Design Constraints Regarding The Use Of Fluids In Emergency Medical Systems For Space Flight.

John McQuillen
NASA Glenn Research Center
21000 Brookpark Road
Cleveland, OH 44135

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Basis

Crew health and performance are critical to successful human exploration beyond low Earth orbit. The Human Research Program (HRP) investigates and mitigates the highest risks to human health and performance, providing essential countermeasures and technologies for human space exploration.

- Behavioral Health and Performance
- Exploration Medical Capability
- Human Health Countermeasures
- Space Radiation

Medical Conditions

- The Space Medicine Exploration Medical Condition List (SMEMCL) was created to define the set of medical conditions that are most likely to occur during exploration space flight missions.
  - Treat Injured or Ill crew members
  - The conditions were gathered
    - Space flight medical incidents
    - The Shuttle Medical Checklist
    - The International Space Station Medical Checklist
    - Subject matter expert opinion
- Watkins, S., Barr, Y and Kerstmanm, E., "The Space Medicine Exploration Medical Condition List", https://www2.sti.nasa.gov/Webtop/ws/asdb/ul/web/ImageDisplay/2011009086.pdf?&docid=2011009086&type=pdf&daa=
- Additional Information at HRP Roadmap: http://humanresearchroadmap.nasa.gov

Some Medical Gaps with a Fluid Handling Aspect

Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities

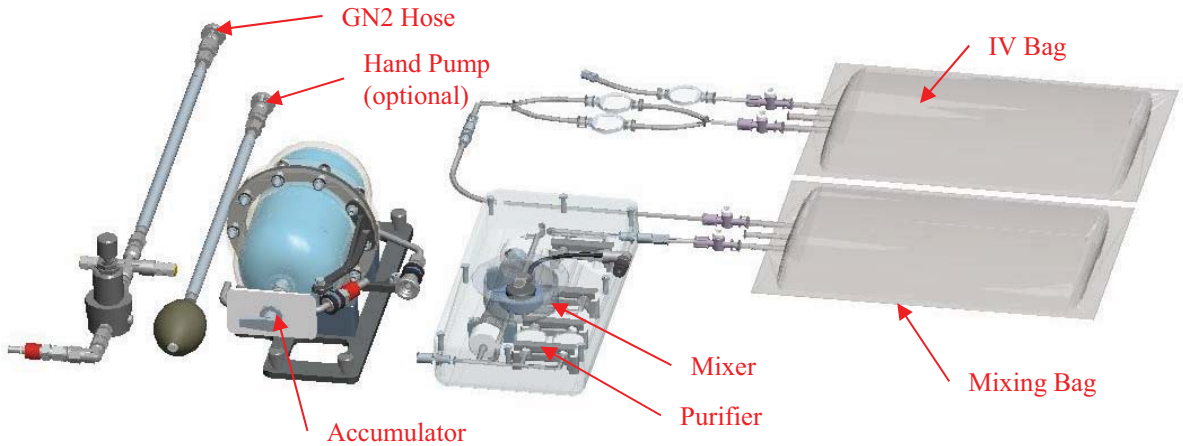
- ExMC 4.09: We do not have the capability to provide medical suction and fluid containment during exploration missions.
- ExMC 4.12: We do not have the capability to generate and utilize sterile intravenous fluid from potable water during exploration missions.
- ExMC 4.21: We do not have a reusable, single-operator capability to irrigate the eyes during exploration missions.
- ExMC 4.25: We do not have the capability to deliver injectable medication to a suited crewmember during exploration missions.

Environmental Constraints

- Acceleration:
  - Mission Dependent, Lunar gravity (0.17 g's) or Martian (0.38 g's)
  - Mission Phase
    - Launch & Reentry (several g's)
    - Predominately, microgravity 10^{-6} g's
- Temperature:
  - Nominal 25 to 30°C
  - "Acceptable" 4 to 40°C
  - Off Nominal
    - -120 to +135 °C
- Pressure
  - Nominal ~ 1 atm
  - EVA – 0 atm
  - Differential 0.35 atm.

Intravenous Fluid Generation (IVGEN)

- Addressed Gap ExMC 4.12: We do not have the capability to generate and utilize sterile intravenous fluid from potable water during exploration missions
- Major Design Constraint: Microgravity
- System Concept
  - Utilizes ISS potable water as source water.
  - Additional purification primarily using packed bed of deionizing resin
  - Mixing with Pharmaceutical (salt)
  - Sterilization of Solution
  - Little or no power consumption

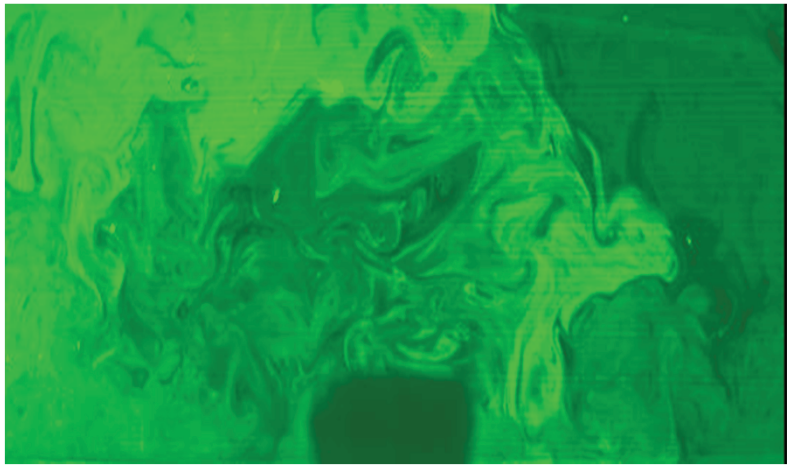


Fluid Concerns

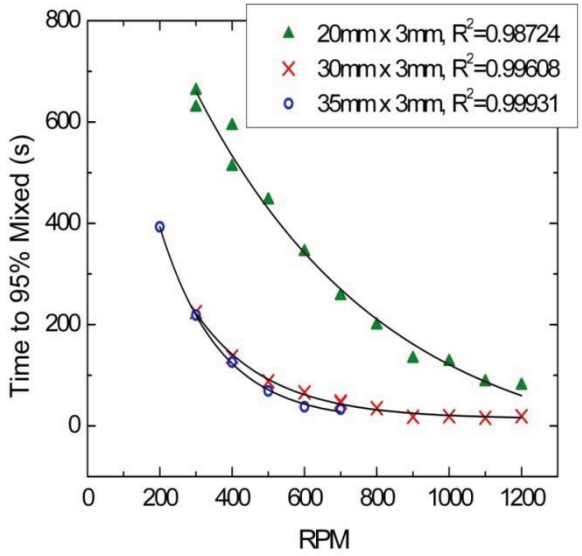
- Two Phase Flow
  - Only water is desired
  - Gas from “dry volume” storage and other sources
  - May cause channeling through packed bed reducing effectiveness in purification
  - Affects measurement of water processed and mixed with pharmaceutical posing concentration issues with solution
  - Mixing issues
- Mixing/Pharmaceutical Dissolution
  - Diffusion is a very slow process for dissolving and mixing
  - Mechanical agitation is required.

Mixing Concept Validation

- Mixing time: Liquid/Liquid
  - 30 mm stir bar at 700 rpm mixes 1 liter of IV fluid in approximately 2 minutes
- Mixing time: Liquid/crystal
  - 30 mm stir bar at 700 rpm mixes 1 liter of IV fluid in approximately 8 minutes
- C-9 Tests
  - Verified that bubbles will not interfere with mixing in microgravity
  - Pharmaceutical particles do not become trapped in corners of a standard IV bag



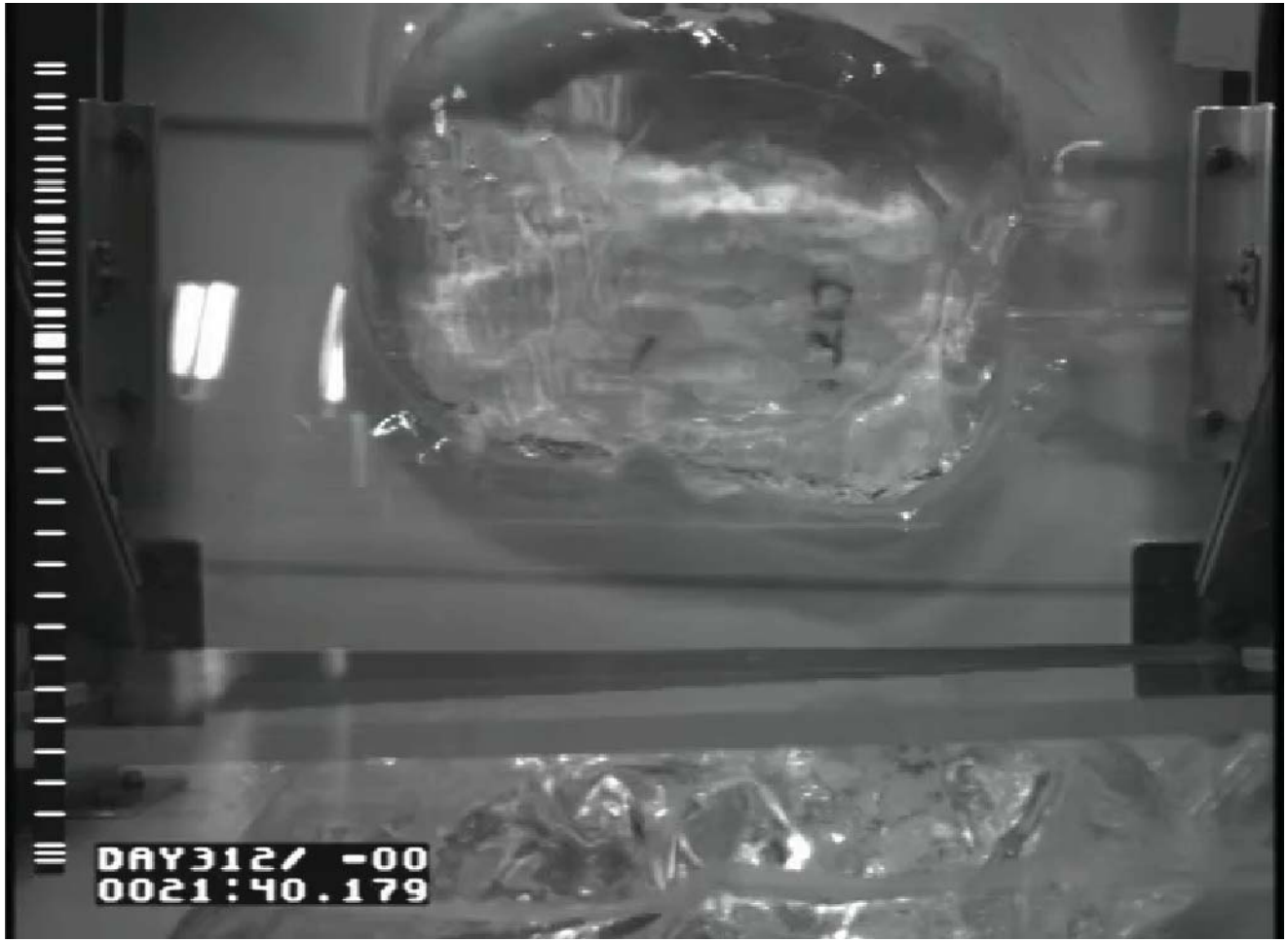
Planar Laser-Induced Fluorescence (PLIF) image of pharmaceutical mixing in IVF



Low Gravity Testing of Magnetic Stir Bar

- Bag shapes (~ 1 liter volume)
  - Rectangular
  - Oval
  - Round
- Stir Bar
  - Rotation Rates
  - Size
- Solute
  - Normal Saline (~ 1 g of Sodium Chloride)
  - D5W (5 grams of Dextrose)
  - Indicator particles

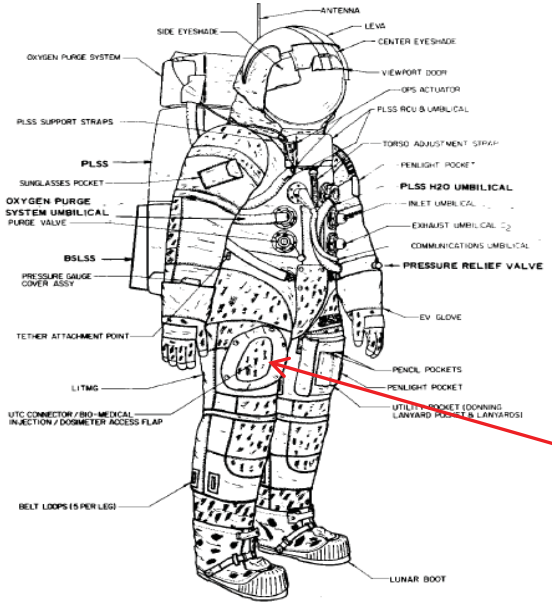
C-9 Mixing Video



In Suit Injection System (ISIS)

- Addressed Gap ExMC 4.25: We do not have the capability to deliver injectable medication to a suited crewmember during exploration missions.
- Major Design Constraints: Temperature & Pressure
- System Concept
  - Pressurized cartridges containing medications.
  - Cartridges need to premixed
  - Thermal storage

Apollo Suit and Pressure Garment Assembly



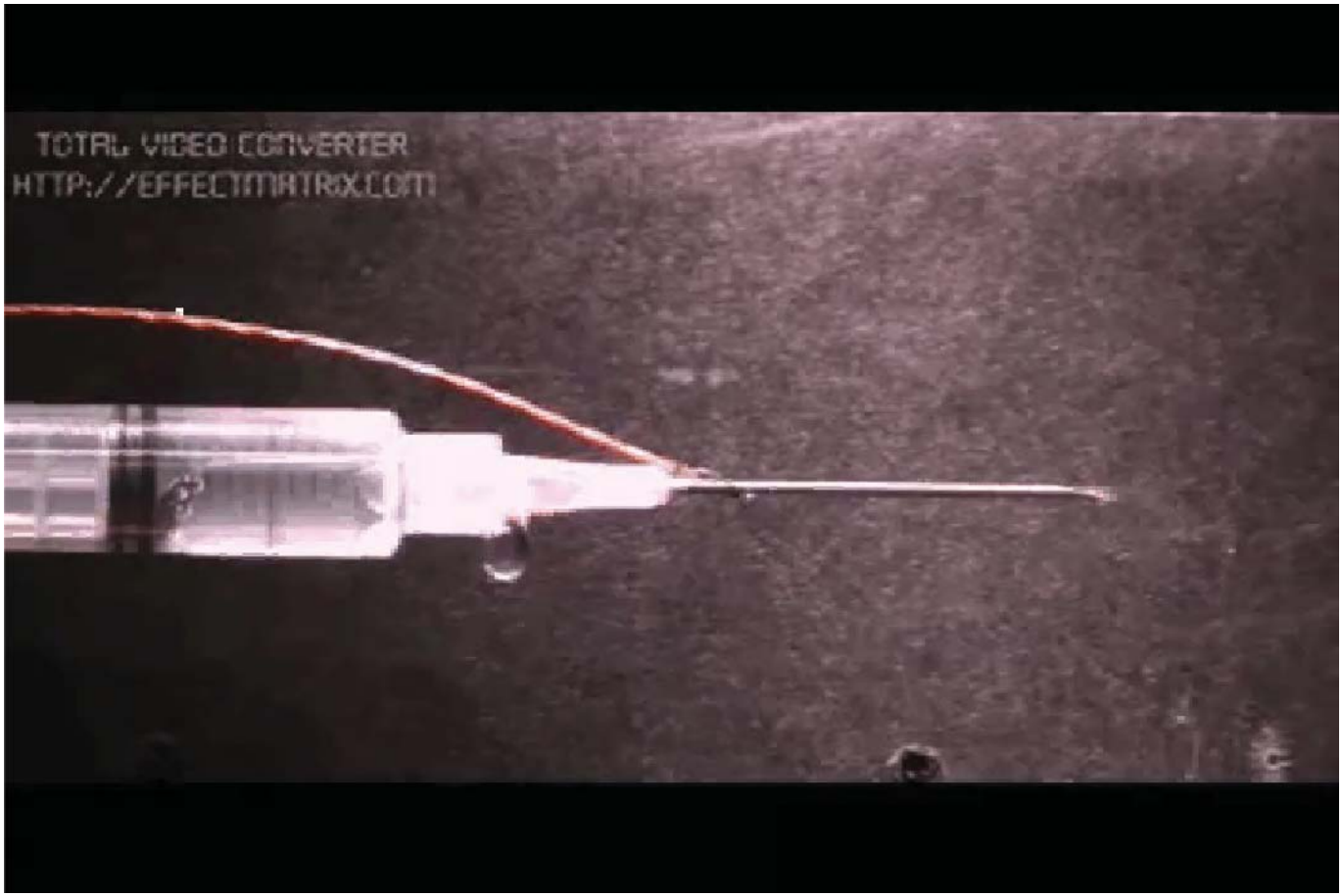
Fluid Concerns

- Temperature
  - Freezing point of aqueous solutions
  - Solubility is a function of temperature
  - Thermal coefficient of expansion for liquid – rupture containers?
  - Fluid viscosity is function of temperature
- Pressure
  - Air bubble typically left in syringes to compensate for liquid volumetric changes due to temperature swings and fluid expansion/contraction. As pressure drops, bubble grows in size.
  - Vaporization of some liquid as pressure drops will cause remaining liquid to freeze.
  - Pressure swing. Device needs to retain fluid as ambient pressure drops, but have sufficient pressure to inject into a “pressurized” suit.

Testing in a Vacuum - Syringe

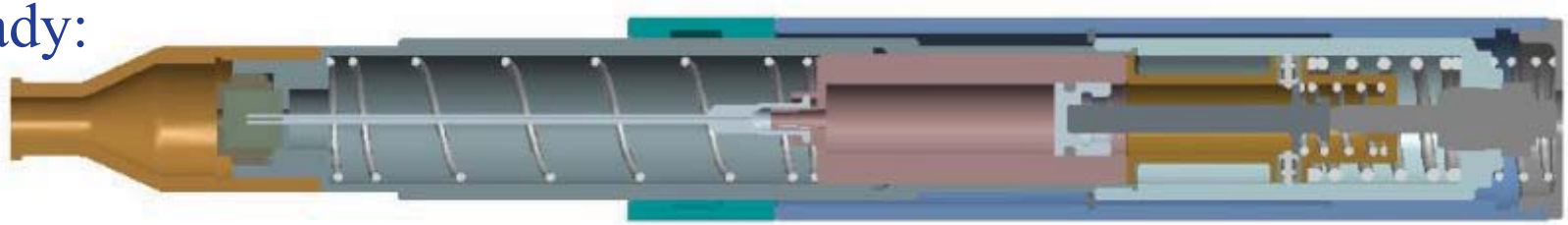
- 5 ml of Normal Saline Solution
- Plastic Syringe
- Small Air bubble in syringe
- Vacuum Chamber
  - ~ 2 ft^3 Volume
  - Large Window
  - Actuator to depress syringe
- Start at atmospheric pressure and pull vacuum to 1 torr.

Testing in a Vacuum - Syringe

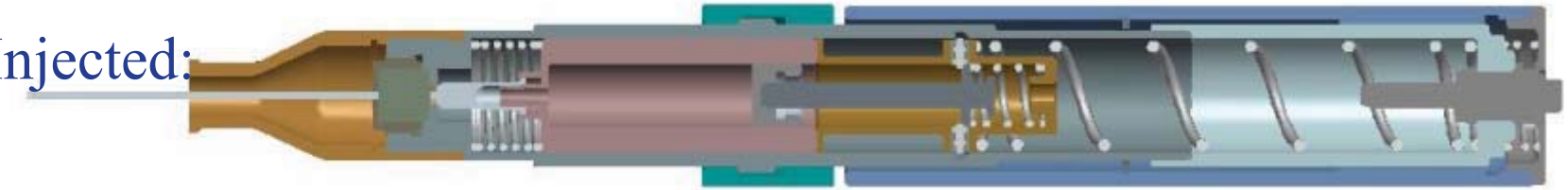


Proposed Design of ISIS – 3 States

Ready:



Injected:



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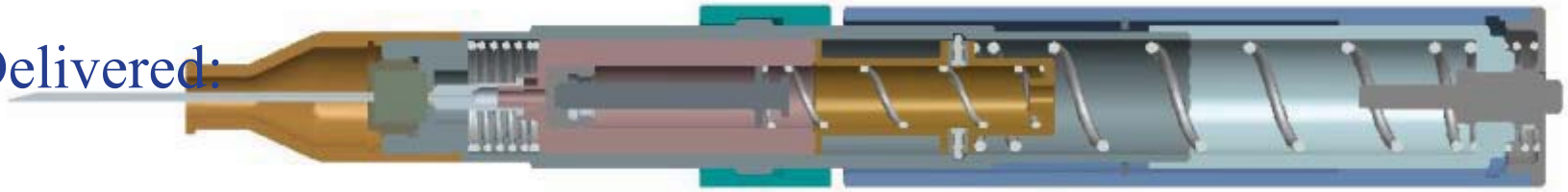
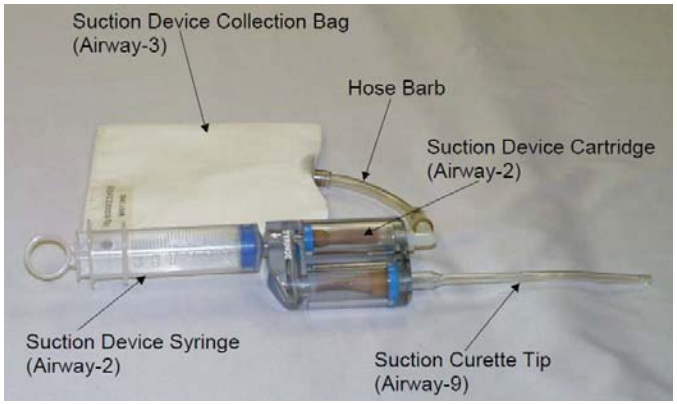


Medical Suction

- Addressed Gap ExMC 4.09: We do not have the capability to provide medical suction and fluid containment during exploration missions.
- Major Design Constraint: Microgravity
- Range of flow rates and vacuum pressures for a variety of medical conditions
  - Clearing Airway
  - Dental procedures
  - Surgery
  - Pneumothorax
- System Concept
  - Separate Gas & Biofluid
  - Vent gas
  - Retain biofluid for safe removal and disposal or storage

Current device on Space Station

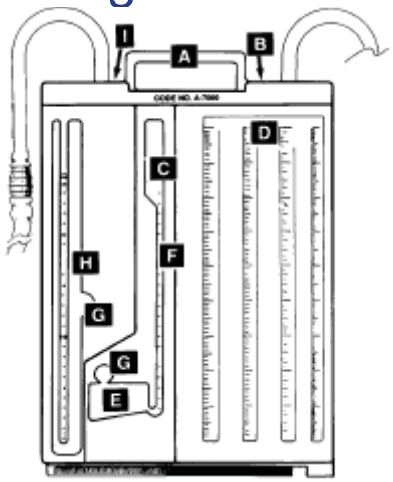


Fluid Concerns

- Microgravity: Two Phase Flow
  - Sufficient vacuum level to achieve flow
  - Gas – liquid Separation
  - Biofluid Containment and disposal.

Pneumothorax

- Treatment of collapsed lung
  - Insert needle into patient's chest cavity
  - If only collapsed lung, need a check (Heimlich) valve to prevent backflow.
- If there is fluid in chest cavity will need also need a Wet Seal device.
  - Multiple chambers to collect biofluid
  - A column filled with liquid to show flow via bubbling
  - A differential pressure measurement



Other Concerns

- Typical Mass and Volume Constraints associated with spaceflight:
  - Dual Purpose is bonus.
  - Minimize hardware exclusive to medical needs.
- Power Issues
  - Nature of Medical Incident may also involve a “sick” spacecraft: Power may be limited.
  - Use of Batteries pose other issues:
    - Source of Potential Energy that needs to released in control manner
    - Maintaining Charge during long missions
    - Weight and size
    - Long period of use?
- Training
  - Small crew size may (or may not) include medical professional

Acknowledgements

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Summary

- Some medical devices will involve fluid systems
  - Gaps have been identified for some shortcomings in medical devices.
  - As other gaps are investigated, other needs may be identified.
- Need to consider
  - Microgravity aspects with regards to fluid handling
  - Thermal aspects to maintain effectiveness of medication
  - Pressure Differences may result in increased leakage.