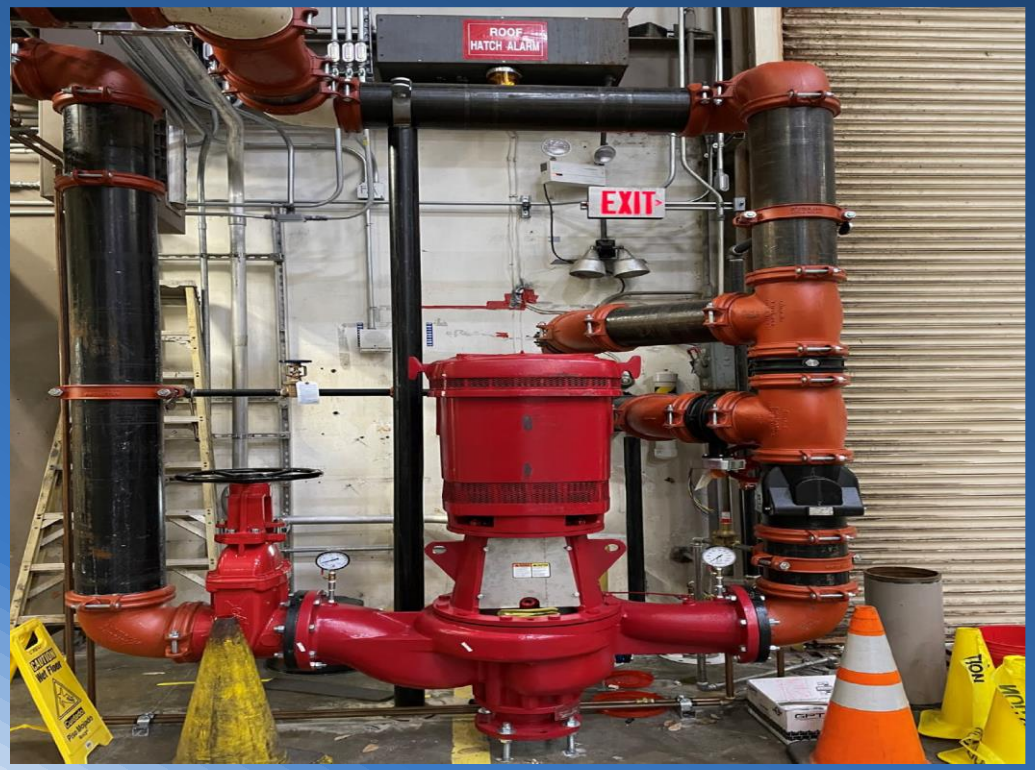
- Requirements/Performance Based Design
  - NASA-STD-3001
  - NFPA-99B Class E/ PVHO
- Facility upgrades
  - Emergency Management System
  - Fire suppression system
  - Environmental control systems
  - Vacuum pumps
  - CO_2 scrubbing system
- Crew habitability
  - Living quarters
  - Sleeping quarters
  - Lighting
  - Recreation
- Science capability/data collection
  - EVA simulation tasks
  - Hypoxia characterization
  - Video system
- Decompression Management
  - DCS TREATMENT FOR EXPLORATION ATMOSPHERE STUDY (Dr. Sanders)



Emergency/Fire suppression

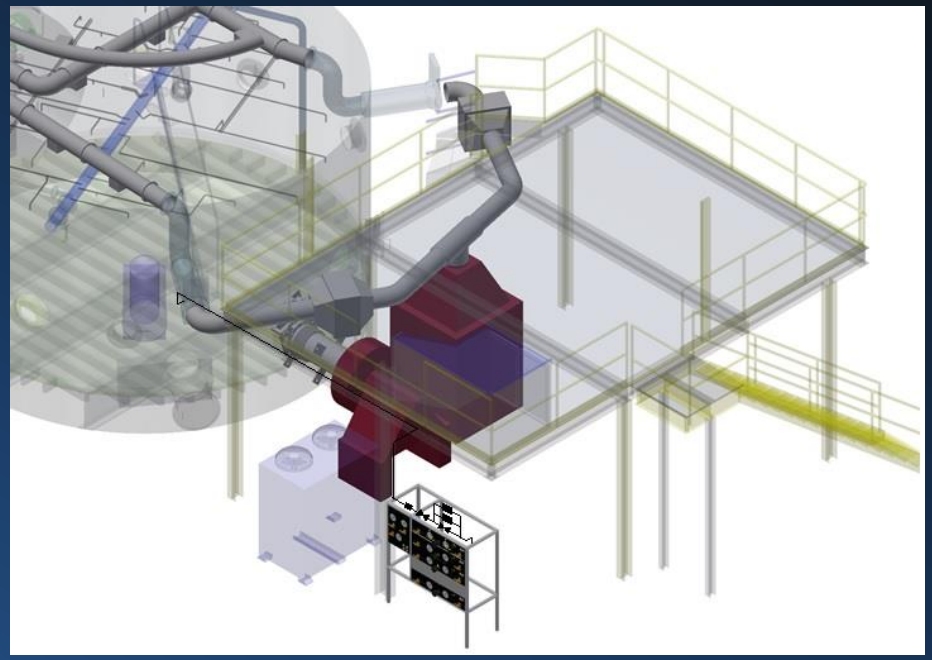
- NFPA 99B Class E – oxygen enriched atmosphere
- NASA STD 8719.11
- Required increasing pipe diameters, pump capacity, and building independently supplied sprinkler array for each floor

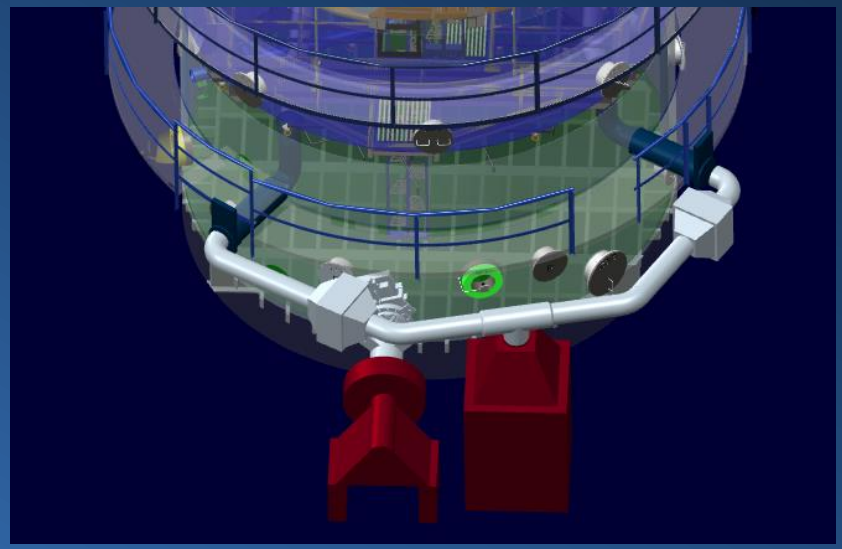




HVAC/Environment Control

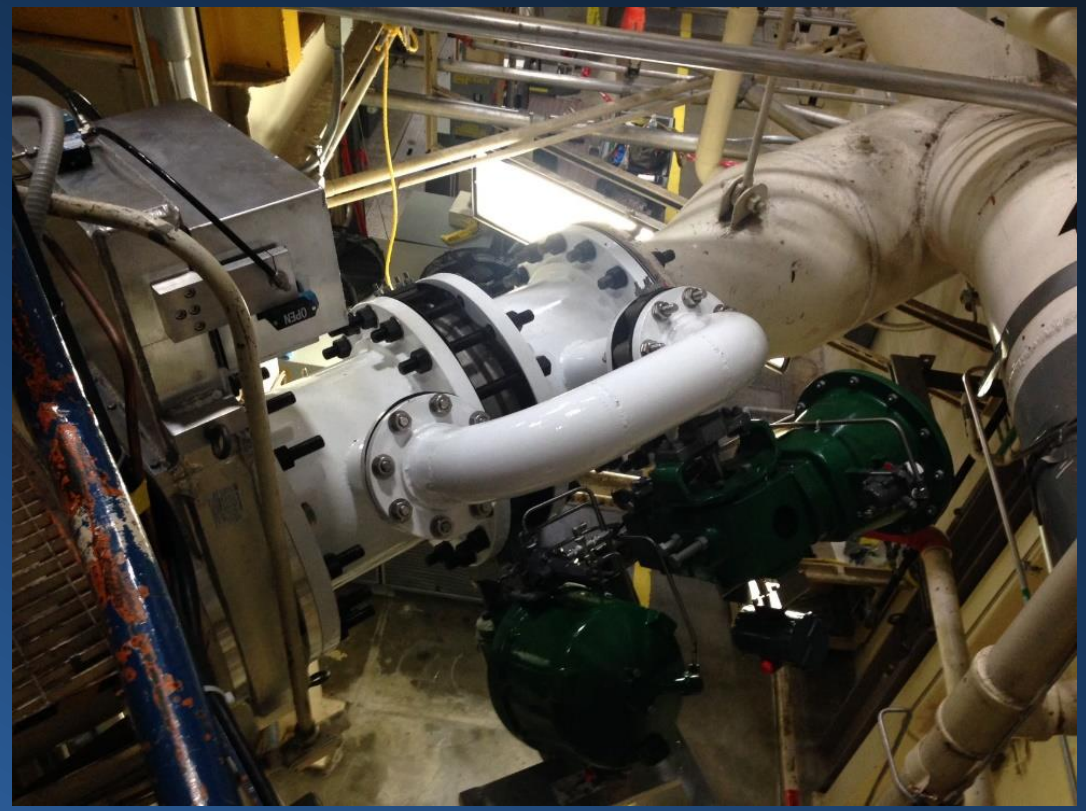
- Controls:
  - Pressure (down to 4.3psi)
  - Fraction of O_2 (21-36%)
  - Temperature
  - Humidity (25-75%)
    - Condensate is drained out of the pressure loop without depressurizing the chamber





Vacuum pumps

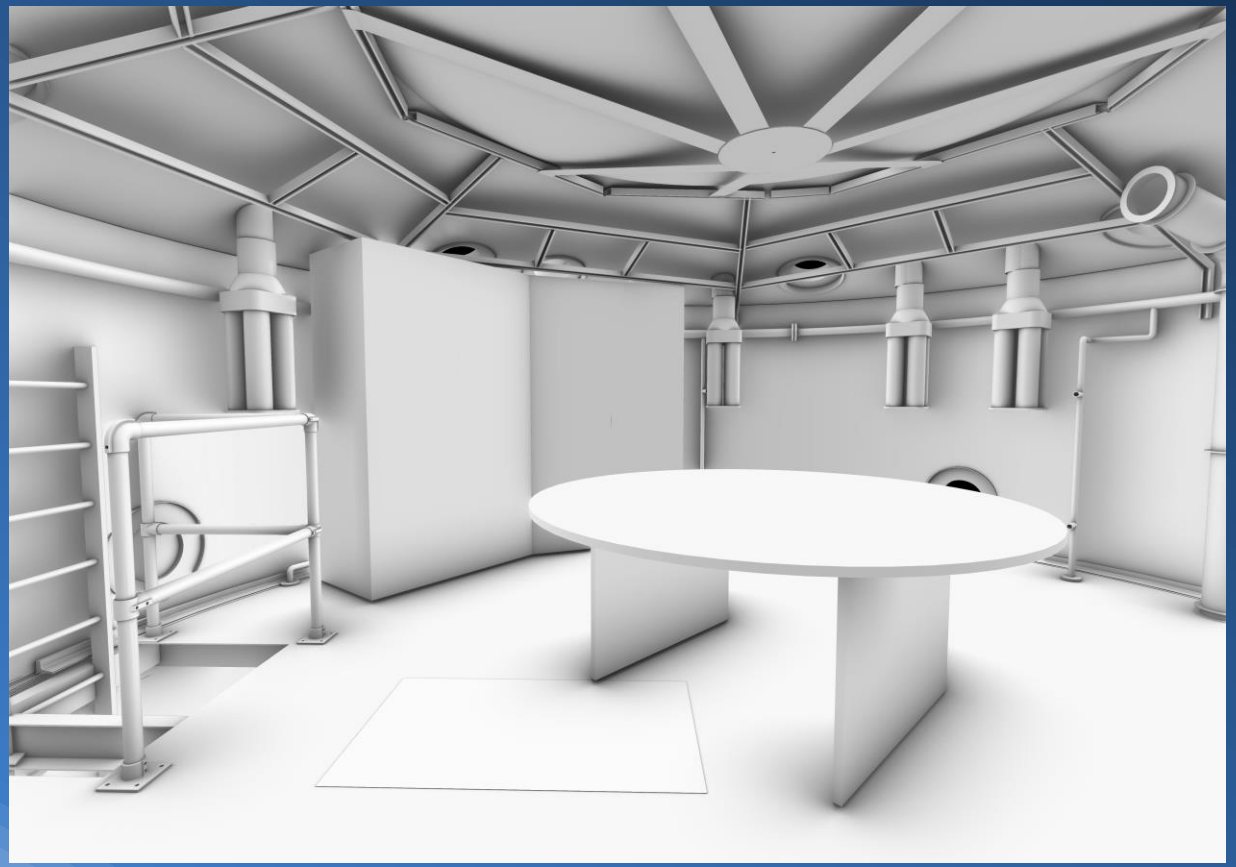
- Two vacuum pumps provide depress capability in ~15min
  - 16” isolation gate valve allow full open/close operations
  - 16” butterfly valve allows precise pressure profile operations
  - 4” butterfly valve provide fine tuning/pressure control
- System is automated with manual backup to ‘fly’ the chamber

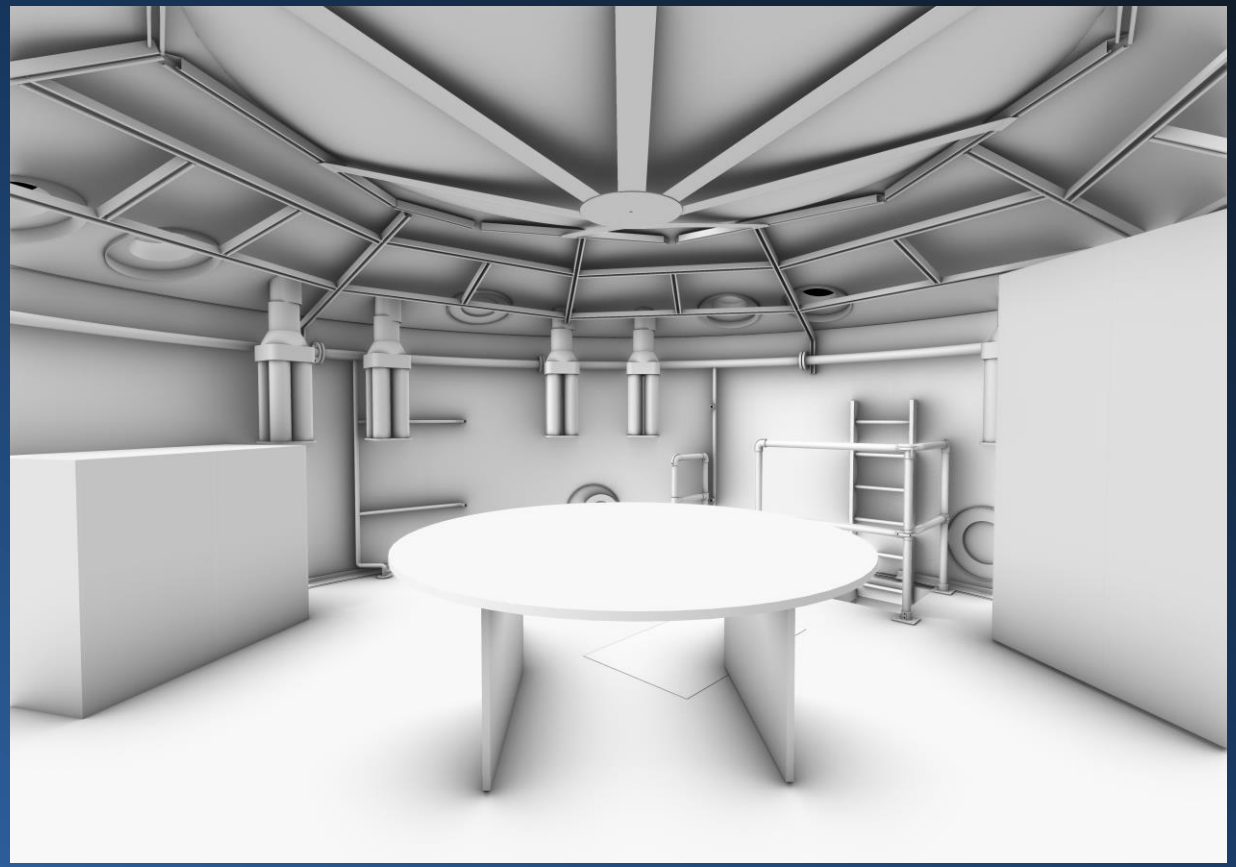


CO2/contaminant control

- Maintain below 3mmHg

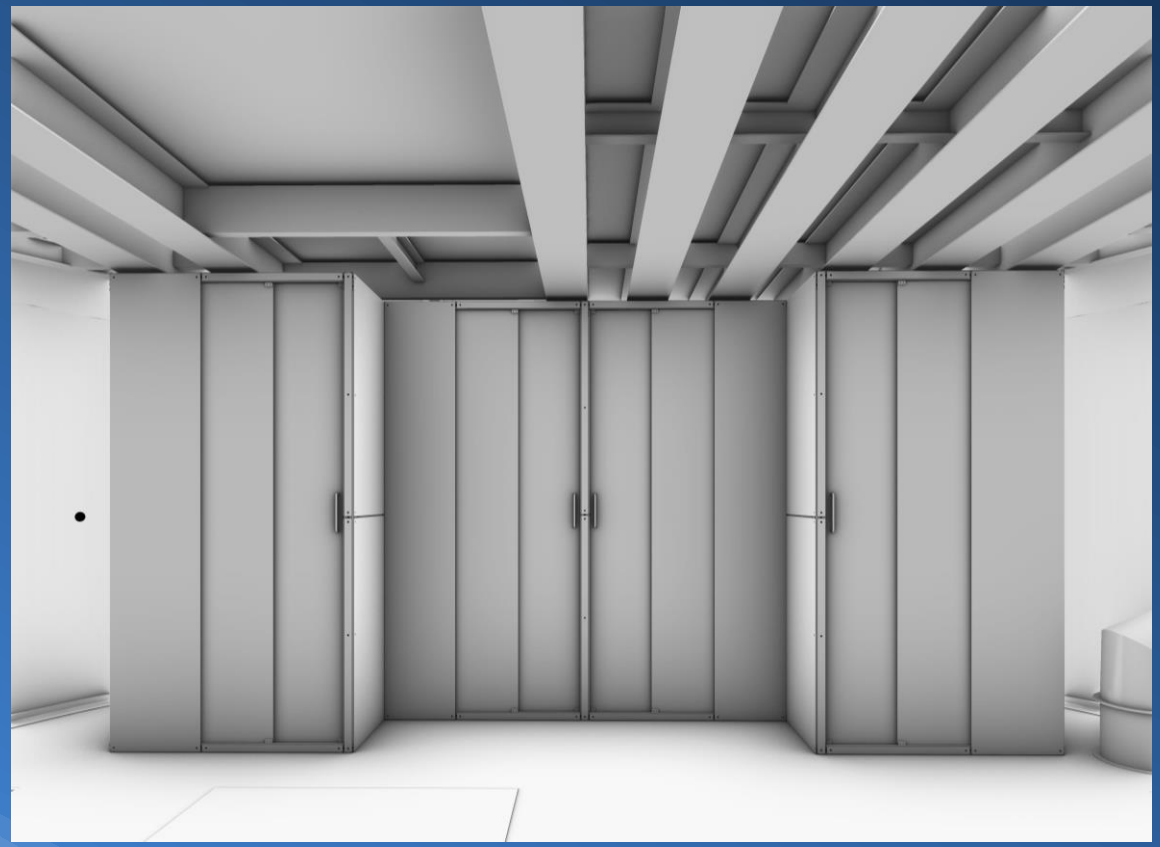
3rd Floor Configuration

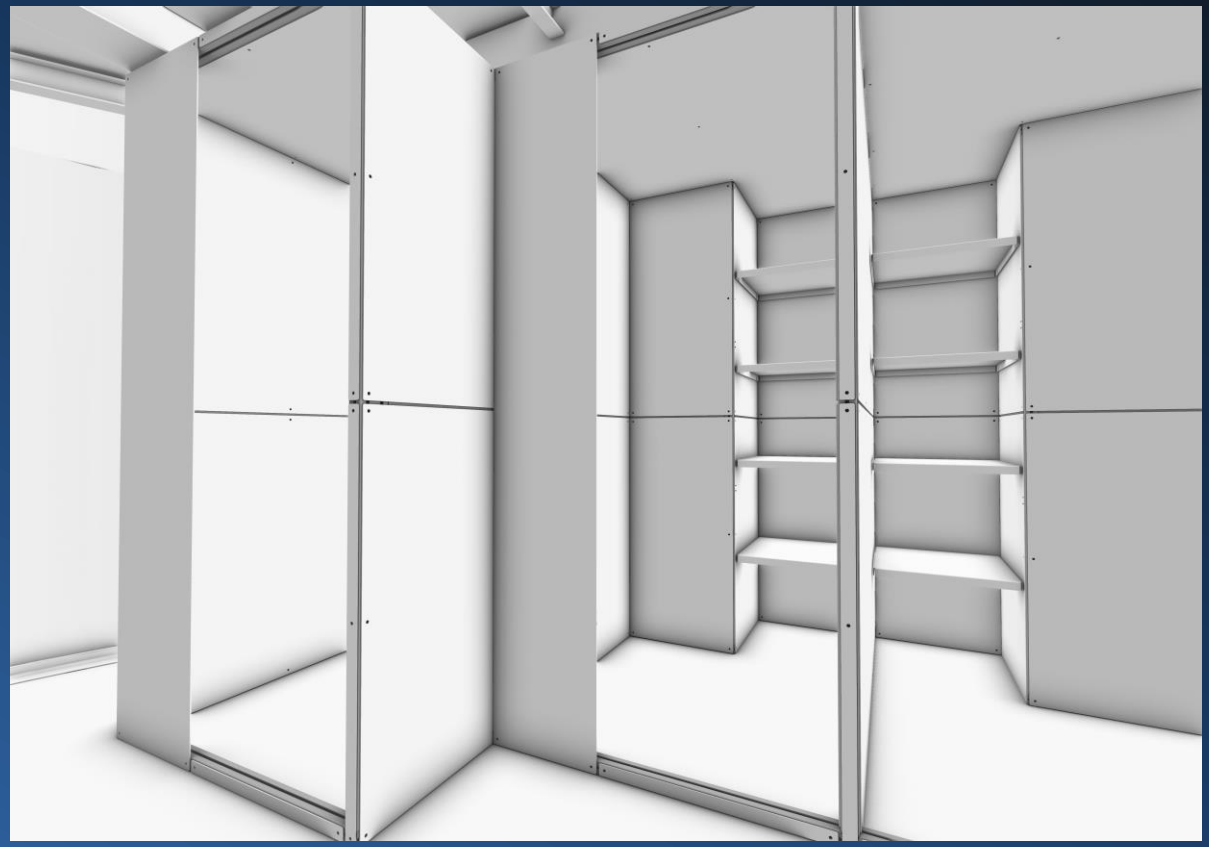




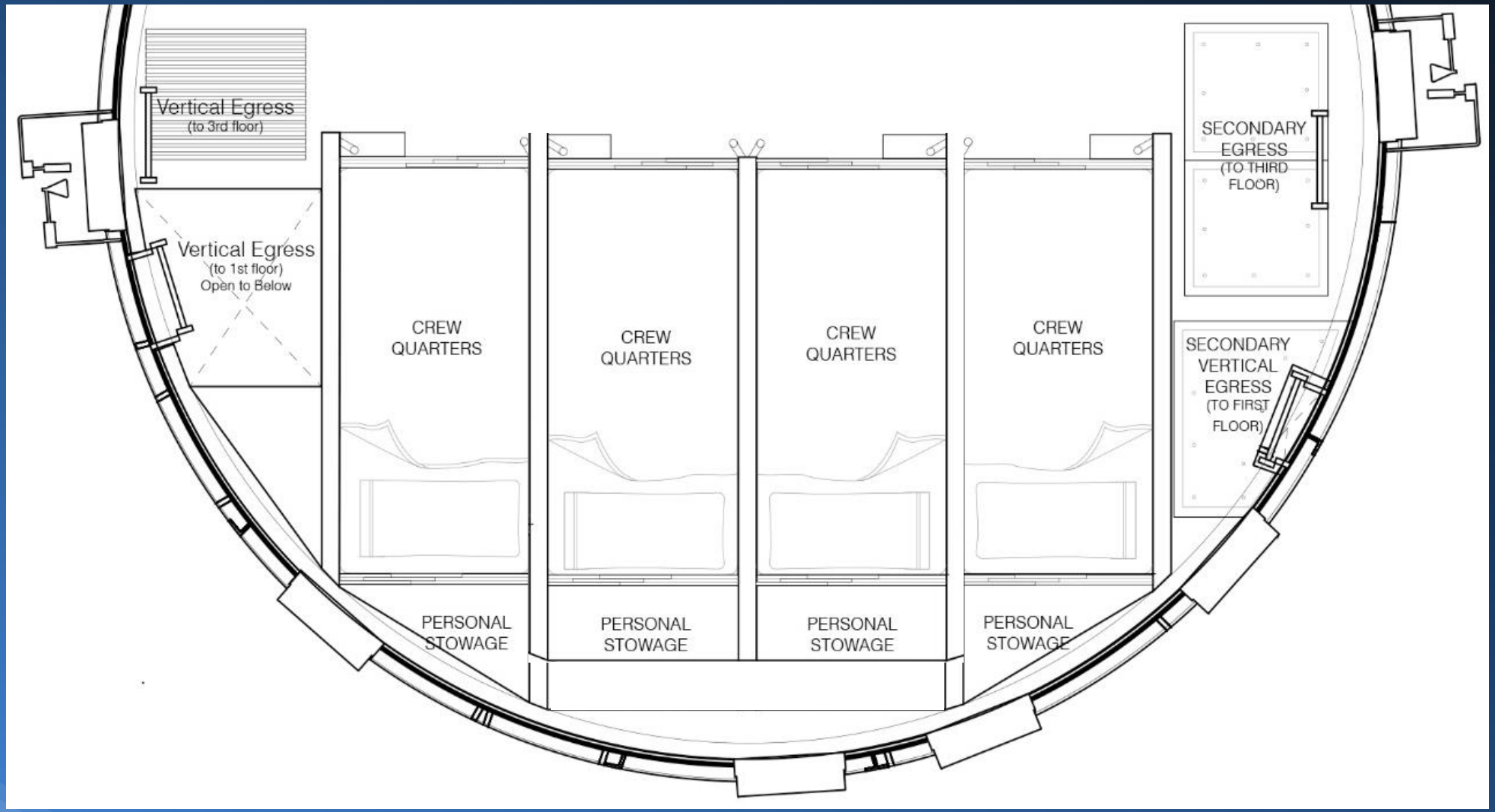
3rd Floor Configuration

2nd Floor – Waste and Hygiene Visual



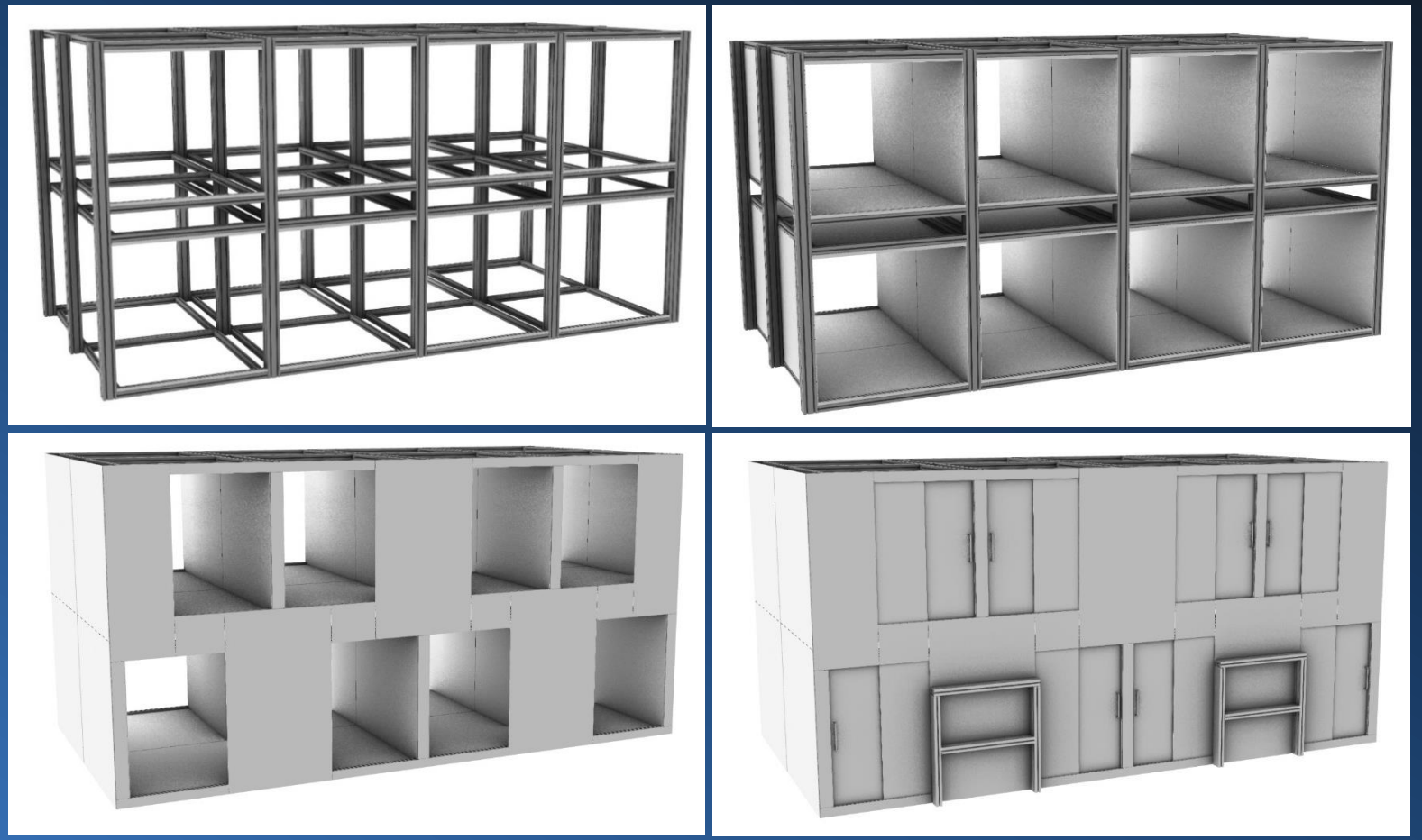


2nd Floor – Crew Quarter Layout



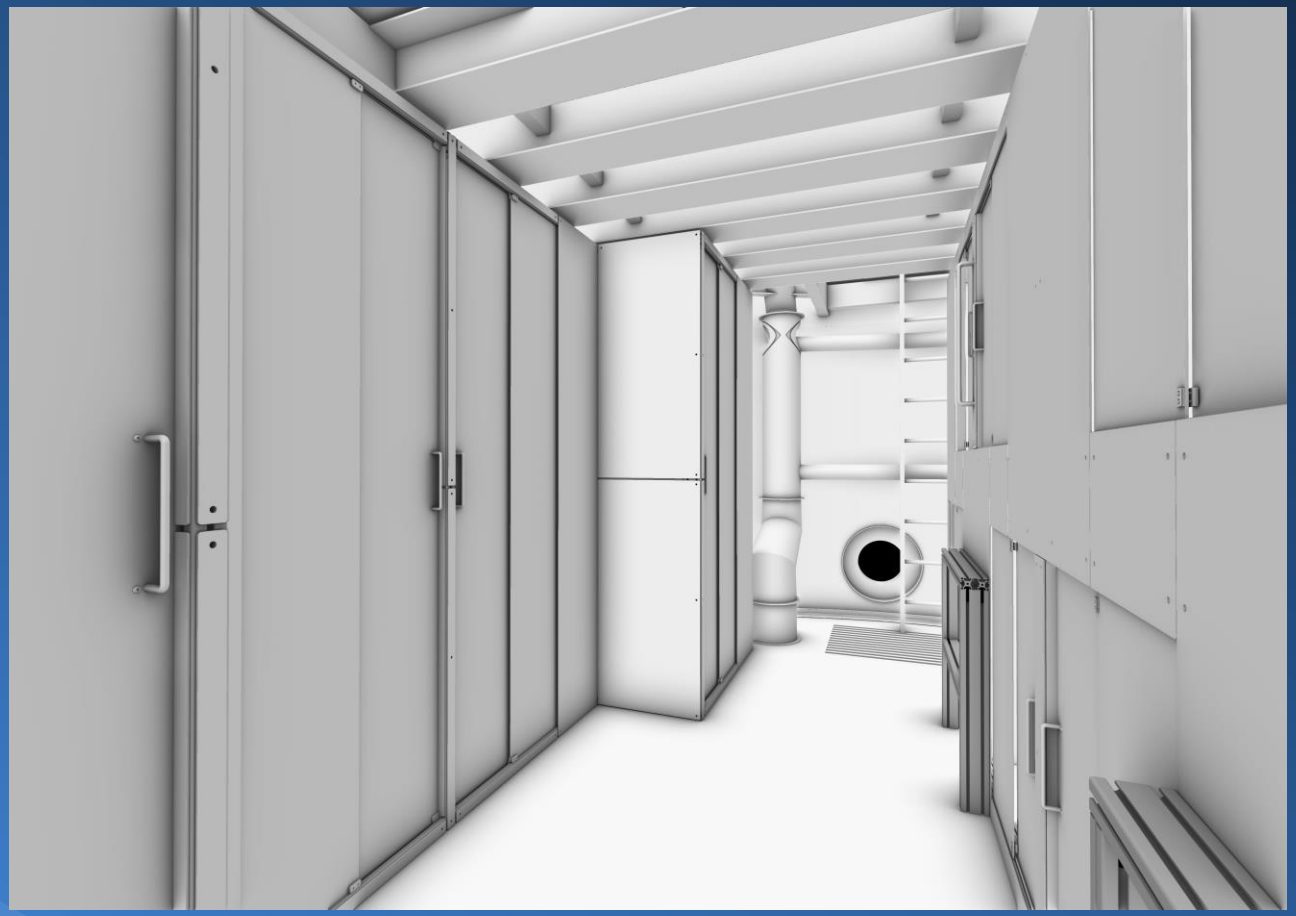
2nd Floor: Crew Quarter Structure

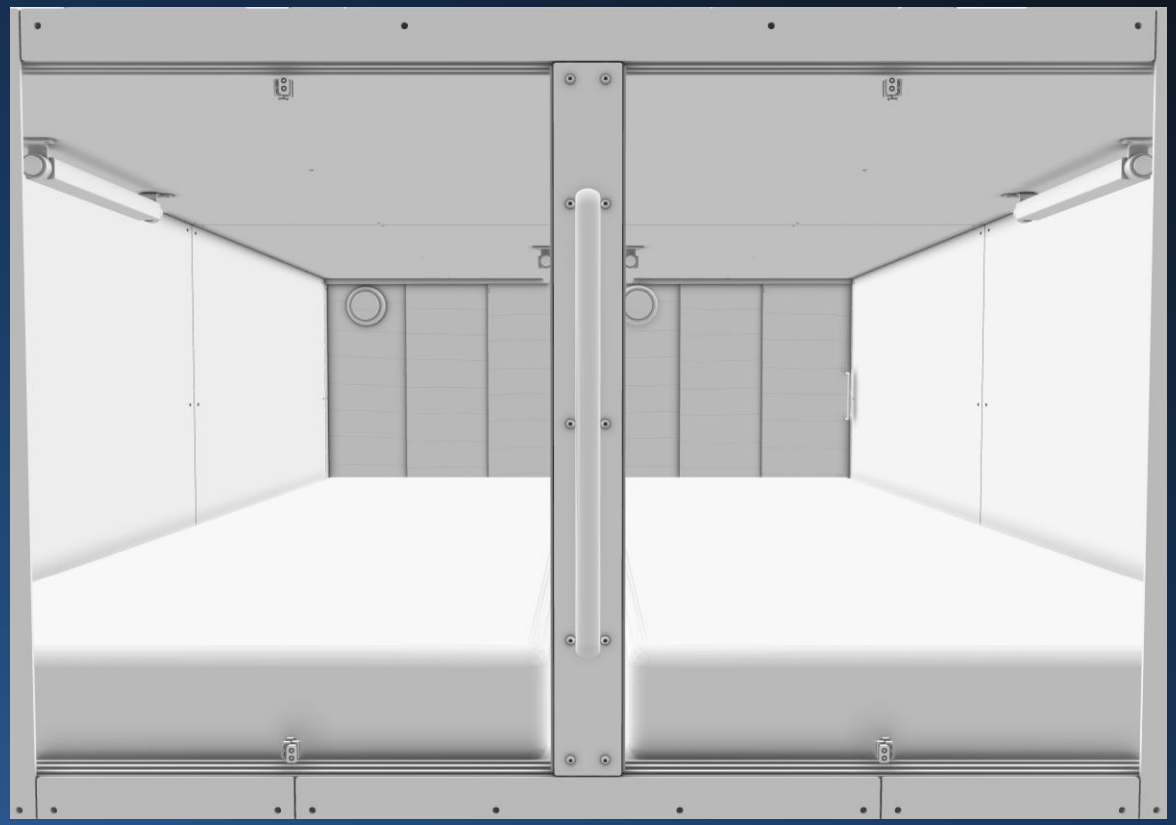
- Uniform structure throughout deck
- Reduced part count and part complexity
- Simplified construction



Individual CQ interior dimensions: 85cm x 90cm x 200cm

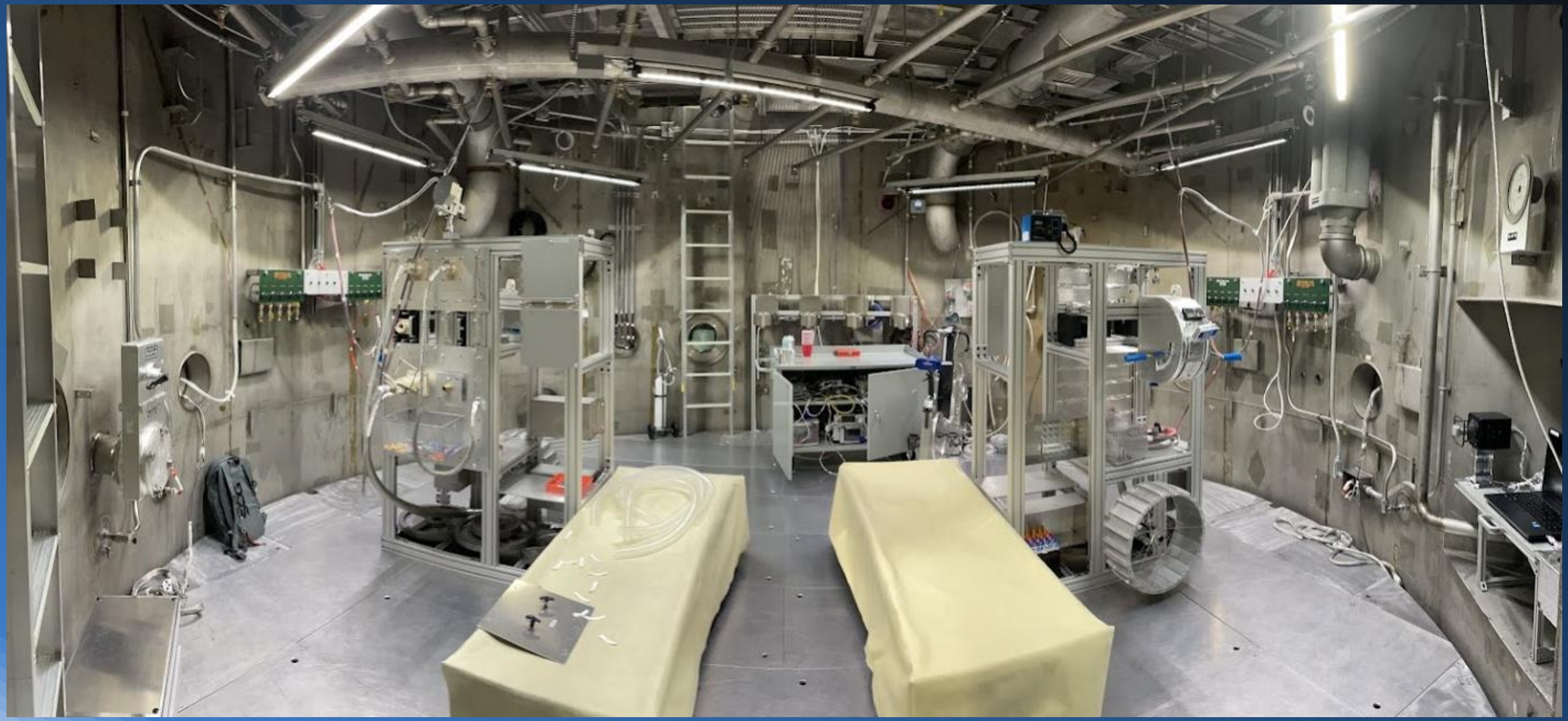
2nd Floor: Secondary Vertical Access and Crew Quarter Visual





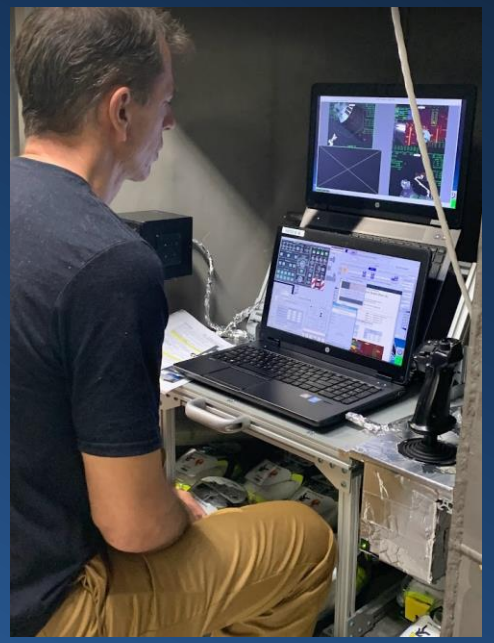
2nd Floor – Crew Quarter Layout

EVA Sim Stations



Hypoxia Characterization

- Coinvestigators will look at:
  - Blood, urine, saliva
  - Recovery from exercise
  - AMS questionnaires
  - Cognitive tasks
  - Visual acuity



Control Room

- Live video and comms to/from chamber

Medical Evaluation/Treatment Area

- Next panel:

  DCS TREATMENT FOR EXPLORATION ATMOSPHERE STUDY (Dr. Sanders)

COVID Guidelines

- Fully vaccinated particpants
- Quarantine 1 week prior to test
- PCR 24hrs prior to chamber entry

Test timeline

- Completed overnight (14.7psi) test Nov 2021 (8 participants)
- Completed 8.2psi/34% and 4.3psi test Feb 2022 (2 participants)
- Planning full 3 day dress rehearsal May 2022 (8 participants)
- Actual 11 day test: June 2022 (8 participants)
- Additional 11-day tests to follow:
  - Increase N at 8.2psi/34%
  - Test additional alternate atmospheres (eg 10.2psi/26.5% O2)
  - Test variable suit pressures (5psi, 6.2psi beyond 4.3psi)

  ~ 2 tests per year

Contact

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Text Questions

- Text questions to the Panel
- Number displayed on the board
- (Fancy App?)

BACKUP SLIDES

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Skylab/SMEAT layout – 1971

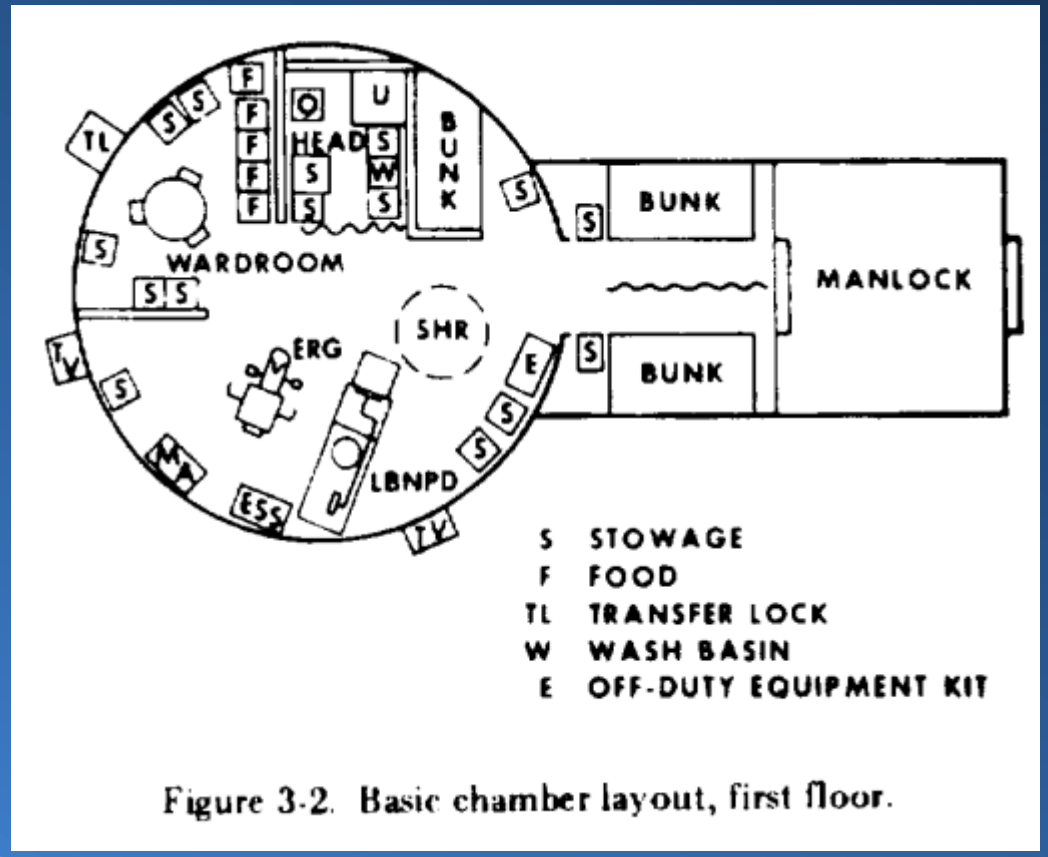
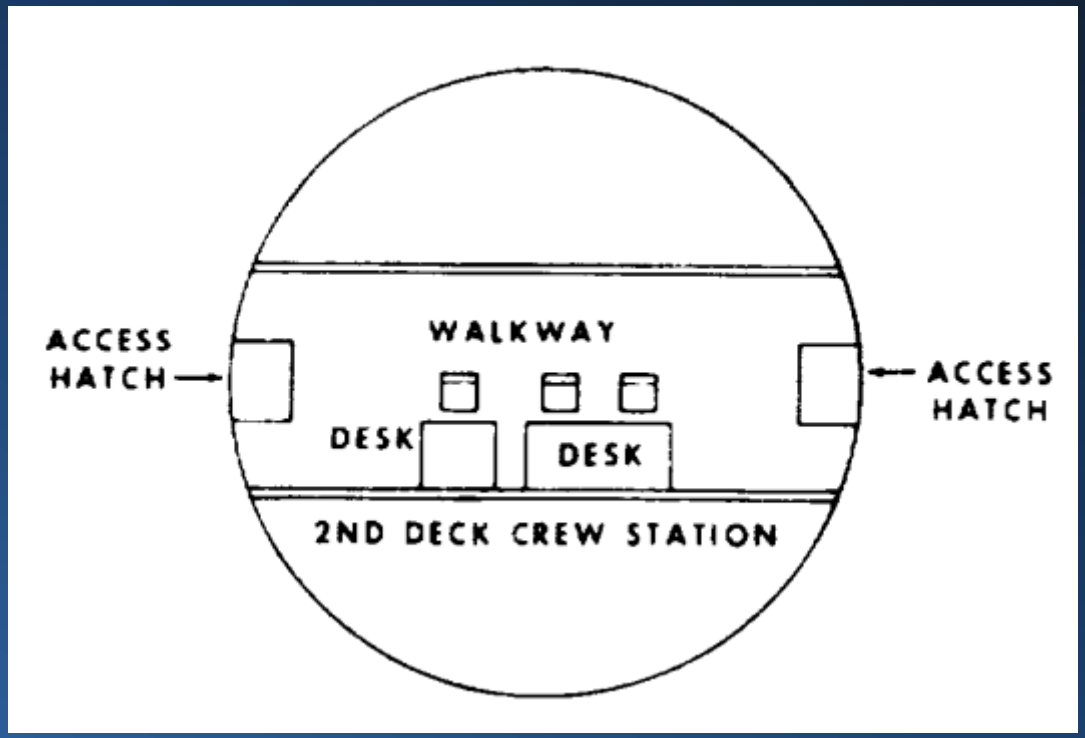


Figure 3-2. Basic chamber layout, first floor.



The Need for Exploration Atmosphere

- Multidisciplinary EAWG recommendation to adopt 8.2 psia / 34% O2 as a capability for future missions; conduct testing in microgravity

Saturation Atmosphere	Microgravity Prebreathe (h:mm)	Estimated Planetary Prebreathe
14.7 psi, 21% O2	4:00	Minimum 4:30 [1]
10.2 psi, 26.5% O2	~2:40 (ISLE)	3:00 [2]
8.2 psi, 34% O2	**0:00-0:15**	**0:00-0:15 [3]**
5.0 psi, 100% O2 (Apollo, Gemini)	0:00	0:00

[1] Abercromby et al. *"Suited Ground Vacuum Chamber Testing Decompression Sickness Tiger Team Report", NASA Technical Report (In Review), 2018*

[2] Abercromby, et al. *"Using the Shuttle Staged Prebreathe Atmosphere and Variable Pressure Spacesuits for Exploration Extravehicular Activity"*. 89th Annual Meeting of the Aerospace Medical Association (AsMA), Dallas, TX, 2018.

[3] Abercromby et al. *"Modeling Oxygen Prebreathe Protocols for Exploration EVA Using Variable Pressure Suits",* 88th Annual Scientific Meeting of the Aerospace Medical Association (AsMA), Denver, CO, 2017.

Test Timeline

- 6 Subjects + 2 Doppler Technicians
- Planetary EVA Simulation

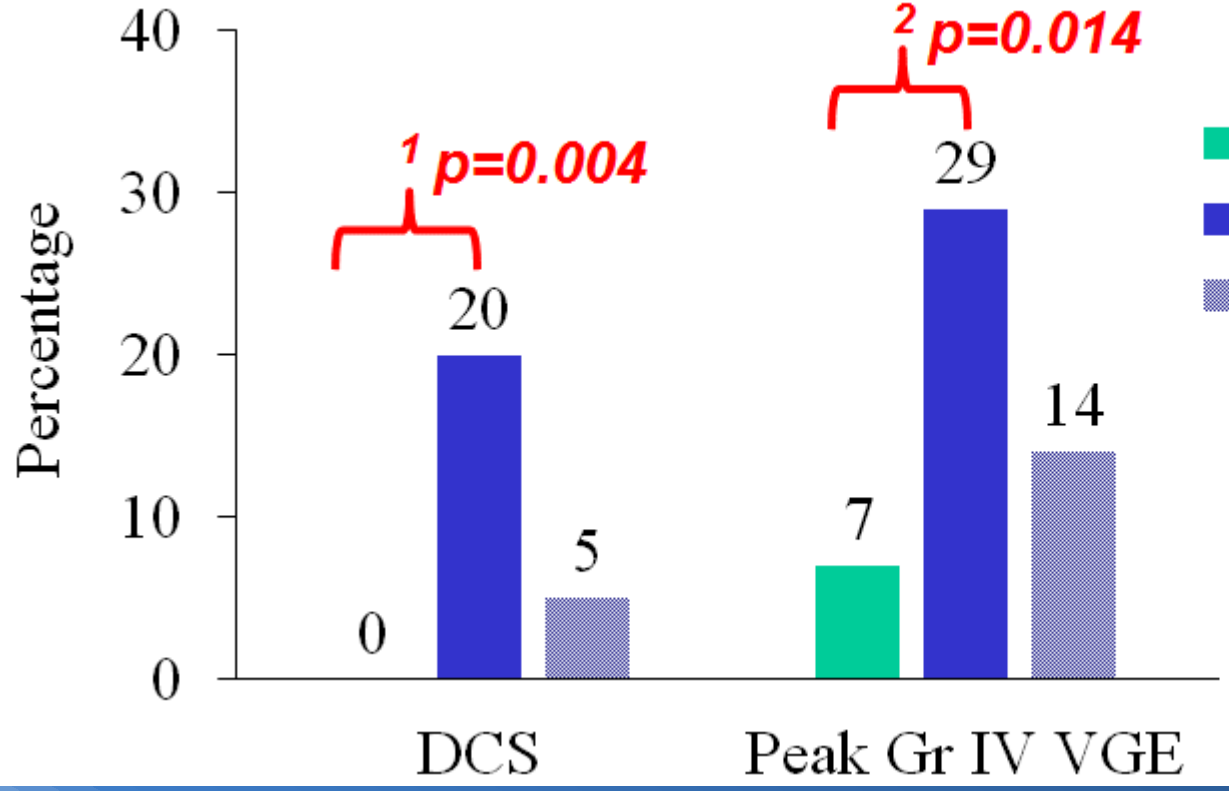
Day 1	3hr @ 100% O2, 14.7 psia; Ascend to 8.2psia / 34% O2; Equilibrate
Day 2	
Day 3	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 4	Rest
Day 5	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 6	Rest
Day 7	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 8	Rest
Day 9	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 10	Rest
Day 11	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2

Hypoxia Characterization

Pressure Profile

Planetary vs. Microgravity

- DCS risk is increased by ambulation and physical activity during altitude exposure [1]



No Ambulation (CEVIS)

Ambulation Before and During Exposure (Expt 1)

Ambulation Before Exposure Only (Expt 3)

	CEVIS	Expt 1	Expt 3
Age (y); Sex (m/f)	32±9 (35/10)	37±9 (15/5)	36±9 (17/4)
DCS	0/45 (0%)[1]	4/20 (20%)[1]	1/21 (5%)
Peak Gr IV VGE	3/45 (7%)[2]	6/21 (29%)[2]	3/21 (14%)
Cum Gr IV VGE	26/630 (4%)	12/262 (5%)	11/286 (4%)

VGE: Venous Gas Emboli

[1]Conkin J, Pollock NW, Natoli MJ, Martina SD, Wessell JH III, Gernhardt ML. Venous gas emboli and ambulation at 4.3 psia. Aerosp Med Hum Perform. 2017; 88(4):370–376.

Doppler Bubble Monitoring

1. TSI DBM9008 w/ TSI-DPA7
   - Used for all bubble monitoring when VGE grade < III

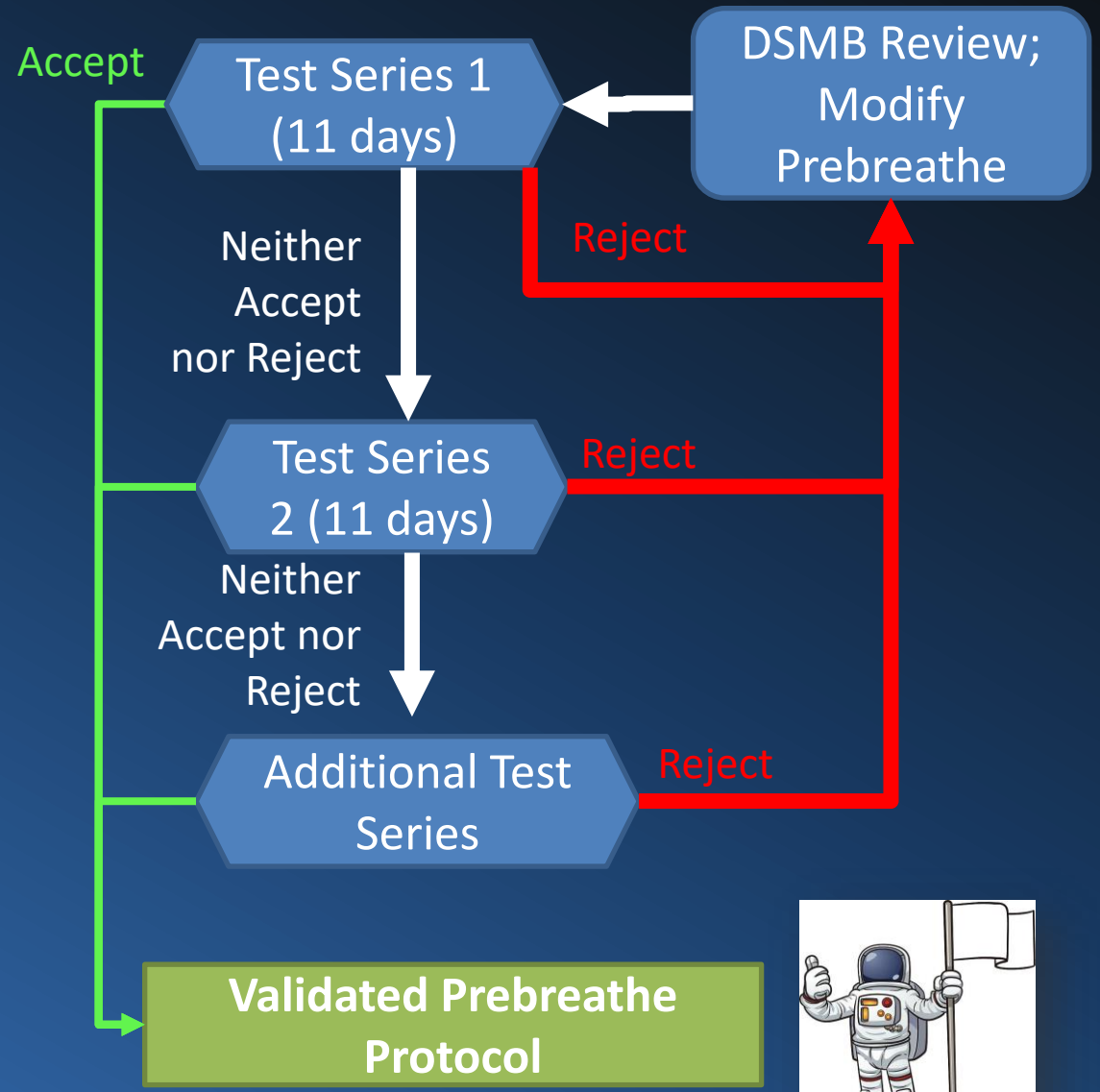
2. Sonosite Elite 180
   - Used when VGE grade >= III
   - Monitor for LVGE to confirm bubbles have not transferred into arterial blood

1

2

Accept-Reject Criteria

- 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 more data!



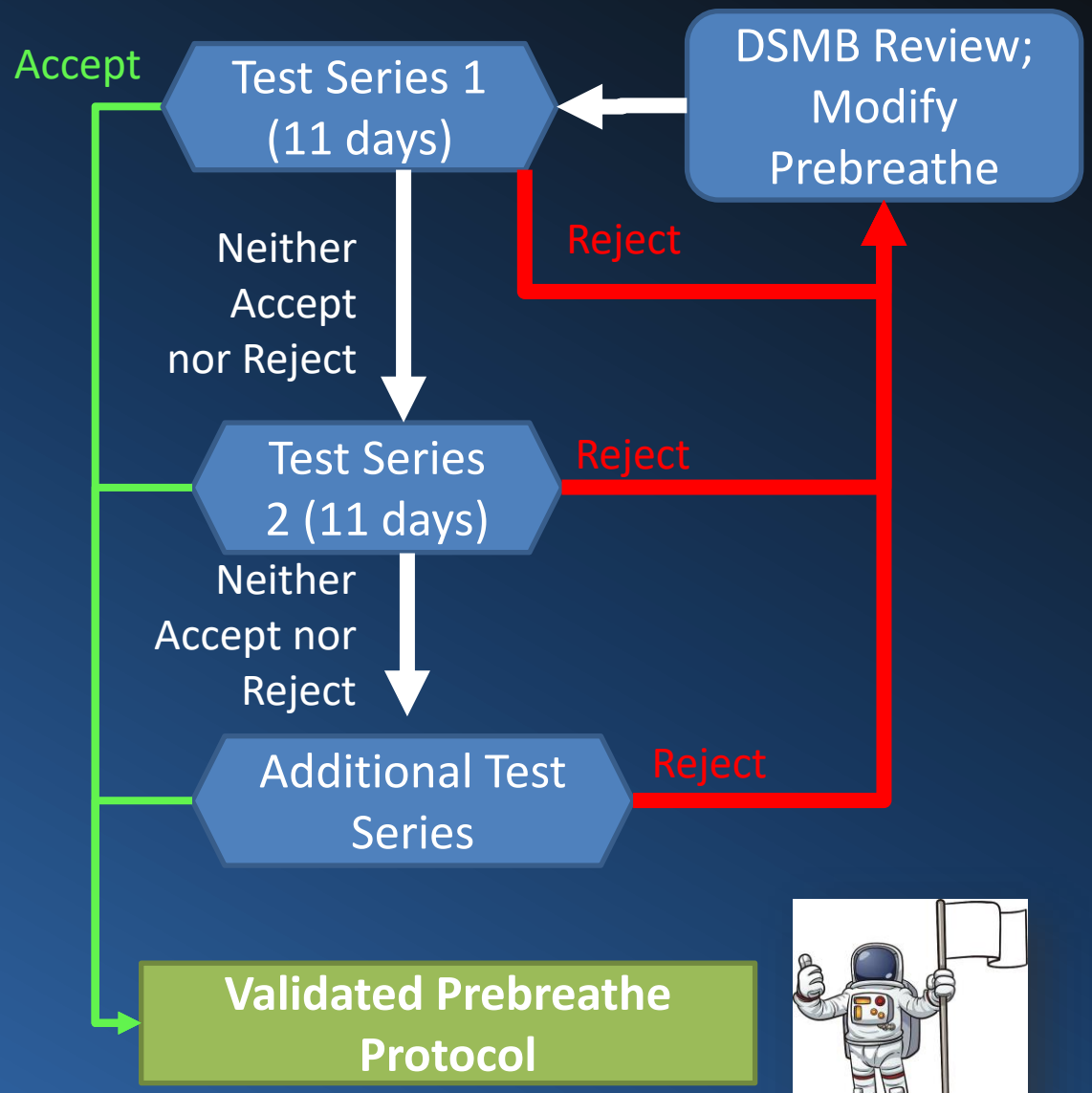
Expected Results

Model Data:

- DCS model (Conkin *et al*., 2014) calculates P(DCS) = 3.1% (1.8 to 5.4%) for planetary test subjects

Power Analysis:

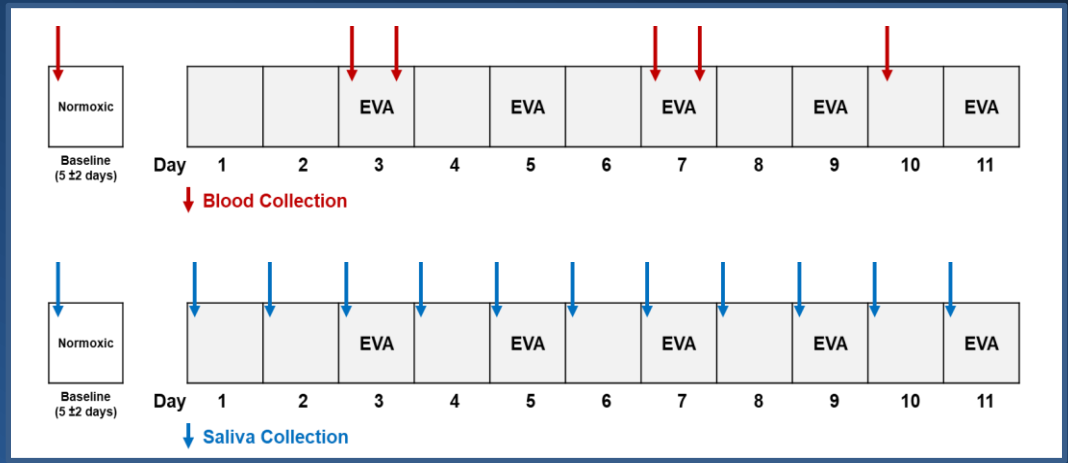
- If $P(DCS_{planetary})$ = 3.1%, then 12 subjects x 5 EVAs has an 88% probability of meeting the accept condition



7. Hematology/Immunology/Inflammatory Response (2/6)

- Materials/Methods:
  - Blood samples: 6.0 ml per crewmember during each blood draw.
    - 36 NaHep tubes (6 crewmembers x 6 collection days)
  - Saliva samples: 1 mL passive drool per crewmember/collection.
    - 72 Swab storage tubes (6 crewmembers x 12 collection days)
    - 72 SalivaBio oral swab (6 crewmember x 12 collection days)

- Protocol:
  - Blood and saliva will be processed by Immunology laboratory personnel in Building 21 Room 1103.
  - Blood (2.5mL), plasma, mitogen stimulated supernatants, and passive drool will be frozen for subsequent batch analysis.
  - Frozen blood (2.5 mL) will be sent to Ludwig-Maximilians-University of Munich for analysis of adenosine and endocannabinoid receptor expressions.



Oxidative Damage

SAMPLE	MEASUREMENT	UNITS	METHOD OF ANALYSIS
Blood	Basic leukocyte subsets	Percentage	Fluorescent staining, Flow cytometry
Blood	Plasma cytokines	pg/mL	Milliplex Multiplex Assay
Blood	Mitogen stimulated cytokine profile	pg/mL	Milliplex Multiplex Assay
Blood	CBC (complete blood count)	Various	Clinical laboratory equipment
Blood	Adenosine		
Blood	Endocannabinoid expressions		
Saliva	Cortisol	µg/dL	ELISA
Saliva	Epstein barr virus	Copies/ng	PCR
Saliva	Varicella zoster virus	Copies/ng	PCR
Saliva	Herpes simplex 1 virus	Copies/ng	PCR
Saliva	Cytomegalovirus	Copies/ng	PCR

SAMPLE	MEASUREMENT	UNITS	METHOD OF ANALYSIS
Blood	Superoxide Dismutase (SOD)	U/mL	Colorimetric
	Glutathione peroxidase (GPX)	U/L or U/g Hb	Colorimetric
	Glucose	mg/dL	Clin Lab VITROS
	Leptin	Ng/mL	RIA
	LDL, Oxidized	U/L	ELISA
	Creatinine	mg/dL	Clin Lab VITROS
	Catalase	nmol/m/mL	ELISA
	Hemoglobin	g/dL	Spectrophotometric
	Hematocrit	%	Electronic calc
	Glutathione, total and reduced	Umol/L	HPLC
	s100beta		
	Neurofilament light		
	Ghrelin	pmol/L	ELISA

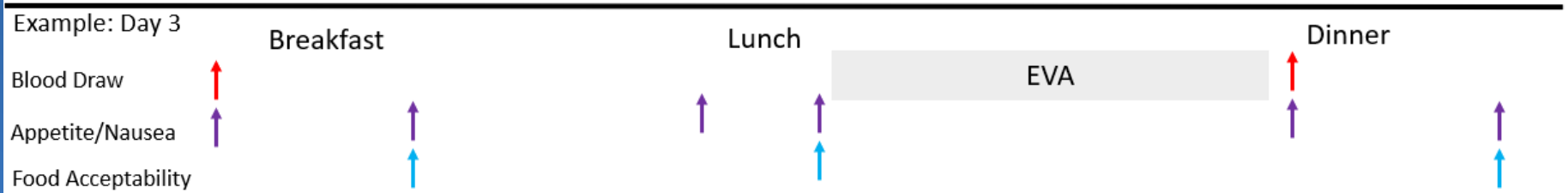
Appetite and Food Intake Impacts

Methods

Pre-Mission						
L-7	L-6	L-5	L-4	L-3	L-2	L-1
Daily Weighed Food Record, Daily Fasted Weight						
				RMR, DXA,		
		Ratings		Ratings		Ratings

Post-Mission		
R+1	R+2	R+3
DXA		

In-Mission										
1	2	3	4	5	6	7	8	9	10	11
Daily Food Record, Daily Fasted Weight										
		EVA		EVA		EVA		EVA		EVA
Ratings	Ratings	Ratings	Ratings	Ratings	Ratings	Ratings	Ratings	Ratings	Ratings	Ratings



RMR = Resting metabolic rate; DXA = dual-energy X-ray absorptiometry. Ratings: Subjective ratings of appetite and nausea will be collected up to 6x and food acceptability will be collected up to 3x on selected days. Orange boxes signify blood draw days, when ghrelin will also be measured. Blood is collected once on Days L-5 and Day 10 and twice on Days 3 and 7.

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Sleep Quality and Duration Impacts

- **Materials/Methods:**
  - Phillips Actiwatch
  - Microsoft SurfacePro 7's

- **Protocol:**
  - Phillips Actiwatch Spectrum is a wristwatch device that measures sleep/wake rhythms, sleep quantity, and sleep quality. Actigraphy will be collected continuously (24/7) throughout the pre-, in-, and post-mission periods. The Actiwatch should only be removed during showers or other activities with exposure to water.
  - Pre-sleep questionnaire administered daily within 30 minutes before sleep (mood, neurobehavioral functioning, workload, caffeine and medication, team and social dynamics)
  - Post-sleep questionnaire administered daily within 30 minutes upon waking (sleep quality, sleep times, and neurobehavioral functioning)