TF16 TERRESTRIAL FLOWER

CALLING ON NATURE TO SOLVE A NASA PROBLEM.

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HeroX Space Poop Challenge, 2016

A Hands-free Space Dump.

The story of poop is a complex story. It's the story of civilization. How we eliminate our organic waste is both personal and universal as elimination is central to the animal kingdom. As humans we are no different.

The problem is complex: How can astronauts relieve themselves while in a hermetically sealed space suit during a six day space journey?

For the last 40 years, they've used a diaper, a maximum absorbency garment exotically named MAG. Only meant to last 12 hours, for blast off and re-entry.

The US National Aeronautics and Space Administration **(NASA)** seeks a proposed solutions for urine, fecal and menstrual management systems to be used in the crew's launch and entry suits over a continuous duration of up to 144 hours, which spans 6 earth days. The NASA Poop Challenge states "there is no commercial product that currently provides fecal waste management safely and effectively for a 144 hour period within the confines of a pressurized space suit".

An in-suit waste management system would be beneficial for contingency scenarios or for any long duration tasks.

The requirements:

- **Hands-free**
- **Male and female fitting options**
- **Hygienic to all space crew**
- **Urine, feces and menses transport**
- **Storage**
- **6 day duration/144 hours**
- **5 minute to put on**

All in 1 space-suit.

In-suit waste management system criteria

A management system for **men.** (Urine & fecal matter)

A management system for **women.** (Urine, Menses & fecal matter)

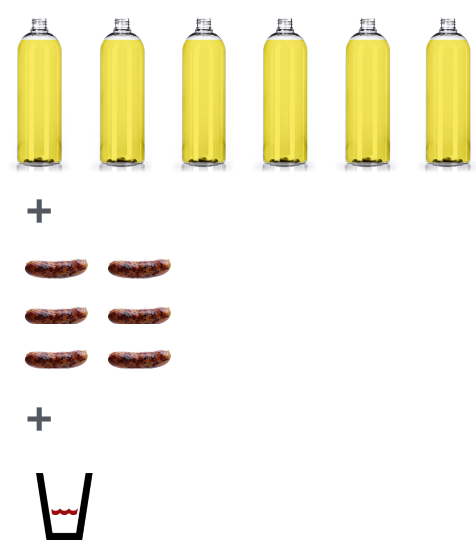
A safe solution that protects the health of all crew members.

1 liter or urine per day per crew member = 6 liters total.

75 grams of fecal mass per day per crew member = 450 grams total.

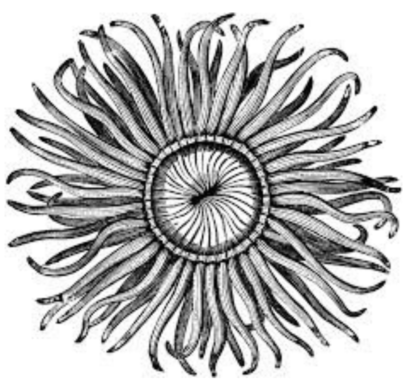
80 milliliters of menses. That's about 1/3 of a cup.

Must take no more than **5 minutes to assemble**.



Taking our cues from nature.

Stem of Sea Anemones



Top of flower with tentacles open

Attached to stone

The proposed solution represents a “bottom up approach”. It starts with a basic understanding of the physics of fluid transport, and the underlying principles that can be harnessed without the use of gravity. The forces used to propel fluids in a microgravity (e.g. vacuum), could be used, however within the confines of a space suit appear problematic. The bottom up approach is more suitable for the challenge, because it breaks down the activities of going to the bathroom, under the construct of microgravity, within the constraint of a fixed space suit environment.

The natural forces taken from a marine biomimicry analog (sea anemone) can be used in a novel way that is passive, and are not encumbered by gravity.

The design and application of an engineered waste collection and processing system called TF16 (Terrestrial Flower) within the space suit while non-trivial, can be facilitated with these considerations. An integrated collection and transport system in zero gravity is proposed that is compatible with existing waste elimination paradigms.

Phase 1

Flow for Urine and Fecal matter

Flow for Urine and Fecal matter

One of the requirements for this challenge is to devise a solution that it take no more than 5 minutes to assemble. In doing so there are several phases of “assembly”. The first phase comprises the activities the astronaut will do before donning the MACES in microgravity. The second phase comprises the activities the system and astronaut will perform in tandem, to fulfill the requirements.

How does new knowledge, acquired for one purpose, develop into useful technology having significant impact and benefits to society?

What differences exist between the technology required for space exploration and the requirements for application to earthly problems?

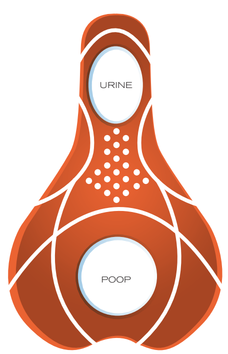
What factors determine the time required to convert new knowledge into viable economic benefits?

Various case examples disclose differing patterns of technological development. By comparing the common and contrasting findings it may be possible to understand better how new knowledge generates real benefits. Starting from a specific "knowledge contribution" previously identified from an analysis of astronaut life support requirements, the origins, adaptations, and eventual significance of the new technology are presented.

-Introduction – “Liquid Cooled Garments” 1975 NASA-CR-2509 [1]

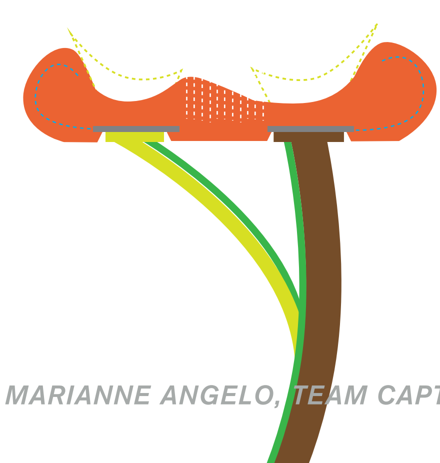
Self-assembly.

Revised MAG with inflatable seat



Inflates when astronaut activate process.

profile view of seat inflating as tubes dock into seat.

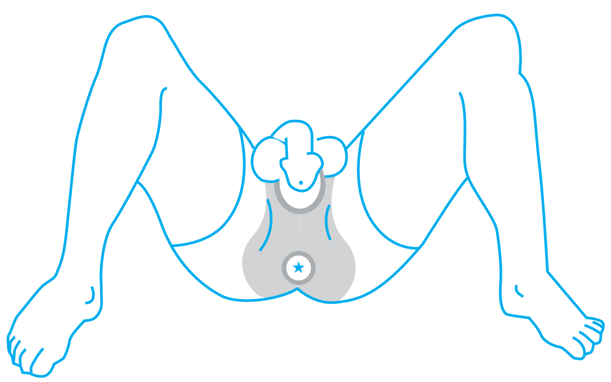


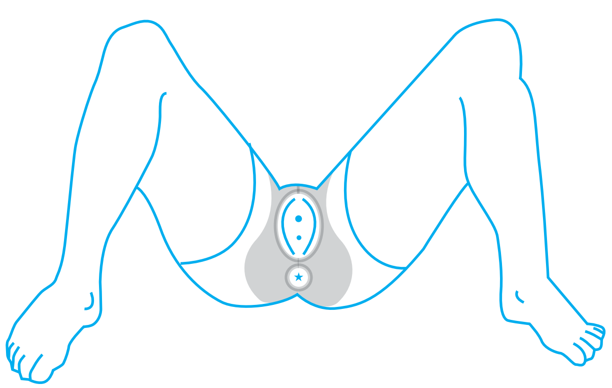
A phenomenon whereby the components of a system assemble themselves spontaneously via an interaction to form a larger functional unit. This spontaneous organization can be due to direct specific interaction and/or indirectly through their environment.

Think of it as Tony Stark free falling from a building as a human, and the pieces of the Iron Man suit respond to his call and individually fly over to him and collectively, and in some organized fashion, cover him until he becomes Iron Man. He then controls the suit before he hits the ground, and flies to safety. In this example, the human Tony Stark is but one of the components in the overall system. He becomes one with the mechanical components, and his actions interact with the actions of these components to make the overall system work. The proposed solution would be analogous to this fictional Marvel comic example. A collection of components are designed and fabricated into a combination Liquid Cooled Ventilation Garment/Portable Life Support System (LCVG/PLSS) suit in advance of donning the MACES.

https://www.youtube.com/watch?v=UUtPhdHedA4

Design Criteria

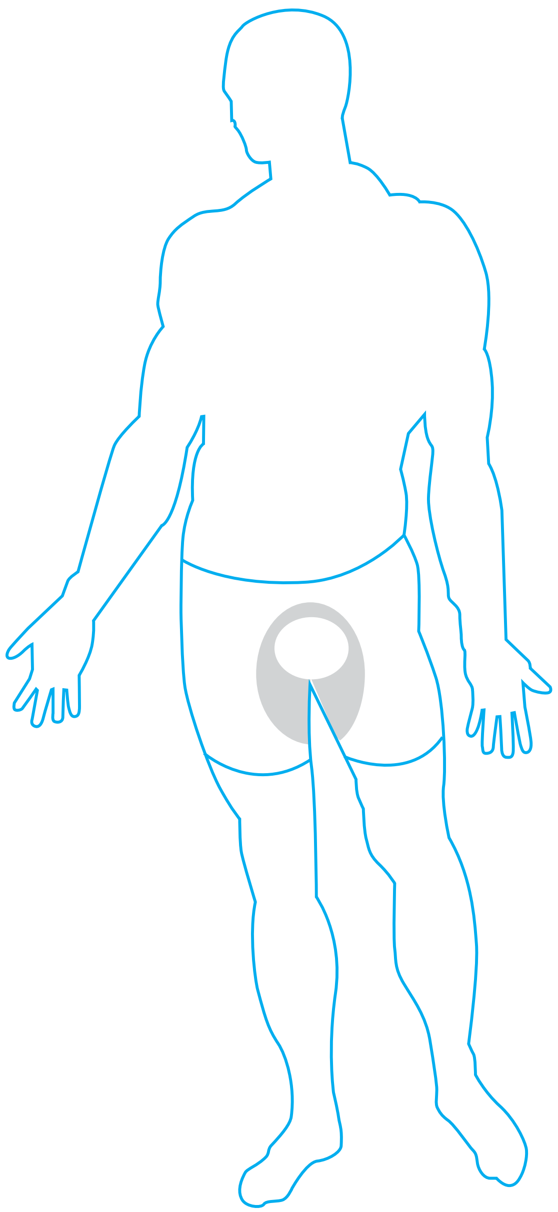




The following design criteria are provided by the NASA Challenge:

1. Applicable to both male and female astronauts
2. Six day duty life
3. Safety and health is prime consideration
4. Urine collection 1 Liter a day per crew member
5. Fecal mass 75 gm a day, 75 mL volume per day (1 gm/cc concentration –water at 20 deg C)
6. Menstrual collection 80 mL per day
7. 5 minute setup time
8. Pressure 4.3 psid 100% O2 environment
9. No use of hands
10. Solution to be integrated with MACES.
11. Gas at 4.5 cubic feet per minute through a waist-level connector enters 2" space between astronaut's body
12. Gas supply of 1000 cc/min over 3 minutes is assumed not to
13. Small power sources of up to 28V with current below 100mA could be provided inside or outside of the suit. (Power = I*E = 28 mwatts).

Assumptions

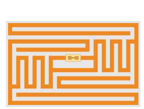


1. Astronauts are within anthropomorphic sizes as determined by NASA
2. Six days of food for survival may be in form of concentrated gel or liquid provided in a separate area and outside the scope of this challenge.
3. Urine, fecal matter, menstrual have fluid density of water, however viscosity is different
4. Assume there is enough emergency rations to create the amount of fecal matter daily as required
5. Astronaut could have eaten several meals before emergency situation without going to the bathroom
6. The power unit will be used to power a mini vacuum pump for each stream (liquid/menses, fecal matter). Sufficient vacuum to draw the previous volumes and rates for urine, menstrual, fecal material
7. Urine collection first stage of astronaut drinking water system (e.g. forward osmosis)
8. MACES not altered however inside garments may be altered
9. Divert 0.01/45 fraction O2 to micro vacuum pumps
10. Female astronauts may start menstrual cycle before or during 6 day period.

Solution Approach

Wearable/Voice activated to track elimination process.

Odor control system example



RFID chip embedded into docking system

The solution approach is called "TF16" – Terrestrial Flower 16

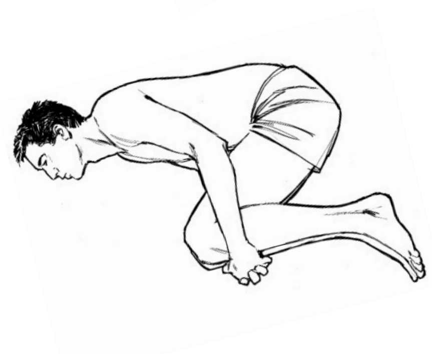
(There are 16 unique functions of this system). The TF16 builds on existing NASA practice of "docking", Radio Frequency Identification (RFID) technology (Maximum Absorbency Garment) to serve as a housing (for comfort) and backup system. Thus while NASA and astronauts may be reticent to replace a novel system all together, that system is the failsafe to the new approach put forth. **Terrestrial Flower** gets its name from the sea anemone, whose functions are adapted for a biomimicry solution.

The fundamental aspects of TF16 includes the following functions

1. Collect, process, isolate store material within a prescribed volume for 6 days
2. Compact odor control system
3. Retractable support platform activated upon demand that includes automatic cheek separation
4. Magnetic latching RFID Guidance system to aid in a wearable docking the system to the astronaut – male and female docking inspired by the sea anemone sphincter capture
5. Combination simultaneous urine/fecal elimination capability
6. Hands free Actuation by astronaut action within the suit
7. Intelligent system that recognizes waste form (micro-viscosity), characterizes and deals with it
8. Micro sensors to detect any residual matter, toxic gas.
9. The potential for self-sanitization of fecal sludge by intrinsic ammonia from urine.
10. The potential to recycle some/most urine for drinkable water
11. Micro-vacuum system to direct waste from the human body under microgravity
12. Directed waste streams to a miniature package/seal system
13. Worlds strongest adhesive tape inspired by nature that allows perspiration to pass through and is "self cleaning".
14. Bioengineered system to break waste down while in storage and isolate/filter
15. Programmable system, display, Graphic User Interface (GUI) located on the outside for astronaut verification (docking)
16. Override to diaper (fail safe)

These issues highlight the fact that an in-human waste collection, processing, and storage is a very complex multi-physics consideration.

Ergonomic Positions For Human Body Waste Removal



Urination can be accomplished in any human position from laying down horizontal to a vertical stand. Many recent studies have shown that for fecal matter elimination, a squatting position will optimize the anorectal angle between puborectalis muscle and the sphincter. **Fig 1** depicts this effect while **Fig 2** shows how it might apply in spaceflight. The outward astronaut angle in the chair is somewhat fixed, however a system that serves as a platform and moves the astronaut angle to more optimal while in that position can be envisioned. Feces will exit horizontally under exertion in microgravity. (mirroring vertical in squatting position on Earth – rotate picture 90 degrees).

Western cultures prefer a sitting position while Eastern the latter. In the latter, the knees are brought towards the abdomen. The orientation of the astronaut for the latter is not necessarily to the vertical, however the orientation can accommodate lift off, reentry, and emergency usage within the astronaut's seat.

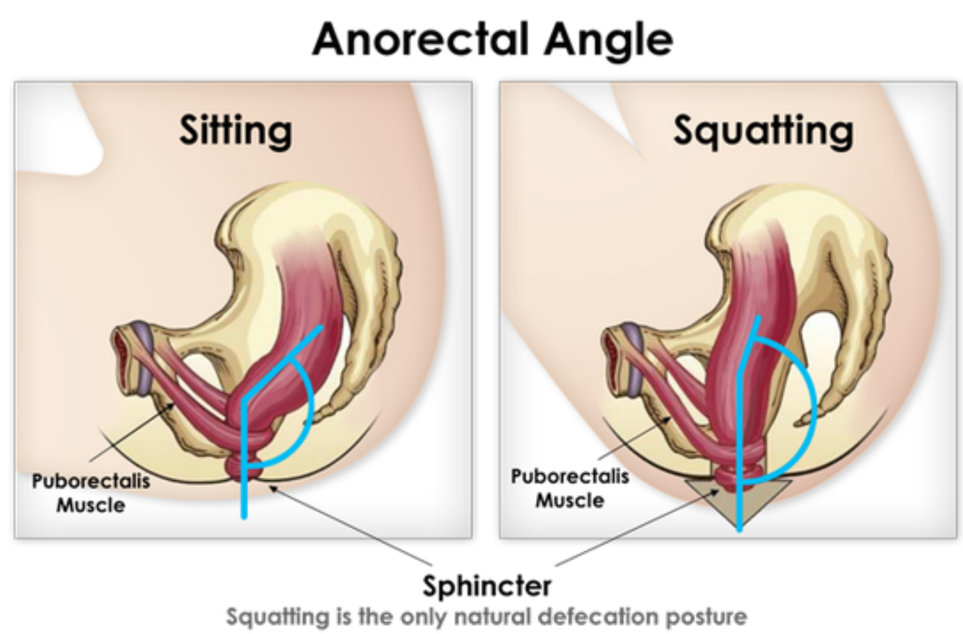
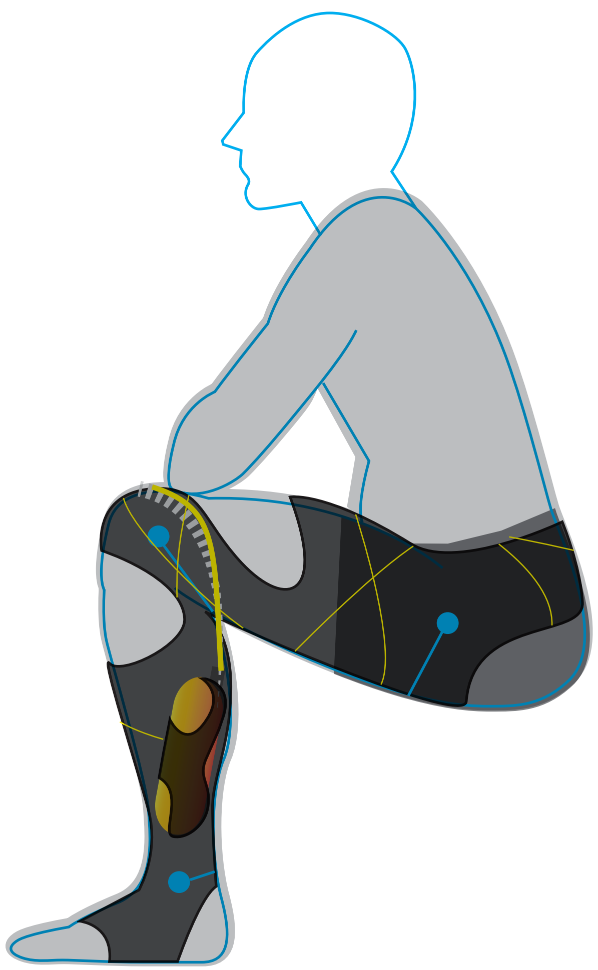


Fig 1 Puborectalis Muscle alignment for different

Fig 2 Astronaut position more in line with Squatting

Design Considerations



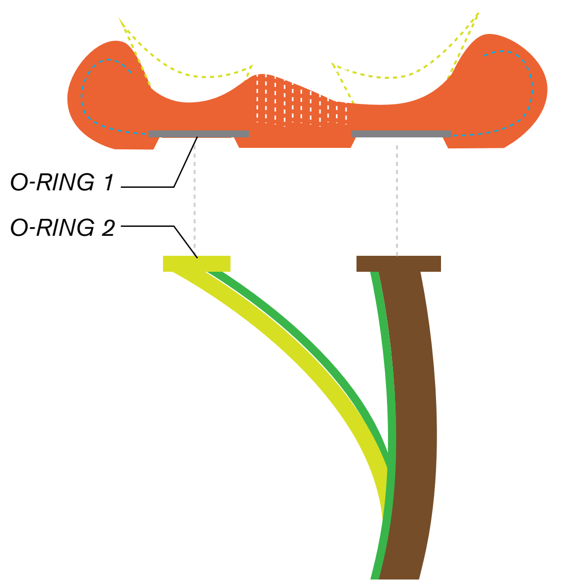
Astronauts that feel the need to address lower extremity bodily functions have 4 options: To urinate, to defecate, to both urinate and defecate at the same time and for female astronauts there is menstrual management.

Thus there could be 4 distinct initiation sequences. It might be easier to combine all these features. Males may be inclined for urination and defecation exclusively, however there may be situations where defecation follows urination, and vice versa. Females can defecate and urinate at the same time.

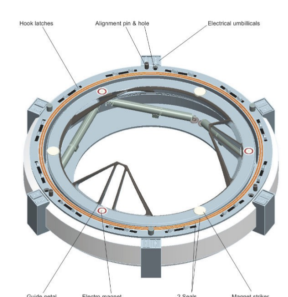
Because the requirement that astronauts cannot use their hands was imposed, it is suggested that the **knees be used to actuate the sequence** desired. A sensor can be applied to the outer and inner knee area for both left and right knees, located on the inner garment (or LCVG). This sensor could be a micro-gyroscopic or piezoelectric that senses movement of the knee to a specific point and angle for a prescribed time as noted in Fig 1. Note the MACES is not being modified to allow for a contact closure on the suit. This is important as astronauts can be trained to obtain a position that will actuate the system given their choice of which bodily fluid to eliminate. This same principle could be applied to each foot or a combination of knee/foot which would require further study.

A micro vacuum system, arrayed in a manner which provides motive power for moving human fluid away from the body. Each vacuum system (urine/menstrual fluid), and feces could be located on individual leg areas of the inner suit (a modified LCGV). The vacuum system draws a fraction of the O2 (0.1/45) as intake and a vacuum is produced within up to 3 separate lines (urine, fecal, menstrual).

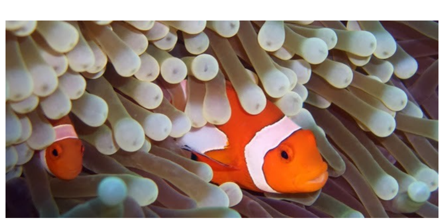
Design Considerations
Cont.



Elimination system detached



Section of O-ring mimics docking ring



Tentacle cups with germicide pull in fecal matter

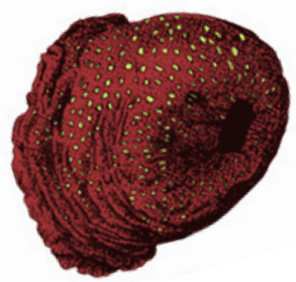
Another consideration for comfort and safety is that **no foreign body such as an annular tube be inserted into the astronaut** for the duration of the 6 days or for any length of time for that matter during the elimination process. Although this approach would ensure an initial tight seal from human orifice to collection system, there is no guarantee that the O-ring system would remain intact due to astronaut movement or even a muscle spasm during take-off, re-entry or any emergency. It would not be very comfortable to the astronaut as well.

For this reason, a passive external **dual O-ring/sphincter system** is devised that mates the artificial sphincter of the collection system, to the human sphincter. The operation of this dual sphincter system is a matter of looking to a neutral buoyancy natural analog. The science of "biomimicry" is the application of solutions in nature to that of complex human undertakings, such as managing human bodily functions within a space suit.

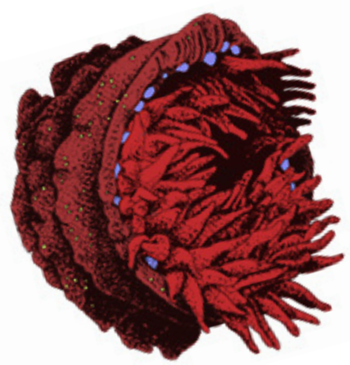
Biomimicry is used to optimize many high technology applications. One example is the gecko-climbing feet used to adapt a very strong adhesive tape. Another example would be adapting the function of an octopus, or sea anemone, which operate in a neutral buoyant environment that could mimic microgravity. Mating octopi attach tentacles to each other. The sea anemone may attach itself to a rock under a very high suction, and catch a fish in its snare, drawing it to its sphincter, which acts as both a mouth and anus. It actually pulls the fish into its mouth with the use of "tentacles". For this solution, a tentacle system can be devised within a special cup that mates up to human tissue.

be stored initially in tubes of the LCVG.

Design Considerations Cont.



O-RING 2 Not launched



O-RING 2 opening

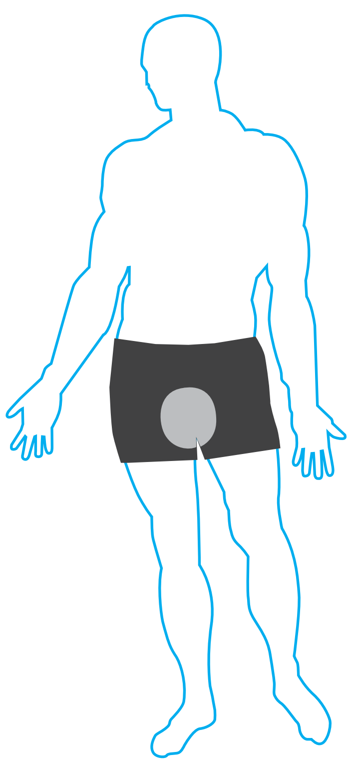
O-RING 2 Launched

There is consideration for an artificial collection sphincter for urine, and an artificial collection sphincter for feces. The menstrual collection for female astronauts uses the same artificial sphincter for urine. A micro-viscosity meter can be used for an automatic control system that will divert high density menstrual fluid – such as a clot to a separate collection system from urine if desired. At this time, the combination urine-menstrual fluid to recycle to an emergency water supply (for 6 days) has not been demonstrated. However the principles of a **micro-forward osmosis system** could in principle be adopted for in-suit urine to water processing system. It would not be practical to introduce up to 12 L of water inside a space suit for 6 days. Although some volume of water may vary.

Any use of "plastic bags" as a storage system should be minimized due to potential rupture, leakage, and contamination exposure to the astronaut. **Flexible carbon fiber tanks** that can withstand vacuum can be durable and flexible for the 6 day duration. Such bags could also be cumbersome to store as they can reshape under the spacesuit and cause concern and discomfort. For this matter, the fluids can be collected with flexible plastic tubing and a mating seal can be accomplished with a **cup-sphincter, o-ring system that magnetically locks.**

Design Considerations
Cont.

The astronaut becomes part of the system by using a "wearable" electronic shorts. This shorts is the link between the TF16 and the human elimination process. The vacuum expands a "platform" or modified bicycle seat on demand which extends the tube(s) from the bottom of the platform. There is a cup on the end of tube to seal to the astronaut. This special seat is located within a MAG (if a MAG is used for backup), or located on the outside of the LVCG if a MAG is not used for backup. Note: a fully functional system need not rely on the MAG as required, however this option is offered for redundancy and a failsafe.

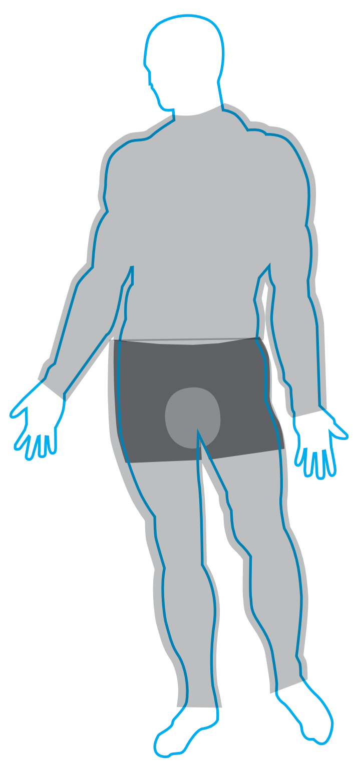


Step 1

Astronaut puts on "wearable electronic shorts.

Revised MAG.

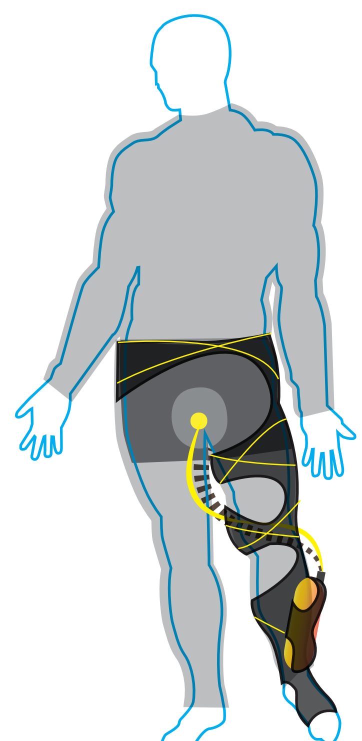
:10 seconds



Step 2

Astronaut puts on LVCS system

:30 seconds

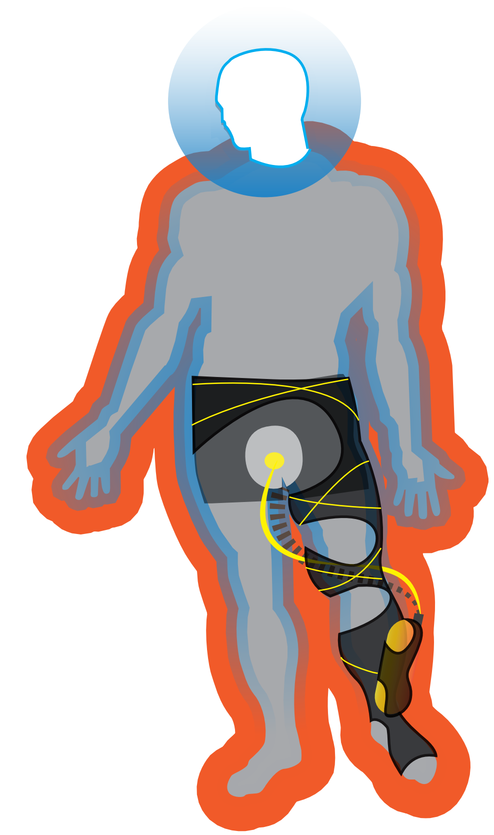


Step 3

Astronaut puts on Leg Holster that houses

elimination system and position system

:30 seconds

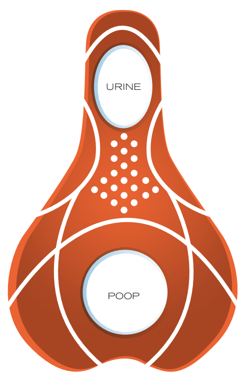


Step 4

Astronaut puts on MACES system

1 minute 30 Seconds

Design Considerations Cont.



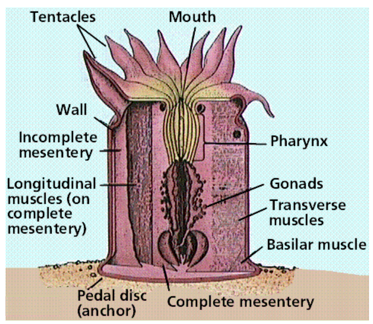
Holster is lightweight with velcro straps

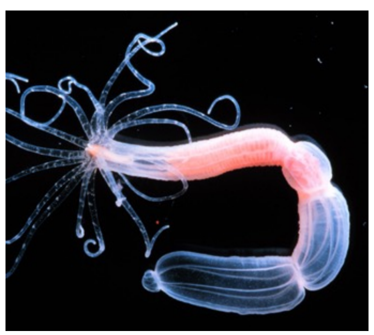
The platform is made of a special porous material that stores air, and stored in a loose rubber case such as an enema or hot water bag. Such a material would be marshmallow-like and cut to a pattern (much like a bicycle seat) Thus as vacuum is applied to the bag, the material expands to the full seat form. This aids in spreading cheeks to ensure the O-ring and sphincter from the appropriate collection tube mates to the human orifice and locks in place. The O-ring on the shorts magnetically locks with the O-ring on the tube.

There are **micro vacuums** that can be manufactured of sufficient voltage to meet the 28 volt, 100 milliamp requirements for the volume and flow rates specified. A storage volume of 4 liters (2 liters per leg) is required if a portable urine processing system is also adapted. This urine can be processed into drinking water sent to a separate storage tank. A combination of two vacuums for each stream would ensure redundancy in the event one vacuum failed.

The strength of the vacuum need not be the same strength as the Space Toilet for the following reason – 1) the ergonomic position of the astronaut will aid in fluid transport. 2) Bodily fluids can be weakly ionic and a series of magnets along the tube length can aid in transport by Lorenz forces or a very scaled down version of “magnetohydrodynamics”.3) If the inner tube wall (before the outer sphincter) were introduced a fluid of different density, and injected into a coiled tube with bodily fluids, a Marangoni effect could help propel the fluid from collection to storage as well. None of these physics effects rely on gravity.

Design Considerations Cont.





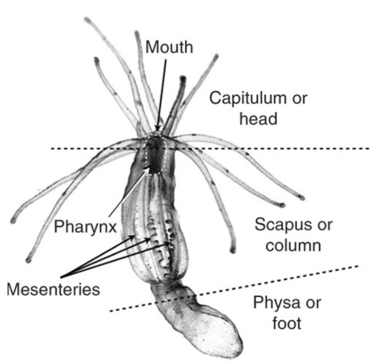


Fig 3 Sea Anemone Biomimicry Analog (Terrestrial Flower)

The entire system can be operated without the use of astronaut hands. Like the Space Toilet, the astronaut may need to wiggle into a position that aligns RFID tags sewn within the garment (or shorts) at the strategic points, to the RFID tag sewn into O-rings. The position is triangulated by an RFID tracking algorithm. The RFID tags within an O-ring on the cylinder with the artificial sphincter are passive however the active RFID tags sewn into the astronaut shorts can be powered from the 28 V, 100 milliamp supply. Once the O-rings are docked, they can be magnetically locked and sealed the appropriate male/female cup. Once the magnetic lock is in place, the vacuum suction can begin, pulling vacuum on the cup as well. **This "docking action" is consistent with the NASA tradition of docking space craft to a space station.**

There is an inner liner attached to the inside of the shorts worn by the astronaut (a setup condition to put on special underwear), or it can be already woven in to preclude changing shorts. It's made from multilayer reversible **"Gecko tape"**, which comprises microspheres with ridges that provide essential level of cleanliness that pulls any particles from the astronaut skin (which is not in contact with the tape surface), and vacuum suction between the ridges. Gecko tape has been shown to provide an increased cleanliness as wear continues. Thus as the emergency duration continues, the astronaut cleanliness could be assured. Any debris that filters through the tape can be captured at the interface between the tape and cloth, and collected to a separate line to the solid storage tank.