# 100-Person Mars Transfer Vehicle using Torpor-Inducing Habitats

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# Introduction

# Motivation

- True **permanent settlement** on Mars will require on the order of **100 settlers**
  - Historical perspective: first European settlements in America started with ~100 settlers each
  - Self-sustainability requires for sufficiently large gene and donor pool (blood, organ, tissue supply)

- Current engineering solutions for near-term exploration missions **do not scale well** to long-term settlement missions

- Using in-space habitats such as NASA DRA 5.0 TransHab would require **17 habitat modules**, or approximately 700 t total launch mass, to transport crew of 100 to Mars

**To enable settlement-class missions, <u>we need a radical, out-of-the-box approach</u> to transporting human crew.**

# Proposal

For deep space transit from Earth to Mars, place passengers in a stasis-like **Torpor** state by leveraging evolving medical advances in **Therapeutic Hypothermia** and **Total Parenteral Nutrition**.

# Key Concepts

| | |
|---|---|
| **Torpor** | **Hibernation state** characterized by decreased physiological activity and reduced metabolic rates |
| **Therapeutic Hypothermia (TH)** | Medical treatment that **lowers a patient's body temperature** (to 32-34°C / 89-93°F) in order to induce torpor |
| **Total Parenteral Nutrition (TPN)** | Medical treatment to feed a patient **intravenously with nutritional fluids** for extended periods of time |
| **Crew / Passengers** | For 100-person mission, **96 passengers** are placed in torpor state during transit to Mars, with an active **crew of 4** serving as caretakers |

# Engineering Advantages

**Passengers are unconscious and stationary in habitat**

- Reduces total **pressurized volume requirement** for habitation and living quarters
- Eliminates need for many ancillary crew accommodations (e.g. food galley, cooking and eating supplies, exercise equipment, entertainment, etc.)
- Allows implementation of rotation-induced **artificial gravity** within a relatively short rotation radius

**Passengers have reduced metabolic rates in torpor state**

- 50% to 70% reduction achievable with modest cooling
- Reduces amount of **consumable** food, water, and oxygen required
- Reduces burden on environmental control and life support systems

# Medical Advantages

- **Bone demineralization** and **elevated intracranial pressure** (ICP) can be minimized with implementation of artificial gravity
  - Recent studies have shown that TH itself can reduce elevated ICP
- **Muscle atrophy** can be addressed with combination of artificial gravity and application of Neuromuscular Electrical Stimulation (NMES)
- Passengers are stationary, so **radiation exposure** from Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE) can be minimized by:
  - Design layout of habitat subsystems and consumables to maximize radiation absorption
  - Addition of dedicated radiation shielding materials to improve coverage as needed
- Passengers are unconscious during transit, avoiding **psycho-social challenges** of long-term confinement and isolation from Earth

# Medical Perspective

# Medical Status

**TH and TPN are both common and well-understood medical procedures.**

- Human patients have already been placed in a **continuous torpor state** using TH for periods **up to 14 days**, a limit due only to lack of medical rationale for longer periods
- Human patients have undergone **multiple TH induction cycles** with no negative or detrimental effects reported in either the near-term or long-term
- Human patients regularly receive nutritional sustenance from **TPN for extended durations** exceeding 1 year

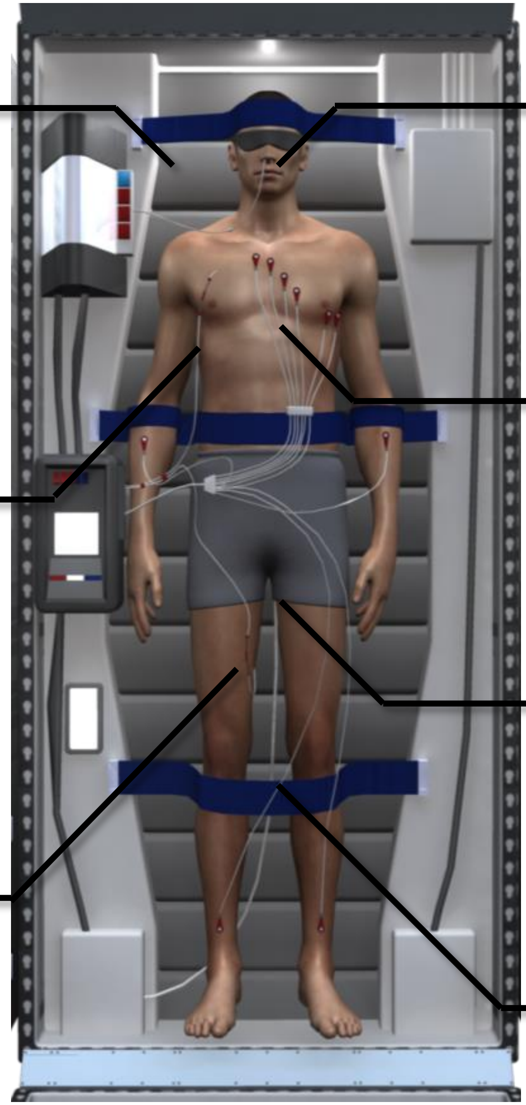
**Conversations conducted with multiple medical practitioners, researchers, and experts have confirmed the medical plausibility of this concept and approach for long duration, deep space application.**

# Implementation of Torpor

Passive **thermal pads** for cooling and rewarming (e.g. KOALA System ™)

TPN administered via tunneled central venous catheter in chest

Alternate tunneled central venous catheter for **TPN** administration in inner thigh



Non-invasive **intranasal cooling** with inert coolant (e.g. RhinoChill System ™)

12-lead ECG sensors across body

Urine collection assembly and drain line

Light restraints for maintaining position during zero-G flight

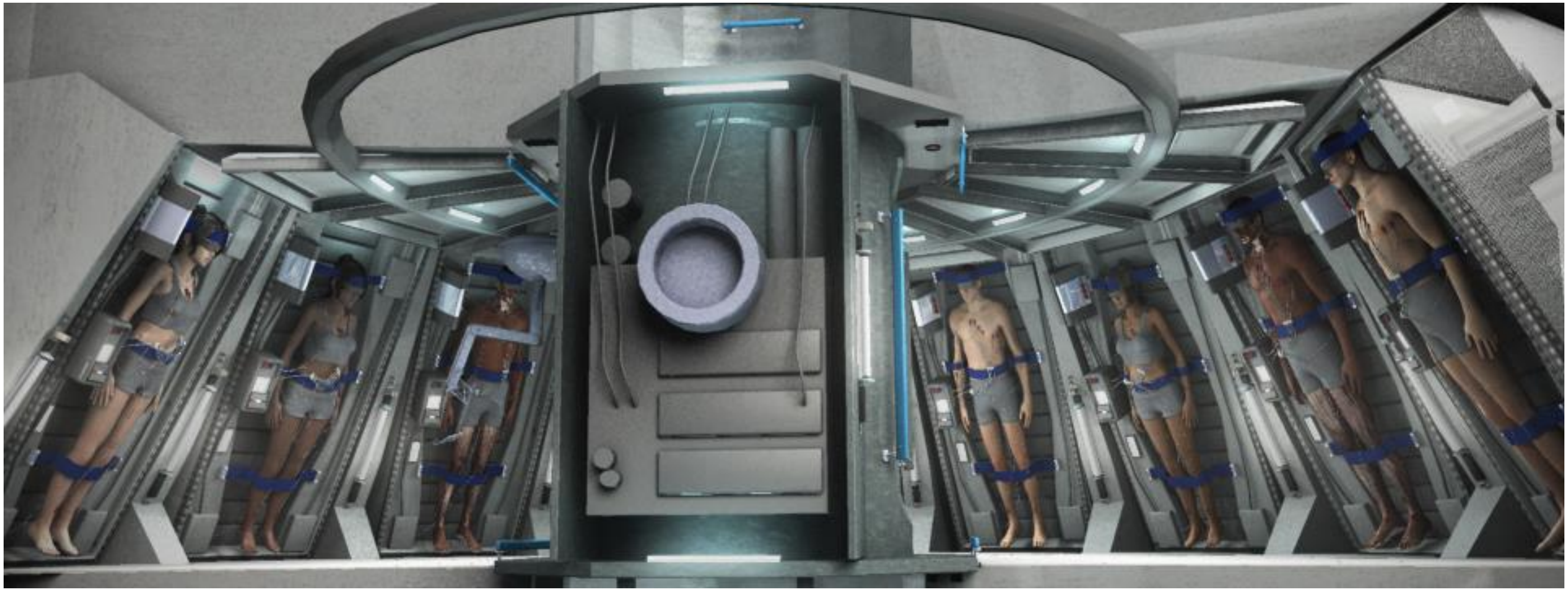
*Human model assets credit: http://tf3dm.com/ and http://www.turbosquid.com/*

# Engineering Perspective

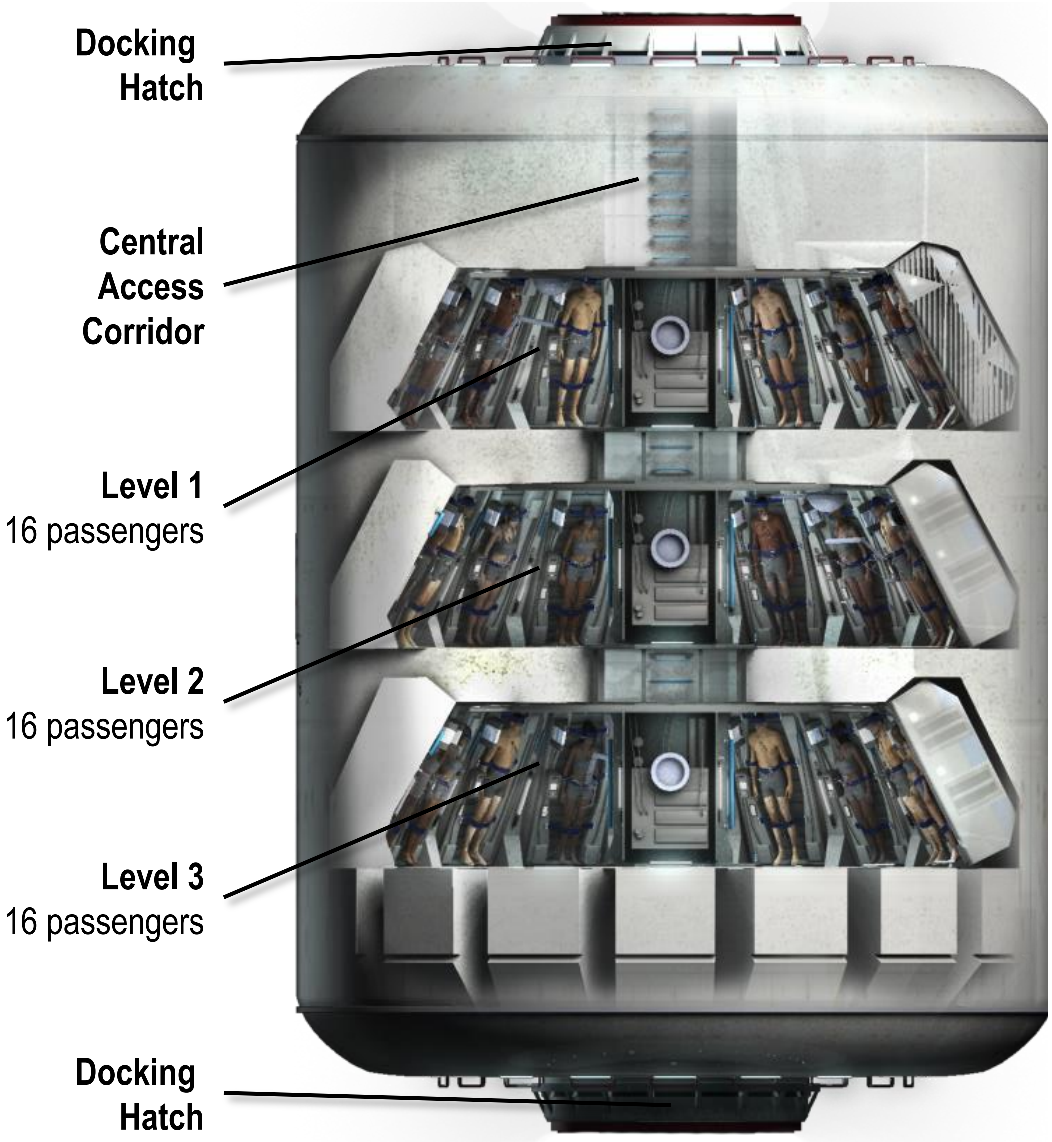
# Habitat Interior Design

- 3 levels per module, each with 16 passengers
- Artificial gravity induced by rotation, acceleration field simulates lying down with head slightly raised
- Two robotic manipulator arms on each level to manage passenger lines, leads, and restraints

| Artificial Gravity | | |
|---|---|---|
| **Analogy** | **Earth Gs** | **Rotation** |
| Moon | 0.16 | 7.1 rpm |
| Mars | 0.38 | 11.5 rpm |
| Earth | 1.00 | 17.6 rpm |

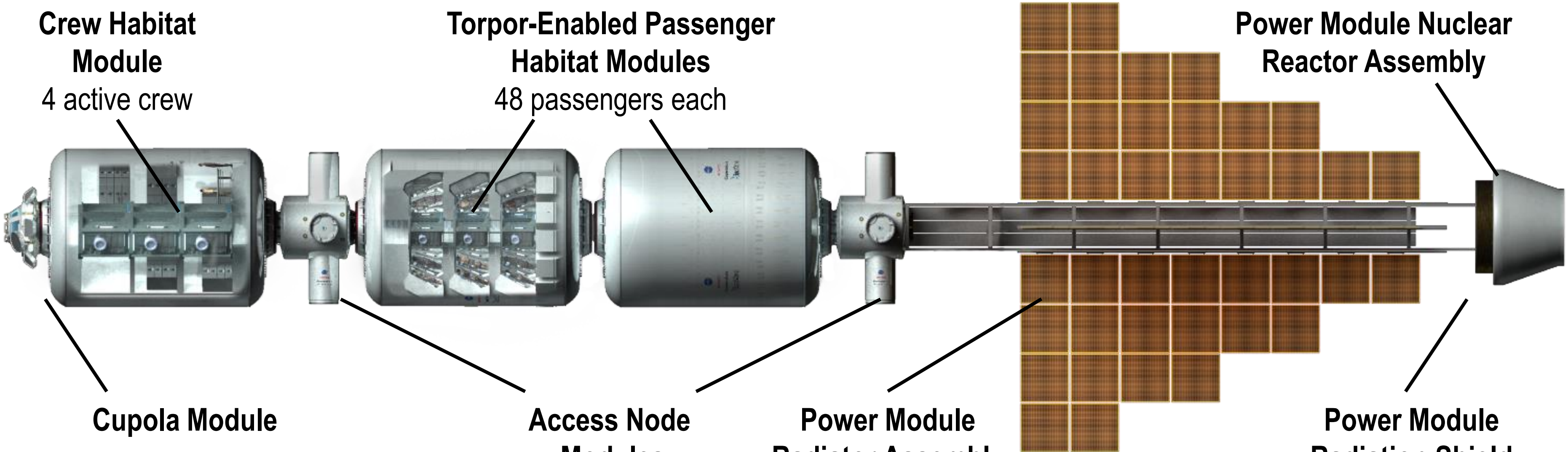


# Torpor-Enabled Passenger Habitat Module



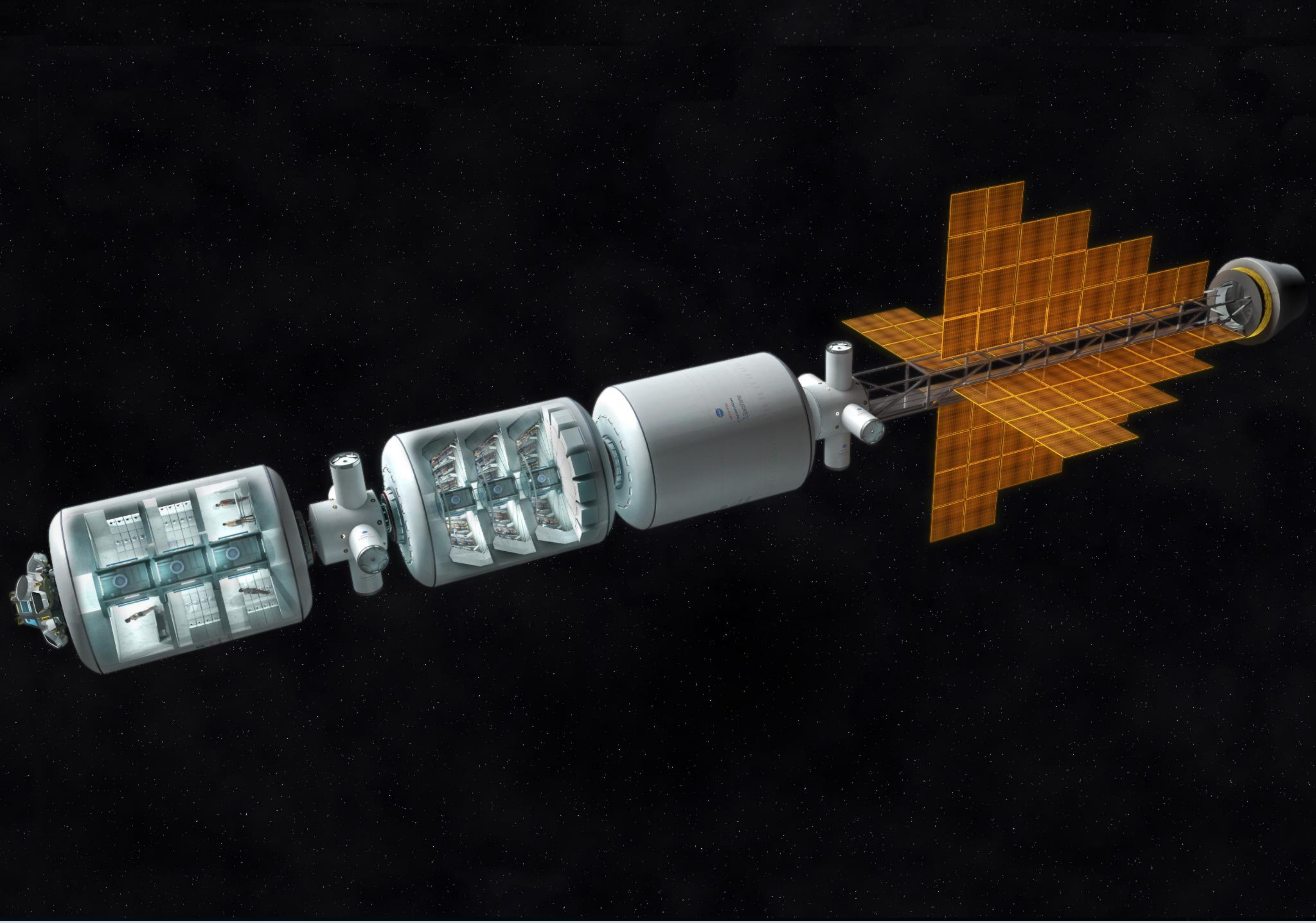

| Summary Metrics | |
|---|---|
| Passengers | 48 |
| Empty Mass | 44 t |
| Gross Mass | 71 t |
| Length | 10.0 m |
| Diameter | 8.5 m |
| Habitable Volume | 250 $m^3$ |
| Power Required | 100 kWe |

# Assembled Mars Transfer Habitat




| Element | Mass | Power |
|---|---|---|
| Crew Habitat Module | 23 t | 27 kWe |
| Torpor Passenger Habitat Module 1 | 71 t | 101 kWe |
| Torpor Passenger Habitat Module 2 | 71 t | 101 kWe |
| Access Nodes & Cupola | 11 t | 3 kWe |
| Power Generation Module | 19 t | 15 kWe |
| **Total** | **196 t** | **297 kWe*** |

* Total power includes 20% margin. Mass margins are carried on all dry masses and included in individual element masses.



# Conclusions

# Conclusions

- A torpor-enabled habitat solution also shows a **number of benefits** with respect to the **medical challenges** of human spaceflight
- Though current 14-day TH durations are significantly short of required 6+ month stasis periods, we believe that with continued advancements **we can achieve these extended torpor periods**
- Mars Transfer Habitat has a total mass of 200 t, a **significant improvement in mass** when compared to scaling current architectures for human exploration of Mars
- Overall, the application of long-duration torpor for humans to space exploration missions appears to be both **medically and technically feasible**

**We believe human torpor is an enabling technology to support the human settlement of Mars.**

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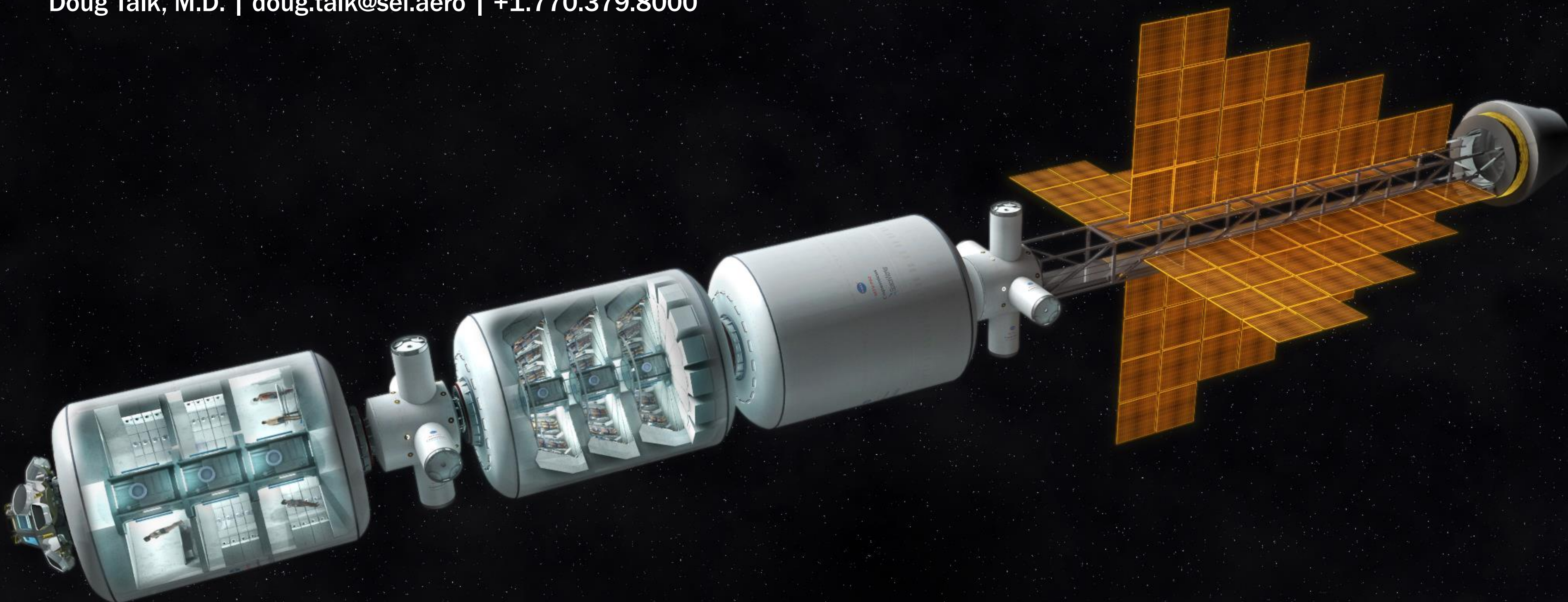

# SPACE IS GO

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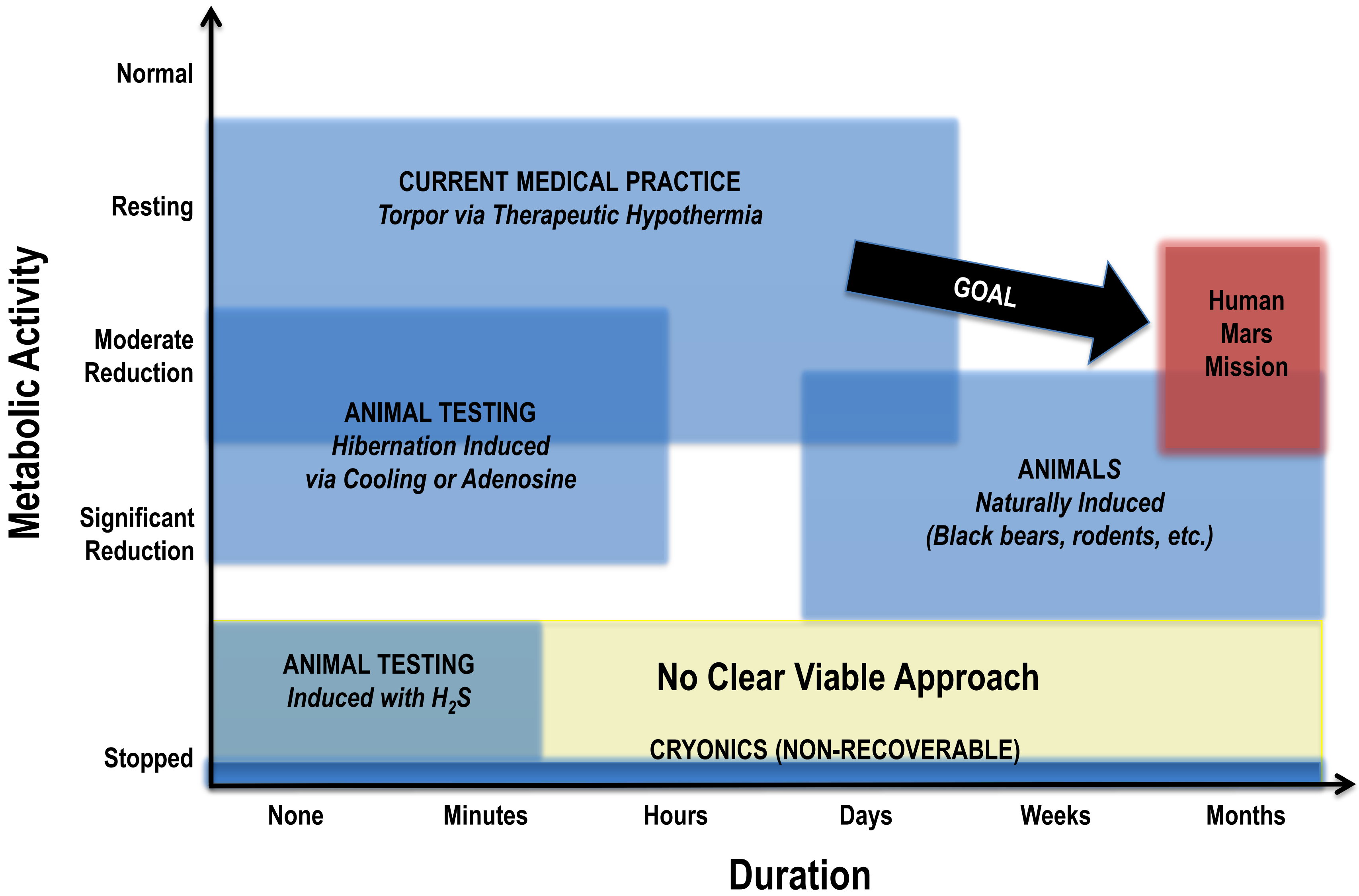
# Appendix

# Going Forward

- New proposals being submitted to start animal testing
  - Number of parallel experiments that can be conducted
- Evaluating nearer-term terrestrial applications for technology
  - Featured speaker for workshop at West Point Military Academy last month
  - Support for war-fighter, assist with organ transplantation, etc.
- Examining applicability to other destinations and missions in solar system beyond Mars
- Medical approaches for how achieve this continues to advance
  - TH is still our preferred approach and most readily available technology to leverage
  - ESA is now in some very early research using alternate approach

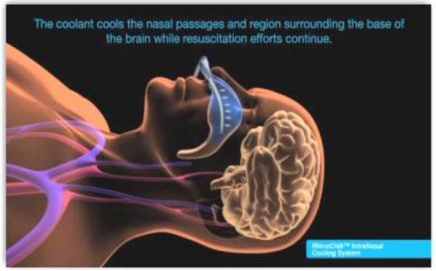
# Metabolic Reduction Knowledge Spectrum



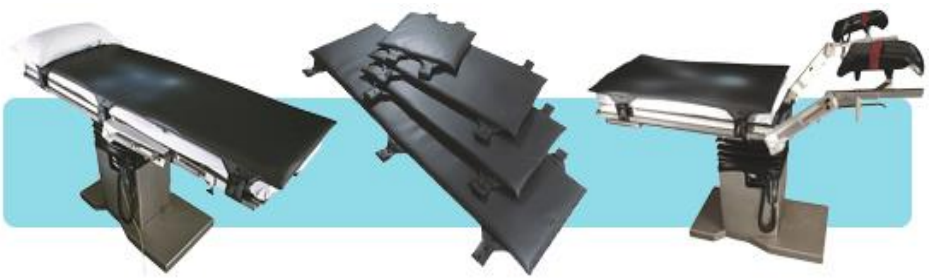
# Body Thermal Management

Incorporate two mechanisms for thermal management of crew. Both are low mass, low power, and easily automated.

1. Non-invasive intranasal cooling with inert coolant
   (e.g. RhinoChill System ™)



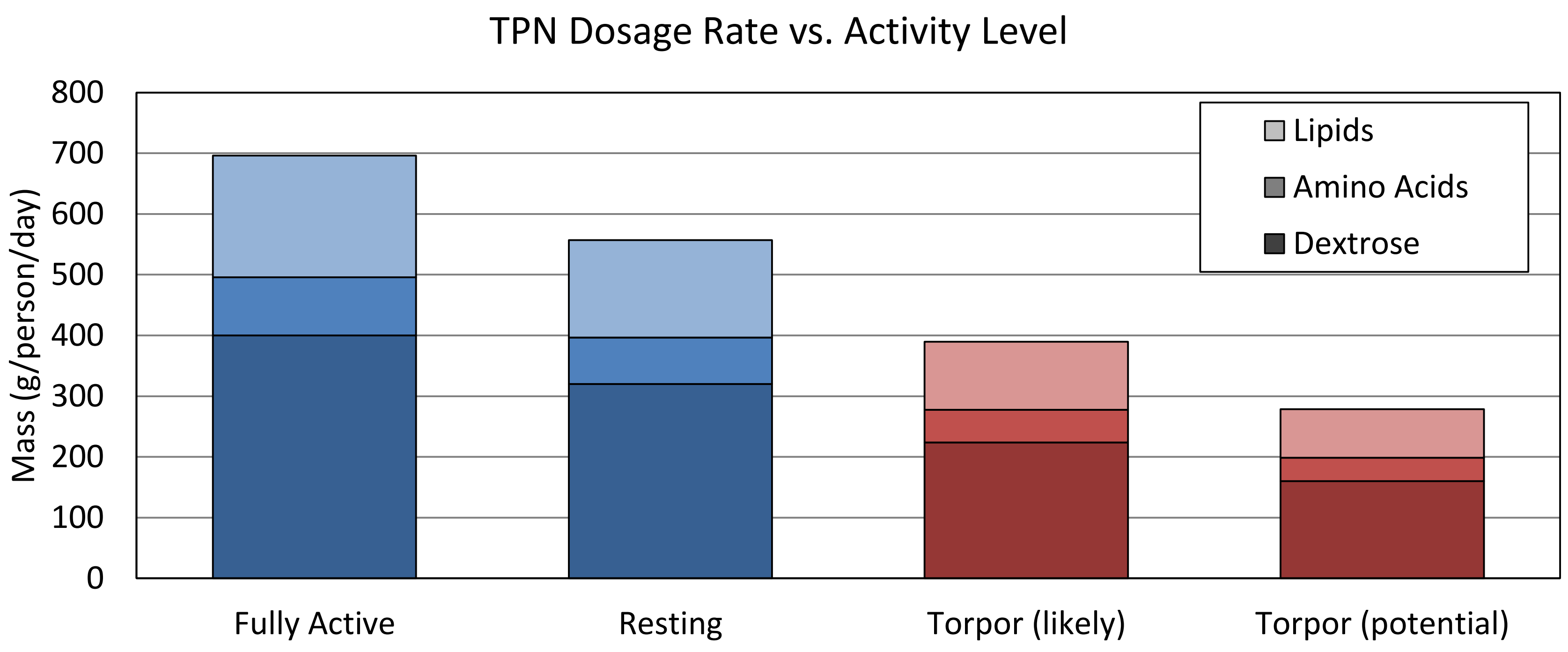

2. Passive thermal pads for cooling and rewarming
   (e.g. KOALA System ™)



| | Cooling | Rewarming |
|---|---|---|
| Target Temperature | 32° to 34° C (89° to 93° F) | 36° to 37° C (97° to 98° F) |
| Rate of Change | 0.5° C (1° F) per hour | 0.5° to 2° C (1° to 4° F) per hour |
| Time Required | 6  hours | 2 to 8 hours |

# Nutritional Management

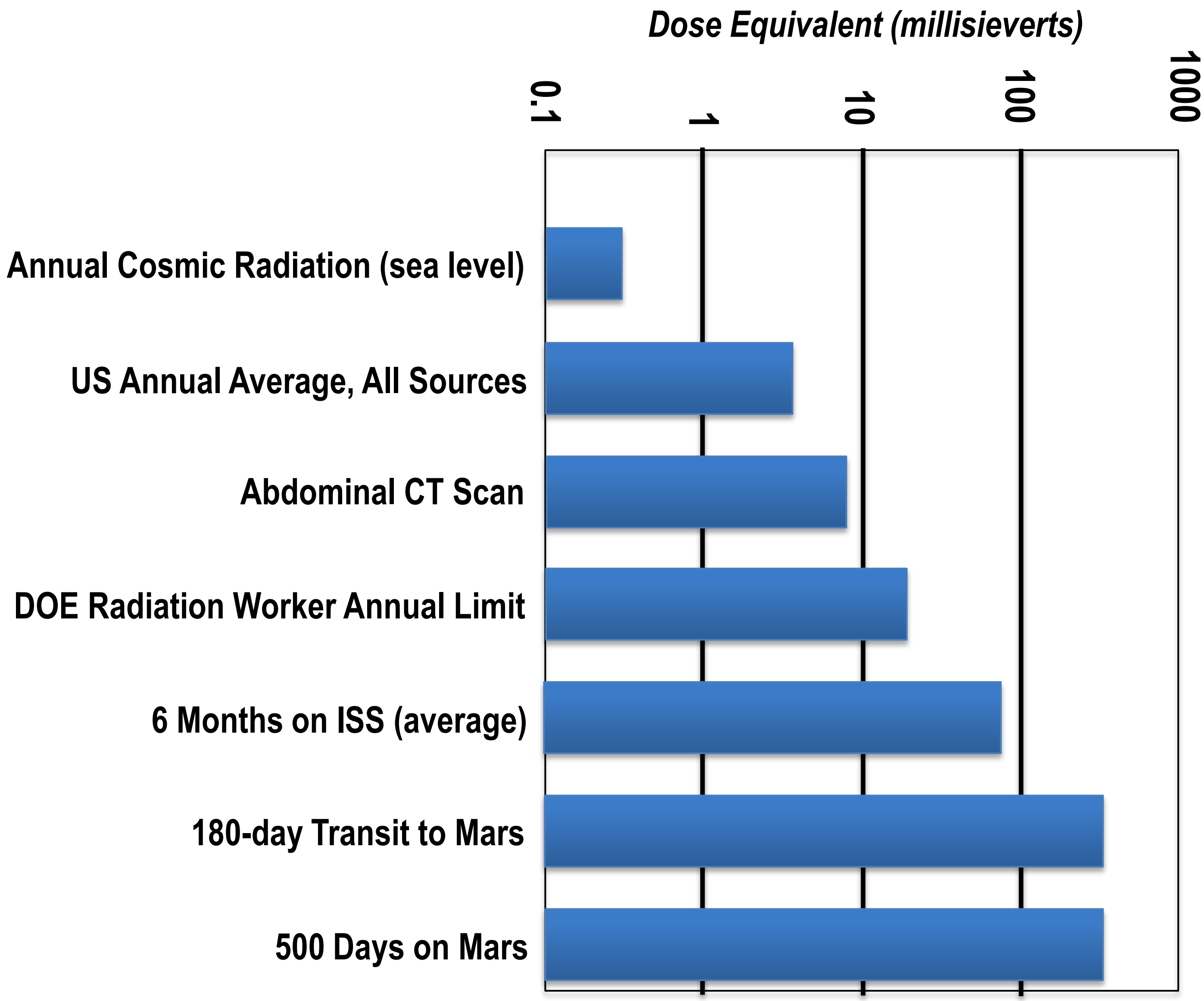
- TPN is feeding a person **intravenously by fluids**, bypassing the usual process of eating and digestion
- Mixture containing dextrose, amino acids, electrolytes, lipids, vitamins, and trace elements contains **all essential nutrients** for human body to function



# Muscle Atrophy and Bone Loss

- Average bone loss rate on Russian Mir Space Station was measured to be 1-2% per month
- During Mars mission, crew members could lose up to 40% of muscle strength even with exercise
- A 30-50 year old crew member could have the strength of an 80 year old (Space.com, 2010)

# Radiation Exposure



# Increased Intracranial Pressure (ICP)

- NASA's VIIP Project looking at impact of long-term microgravity on eye
- First time examined on ISS
- Numerous astronauts have reported persistent vision issues after mission
- First completed case study results in 2015 indicated TH reduced elevated ICP

| Risk Rating | |
|---|---|
| ISS-12 | Partially Controlled |
| Lunar | Partially Controlled |
| Deep Space Journey | Uncontrolled |
| Planetary | Uncontrolled |

**"if left untreated, could lead to deleterious health effects"**
***- NASA Tech Roadmap***

# Psychological Challenges

- NASA HI-SEAS IV mission
- Year-long Mars analog mission
- Crew of 6 in habitat on Mauna Loa, Hawaii
- Longest HI-SEAS mission to date