Operational Considerations for Death In Space: Hardware Considerations for Preparation, Stowage, and Potential Return Of Remains

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Disclosure Information

91st Annual Scientific Meeting
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I have no financial relationships to disclose.

I will not discuss off-label use and/or investigational use in my presentation

Problem Framing

- Terrestrial management of decedent remains in the developed world is built around the ready availability of refrigeration, even in the most austere of locales and conditions.
  - Military hospitals in Iraq and Afghanistan
  - Closest terrestrial analog to ISS is Strategeic Ballistic Missile Submarine on deployment

- In the developing world without refrigeration, interment of remains is typically done before undesirable effects of decomposition arise.

Problem Framing

- Large-scale refrigeration capability does not currently exist on the International Space Station, and would be cost prohibitive to develop, unless there was further science that could be conducted utilizing the capability.
- "Burial at Sea" via Extra-Vehicular Activity (Spacewalk) increases risk to surviving crewmembers, and introduces the risk of recontact with the station on a subsequent orbit.
- If refrigerated storage and "interment" are not viable options, we are left with the question: "What do we do with the remains?"

Total Containment

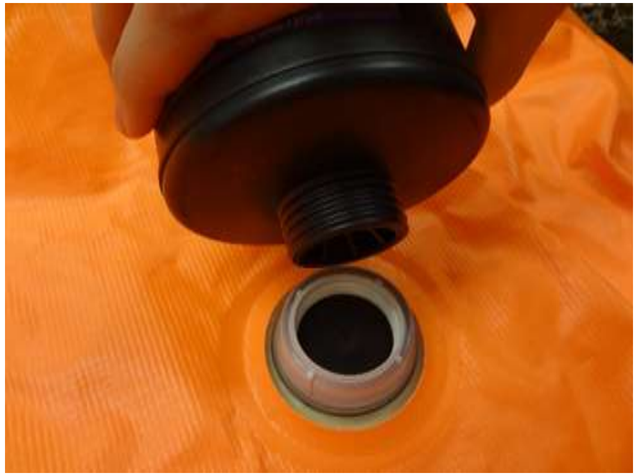
Problem Framing

- Containment options
  - Spaceflight pressure suit
    - Difficult to place remains into suit
      - Rigor may be present
    - Many gaseous products of decomposition have a higher vapor pressure than the gasses the suits are designed to contain, may not actually be sufficient to the task.
      - Very costly to test
  - Body bag
    - Most terrestrial body bags are not designed to be used outside of refrigeration capability, and have limited odor containment.
    - Military bags designed for use on casualties of chemical warfare agents offered some promise

Legacy Solution

- HRCU previously on ISS
  - Flown on SpaceX-1, October 2012
  - Located in Permanent Multipurpose Module (PMM)
  - Odor controlled by screw-on charcoal filter canisters
  - Fluid contained by absorbent material lining within the bag
  - Forensic sampling kit co-located with bag in PMM

Limitations of Legacy Solution



- Filter port design does not include a baffle to prevent liquid products of decomposition from contacting the filter surface
  - When the filtration membrane gets wet, it solidifies and will cease to pass gasses across it.
- Additionally, the design does not permit changing the filter if needed. Removing the filter releases gaseous products of decomposition into the Station atmosphere
- Testing was not conducted prior to flight to determine maximum use duration, or if it could fit into a spacecraft for return.
- 10 year shelf life, no longer in production

Design Considerations for New Bag

- Must contain all liquid and gaseous products of decomposition for as long as possible, at ISS atmospheric conditions.
  - Threshold was 48 hours, objective was 72 hours
  - Provides an operational "sandbox" in which Flight Directors and ISS management can determine disposition of remains.
- Sized sufficiently to accommodate remains
- Able to function across a significant pressure differential without leakage
- Storage life of at least 10 years
- Maintenance free

Selection of Replacement Hardware

- ISOVAC produces two models of Contaminated Human Remains Pouches
  - One is rated for Chemical Warfare Agent containment, the other for biological contaminants such as Ebola
  - Both were evaluated
  - Manufacturer made modifications to their base design to meet specific needs for use in space: the “NASA Special”.

Specific Modifications

- Addition of circumferential absorbent lining
  - Original design only had absorbent lining on the bottom, use in microgravity necessitates absorbent lining on all sides
  - In the form of an inner shroud

Specific Modifications

- Reverse orientation of zipper pull
  - Reversing the pull direction allowed the bag to be closed from head to foot, preserving the option for family member viewing of remains without exposing the entire cadaver.

Specific Modifications

- Relocation of filter port from foot to head
  - Necessary to preserve option to return remains to Earth
  - More available volume around the head portion of spacecraft seat
    - Easier for surviving crewmembers to “burp” bag in the event of pressure buildup

Specific Modifications

- Application of a loop panel on the outer portion of the bag lid
  - Allows placement of Crewmember's Nametag and EVA National Flag patch

Specific Modifications

- Securing straps added to hand loops to reduce snag hazard while navigating through the Station

Specific Modifications

- Securing straps added to the “shoulders” of the bag
  - Facilitates securing bagged remains in a spacecraft seat restraint

Verification of Hardware Capability

Fit Testing

Verification of Hardware Capability

Containment Testing

- An experiment was conducted with the assistance of the Applied Anatomical Research Center at Sam Houston State University
- Three cadavers were placed into an ISOVAC Human Remains Containment Unit (HRCU) on 9/24/19 and stored at temperature and humidity conditions matching those of the International Space Station
  - 1 cadaver served as a control, and was placed in an unmodified chemical HRCU; this HRP was opened daily to monitor decomposition as a proxy for the two experimental cadavers
  - 1 cadaver was placed in a Bio rated HRCU
  - 1 cadaver was placed in a modified HRCU with circumferential absorbent lining.
- Chemical sampling was conducted at the filter port and at the zipper closure.

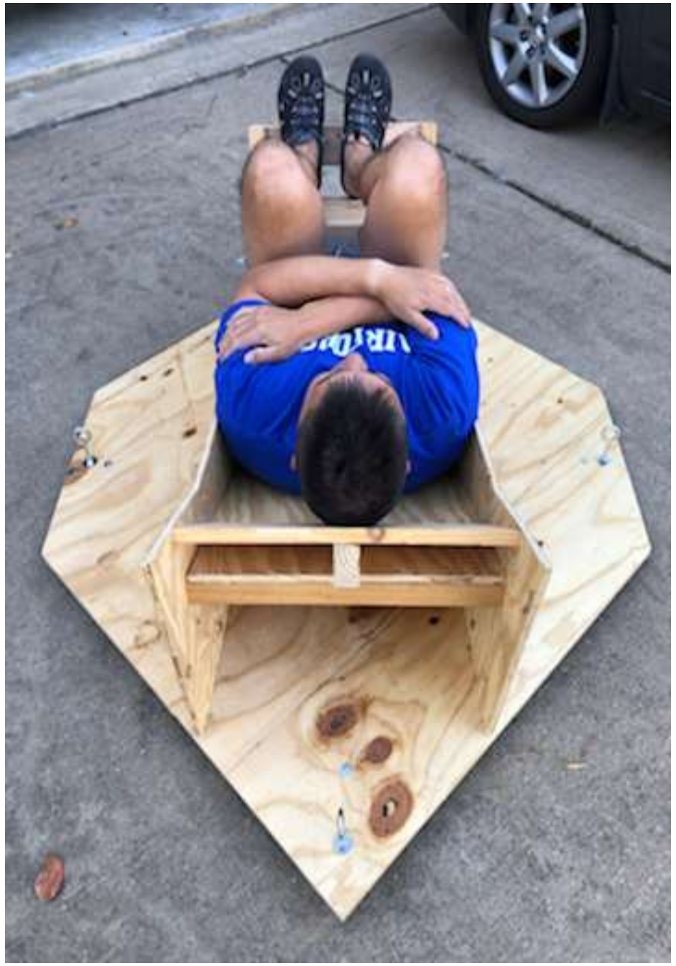
Verification of Hardware Capability

Impact Testing

- After both experimental HRCUs had experienced chemical breakthrough, a test was conducted on 10/24/19 to evaluate the bag's structural integrity under known landing forces.
  - A mock up of a seat pan in a Soyuz was built, remains were secured inside it, and it was dropped from a crane at a height sufficient to replicate impact velocities of that spacecraft.
  - Two separate impact tests were conducted at a velocity of 3 m/s and 10.5 m/s to simulate nominal and worst case survivable impacts.

Verification of Hardware Capability

Impact Testing



Impact Testing

Limitations of Testing

- The most obvious limitation of our testing was the inability to replicate the microgravity environment.
  - This will change the behavior of liquid products of decomposition, and could impact the rate at which gaseous products of decomposition are produced.
  - Additionally, it is possible that the effect of gravity may have actually *contributed* to a failure mode we observed in the chemically rated HRCU
- Another potentially significant limitation of testing was the inability to replicate the specific makeup of the ISS atmosphere
  - This could potentially impact the rate of decay observed in the remains

Limitations of Hardware / Failure Point

- The Biological rated HRCU experienced breakthrough of hydrogen sulfide and methane thiol after 8 days.
- After impact testing was completed, the chemical rated HRCU was allowed to continue in the experiment, to find an upper limit of containment.
  - Breakthrough of the same compounds was observed at 43 days
- Prior to conducting impact testing, it was noted that some of the liquid products of decomposition had begun to seep through the outer shell of the HRCU.
  - Observed specifically underneath the shoulderblades
  - This is assumed to be due to a combination of pH of the fluid, and the pressure from the weight of the remains
  - It is possible that this phenomenon would not occur in microgravity

Limitations of Hardware / Failure Point

Future Applicability

- Based on the testing conducted, the HRCU should prove sufficient for any mission conducted within the cislunar system

- Human exploration missions to farther destinations will likely require an engineering solution to be built into the spacecraft
    - Morgue tray freezer
    - Burial at sea

Publication intended, anticipated 2022