SpaceWorks®

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FREQUENTLY ASKED QUESTIONS (FAQ)
TORPOR INDUCING TRANSFER HABITAT FOR HUMAN STASIS TO MARS

Questions on the Concept and Motivation

[C.1] Could you explain a little bit about how you came to work on this project?

SpaceWorks has evaluated a number of Mars mission architectures over the years, from both a performance and cost perspective. Mars exploration is a tough problem that will require a lot of technology development work to get to a feasible system in the foreseeable future. Traditionally, the technology focus is on the propulsion system, as there are a lot of gains to be made there. However, propulsion technology tends to be a very expensive investment area. We wanted to focus on a different aspect of the mission that may be equally advantageous and could be synergistic with any advances in propulsion capability. This naturally led to a focus on the crew and associated systems, with a goal of trying to reduce their 'footprint,' or mass contribution to the system.

[C.2] What is the purpose of this project?

In short, we are studying the feasibility of putting a Mars-bound crew in a deep-sleep stasis during the 6 to 9-month transfer periods between the Earth and Mars. Currently, we are not performing any actual experiments or clinical trials. Our medical team is examining the existing body of data and case studies for the application of Therapeutic Hypothermia (TH), our baseline approach. For this initial 9-month phase being funded by the NASA Innovative Advanced Concepts (NIAC) program under the Space Technology Mission Directorate (STMD), we are focused on addressing the question of feasibility, evaluating engineering solutions, and exploring the implications for human exploration of Mars.

NIAC

Website: http://www.nasa.gov/directorates/spacetech/niac/

[C.3] Why put the crew to sleep?

With the crew in a torpor state, we believe we can significantly reduce the mass and volume of the in-space habitat during the outbound and return segments of the mission. This ultimately reduces the entire launch mass for the system. The habitat itself will be a very small module, nominally containing 4 to 6 crewmembers each in their own sleep chamber. By contrast, a typical habitat for an active crew is required to have space for food preparation/eating, exercise, science stations, bathrooms, sleeping quarters, entertainment, etc.

Many of the psychological-social challenges of prolonged space flight can be eliminated with this system. On a Mars mission, it is typically assumed that a small crew will be confined to a very small space for an extended period of time. The crew is under a lot of stress, a long way from home, and has no way to abort if there is a problem. This environment creates a lot of requirements and constraints pertaining to crew selection, increases the burden on the medical teams to monitor mental well-being, and consequently adds uncertainty to the mission. A lot of these issues are solved if the crew is asleep during peak periods of stress and likely boredom. Ultimately, we think it will be the preferred way to travel! We are eliminating the most mundane portion of the mission. Just imagine going to sleep and waking up on Mars 6 months later, no worse for the wear!

[C.4] Isn't this science fiction?

Absolutely not! While it has certainly been inspired by sci-fi, we are taking a much more practical approach. We have volumes of medical research and case studies involving humans that gives credence to and bolsters our claims that this approach is achievable. We are adapting and extending ongoing efforts in medical practice and science.

[C.5] Has anyone ever done this before?

Good question! No – only various aspects of the approach have been performed here on Earth. Scientists are actively looking at inducing hibernation states in non-hibernating animals. Both the Department of Defense (DOD) and National Institute of Health (NIH) have sponsored work aimed at putting humans in a preservation state in order to extend the time period under which critical care could be administered.

[C.6] Is this technology real?

Yes. Both the use of Therapeutic Hypothermia (TH) and Total Parenteral Nutrition (TPN) used in our approach are proven medically. For example, people are routinely fed using TPN for durations lasting over a year here on Earth. So we know that solution works well and is understood. We have a small set of data for people undergoing hypothermia therapy for periods of up to 14-days. We have considerably more data for people undergoing TH for shorter periods of 2 to 4 days. We also have instances of individuals undergoing multiple/repeated TH cycles. In all these cases, there have been no reported complications with the patients associated with the TH.

[C.7] At the end of this study phase, what do you hope to have achieved?

We expect to have a baseline approach from a medical standpoint of how induced torpor for a space crew can be achieved. We hope to have some solid data that our system can significantly impact the design of the Mars architecture. We believe we can show benefits that can be applied to the near-term feasibility of going to Mars, possibly with this technology being the key enabler. We also think we can show benefits for exploration in the longer term, so this is not a capability that would be phased out after a few initial missions.

[C.8] What other spin off benefits do you anticipate?

Medically, the alternate uses of therapeutic hypothermia and sustaining a reduced metabolic condition are still being determined. Research has shown some benefits such as significantly reducing the growth rate of tumors (growth currently resumes upon rewarming) and lowering internal cranial pressure (ICP).

The U.S. military is already very interested in the ability to slow down human metabolism in order to increase the time available to provide critically wounded soldiers with proper care. Our proposed approach is obviously synergistic with those goals.

Similar to the military's goal, this capability could be used on non-Torpor Mars missions in the event of a serious injury. After putting the injured crewmember in stasis, the rest of the crew would have more time to communicate with doctors on Earth to evaluate the situation and recommend the best solution. This is especially important given the signal time delay between Earth and Mars that can range from 4 to 21 minutes.

[C.9] How can I learn more?

You can view an overview briefing on the project here:
http: www.sei.aero/eng/papers/uploads/archive/NIAC-Torpor-Habitat-for-Human-Stasis-2-28-2014.pdf

You can get periodic updates via the Space Torpor blog at:
http://spacetorpor.blogspot.com

You can also get more information from the NASA NIAC project page at:
http://www.nasa.gov/content/torpor-inducing-transfer-habitat-for-human-stasis-to-mars

Questions on the Medical Aspects

[M.1] How does this idea work?

Torpor (or Hibernation) is a state of inactivity characterized by low body temperature, slow breathing and heart rate, and low metabolic rate. Many animals in nature hibernate to conserve energy during periods when sufficient food supplies are unavailable. To achieve this, hibernators will decrease their metabolic rate, which then results in a decreased body temperature. Hibernation may last several days, weeks, or months depending on the species, ambient temperature, time of year, and individual's body condition.

Doctors in patient care for extreme trauma are currently applying this idea. Medically induced Torpor (called Therapeutic Hypothermia) is a medical treatment that lowers a patient's body temperature in order to help reduce the risk of the injury to tissue during a period of poor blood flow. Examples include patients that suffer from cardiac arrest, stroke, trauma and brain injuries, as well as infants that are premature or had a complicated delivery. Lowering the patient's temperature by even a couple of degrees (to 34^{o}C or 93^{o}F) can produce the same effects that are seen in animals, including slowed breathing and heart rate, and a decreased metabolic rate. This reduced metabolic rate means a lower need for oxygen by cells in the human body, protecting them from damage during the medical emergencies listed above.

[M.2] Won't the crew get hungry?

Crew members that are in a Torpor state will get their nutrition through a process called Total Parenteral Nutrition (TPN). With TPN the crew member will obtain all nutrients (such as glucose, amino acids, lipids, added vitamins and dietary minerals) through an intravenous (IV) line, bypassing the usual process of eating and digestion. TPN is a well-known and often used medical process for the long-term care of preterm infants and adults that are suffering from medical conditions that do not allow them eat.

The physical sensation of hunger is related to contractions of the stomach muscles. These contractions, sometimes called hunger pangs, are believed to be triggered by high concentrations of the hormones (Ghrelin is the most common) that is released if a person's blood sugar levels get low.

[M.3] Are they breathing?

Yes! Astronauts that are in Torpor are in a deep sleep similar to that of bears and other hibernating animals. Because their body is at a decreased temperature they will experience a decrease in metabolism. This will result in a decrease in their respiratory rate, heart rate, and blood pressure. However, crewmembers in Torpor will continue to have normal physiologic processes.

[M.4] What kind of special equipment does this take?

Torpor is achieved by decreasing a crewmember's core temperature to approximately 34^{o}C (93^{o}F). There are several techniques that can be used to accomplish this. Some are invasive, involving injecting a cooled saline solution into the femoral vein, while others are non-invasive, such as circulating cold water through a blanket or body pads. Our preferred solution is called Trans Nasal Evaporative Cooling. With this approach, a small plastic tube is inserted into a crewmember's nasal cavity. This is used to deliver a spray of coolant mist that evaporates directly underneath the brain and base of the skull. As blood passes through the cooling area, it reduces the temperature throughout the rest of the body. The current terrestrial variant of this system is called RhinoChill® by BeneChill, Inc.

Administering nutrition and hydration via Total Parenteral Nutrition (TPN) requires use of an intravenous (IV) line and no additional equipment.

Crewmembers will also have monitoring equipment similar to those seen in a normal hospital setting to monitor their vital signs while in the Torpor state.

[M.5] Will humans that are hibernating age?

There is no direct evidence on what effect Torpor will have on aging. This is primarily due to the fact that current uses for Torpor in the medical community are limited to several days or weeks. However, there is evidence from multiple animal studies that show that hibernating animals do live longer than non-hibernating animals. It is physiologically possible that since torpor decreases a crewmember's metabolism it would cause cells to age and die at a slower rate, slowing the "aging" process.

[M.6] Will all the senses be working (seeing, hearing)?

Yes, human senses continue to work while we are sleeping. Similarly crewmembers in a Torpor state will continue to be able to feel, hear, and see bright lights in their sleep state. However, typically humans require a very small amount of a mild sedative to suppress the body's natural shiver response that occurs while undergoing Torpor. This sedative would prevent normal sensory stimulation from affecting the astronauts while in hibernation.

[M.7] What is known about the effect of therapeutic hypothermia or torpor on the mental state and cognitive function of the patient? My concern is that upon waking up after ~180 days of sleep, some or all of the crew might not be prepared to function at a high level in a demanding environment.

Currently there is no data available on the effects of long-term Torpor on mental, physical or cognitive function. Therapeutic Hypothermia (TH) is only used by the medical community on critically injured or ill patients. These patients have baseline mental, physical and/or cognitive function impairment due to these injuries, making isolating the long-term effects of Torpor hard to predict.

However, hibernating animals like the black bear can be aroused and fully functional in a very short period of time to protect themselves while in torpor. This would suggest it is plausible that humans may be able to awaken from prolonged torpor with minimal affect to mental, physical or cognitive function. Researchers around the world are actively studying this process in animals to understand exactly how and why it works. This is also something we can conduct human trials for here on Earth before attempting it in a space environment.

[M.8] What does the lack of gravity affect in terms of muscle, bone and blood? Changes to the musculoskeletal system and the cardiovascular system are a well-known complication of prolonged space travel.

Skylab and Russian Space data shows us that astronauts lose approximately 8% bone mineral density after 84 days in space. This increases to 19% by 140 days. Theoretically, an astronaut could lose up to 50% or more of their bone mineral density over a 3-year space mission.

Significant atrophy of skeletal muscle starts after only 5 days in space, and there is no idea if and when a plateau of atrophy would be reached. Most of these changes appear to be due to deconditioning and not any particular microgravity pathology. However, cycling and treadmill activity do not appear to affect muscle density loss but do prevent biophysical changes (gait changes, foot drop) that worsen density loss and recovery.

There are some changes in the cardiovascular system (decreased fluid volume, decrease in stroke volume and cardiac output by about 15%) with prolonged space travel. However, there are no noted changes in heart rate or function so these changes do not appear to be a health risk at this time.

NASA has extensively worked to identify therapeutic and preventive measures to combat these issues.

[M.9] Won't the intranasal cooling system and gas dry out the crew's nasal cavity – is this viable in long run?

Many studies have been performed on Trans Nasal Evaporative Cooling systems. Studies have shown that for the methods used currently it does <u>not</u> occlude the nostrils and <u>no erosion</u> of the nasal mucosa was seen, although care and lubrication was required when inserting the nasal catheters to avoid causing nosebleeds. There was no evidence of sinusitis, tympanic membrane injury or olfactory dysfunction. We would also note that the flow rate of the gas is very low and that it is not always being released. It is only used when the body temperature starts to rise and exceed the target temperature range.

Many reseachers have noted that the procedure may cause an oppressive feeling due to the high volume of circulating air and that it is only suitable in sedated patients. With high flow systems the large amount of dry air was noted to cause stinging and dryness of the nasal mucosa during initiation, but this was temporary and counteracted by either moisturized air or lubricant when placing the tubes.

[M.10] How do you prevent corneal stenosis?

Corneal stenosis is a disorder of the eyes characterized by damage or erosion to the outermost layer of cells of the eye. The condition is excruciatingly painful because the loss of these cells results in the exposure of sensitive corneal nerves. Corneal stenosis can occur in medical patients that are in a coma or other prolonged sleep state as the cornea tends to dry out the longer the eyelids are closed. Prevention of this condition includes ensuring that the air is humidified rather than dry, maintaining general hydration levels with adequate fluid intake, applying long-lasting eye ointments before starting the sleep cycle, and applying artificial tear drops under the inner corner of the eyelids before opening eyes upon waking.

[M.11] Will the crew develop pressure sores due to lack of movement?

Pressure ulcers (also known as decubitus ulcers or bedsores) are injuries to the skin or underlying tissue. They occur due to pressure applied to the tissue resulting in partial or complete blood flow blockage of the blood supply to soft tissue. Pressure ulcers most commonly develop in persons who are not able to move on their own. Fortunately these injuries are easily preventable and treatable if detected early. Primary prevention is to redistribute pressure by turning the patient regularly. In addition to turning and re-positioning, eating a balanced diet with adequate protein and keeping the skin free from exposure to contaminants is also helpful.

In a microgravity environment crewmembers would have minimal pressure applied to the skin and soft tissue, which would greatly reduce the incidence and severity of pressure ulcers during a torpor state

[M.12] Have any animals ever been tested?

As noted above, Therapeutic Hypothermia and Total Parenteral Nutrition are medical procedures that are used in every major medical center in the United States. They have been well studied in both animal and human investigative trials. Current human studies have shown the safety and medical benefit of Torpor for as long as 14 days straight and as many as 5 repeat cycles. Prolonged Therapeutic Hypothermia resulting in Torpor greater than that has not been studied at this point and would need to be investigated further.

[M.13] What about the increase in intracranial pressure?

Microgravity-Induced Visual Impairment/Intracranial Pressure (VIIP) is of recent concern at NASA regarding long-duration space missions. Although its exact cause is not known at this time, it is suspected that the low gravity space environment causes a fluid shift to the brain. This causes an increase in the crewmember’s intracranial pressure (ICP) resulting in optic disc edema and globe eye flattening that can cause mild but persistent changes vision. NASA is currently looking at how to address this medical concern.

Medically therapeutic hypothermia has remained a controversial issue in the debate concerning the management of elevated intracranial hypertension. It is not currently recommended as a standard treatment for increased intracranial pressure in any clinical setting. However, recent studies suggest that hypothermia can lower ICP and may improve patient outcomes. Hypothermia also appeared to be effective in lowering ICP after other therapies have failed.

[M.14] Is there a way to predict or prevent the medical side effects from occurring (while the crewmembers are in Torpor)?

Patients that undergo Therapeutic Hypothermia do not all respond in the same physiologic manner. Some patients have a very strong shiver response that requires multiple large doses of sedation medications to control while others have only mild or no shivering response at all. Similarly, the effects on patient heart rate, blood pressure, coagulation factors, white blood cells and blood sugar are all widely variable. This would indicate that some patients are just better suited to handle the physiologic effects of TH than others. In addition, there is some evidence from patients that have undergone repeat cycles of Therapeutic Hypothermia that the body becomes accustomed to the physical changes that occur, resulting in decreased physiologic complications.

Because of this it would be feasible to place all available astronauts from the mission pool under short test cycles of TH and identify which ones are least likely to have complications. In addition, crew members that were mission critical or had moderate to mild complications may be able to be conditioned for the Torpor state by undergoing short repeat cycles.

Questions on the Mars Architecture

[A.1] What if something goes wrong?

We are considering emergency-wake procedures for the crew. The best rewarming process for TH patients is an ongoing area of research and study. Generally, a slower warming process that is on the order of a few hours is preferred. But, this dataset is based on patients that have experienced some traumatic injury. A combination of approaches including cessation of the cooling process, active warming, and injection of adenosine, for example, could permit acceleration of the emergency-wake procedure.

Alternatively, we have evaluated an operational protocol that would have at least one crew member awake at all times and the remaining crew members on a 14-day torpor cycle. The impact to our baseline habitat mass for this approach is minimal to support this approach.

[A.2] How do those in torpor respond to the short warnings on incoming radiation?

Ultimately, we would plan to have the crew stasis pods shielding to be on par with a storm shelter. Since the surface area of these pods is fairly low, the parasitic shielding mass is tolerable.

We are also looking at the option to surround the habitat with the liquid hydrogen being used for the trans-Earth injection (TEI) propulsive burn upon Mars departure. With this, the crew would have additional protection during the outbound trip to Mars and in the event of an aborted surface mission that leaves them in orbit. During the return segment, the shielding level would be reduced, however.

With the mass savings provided by our approach, we can offer and afford radiation shielding levels that would otherwise be prohibitive for an 'active' habitat design.

[A.3] What medical problems with torpor have been noted on Earth and how do we mediate them with the limited resources carried into space?

There are several potential complications associated with Torpor. The most significant risks are increased risk of bleeding and increased risk of infection. In addition, TH can adversely affect several other physiologic processes. It should be noted that all of the complications listed below are rare, and can be completely corrected through autonomous systems and monitoring of crewmembers if needed.

1. Torpor induces a mild coagulopathy (increased risk of bleeding). With body temperatures below 35ºC, clotting factors operate more slowly and platelets function less effectively. As a result, some bleeding is seen in up to 20% of patients treated with TH, although bleeding that needs to be treated with medication is rarely seen even in trauma patients and blood transfusions are rarely required.

No treatment is required for mild coagulopathy. Even mild bleeding from the nose and IV sites will still stop without treatment. The treatment for heavy bleeding associated with trauma would be the addition of clotting factors through the IV line and increasing the crew member's blood volume with both IV fluids and blood products. Since the crewmembers will already have an IV line the process would require someone to just defrost and hook-up the needed product. Clotting factors and blood can be frozen for as long as 10 years. After thawing blood products are only usable for 42 days.

2. Torpor can impair white blood cell function. The incidence of significant infections is likely to increase if hypothermia is maintained longer than 24 hours. While an increase in infection rates has been noted in several studies, these infections have not been associated with any increased mortality (risk of death) and are usually easily treated.

Preventing the infection from occurring is the best and easiest method. This includes using improved sterile techniques for IV placement and care and for utilizing improving technology in antimicrobial IV equipment. IV antibiotics antibiotic are used if an infection does occur, and are easily administered in space.

3. Hypothermia slows heart conduction and can cause irregular heart beat patterns called arrhythmias, including bradycardia and QT interval prolongation. A heart rate in the 40's is common at 33ºC, but does not require intervention if the blood pressure is in the normal range. Multiple studies show that TH is not associated with an increased need for medications to increase blood pressure. This would indicate that most cases of hypotension (low blood pressure) in TH patients are due to either injuries or shock and not Torpor itself.

Treatments for hypotension include increasing IV fluids to increase blood volume and the use of medications called "pressors" to artificially increase blood pressure, both of which can be performed easily in space.

4. Hyperglycemia (high blood sugar) due to insulin resistance has been noted during TH. IV Insulin may be needed in severely hyperglycemic patients.

5. Hypothermia leads to a "cold diuresis," which in turn can cause hypovolemia (low blood volume), hypokalemia (low potassium), hypomagnesaemia (low magnesium), and hypophosphatemia (low phosphates). In addition, temperature fluctuations during the induction of TH and rewarming can cause potassium to move between the extracellular and intracellular compartments. Therefore, careful monitoring of volume status and measurement of basic electrolytes approximately every three to four hours during temperature manipulation should be done. This can easily be corrected with IV fluids.

[A.4] Does torpor help or hurt with respect to the degeneration of the body in extended weightlessness?

This is a question we are attempting to address but it will be some time still before it can be answered fully. While there appear to be potential benefits with torpor, we are also considering different options enabled by the use of torpor for addressing common spaceflight physiological issues. For instance, with the crew in an unconscious state, we can induce artificial gravity at higher rotation rates and lower radii without concern for discomforting Coriolis effects and gravity-gradients. Similarly, to reduce muscle atrophy, we can routinely apply electrical neuromuscular stimulation to the crew - something that would not be possible with an active crew. They may actually arrive at Mars in better physical shape than when they left Earth!

[A.5] Is the mission architecture predicated on the use of torpor for transit both to and from Mars?

Yes, to obtain the most benefit from our approach, the crew would ideally be in stasis for both outbound and return phases. If medical technology is capable of supporting the extended torpor period, current medical evidence shows there is no detrimental impact to undergoing repeat cycles.

Questions on the Concept Overview Presentation

In reference to:

www.sei.aero/eng/papers/uploads/archive/NIAC-Torpor-Habitat-for-Human-Stasis-2-28-2014.pdf

[P.1] Chart #31 indicates that the use of induced torpor would result in a savings of 70% in total consumables mass (total food mass, really). However, on slide #22, the savings offered by torpor in terms of nutrition mass/crew/day is no more than 59% (more likely 27-42%). What am I missing here?

The bar chart on slide #22 shows dosage rates for TPN-based nutrition only. For a fully-active person, this is about 0.7 kg/day of the aqueous dextrose/amino acid/lipid solution. By comparison, the typical mass allocation with traditional solid/partially-hydrated food used by astronauts, based on spaceflight experience and the ISS, is over 2 kg/day.

For our baseline habitat, we used the "resting-level" TPN dosage rate (0.55 kg/day) to determine our food stores. This is a conservative approach since we did not take any further reductions for the Torpor-state. This handles our contingency case if the crew were to awake and remain in a conscious state.

So, we don't think you are missing anything here, just using the wrong basis number for comparison!

[P.2] Is the on-orbit assembly of the transfer "stack" assumed to be performed robotically? If not, does the human assembly crew have to live in the torpor-optimized habitat during assembly operations?

Yes, the baseline architecture calls for robotic, on-orbit assembly. Note though either way, between the crew transfer vehicle (e.g. Orion), the habitat, the pressurized docking node, and the Earth Return Vehicle (ERV), there is still a lot of habitable volume available.

[P.3] What happens if a crewmember wakes up halfway to Mars? Does that affect energy/mass budget? What if they all wake up halfway there?

For our baseline habitat, the consumables for both the transit phases as well as the contingency stores are based on the required TPN dosage for a resting state. We did not take further reductions to account for the lower metabolic state associated with cooling. Thus, the habitat is designed for the off-nominal situation of a conscious crew.

See response P.1 for additional, related information on this subject.

[P.4] Is the 85-ton saving a round trip or one-way?

The 85-ton IMLEO mass savings is in comparison to the baseline NTR-powered DRA 5.0 architecture. This is a Conjunction-class (180-day out, 500-day surface stay, 180-day return), round trip mission to Mars with a crew complement of 6.

[P.5] What happens if there is a catastrophic failure – meteor impact, failure in the system?

We think a catastrophic system failure is unlikely since we have a number of redundant systems. The torpor-specific hardware consists of fairly simple systems and would all fail benignly. For example, a failure with the thermal control cooling system would merely cause the crew to awake from stasis due to the warming. In the event of a shut down with the TPN distribution system, the crew member(s) would be awoken to correct it. They could actually survive for 3-4 days without hydration or TPN injection, so plenty of time to correct any issue and/or awaken crew.

The non-torpor hardware (e.g. ECLSS, power, etc.) is identical to NASA's planned system designs and have their own margins and redundancies.

For a major external event like a meteor impact, we are considering emergency-wake procedures for the crew. The best rewarming process for TH patients is an ongoing area of research. Generally, a slower process that is on the order of a few hours is preferred. But, this dataset is based on patients that have experienced some traumatic injury. A combination of approaches like cessation of the cooling, active warming, and injection of adenosine, for example, could permit acceleration of this process.

Alternatively, we have evaluated an operational protocol that would have at least one crew member awake at all times. The remaining crew members would be on 14-day torpor cycles. For this case, the impact to our baseline habitat mass is minimal to support this approach.

[P.6] What do we know about the human digestive system not working for that long of a time?

There are many groups of medical patients, including preterm infants, coma patients, and cancer patients that undergo long periods of TPN use as their only source of nutrition. As a result, doctors have long had concerns over the effects of TPN and its long term affect on the human digestive system. Thirteen different studies have been conducted on over 400 infants and children between the ages approximately 4 months to 17 years old, and almost 100 healthy adults control subjects to identify complications such as gastrointestinal bacterial overgrowth and sepsis, impaired immune functions, overall mortality including bowel or stomach perforation, intestinal villous atrophy, and the effects of TPN on gut mobility. Based on this literature there is no evidence suggesting that TPN promotes bacterial overgrowth, impairs neutrophil functions, inhibits blood's bactericidal effect, causes villous atrophy, or increases the risk of death due to gastrointestinal complications. The hypothesis of a negative effect of TPN, while commonly cited by many doctors, was also unproven in these studies.

The most common complication that can occur in adults from prolonged TPN use is a complication after returning to normal food called "refeeding syndrome". "Refeeding syndrome" is a complication in patients that have gone without food for a long period time (usually greater than 5 days). When food is reintroduced to the patient they can have rapid disturbances in their electrolyte levels, causing complications with their body chemistry. This is a rare complication with TPN and can be easily prevented with the proper re-introduction of oral food and the proper monitoring and correction of the person's electrolytes.

[P.7] What are you doing for Galactic Cosmic Ray (GCR) shielding and providing a 'safe place' for the crew?

The NASA DRA 5.0 architecture design does not include a dedicated storm shelter or any parasitic radiation protection shielding for the crew. To enable a direct comparison of the torpor-system, we have made similar assumptions with our baseline design.

However, with the significant mass savings we are obtaining, we have the system mass margin to now include additional shielding for the crew. Not only can we add additional shielding, we only have to protect a smaller volume inhabited by the crew. Thus, we can increase safety and wellness for the crew and still reduce the IMLEO for the architecture.

[P.8] Are you considering the use of any artificial gravity?

Yes. While DRA 5.0 baseline was a zero-G architecture, we have developed a habitat configuration that would easily permit inducing an artificial gravity field. While the radius of rotation in this habitat is fairly small, less than 3-meters, with the crew in an unconscious state we do not have to be concerned with the typical issues of uncomfortable gravity gradients or Coriolis effects. If we are going to have an active crew member, we would need a slightly more complex design that would have a larger radius.

Please submit any additional questions to: spacetorpor@sei.aero

Thank you!