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Cis-Lunar Orbital Medical Facility and Roadmap

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Abstract

Exploration is intrinsic to human nature and is accompanied by inherent risks to the explorer, particularly in the extreme environment of long-duration space habitation due to the distance from assistance, services, and replenishment of consumables. One major risk to extreme environment survivability is lack of access to emergency medical care. This risk is further amplified in the microgravity environment. Problem Statement – What is the best practice for handling a medical casualty in which access to advanced medical care necessitates rapid stabilization and evacuation utilizing NASAs Lunar Gateway? Hypothesis – When a medical casualty is time critical, it is imperative that rapid access to a stabilization-for-transport facility is readily available. To best meet this requirement, it is suggested to provide a fully functional medical facility on Lunar orbit as well as provide a Medical Operations Roadmap for its use. Microgravity presents unique challenges to human psychology and physiology with the added risk of limited access to emergency medical care. In this environment, minor trauma is exacerbated by time to next level care and mundane injuries can become life-threatening. As such, systems should be in place to prevent initial injuries as well as to mitigate exacerbation of existing traumas or those occurring during or as a result of the mission and be designed with casualty response as a critical component of a trauma stabilization-for-transport system as a high priority alongside allowing for complete autonomy and provision for all other necessary services, automations, and self-sustainability during the lifespan of long-duration missions. These systems must be conceptualized with microgravity as a primary driving factor. Emphasis is placed on physical and cognitive ergonomics including traffic flow analysis, system resilience to major disruption, and modularity in congruence with the usability of legacy and novel space systems. Design methodology used herein is from nominal to worst-case scenario based with a focus on emergency evacuation from the Lunar surface all within the scope of Human Centered Design. Given the complexities of off-planet habitation and the increased risk during prolonged missions, especially wherein mining operations and construction are considered, it is imperative to maintain a fully functional medical facility within close proximity to the operations. This will be beneficial in time-critical medical emergency scenarios.

Keywords: Microgravity, Medical System, Human Spaceflight, Spaceflight Safety, Human-Centered Design

Acronyms/Abbreviations

B330 – Bigelow Aerospace 330m^3
EPI – Environment Protected from Individual
EVA – Extravehicular Activity
GEM – Group Elicitation Method
HITL – Human-in-the-loop
IPE – Individual Protected from Environment
IVA – Intravehicular Activity
OMF – Orbital Medical Facility
PECS – Personal Environmental Containment System
SME – Subject Matter Expert
WOZ – Wizard-of-Oz

1. Introduction

Microgravity is the primary driver in architecture of orbital medical systems; the context of this project is related to the near future lunar mission architecture developed by NASA. A concept of an Orbital Medical Facility was developed in the scope of an inflatable habitat architecture similar to that of the B330 which will be a part of the NASA Lunar Gateway station. Likewise, it was the intent of this research to culminate with not only the architectural requirements of a fully functional medical bay of which would be placed within orbital and/or surface based habitats, but to also include a roadmap of its capabilities, uses, and methodology based upon human-centered design, particularly within the scope of scenario based references, e.g., what actions during what scenario provide the highest outcome of survivability utilizing the available orbital medical facility with known and perceived risks to mission personnel. While the OMF systems have been developed on a conceptual level, the strategic components of roadmap are still to be discovered through numerous experimentation and Humans-In-The-Loop simulations.

During the state-of-the-art portion of this research, a gap was found that would not only answer some of the issues mentioned within the abstract of this paper, but also gaps that exist beyond the scope of the original orbital medical facility. That is, while a facility is capable of handling a wide variety of medical emergencies, it is equivalent to an emergency room or trauma center. The casualty must still be transported and/or isolated.

That is where the new system, which is a critical component of the OMF, has its roots, a method of transporting a casualty to a higher level of medical care. Therefore, this research focuses on an integral part of the system, the creation of architecture for a Personal Environmental Containment System (PECS) and its integration within the OMF. A system devised with multiple modalities (modular in use) by utilizing several scenarios during concept creation resulting in two primary functions; to protect an individual from the environment (IPE) and to protect the environment from an individual (EPI). Both of these functions will be discussed with example scenarios as well as PECS from concept to its current iteration as a functional mock-up.

The initial concept of PECS was approached with similar problem and hypothesis statements as the orbital medical facility, with an emphasis in scenario-based design.

1.1 Casualty and Risks

In the event of a casualty event in which environmental isolation is necessary due to risk either to the individual or from the individual, what is the best practice for handling that emergency during Lunar Gateway long-duration missions in which environmental isolation of an individual is necessary.

Along with the above statement, were a series of suggested requirements that would become incorporated into concept design or set aside for future iterations of the concept. Those follow and are in no particular order:

1) Maintain biological isolation, but not psychological isolation
2) Function as a crewmember as capable (at minimum, ability to communicate)
3) Maintain normal or PRN nutritional/medicinal intake and waste management
4) Be accessed through sealed glove ports and/or the possibility of robotic entry points
5) Be handled if palliative care is required or casualty becomes terminal
6) Not utilize a large footprint within the habitat either in use or stowed configurations

1.2 Hypothesis

When environmental isolation is time critical, it is imperative that rapid access to a system for isolation is readily available. To best meet this requirement, it is suggested to provide portable and rapidly deployable single person containment systems within the Lunar Gateway.

2. Background

Microgravity presents many unique challenges to human psychology and physiology with the added risk of limited access to emergency medical care. In this environment, minor trauma is exacerbated by time to next level care and mundane injuries can become life-threatening. It is known that spaceflight inhibits human immune response and has an effect on microbial life including increased reactivity of dormant virulent strains [1]. It is proposed that PECS would mitigate risk of further infection or spread of biological hazardous waste to the rest of the crew and vessel when considering such issues as viral shedding, biological waste, or will facilitate protection of the individual crewmember from a contaminated environment on station.

PECS is designed on two primary principals; microgravity as the operational environment, although future iterations may include variable gravity modularity as well as space EVA environments which will be discussed in section (*5.1 Future Iterations/Modularity*), and human-centered design. This includes experimentation of human-in-the-loop (HITL), wizard-of-oz (WOZ), and Group Elicitation Method (GEM) elicited design requirements utilizing Subject Matter Experts (SMEs) where and when available.

This, of course, was completed and/or scheduled after completion of state-of-the-art analysis which further indicated necessity of a system in which PECS would mitigate, prevent, or be used as part of a treatment method which will be discussed in section (*4.1.1 DCS Symptoms After EVA*).

2.1. Risk Assessment Based on State-of-the-Art Data

To start, it was necessary to ascertain what risks would indicate need for medical care in an orbital facility and, as it turns out, there are many. Therefore, it became necessary to also elicit which risks carried the highest probability and the consequences thereof in order to create the scenarios in which design requirements would be based. More than nineteen print and web sources, as well as SME input were utilized to ascertain medical risks and mitigations for spaceflight in the microgravity environment. For medical risk and mitigation prioritization, the following limits were used:

- Medical Care Level 4 -
  NASA-STD-3001 VOL.1 [2]
- Classification Level III
  NASA/TP-2015-218570 [3]
- Risk Rating Priority 1
  NASA/SP-2005-6113 [4]
- Significant Concern
  NASA SP-2009-3405 [5]

- ALERTS Risk Matrix
  ISU Masters, 2008 [6]
- SME Contribution

NASA-STD-3001 VOL.1, the NASA Space Flight Human-System Standard Volume 1, Revision A: Crew Health document Categorizes Levels of Care into six sections (0-5). Priority in this SOA was given to Level of Care 4 (Lunar/Mars Outposts) [2]. These risks were further detailed within NASA/TP-2015-218570 (Life Support Values and Assumptions Document) and indicate that risk is greater for Beyond Ambulatory Routine Medicine and, again, suggest that procedures and/or standards be created to encompass Termination of Care [3].

The NASA/TP-2015-218570 Life Support Values and Assumptions Document places medical risks in three classifications. Class III risks are illustrated as Explosive Decompression, Complicated Heart Malfunction, Overwhelming Infection, Crush Injury, Brain Surgery, and Burns encompassing more than forty percent of body surface area. Current mitigation proposed therein is to promptly evaluate and transport or to take measures to store, return, or destroy the body. It should be noted that although these mitigation suggestions are given, no procedures or standards were available [3].

The NASA/SP-2005-6113, Bioastronautics Roadmap, outlines Risk Rating Levels with Risk Level 1 being of highest priority. The risks ascertained from this document are Risk 18 – Major Illness or Trauma (Level 1 Risk Rating Priority, Lunar) and Risk 28 – Carcinogenesis (Level 1 Risk Rating Priority, Lunar) [4].

NASA SP-2009-3405, Human Health and Performance Risks of Space Exploration Missions identified Acute Radiation and Inability to Treat Casualties as Significant Concern and noted Inadequate Design of systems concerning Safety and Efficiency as a human centered design gap. Of important note within this document is the risk (designated as “Important’) of exposure to lunar dust [5].

The ALERTS Risk Matrix was part of the ISU Masters, 2008 document of the same name. Their findings indicated Chronic Radiation as the highest risk tied with Delay and Insufficient Time for Transportation of a Casualty. The second highest rated was a tie in scoring between Insufficient Rescue Time (retrieval of Stranded) and Insufficient Equipment (Retrieval of Stranded). These were scored on a 5x5 risk matrix as 19, 19 and 17, 17 respectfully [6].

Lastly, the Space Medicine Exploration Medical Condition List (JSC-CN-23330) was combined with those risks and suggestions given by SMEs which included Hypoxia, Decompression Sickness (DCS) and Quarantine as high priority risks [7]. These risks were all listed and further prioritized through Risk Assessment of the Most Critical and Most Probable occurring medical emergencies. This indicated twelve risks (see *Table 1: SOA Derived Medical Risk Sheet*) scored using the same 5x5 matrix and scoring card (*Figure 1: ALERTS 5X5 Risk Matrix and Score Card*) found in the ALERTS document [6]. These were further vetted through NASAs online Human Research Roadmap Risk Sheets [8]. The scores of these risks ranged from 10 to 19 wherein scores higher than 19 are considered an unacceptable risk. With one exception, risks with a score below 17 were dropped to focus research into highest priority medical casualty risks. Those risks that scored 17-19 were further narrowed through collaboration with SMEs to allow focus and are as follows:

- *Carcinogenesis*
  5x5 = C4
  Score 19
- *Transfer of Injured (Delayed/Insufficient Time)*
  5x5 = C4
  Score 19
- *Quarantine*
  5x5 = B5
  Score 17
- *Hypoxia (SME Suggested Inclusion)*
  5x5 = C3
  Score 15

Table 1: SOA Derived Medical Risk Sheet

RISK	5X5	SCORE
Acute Radiation	A5	10
Carcinogenesis	C4	19
Chronic Radiation	C4	19
Decompression Sickness	C4	19
Hypoxia	C3	15
Inability to Adequately Treat Casualty	B5	17
Lunar Dust Exposure	E2	16
Major Illness or Trauma	B5	17
Quarantine	B5	17
Retrieval of Stranded – Insufficient Equipment	B5	17
Retrieval of Stranded – Insufficient Time	B5	17
Transportation of Injured – Delay/Insufficient Time	C4	19

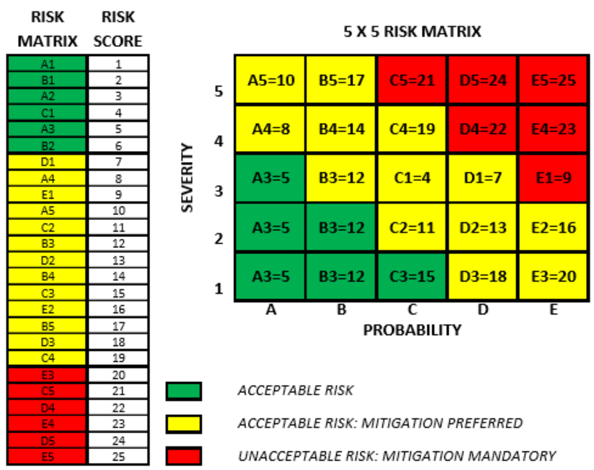

Figure 1: ALERTS 5X5 Risk Matrix and Score Card

The culmination of data obtained from the SOA and collaboration with SMEs from NASA-Human Factors, UCF-Aerospace Medical concludes that a biologic/environmental isolation system is a gap in current research with notes that occupants of the system should not be psychologically isolated and that operability of such a system should be possible from the occupant's position within the system. Further noted by SMEs were the consideration of sudden expectoration of blood as an acute symptom of decompression sickness (DCS), sudden necessity of IVA suit donning such as rapid decompression of vessel, and as a tool for preliminary treatment of DCS which includes high O_2 percentages at higher than average pressures in order to washout nitrogen from the bloodstream. These notes have been taken into account with the preliminary design of PECS.

4. Concept

Once general and suggested requirements were established, preliminary system drawings were made based off of created scenarios and utilizing various NASA standards as definitive design requirements such as hatch minimum diameters and translation requirements in order to determine overall maximum sizes allowable; e.g., NASA/SP-2010-3407 the Human Integration Design Handbook indicates translation path and passageway standards, NASA IDSS indicates international standards for hatch sizes and requirements [9,10].

4.1 Scenarios

A total of five scenarios were devised to iterate rapid necessity of an isolation system and are further classified as IPE or EPI and noted as to PECS usage ideology as well. These were based off, primarily, emergent need for isolation due to perceived possibilities in microgravity spaceflight and/or habitation and are described below (sections 4.1.1 through 4.1.5). For summary see *Table 2: Summary of considered scenarios determining the purpose of the PECS.*

Table 2: Summary of considered scenarios determining the purpose of the PECS.

#	**SCENARIO**	**EPI IPE**	**USE**
1	*DCS Symptoms After EVA*	EPI	Used as Treatment System
2	*Multiple Lacerations*	EPI	Utilized for Isolation
3	*Unknown / Unexpected Material Contaminant*	EPI	Modularity as External Spacecraft Device
4	*EVA Suit Breach*	IPE	Modularity as Surface System Utilized as an Emergency EVA System
5	*Emergent Necessity to Don IVA Suit*	IPE	Utilized as an Emergency IVA System

4.1.1 Scenario 1 - DCS Symptoms After EVA

EPI - PECS Utilized as Treatment System

After a nominal 8-hour EVA to install a science package on the external hull of Gateway's Habitation Module, Astronaut S. Mundy began the normal debriefing process. A nonchalant comment from Mundy was noted but dismissed due to the length of the spacewalk, "Wow, I'm beat!". It went unnoticed that Mundy that breathing became harder, but, again, was passed off by Mundy as a result of the laborious EVA that was just completed. As Mundy was conversing with Astronaut L. Trakya while filling out the EVA event log, Mundy coughed lightly, noticing a small blood droplet that had been ejected onto the tablet he was using. Shortly, Mundy began to exhibit symptoms of severe pulmonary decompression sickness (DCS). Another cough expectorated more blood and mucous. It is imperative to not only begin medical intervention for Mundy, but to also isolate the astronaut from the rest of the crew and spacecraft. PECS is activated and Mundy is placed inside the system. PECS allows the astronaut to be isolated to prevent spread of body fluids being expectorated by the injured astronaut and also allows for a high oxygen exposure (preliminary treatment of DCS) at a higher pressure than the environment (to assist in nitrogen removal).

4.1.2 Scenario 2 - Multiple Lacerations

EPI – Utilized for Isolation

While servicing a pressurized piece of equipment, a sudden increase in pressure causes a seal to burst which sends multiple small fragments outward inflicting multiple lacerations and punctures to the clothing and skin of Astronaut T. Jenson. Jenson quickly begins bleeding, prompting isolation procedures to be enacted to limit exposure of the remaining crew and spacecraft from biohazardous fluids. Due to the number and uncertainty of lacerations and punctures as well as exposure to blood requiring remediation; PECS is activated, and Jenson is placed inside the system. PECS allows the astronaut to be isolated to prevent spread of body fluids by lacerations and punctures of the injured astronaut. Once within PECS, Astronaut L. Frieda can begin to assess the injuries with Jenson and provide first aid treatment through usage of side access glove ports and medical passthroughs. Once all wounds are covered and have ceased bleeding, the PECS interior may be cleaned, and Jenson may doff PECS.

4.1.3 Scenario 3 - Unknown/Unexpected Material Contaminant

EPI – PECS Modularity as External Spacecraft Device

Astronaut C. Yasi is nearly finished with a short, 5-hour EVA switching out a piece of equipment that has failed for an unknown cause. Just prior to entry, Astronaut S. Mundy notices that Yasi has a discolored fluid on the exterior of the EVA suit. Mundy has Yasi check over Mundy’s suit, determining that there is no such contamination to Mundy, and it is determined that it would be best to isolate Yasi from the atmosphere inside the habitat until it can be determined what the contaminant is. Mundy acquires the external PECS unit and activates it, taking care to don the system over Yasi in such a way that the contaminant is retained within the PECS interior. Mundy assists Yasi, within PECS, through the hatch into the habitat. A sample of the material was taken while Yasi was donning PECS. If the contaminant is found to be benign, Yasi may doff PECS. During Yasi’s time within PECS, the suit umbilicus was attached to ports located within the PECS bulkhead.

4.1.4 Scenario 4 - EVA Suit Breach

IPE – PECS Modularity as Surface System Utilized as an Emergency EVA System

During a routine EVA, Astronauts S. Mundy, C. Yasi, and T. Jenson are collecting geologic samples on the surface. As Mundy turns to look back at the habitat, the ground gives a bit causing Mundy’s boot to slip, the leg of the EVA suit dragged across the jagged surface of a large protrusion of geologic formation as he fell. Mundy’s EVA suit has been compromised and is losing internal environment. With haste, Yasi and Jenson remove PECS from its protective cover and activate the system, placing Mundy within the main envelope and connecting the suit umbilicus port to the life-support connections on PECS bulkhead. PECS and Mundy are placed on a litter and taken back to the habitat.

4.1.5 Emergent Necessity to Don IVA Suit

IPE – PECS Utilized as an Emergency IVA System

At 0330, Astronaut J. Terry was translating through the core of the Habitat Module performing an inventory of materials stowed near the aft docking hatch. While taking notes, an alarm began to blare, the alarm that signified a hull breech. Unsure of the cause, micrometeorite possibly, or the amount of damage and rate of depressurization, Terry decides that translating back towards the IVA suit storage may take too long, risking loss of consciousness. Just a few feet from the aft hatch is one of the PECS stations on-board. Terry quickly swings the system out of the stowed position which activates the structural portion of PECS, maneuvers inside the main envelope and pulls the zip shut, activating the automated life support portion of PECS.

4.2 Habitat Module with OMF

Given the complexities of off-planet habitation and the increased risk during prolonged missions, especially wherein surface operations such as mining and construction are proposed, it is imperative to maintain functional medical capabilities within close-proximity to the operations and at each waypoint (EVA, Surface Habitat, Transfer Craft, Gateway). This may assist to mitigate exacerbation of time-critical traumas which may require isolation. This system, PECS, would be of great benefit if it were rapidly deployable as well as highly portable/easily stowable.

The concept of operations and testing for this system is based upon NASAs Lunar Gateway system. NASAs Lunar Gateway is a proposed Lunar orbit outpost designed to act as a platform to extend human presence in space as well as a waypoint to Mars and beyond. This system is currently planned for a Near Rectilinear HALO orbit in Cislunar space and will act as a Lunar space station for prolonged Lunar habitation missions which include mining operations and establishment of Lunar surface habitation [11].

Habitat Module Crew Capacity – 4 [12]

Proposed Mission Duration – 21 Days (11 aboard the Habitat Module) [11]

Proposed Gateway Orbit - Near Rectilinear HALO Orbit (NRO) ΔV=840 of ΔV=1250 [11]

In order to better visualize these translation path requirements and to provide a higher fidelity environment for a PECS mock-up to be tested, a ¼ section of a 1:1 mockup was done to simulate the interior core of a an inflatable habitat based on available Lunar Gateway Habitat module data. The Habitat module core mockup, as shown below in *Figure 2: Habitat Module Core Simulator ¼ of 1:1*, is the simulator which is currently constructed in the Human Space Flight Lab at the Human-Centered Design Institute of the Florida Institute of Technology and will be utilized as the base for PECS design research.

Figure 2: Habitat Module Core Simulator ¼ of 1:1

4.3 PECS

PECS is designed as a single occupant environmental isolation system utilized to isolate a crewmember from the environment in the event that the environment is contaminated/hazardous in some way (EPI), or, to isolate a crewmember who poses a risk to contaminate the environment and/or other crew members (IPE). It is comprised of a bulkhead that contains life support and controls on one end with structural ribs that inflate to; in configuration 1, pull the main envelope over the casualty who has been secured head towards bulkhead utilizing the 'tie method' of closure or, in configuration 2, to hold the main envelope extended for entrance via the longitudinal or circumferential YKK Bio Zipper access points on the other side of the bulkhead.

PECS, in its first iteration configuration, can be found below in *Figure 3: 3D Habitat Module w/PECS Deployed* and the second iteration configuration can be found in *Figure 4: 2D Habitat Module w/PECS Deployed*. Both are shown as integrated in the deployed position within the Habitat Module of NASAs Lunar Gateway system.

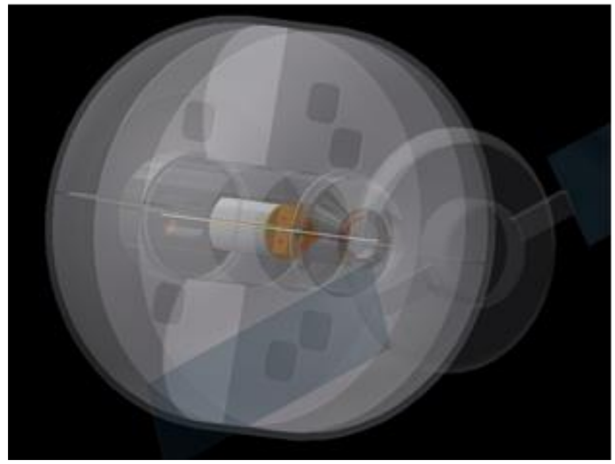

Figure 3: 3D Habitat Module w/PECS Deployed

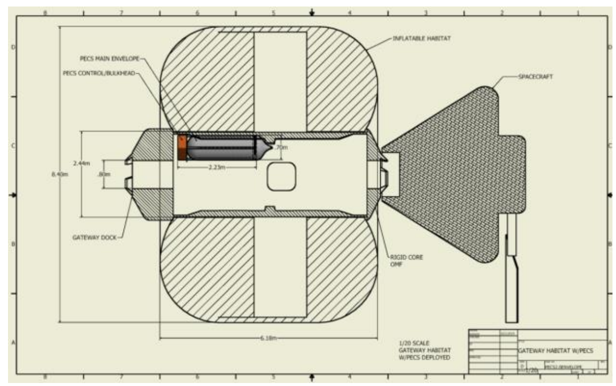

Figure 4: 2D Habitat Module w/PECS Deployed

Through HITL testing, it was determined that some features of the first iteration of PECS (see *Figure 5: PECS Deployed / Iteration 1*) required design changes for better usability and maintainability throughout the system lifespan. Some of these changes can be found in the latest, current iteration, which can be seen in *Figure 6: PECS Deployed / Current Iteration*. These include a smaller diameter main envelope which places the structural ribs outside the main envelope as opposed to inside as in Iteration 1. This is done for maintenance purposes, allowing the structural ribs to be replaced as needed, even if the main envelope is occupied. Further, there are now three access points for testing and various entry scenarios, and will include new methods of entry, which will be discussed in section (*4.4 USE CASE*).

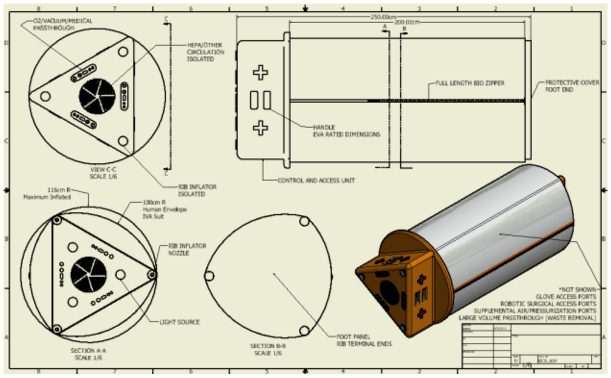

Figure 5: PECS Deployed / Iteration 1

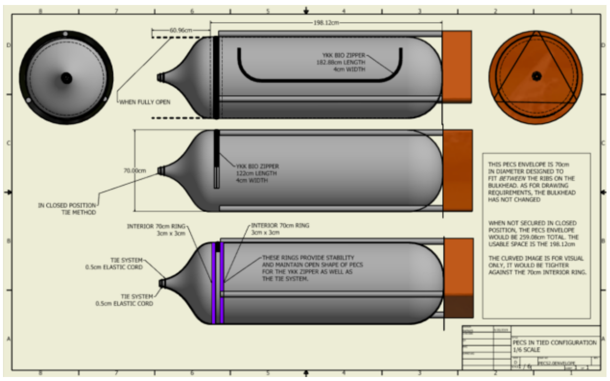

Figure 6: PECS Deployed / Current Iteration

These drawings are a represent the concept of the design of PECS and are indicative of only some of the necessary requirements and features. Some of these features, such as the separation of inflatable ribs and inflatable envelope as well as ports for medical passthroughs which would include gasses (O2, anesthetics, etc.), vacuum, fluids (intravenous, irrigations, etc.), and electrical sensor connections, have been omitted. Further, these images do not show PECS in a stowed or pre-deployed state, suffice to say that the configuration in a stowed state would have the inflatable ribs and envelope deflated and compressed between the Control/Access Bulkhead and a stowage feature. Of significant omission within this rough iteration, are sealed glove ports; inward for casualty manipulation and outward for casualty mobility and inclusion, as well as proposed ports, sealed, for passthrough of necessities or possible manipulator entry for robotic surgical care, if possible, in the future. Overall, the entire system would be self-reliant (in a manner of individual, short-term life support) as needed in IPE scenarios or connectable to craft life support systems. The time frame for self-reliant run-time is estimated to be similar to that of EVA ECLSS.

4.4 USE CASE

Use case for PECS is derived from the scenarios mentioned within section *4.1 Scenarios* and can be broken down into steps as such as those concerning scenario *4.1.1 DCS Symptoms after EVA*. The following steps are for an idealized version of PECS; however, several design elements were derived during PECS mock-up creation from HITL interaction and scenario-based brainstorming.

Scenario start → PECS is in Stowed Position → Incident Occurs → PECS is removed from Stowed Position: BEGIN DONNING

Configuration 1 – Tie Method: Casualty is placed head towards bulkhead and secured in place (method not ascertained at this time), *Figure 7: Casualty Placement / Envelope in Stowed Position*. PECS Structural Ribs are activated which pulls the main envelope over the casualty (tie method is stowed in open position, *Figure 8: Structural Ribs Deployed, Envelope over Casualty*. The Tie system is secured and Longitudinal zipper is pulled towards bulkhead utilizing parallel hand straps to overcome microgravity *Figure 9: Tie System is Secured, Casualty is Isolated*. Closing of Longitudinal YKK Bio zipper (not shown) activates life support and main envelope inflation. Similarly, the life support can be controlled from the exterior bulkhead panel, *Figure 10: Life Support Active, PECS Deployed State*.

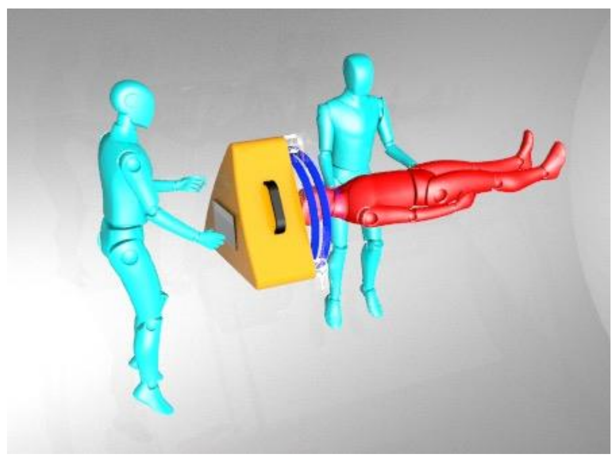

Figure 7: Casualty Placement / Envelope in Stowed Position

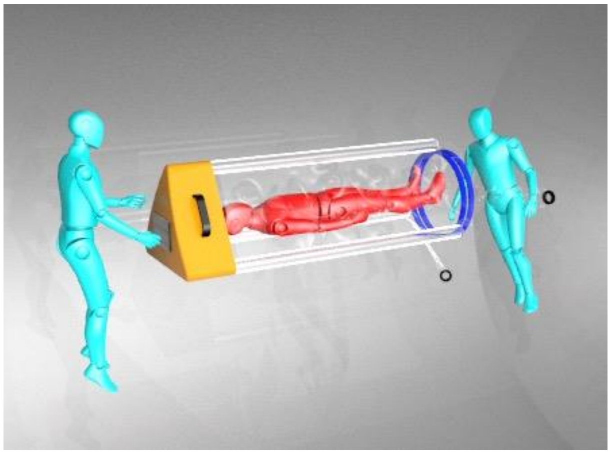

Figure 8: Structural Ribs Deployed, Envelope over Casualty

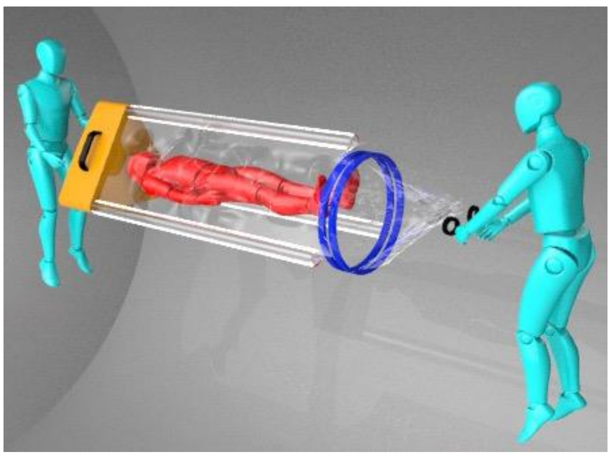

Figure 9: Tie System is Secured, Casualty is Isolated

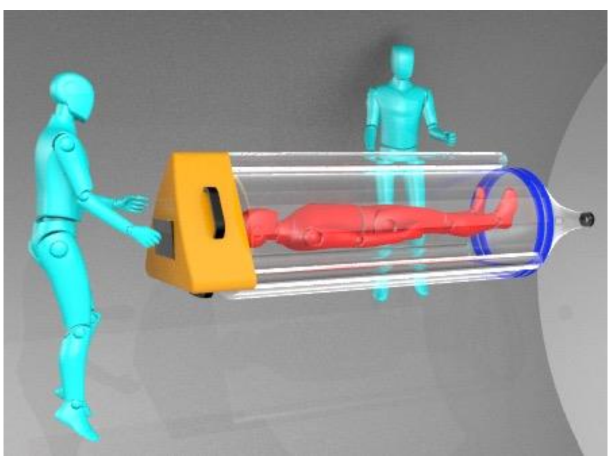

Figure 10: Life Support Active, PECS Deployed State

Configuration 2 – End Zipper Method: Structural Ribs begin automated activation once PECS is released from stowed position and locked into ready position (*Figure 11: Automated Structural Deployment*), (tie method is stowed as secured in this configuration) access of casualty is gained through already open circumferential YKK Bio zipper at the foot end as the main envelope is extended to full position (*Figure 12: Casualty Entrance, End Zipper*). Operator pulls zipper to closed position using parallel hand straps to overcome microgravity and proceeds to pull longitudinal YKK Bio zipper closed, also utilizing parallel hand straps (towards the bulkhead for access to controls if necessary). Once zippers are in closed position, automated life support commences (*Figure 13: PECS Deployed, Life Support Active*). Casualty may be assessed at this time.

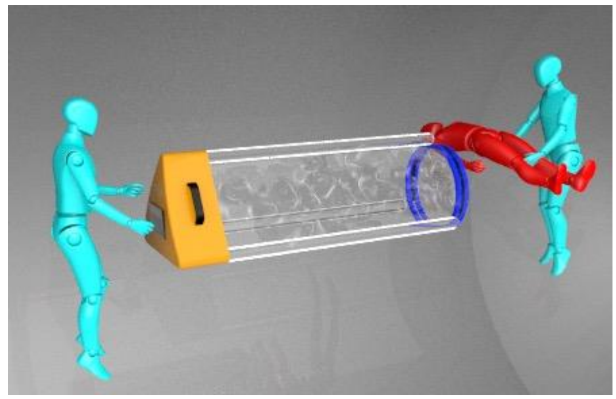

Figure 11: Automated Structural Deployment

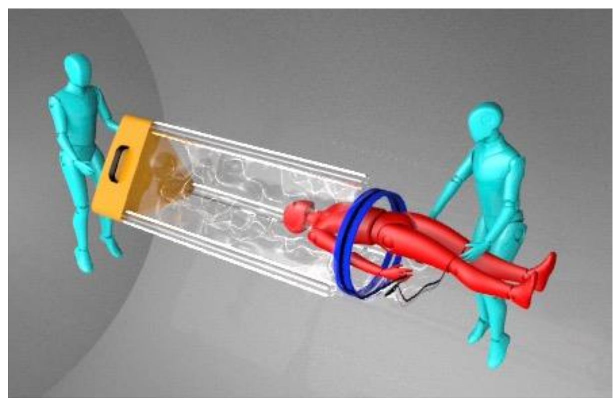

Figure 12: Casualty Entrance, End Zipper

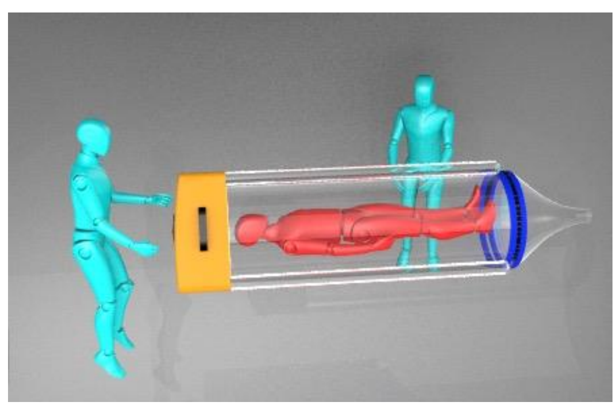

Figure 13: PECS Deployed, Life Support Active

Configuration 3 – Longitudinal Zipper Method: Structural Ribs begin automated activation once PECS is released from stowed position and locked into ready position (*Figure 14: Automated Structural Deployment, Side Entry*), (tie method and circumferential zipper are stowed as secured in this configuration) access of casualty is gained through already open longitudinal YKK Bio zipper as main envelope is extended to full position (*Figure 15: Casualty Entrance, Side Entry*). Operator pulls zipper to closed position using parallel hand straps to overcome microgravity (towards the bulkhead for access to controls if necessary). Once zipper is in closed position, automated life support commences (*Figure 16: PECS Deployed, Side Entry*). Casualty may be assessed at this time.

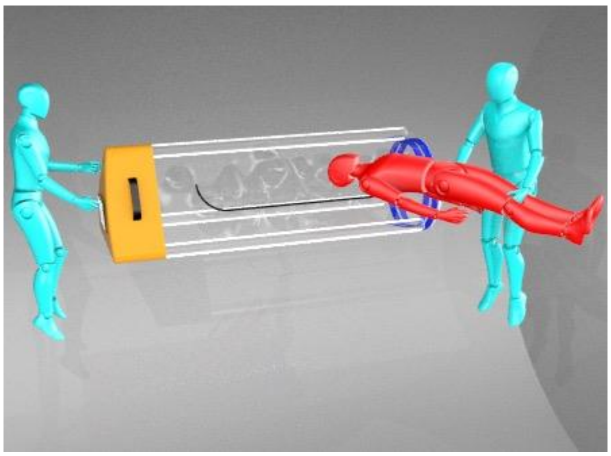

Figure 14: Automated Structural Deployment, Side Entry

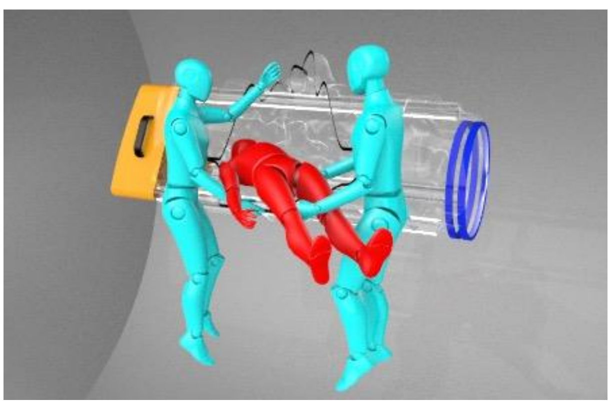

Figure 15: Casualty Entrance, Side Entry

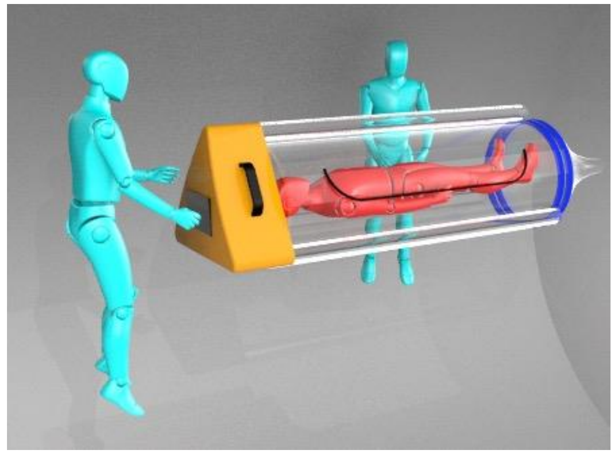

Figure 16: PECS Deployed, Side Entry

It should be noted that HITL interaction during initial mock-up creation led to several requirements such as the parallel hand straps as well as handle placement on the bulkhead to assist in stow/unstow of PECS as well as an anchor point for manipulation of casualty. Further, it was decided that PECS should, in a microgravity, be anchored prior to activation of the structural ribs to prevent sudden movement of operator or damage to surrounding crew or craft.

Overall, PECS has the following methods of entry:

1) Tie Method – Assisted or self-entry with modified methods
2) Circumferential YKK Bio zipper – Assisted or self-entry with modified methods
3) Longitudinal YKK Bio zipper – assisted or self-entry

5. Discussion

This system is in an early design phase. Continued modifications and changes are sure to come as continued collaboration with SMEs and continued HITL simulation is done at each step of the design process and as modifications are completed on the current mock-up. The culminating result will maintain a human-centered design approach that looks wholly at the human operators and inhabitants for creation of the primary design requirements as they pertain to a microgravity environment.

5.1 Future Iterations/Modularity

PECS may have the benefit of being able to sustain multiple modalities based on interchangeable parts to fit the requirements of the mission and environment. This may include interchangeable main envelopes to fit requirements on-board microgravity habitats or microgravity transfer craft, surface EVA and surface habitats at variable gravities less than 1g, or designed with re-entry in mind, all dependent on materials abilities. Likewise, interchangeable structural ribs, adjustable structural ribs and main envelope, varied port and passthrough availabilities as well.

5.2 Conclusions

With a previous mock-up, design changes were made (in-line with human-centered design) although the concept was functional in. These changes reflect newly derived requirements and mitigate ascertained design flaws. It is concluded, for now, that there will continue to be design changes as new data are collected through research.

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References

[1] Rooney BV, C. B. Herpes Virus Reactivation in Astronauts During Spaceflight and its Application on Earth. Frontiers in Microbiology, 10-16. doi:10.3389/fmicb.2019.00016. 2019.

[2] National Aeronautics and Space Administration. NASA Standard 3001. Human Space Flight System Standard Vol. 1, Rev. A: Crew Health. 2017.

[3] National Aeronautics and Space Administration. NASA/TP-2015-218570. Life Support Baseline Values and Assumptions Document. 2015.

[4] National Aeronautics and Space Administration. NASA/SP-2005-6113. Bioastronautics Roadmap-a Risk Reduction Strategy for Human Space Exploration. 2005.

[5] National Aeronautics and Space Administration. NASA/SP-2009-3405. Human Health and Performance Risks of Space Exploration Missions. 2009.

[6] Galindo R.A., Bodkin, D, Htike A.C., Chasseigne R, Demel M, Doule O, Hochstein J, Hu W, Igland J.A., Jagula D, Lemberg M, Messina V, Mulugeta L, Musa Z, Ng J.A., Oprong A.A., Panopoulou A, Park J, Quemet L, Gutierrez J.P.S., Sano M, & Turnock M, ALERTS Analysis of Lunar Exploratory Robotic Tasks for Safety. ISU Masters. 2008.

[7] National Aeronautics and Space Administration. JSC-CN-23330. The Space Medicine Exploration Medical Condition List. 2011.

[8] National Aeronautics and Space Administration. Human Research Roadmap Risk Sheets. Available Online: https://humanresearchroadmap.nasa.gov/Risks/ (Accessed 24 April 2019)

[9] National Aeronautics and Space Administration. NASA/SP-2010-3407/REV1. Human Integration Design Handbook. 2014.

[10] National Aeronautics and Space Administration. IDSS IDD. International Docking System Standard Interface Definition Document. 2010.

[11] Whitely R, M. R. Options for Staging Orbits in Cis-Lunar Space. 2016 IEEE Aerospace Conference. Big Sky, MT, USA: IEEE Xplore. doi:10.1109/AERO.2016.7500635. 2016.

[12] Pearlman R.Z., Inside Sierra Nevada's Inflatable Space Habitat for Astronauts in Lunar Orbit. Space.com. 22 August 2019.