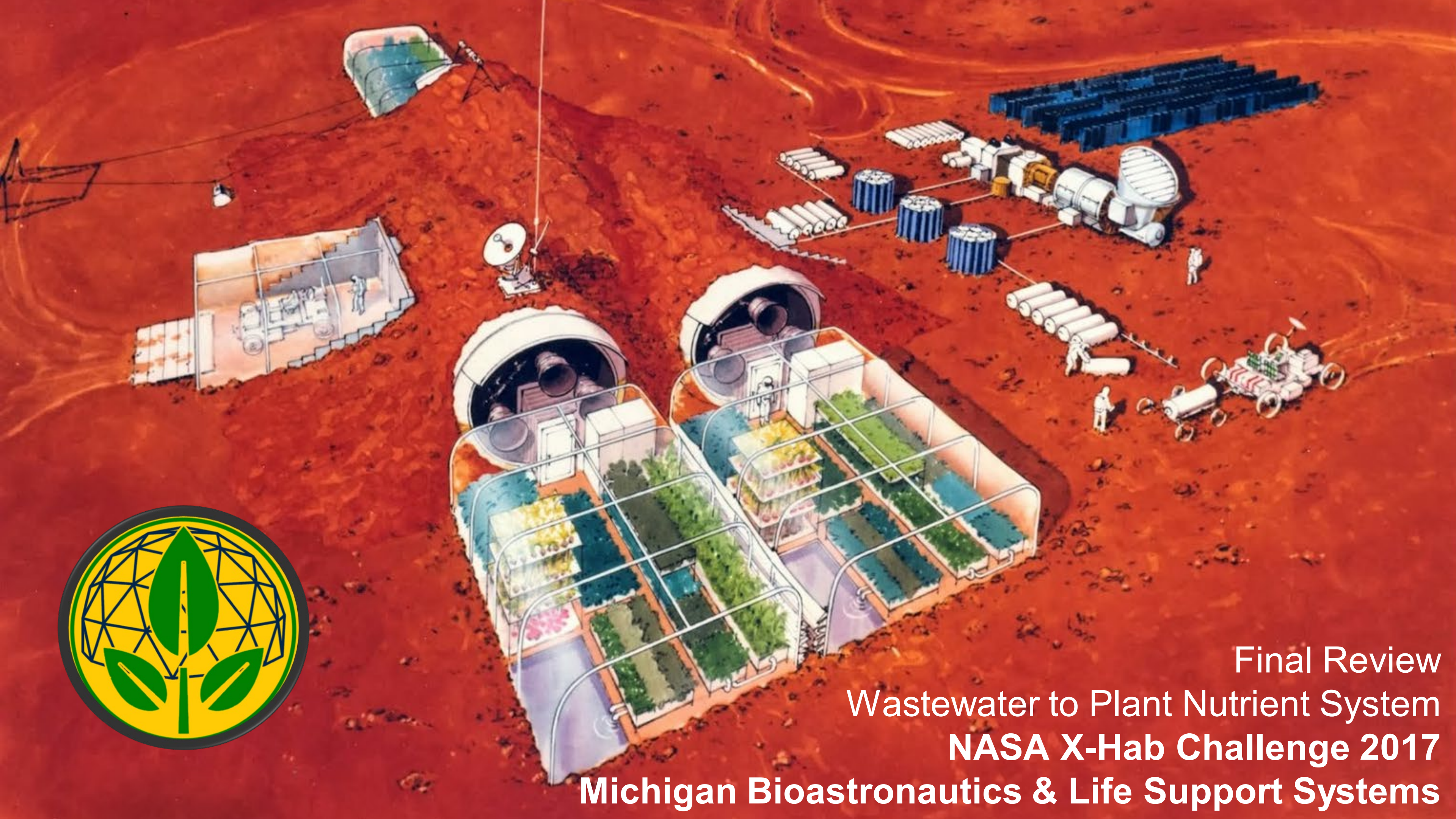

Final Review

Wastewater to Plant Nutrient System

NASA X-Hab Challenge 2017

Michigan Bioastronautics & Life Support Systems

Overview

- Team Members
- Review of Design Process
- Review of Testing Program
- System Demo
- Results
- Notional Operational System
- Outreach
- Program Summary

Team Members

Team Leaders

Robert Gitten (Project Manager)
Benjamin Greaves (Chief of Assembly, Test and Integration)
Nicholas Krawec (Chief of Assembly, Test and Integration)

Team Members

Athip Thirupathi Raj (Bio-Chemistry Lead)
David Szefi (Pre Treatment Lead)
Adrian Arteaga (Main Treatment Lead)
Sam Nuzbrokh (Post Treatment Lead)
Amanda Hansen (Integration Lead)
Haroon Syed

Advisors

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Professor Mark Moldwin

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Hossein Zabihian
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Heather Goetsch
Kunwar Kochar

Miekyn Cotton
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Andrew Burek
Allison Ward
Nick Folz
Ryan Huffnagle

Vision, Mission and Definition

Vision and Mission Statement

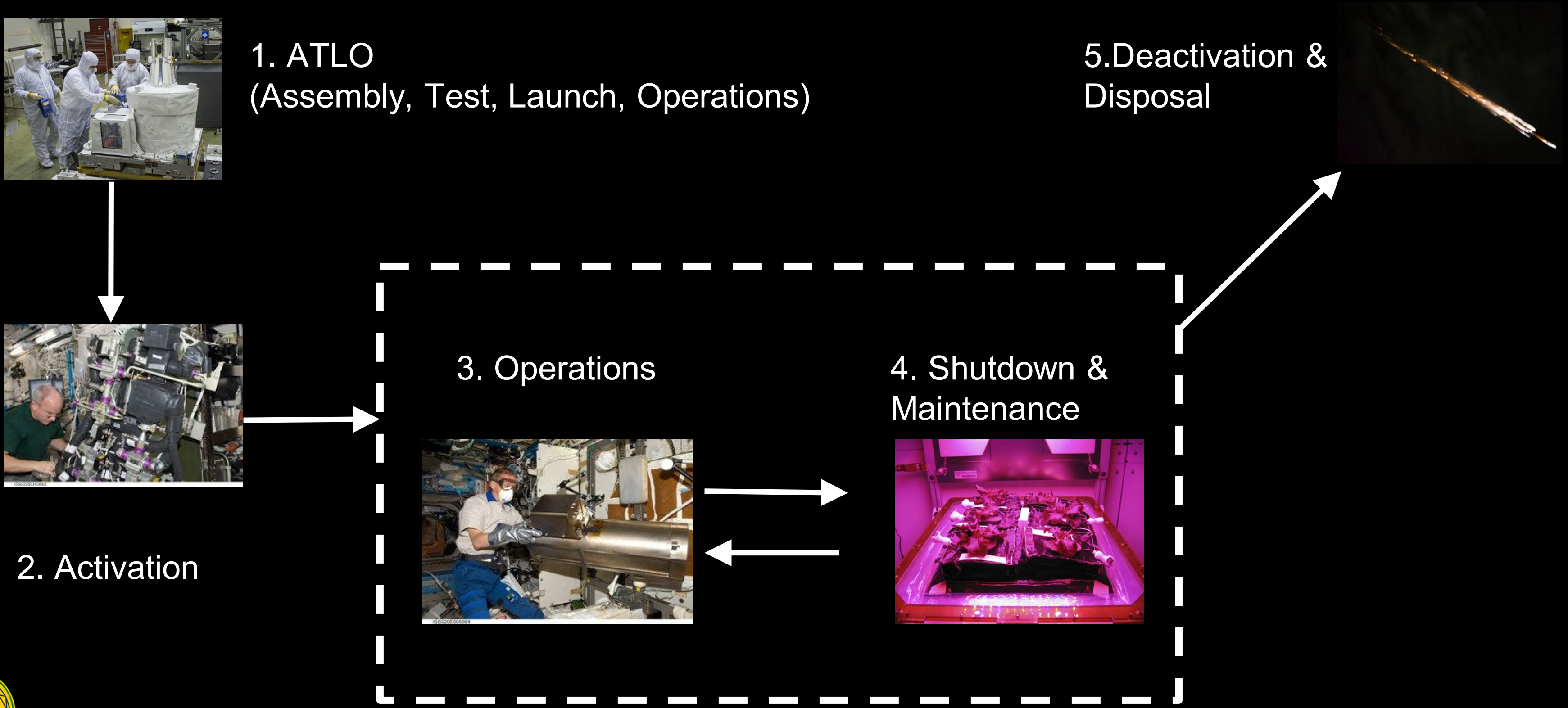
During human space exploration missions longer than 30 days (500 days to indefinite; as defined by NASA strategic plan), a spacefaring crew will generate liquid waste that can be recovered and processed to create nutrients for a plant food production system. In addition, the sodium in urine has a potential to build-up in the system and is not useful as a plant fertilizer since it can stress plants at high concentrations.

Finding a way to separate these products and retrieve them for other use is critical for long duration missions. This is useful since it can greatly reduce the amount of overall mission mass.

System Definition

The system will extract water and plant nutrients for food production along with edible sodium from human urine and other wastewater sources. The system will be implemented on a human space exploration mission and be sized for a crew of 4, operating in a microgravity environment.

Mission Concept



1. ATLO
(Assembly, Test, Launch, Operations)

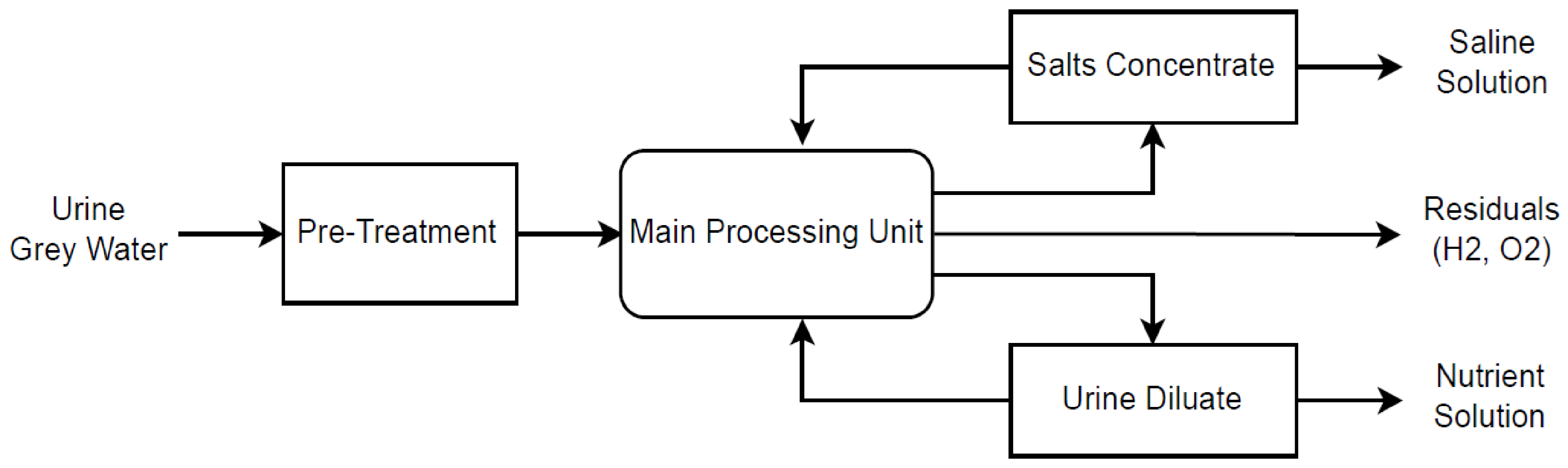
2. Activation

3. Operations

4. Shutdown & Maintenance

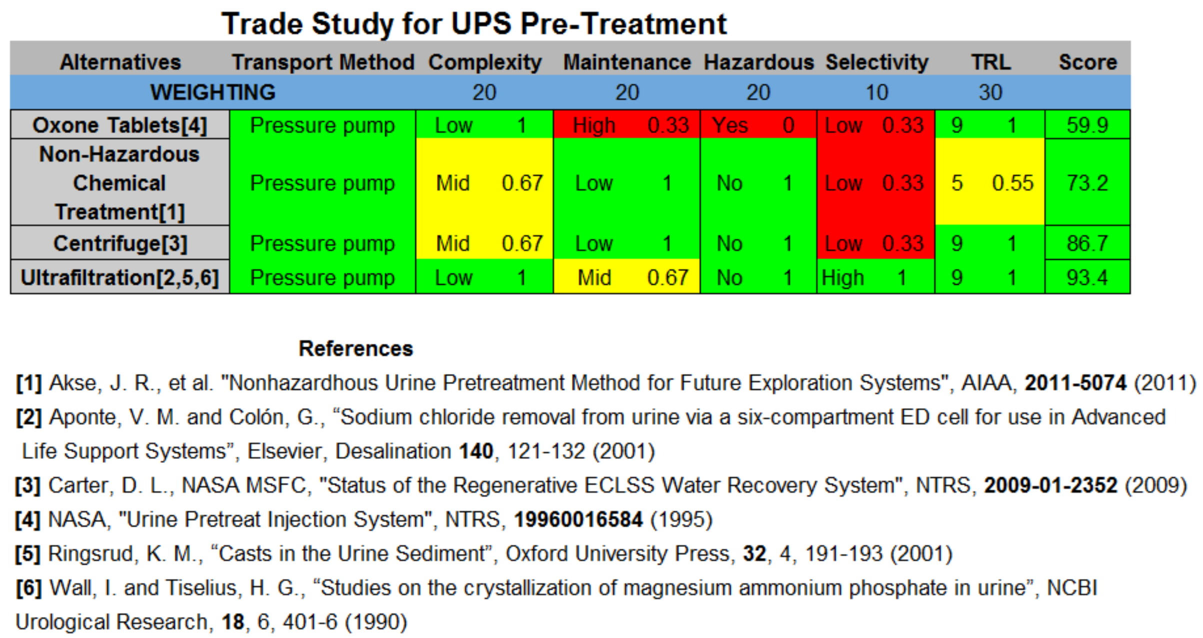
5.Deactivation & Disposal

Concept of Operations



System is adaptable: secondary inputs such as grey water may be mixed with urine.
System may interface with vehicle subsystems which provide inputs or utilize outputs.

Preferred System Solution



Trade Study for UPS Pre-Treatment

Alternatives	Transport Method	Complexity		Maintenance		Hazardous		Selectivity		TRL		Score
WEIGHTING		20		20		20		10		30		
Oxone Tablets[4]	Pressure pump	Low	1	High	0.33	Yes	0	Low	0.33	9	1	59.9
Non-Hazardous Chemical Treatment[1]	Pressure pump	Mid	0.67	Low	1	No	1	Low	0.33	5	0.55	73.2
Centrifuge[3]	Pressure pump	Mid	0.67	Low	1	No	1	Low	0.33	9	1	86.7
Ultrafiltration[2,5,6]	Pressure pump	Low	1	Mid	0.67	No	1	High	1	9	1	93.4

References

[1] Akse, J. R., et al. "Nonhazardhous Urine Pretreatment Method for Future Exploration Systems", AIAA, **2011-5074** (2011)

[2] Aponte, V. M. and Colón, G., "Sodium chloride removal from urine via a six-compartment ED cell for use in Advanced Life Support Systems", Elsevier, Desalination **140**, 121-132 (2001)

[3] Carter, D. L., NASA MSFC, "Status of the Regenerative ECLSS Water Recovery System", NTRS, **2009-01-2352** (2009)

[4] NASA, "Urine Pretreat Injection System", NTRS, **19960016584** (1995)

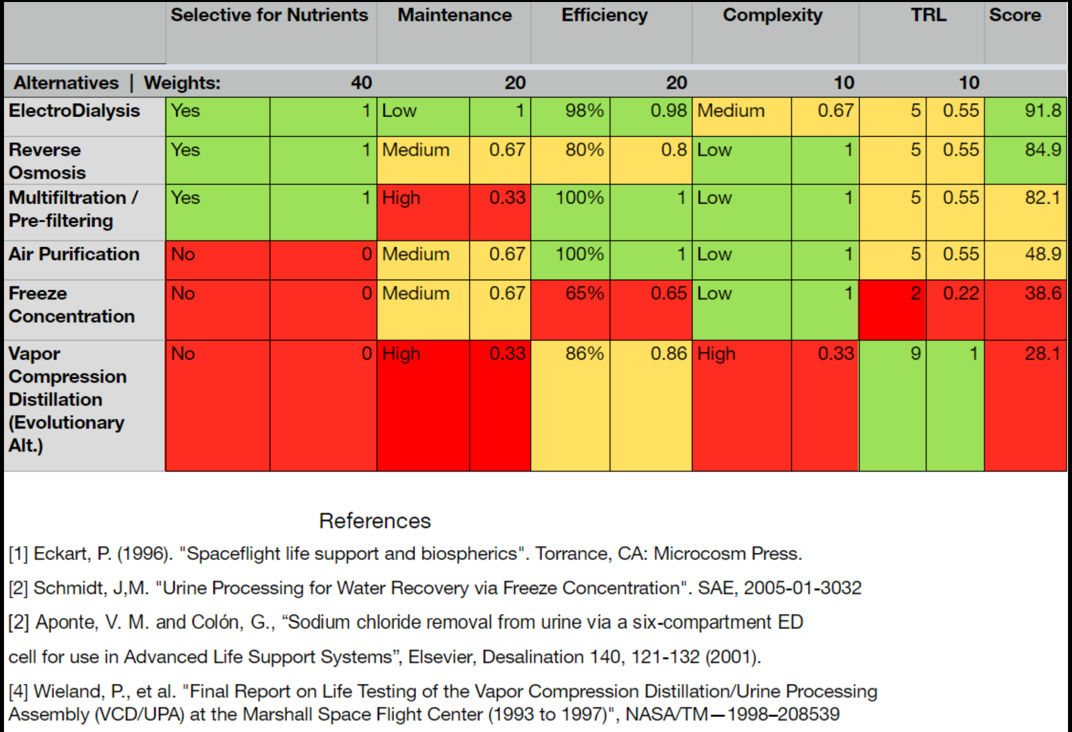
[5] Ringsrud, K. M., "Casts in the Urine Sediment", Oxford University Press, **32**, 4, 191-193 (2001)

[6] Wall, I. and Tiselius, H. G., "Studies on the crystallization of magnesium ammonium phosphate in urine", NCBI Urological Research, **18**, 6, 401-6 (1990)

Based on trade study, an ultrafiltration unit is preferred as the pretreatment method.

- Simplicity of Design
- No hazardous chemicals
- Selective pore size

Preferred System Solution



	Selective for Nutrients		Maintenance		Efficiency		Complexity		TRL		Score
Alternatives | Weights:		40		20		20		10		10	
ElectroDialysis	Yes	1	Low	1	98%	0.98	Medium	0.67	5	0.55	91.8
Reverse Osmosis	Yes	1	Medium	0.67	80%	0.8	Low	1	5	0.55	84.9
Multifiltration / Pre-filtering	Yes	1	High	0.33	100%	1	Low	1	5	0.55	82.1
Air Purification	No	0	Medium	0.67	100%	1	Low	1	5	0.55	48.9
Freeze Concentration	No	0	Medium	0.67	65%	0.65	Low	1	2	0.22	38.6
Vapor Compression Distillation (Evolutionary Alt.)	No	0	High	0.33	86%	0.86	High	0.33	9	1	28.1

References

[1] Eckart, P. (1996). "Spaceflight life support and biospherics". Torrance, CA: Microcosm Press.

[2] Schmidt, J,M. "Urine Processing for Water Recovery via Freeze Concentration". SAE, 2005-01-3032

[2] Aponte, V. M. and Colón, G., "Sodium chloride removal from urine via a six-compartment ED cell for use in Advanced Life Support Systems", Elsevier, Desalination 140, 121-132 (2001).

[4] Wieland, P., et al. "Final Report on Life Testing of the Vapor Compression Distillation/Urine Processing Assembly (VCD/UPA) at the Marshall Space Flight Center (1993 to 1997)", NASA/TM—1998–208539

Based on trade study, an Electrodialysis (ED) cell will be the primary filtration unit

- Selective Filtering
- Low Maintenance
- High Efficiency

Bio-Chemistry

Preliminary Functional Baseline

Minimum Plant Nutrient Requirements and Amount Available in Urine

Item	Formula	Formula Weight (kg/kmol)	Amount in Solution		Minimum Requirement per Plant (mg/L/plant)	Amount from 4 Astronauts (From 7.5L of Urine) (mg/day)
			Before Electrodialysis (mg/L)	After Electrodialysis (mg/L)		
Phosphorus	P	31	1070	40	175	300
Potassium	K	39	2610	2422	4150	18165
Calcium	Ca	40	390	24	30	180
Magnesium	Mg	24	205	196	208.3	1470
Sulphur	S	32	1800	825	479	6187.5

REFERENCES:
http://www.ctahr.hawaii.edu/mauisoil/c_nutrients.aspx
http://www.cropnutrition.com/efu-micronutrients
New England Vegetable Management Guide: https://nevegetable.org/cultural-practices/removal-nutrients-soil
International Plant Nutrition Institute (IPNI): http://www.ipni.net/
Nutrient Recommendations For plant Crops in Michigan:
http://macd.org/_literature_128140/Nutrient_Recs_for_Vegetable_Crops_in_MI

Output Solution

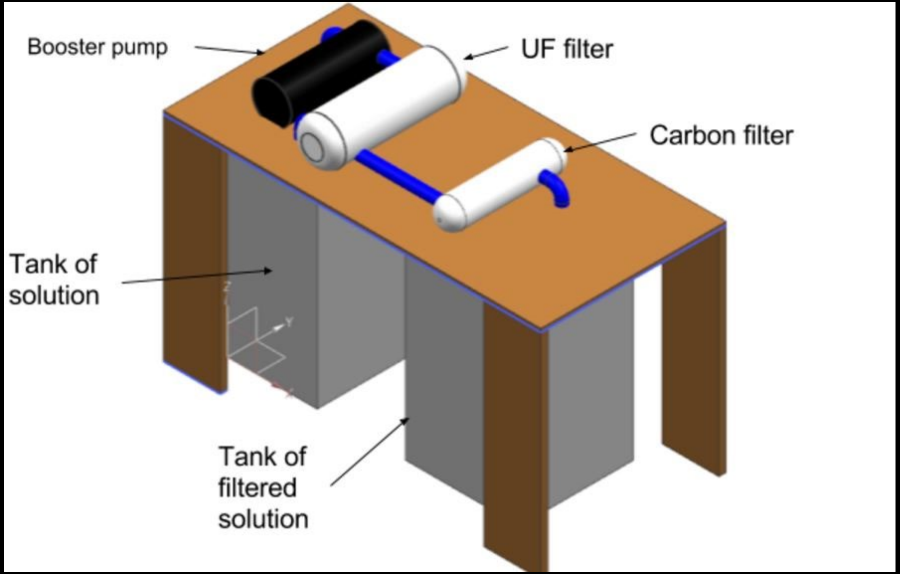
Solution	Water (L)	Nutrients (L)
Initial	5.7	0.3
Final	5.7	0.254

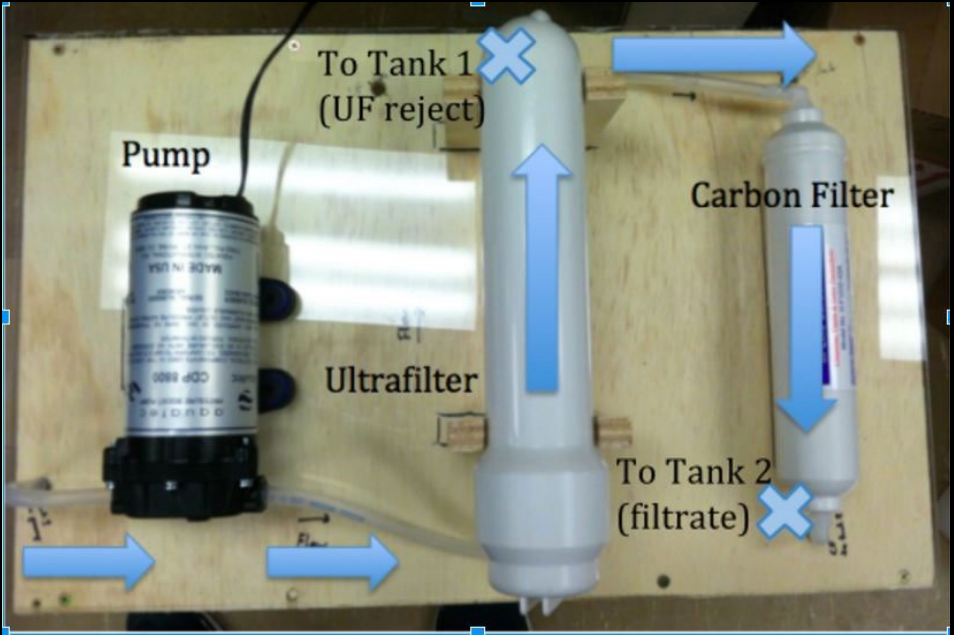
Assuming that 90% of Chlorine ions leave and and 30% of all other monovalent ions leave.

Constituent	Concentration in Final Solution (mg/L)
Urea	1640
KH2PO4	524.594
NaCl	290.58
K2SO4	501.97
NH4Cl	34.965
(NH4)2SO4	327.307
CaCl2	37.403
MgSO4	71
NaHCO3	470.171
Miranol C2M Conc.-NP	558
STEOL CS-330	854
Total	5309.99

Astronaut Urine Repurposing Apparatus Flow Demonstration

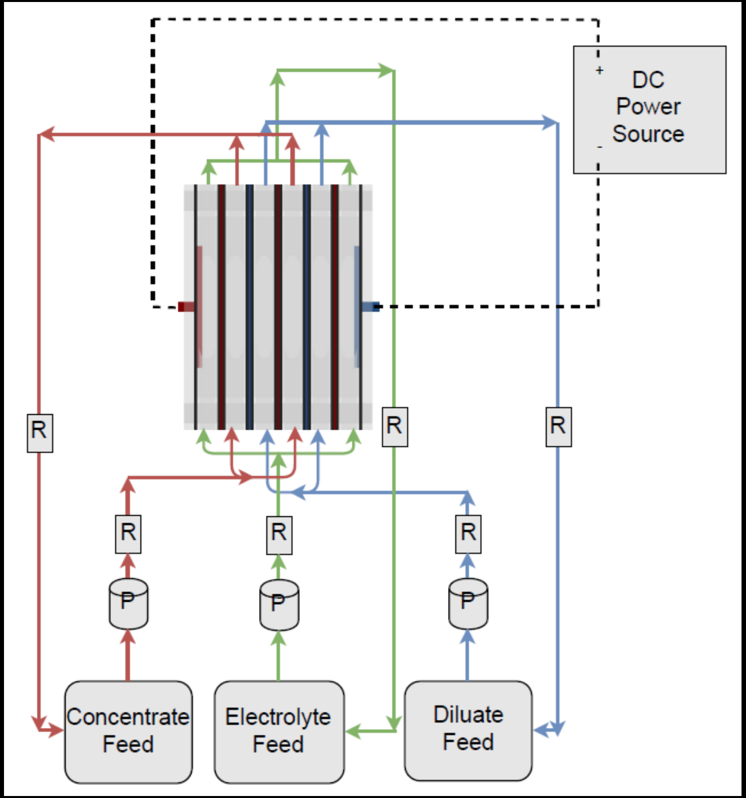
Urine Pre-Treatment System





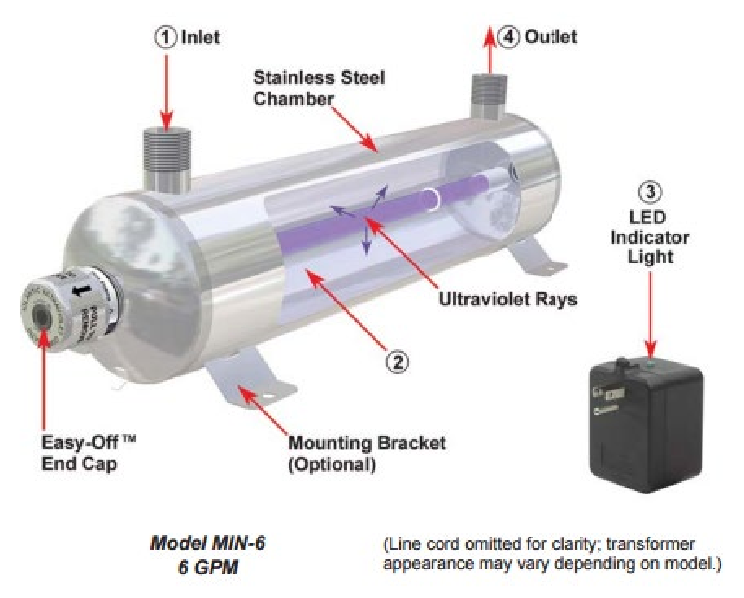
Main Treatment System

- DC power source drives a current through EDC, promoting ion movement, while Ion Exchange Membrane separate ions into specific streams.
- Pretreated Urine from UPS (diluate) circulates through EDC, losing NaCl to the concentrate streams.
- Electrolyte feed (0.2 Mol NaCl solution) donates ions through desalination process to increase efficiency.

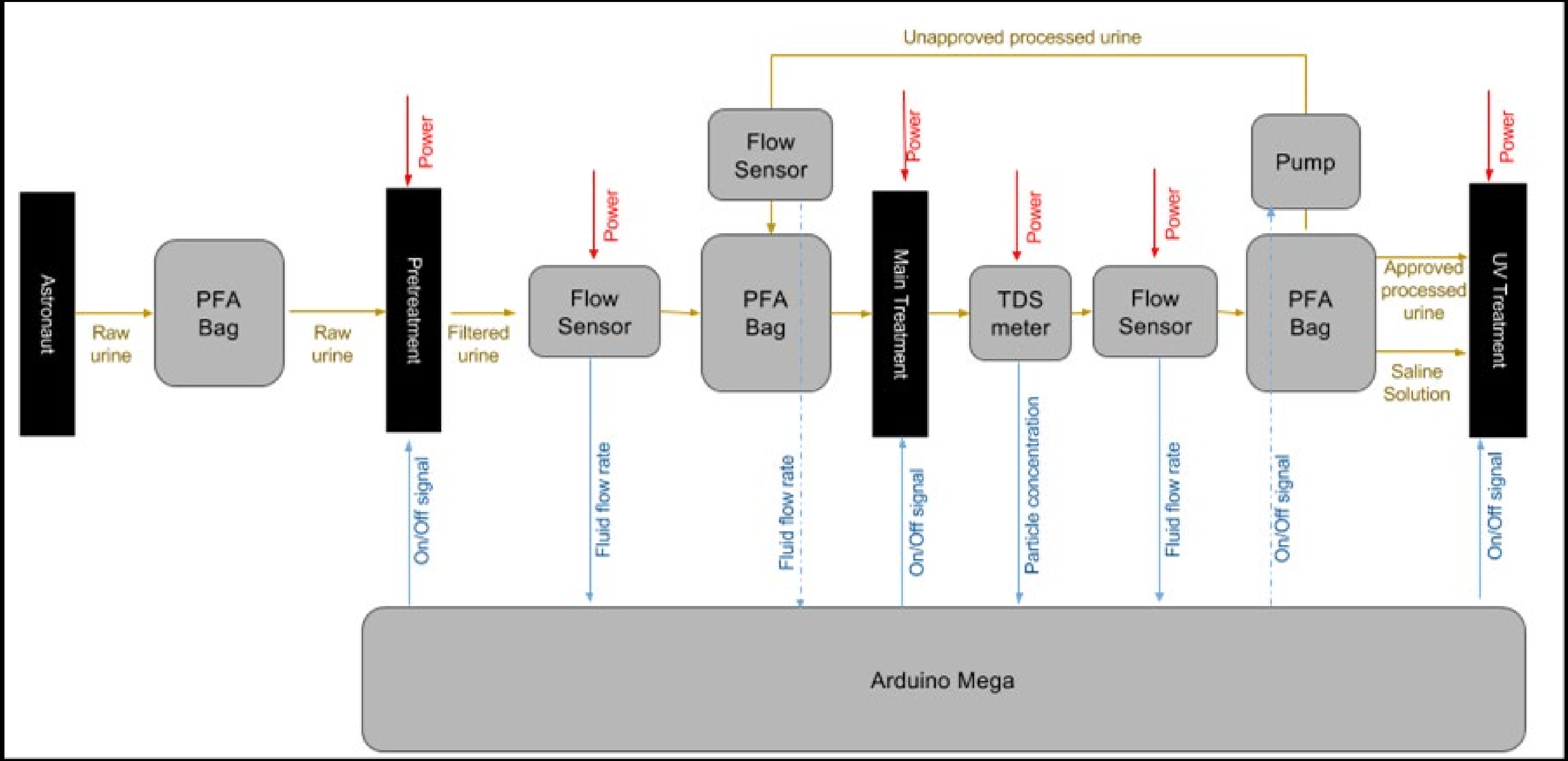


Post Treatment System

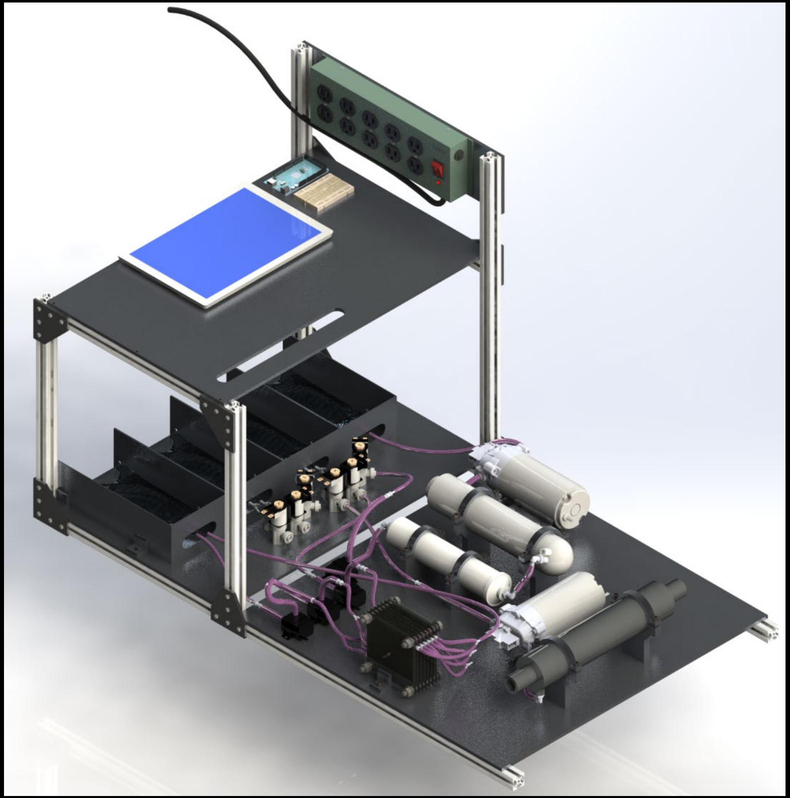
- Series of UV tubes ensure that output solution is sterile
- Outer stainless steel chamber houses a mercury lamp with a quartz sleeve cover.
- Simple system: plug and radiate (~ 254 nm).
- Can treat (30,000 μJ/sq cm) a flow rate up to 5.68 Liters per minute.
  - > 99.9% inactivation of microorganisms

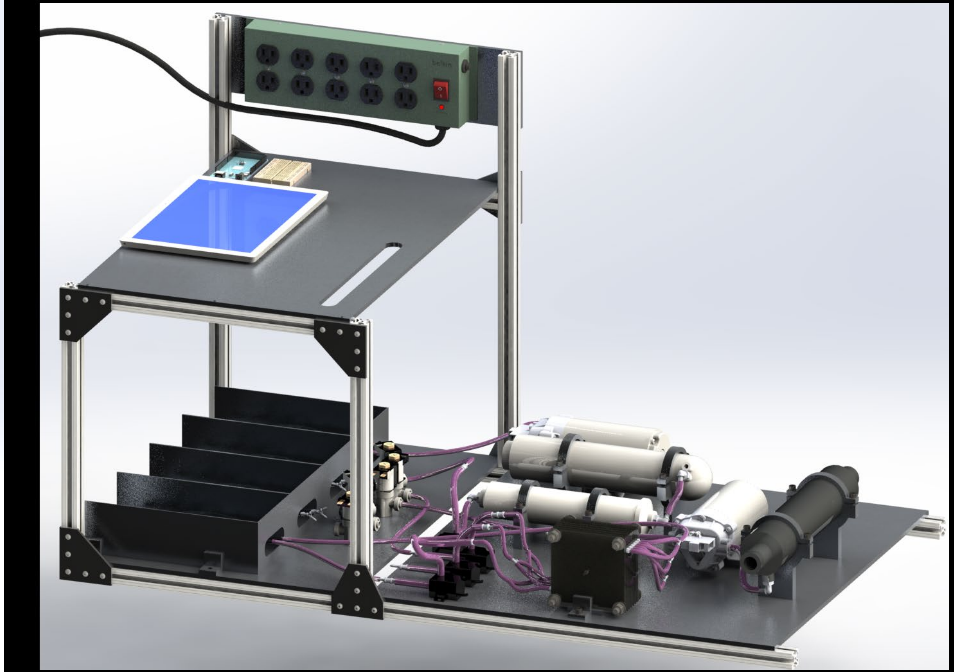


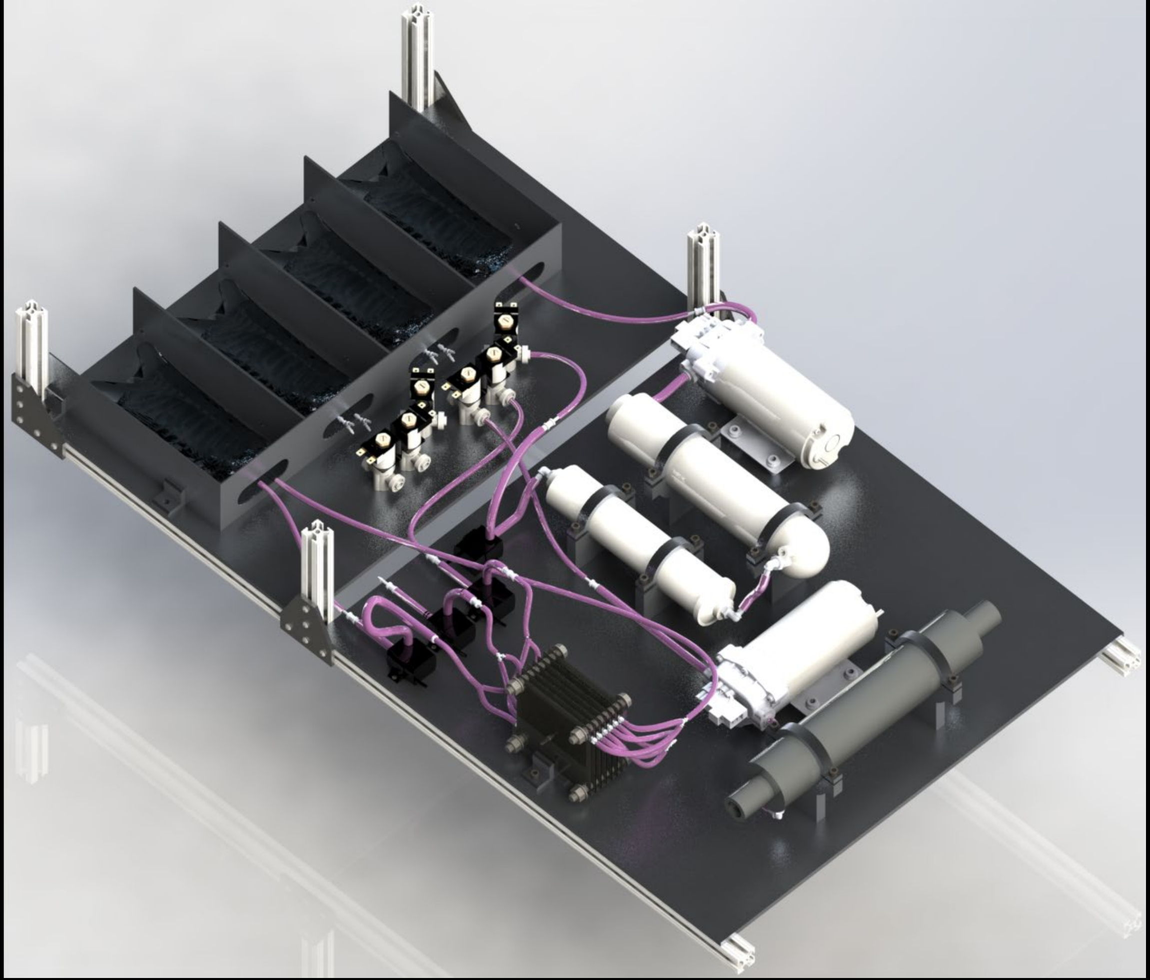
Integration and Management System



AURA - CAD



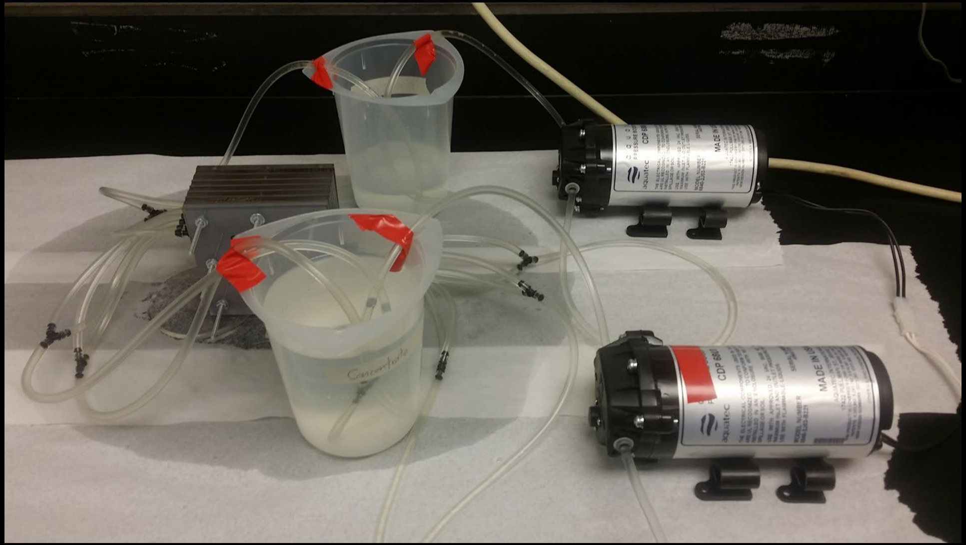


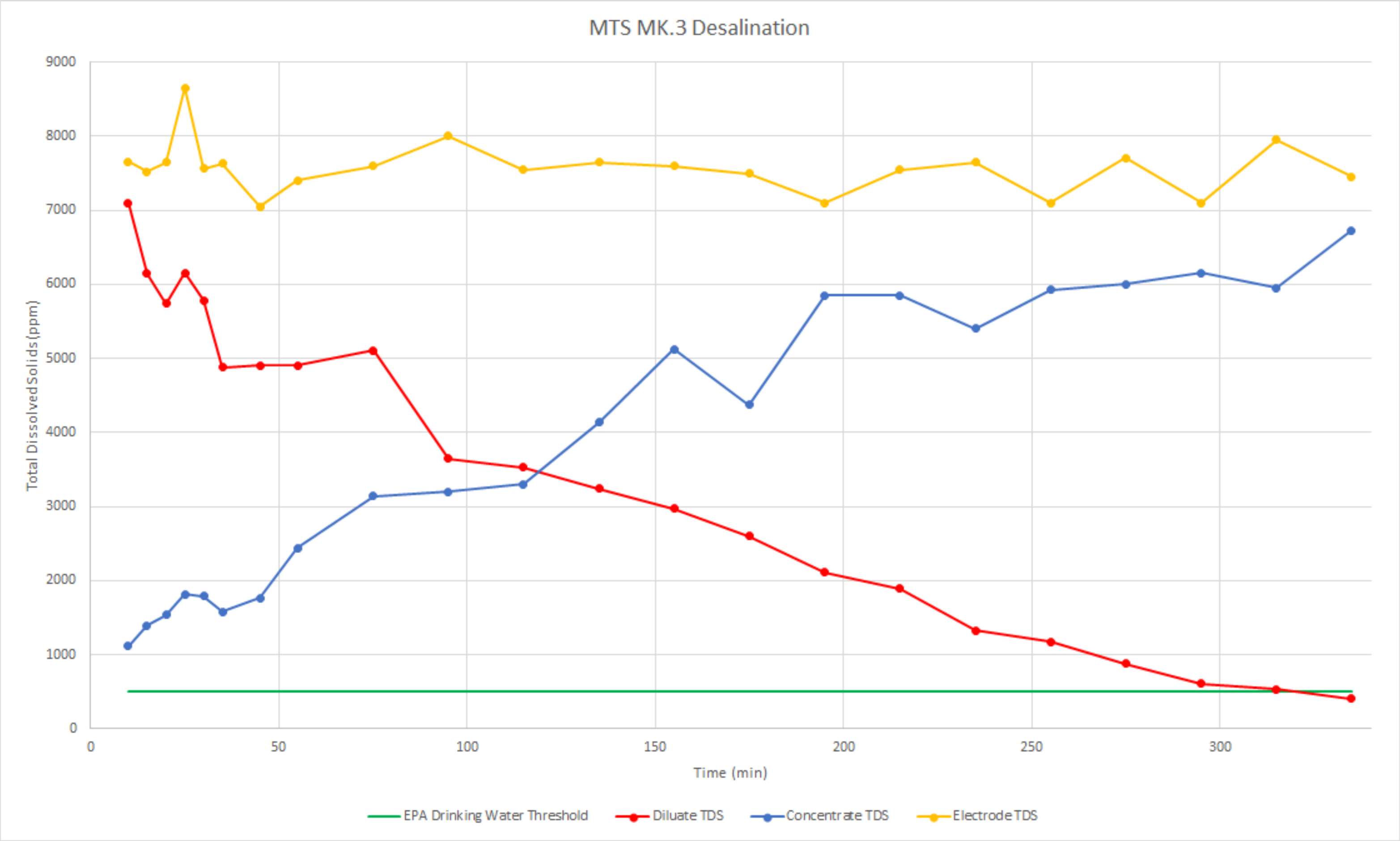


Validation Tests

MTS Mk. 4 Validation

- Leakage and flow tests
  - Optimized o-rings and gaskets
- Desalination tests
  - Demonstrated desalination of input stream




MTS MK.3 Desalination
Total Dissolved Solids (ppm)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
300
Time (min)
EPA Drinking Water Threshold
Diluate TDS
Concentrate TDS
Electrode TDS

Output Verification

- Was the crown ether effective?
- Will use ion-selective electrode to measure Ka concentration in output solutions
    - Sensitive from 90-39000 ppm
    - Unknown if Na will confound

AURA Output Effectiveness

- Purpose
  - To compare radish growth rate and health between commercial fertilizer and analog. Grow radishes with commercial fertilizer and analog solution of predicted output to confirm BLiSS output can support plant life.
- Due to set up malfunction, both sets of plants died before we were able to take measurements but, both solutions achieved initial growth.

Future Plans

- Run comparison test in a more controlled environment
- Harvest radishes and compare radish size, stem height, and leaf color
- Determine from analysis whether our output is as good as commercial fertilizer

Demo

Performance Results

MTS Electrodialysis Overview

- Power Consumption: **0.012 kW**
- Heat Generated: **0.012 kW**
- Volume: **4.235e-4 m^3**
- Mass: **0.4323 kg**
- Nominal Operating Temperature: **293 K**
- Nominal Operating Pressure: **1 atm**
- Operation Mode: **Batch (6L)**
- Nutrient Recovery Efficiency: **98%**
- TRL: **7**

MTS Electrodialysis Overview

Timeline

- Pre-Treatment: 3 hrs
- Main Treatment: 6 hrs
- Post Treatment: 1.5 hrs
- Driven by
    - Total volume (6L)
    - Concentration

MTS Electrodialysis Overview

Advantages

- Ion selectivity
- Low power consumption
- Does not require large pressure gradients
- High power efficiency
- Simple
- Easily scalable, becomes more efficient at higher powers
- Electrodialysis is widely used in terrestrial applications

Disadvantages

- Membranes require replacement
- Membranes must always remain wet
- Produces trace amounts of Chlorine and Hydrogen gas
- Electrodes must be of high quality

System Comparison

MTS Electrodialysis

- Power Consumption: 1.2e-2 kW
- Mass: 0.4323 kg
- Volume: 4.235e-4 m^3
- Temperature (nom): 293 K
- Pressure (nom): 1 atm
- Efficiency: 98%

Supercritical Water Oxidation[1]

- Power Consumption: 3.6e-1 kW
- Mass: 694 kg
- Volume: 2.12 m^3
- Temperature (nom): 923 K
- Pressure (nom): 250 atm
- Efficiency: 100%

System Comparison

MTS Electrodialysis

- Power Consumption: 1.2e-2 kW
- Mass: 0.4323 kg
- Volume: 4.235e-4 m^3
- Temperature (nom): 293 K
- Pressure (nom): 1 atm
- Efficiency: 98%

Reverse Osmosis[1]

- Power Consumption: 2e-2 kW
- Mass: 8.5 kg
- Volume: 0.056 m^3
- Temperature (nom): 295 K
- Pressure (nom): 27.2 atm
- Efficiency: 80%

System Comparison

MTS Electrodialysis

- Power Consumption: 1.2e-2 kW
- Mass: 0.4323 kg
- Volume: 4.235e-4 m^3
- Temperature (nom): 293 K
- Pressure (nom): 1 atm
- Efficiency: 98%

Multifiltration[1]

- Power Consumption: 3.8e-4 kW
- Mass: 3.9 kg
- Volume: 1.24e-3 m^3
- Temperature (nom): 298-328 K
- Pressure (nom): 0.69-2 atm
- Efficiency: 99.9%

System Comparison

MTS Electrodialysis

- Power Consumption: 1.2e-2 kW
- Mass: 0.4323 kg
- Volume: 4.235e-4 m^3
- Temperature (nom): 293 K
- Pressure (nom): 1 atm
- Efficiency: 98%

Rotating Hollow Fiber Membrane Bioreactor (Alternate Water Processor)

- Power Consumption: --
- Mass: --
- Volume: ~5.408e-4 m^3
- Temperature (nom): --
- Pressure (nom): --
- Efficiency: ~92%

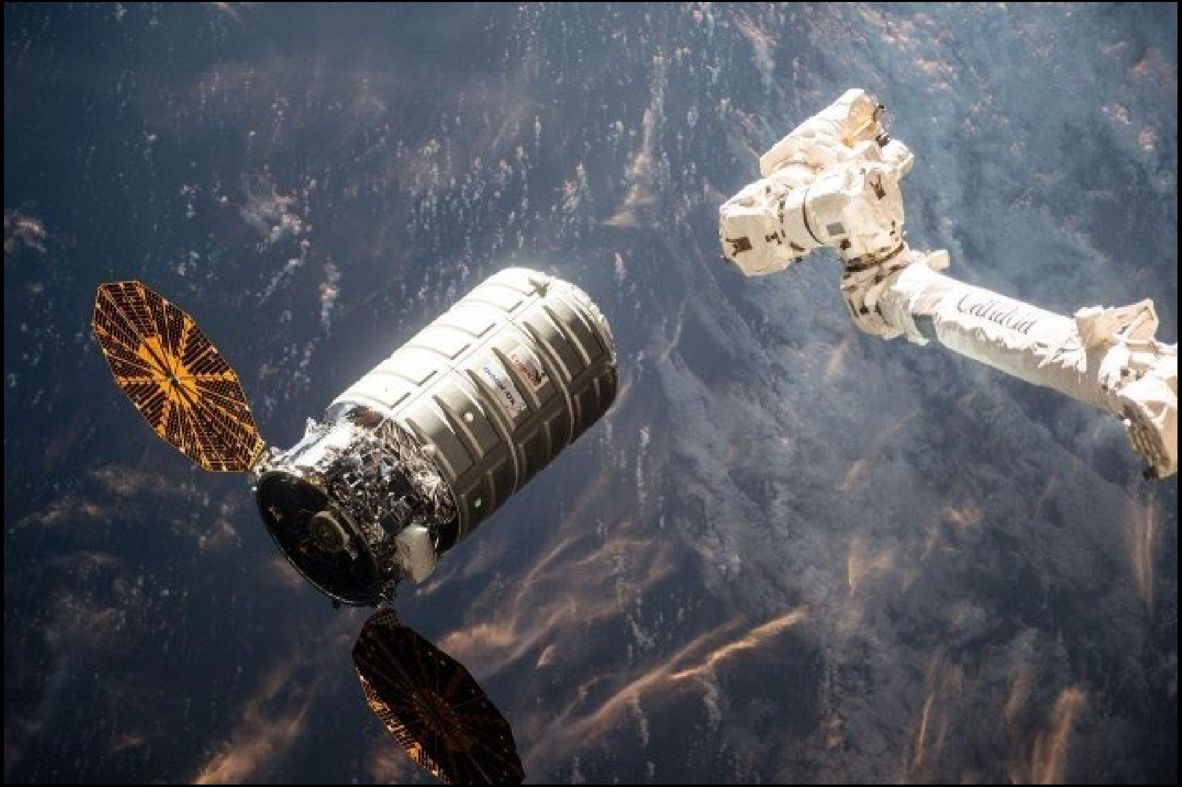
System Comparison

1. Peter Eckart, *Space Life Support and Biospherics*, Torrance: Microcosm Press, 1994

AURA Future Work

- Development of flight like pre and post treatment systems and plumbing
- Designing for membrane replacement
- Characterization of membrane lifetime
- Optimizing electrode materials
- Enhancing sensor capabilities
    - More sensors
    - Lower ppm resolution

Cygnus Habitat for Life off Earth (CHLOE)



Mission Objectives

Primary Objectives:

1. To design interior of enhanced Cygnus spacecraft to provide **wastewater treatment**, **air revitalization**, and **plant growth** to a crew of four astronauts.
2. Develop mission architecture as the Advanced LSS module of Exploration Mission 4.

Secondary Objectives:

1. Develop **autonomous growth** procedures for onboard plants.
2. Incorporate **AURA wastewater treatment** into CHLOE.

Stakeholders & Ongoing Collaborations

- Stakeholders
  - NASA NextSTEP
  - Orbital ATK
    - Dan Abramov
  - Prof. Renno & Chris
- Collaborations
  - U Michigan / AURA

NASA

Orbital ATK

UNIVERSITY OF MICHIGAN

University of Colorado Boulder

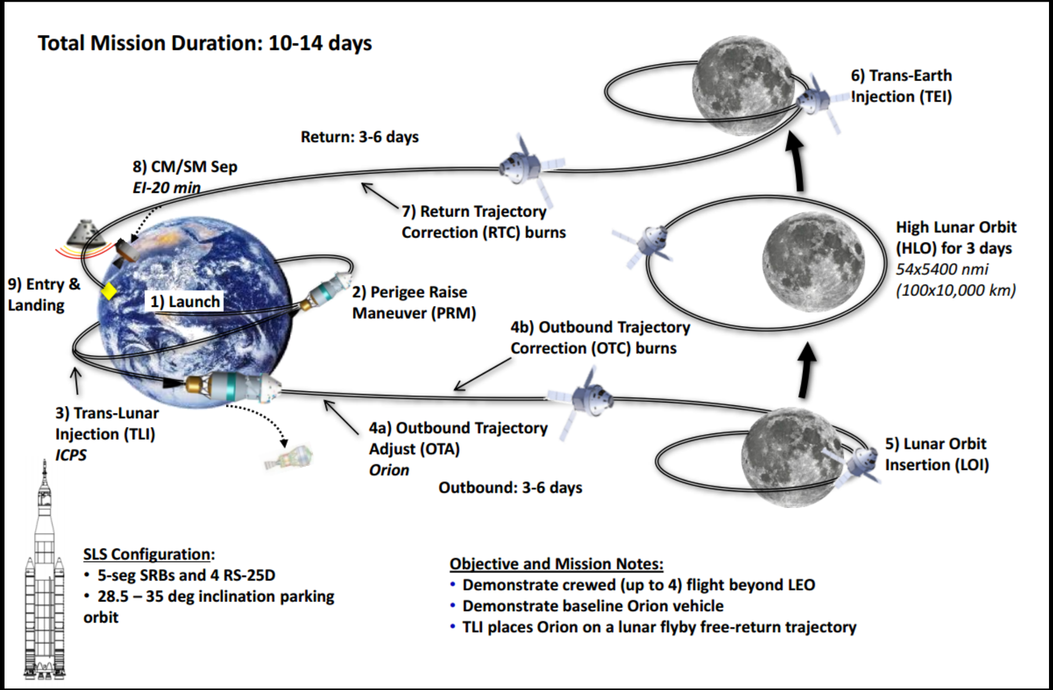
Technical University of Munich

Concept of Operations

Exploration Mission Architecture

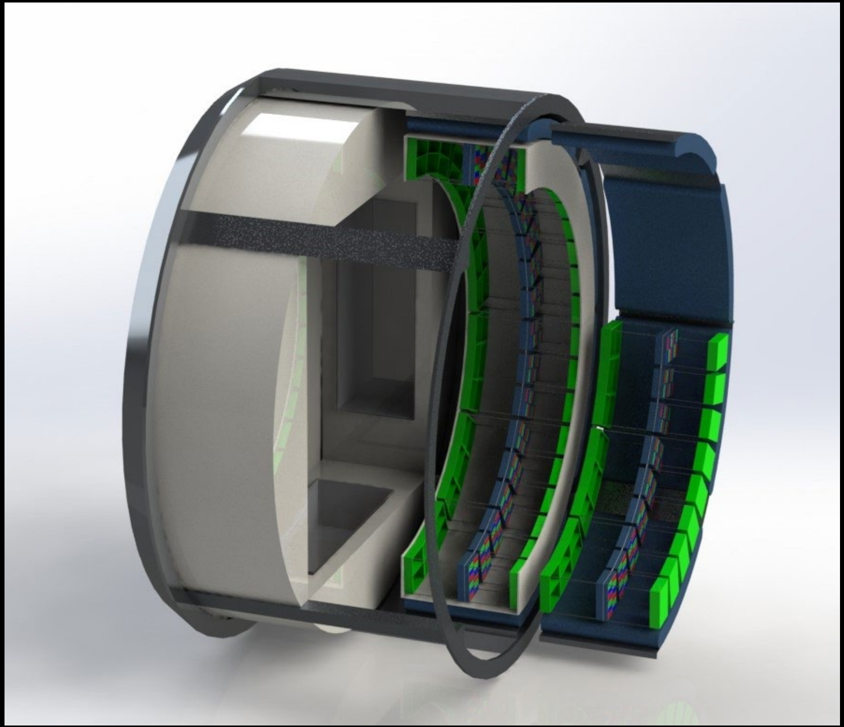
- Proposed for SLS / Orion
- Construction of lunar habitat
- Modular Architecture
- Propulsion module on EM-3
- CHLOE launched on EM-4
- Dock with propulsion bus in lunar orbit
- Crew Stay

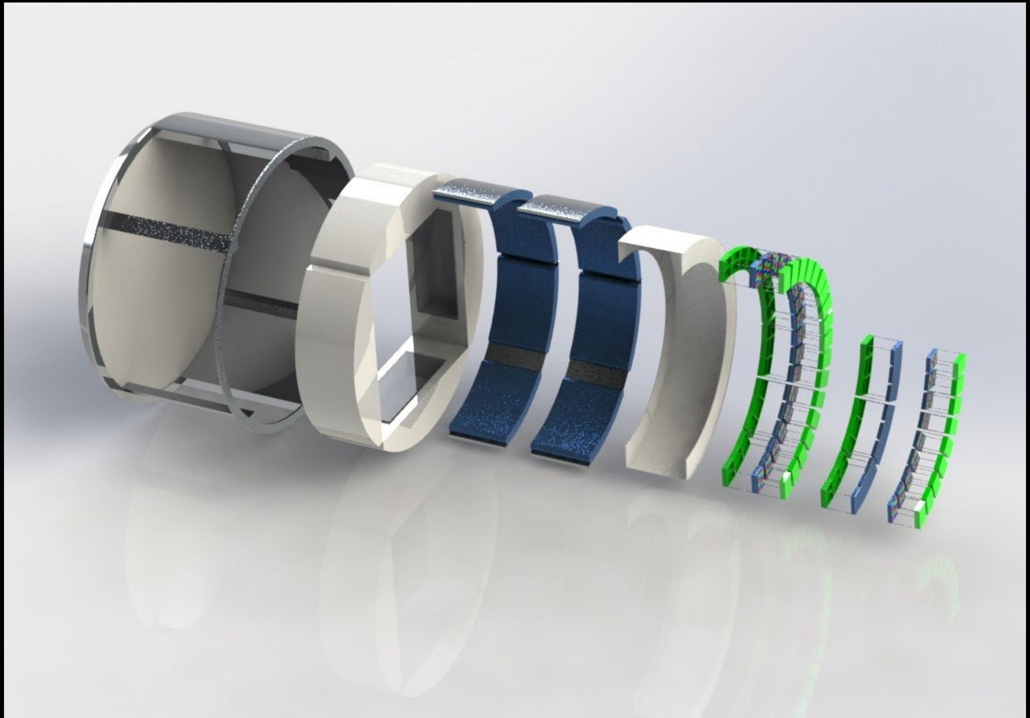
EM-2: Crewed (High) Lunar Orbit



SLS Configuration:
- 5-seg SRBs and 4 RS-25D
- 28.5 – 35 deg inclination parking orbit

Objective and Mission Notes:
- Demonstrate crewed (up to 4) flight beyond LEO
- Demonstrate baseline Orion vehicle
- TLI places Orion on a lunar flyby free-return trajectory





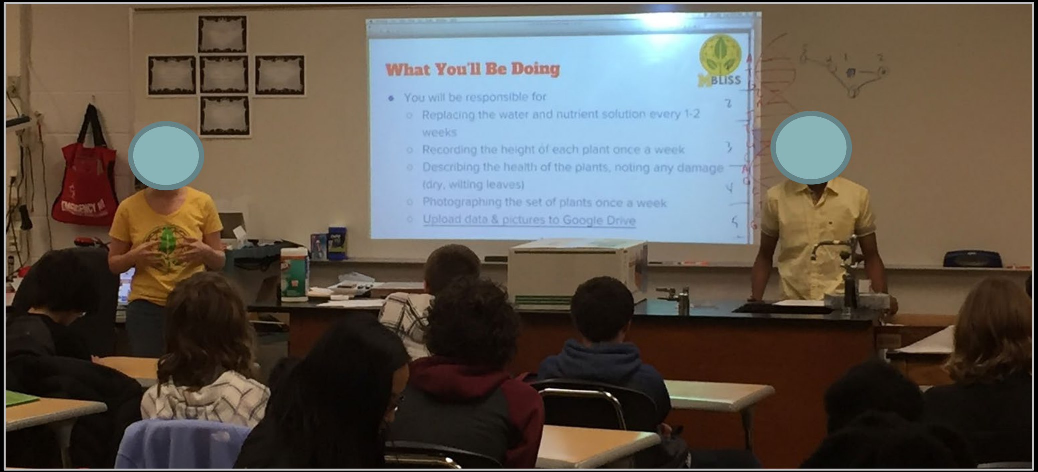
Outreach

Outreach: Phase 1

Collaborated with two biology classes at Huron High School

Hydroponic Plant Growth Experiment: Commercial vs Predicted Output Solution

1. Compare plant growth rates and signs of health
2. Confirm that the predicted BLiSS output has sufficient nutrients for plant growth



[redacted] [redacted]

What You'll Be Doing

- You will be responsible for
  - Replacing the water and nutrient solution every 1-2 weeks
  - Recording the height of each plant once a week
  - Describing the health of the plants, noting any damage (dry, wilting leaves)
  - Photographing the set of plants once a week
  - Upload data & pictures to Google Drive

Engineering Specialty Plans

1. **Contamination Control (ESP-00)**

   Strategies to ensure solution is not contaminated during any phase

1. **Reliability and Maintainability (ESP-01)**

   Methods that work alongside Risk Assessment document to mitigate failure rate, extreme failure, and system downtime after failure

1. **Test and Evaluation (ESP-02)**

   Strategies to conduct accurate tests and properly evaluate system

*See attached (3 documents)

Risk Assessment: System & Subsystem Testing

System and Subsystem Testing

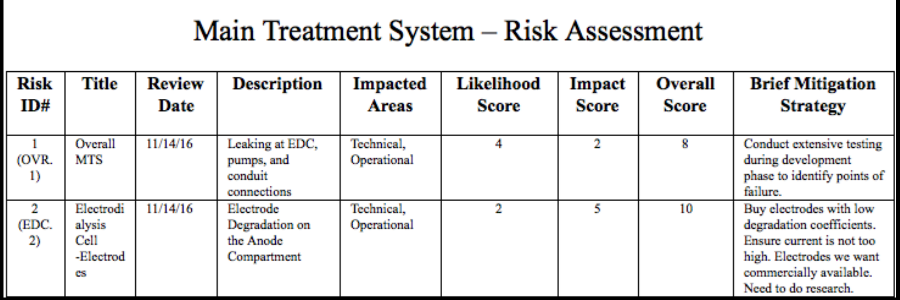
1. Testing Risk Assessment

Subsystem Breakdown

1. Pre-Treatment Risk Assessment
2. Main Treatment Risk Assessment
3. Post-Treatment Risk Assessment
4. Integration and Management Risk Assessment

*See attached (5 documents)

Example



Main Treatment System – Risk Assessment

Risk ID#	**Title**	**Review Date**	**Description**	**Impacted Areas**	**Likelihood Score**	**Impact Score**	**Overall Score**	**Brief Mitigation Strategy**
1 (OVR. 1)	Overall MTS	11/14/16	Leaking at EDC, pumps, and conduit connections	Technical, Operational	4	2	8	Conduct extensive testing during development phase to identify points of failure.
2 (EDC. 2)	Electrodialysis Cell -Electrodes	11/14/16	Electrode Degradation on the Anode Compartment	Technical, Operational	2	5	10	Buy electrodes with low degradation coefficients. Ensure current is not too high. Electrodes we want commercially available. Need to do research.

Total Program Costs

- X-HAB Seed Money Spent $
- Aerospace department funding $
  - ➔ Pretreatment Prototype Development $
  - ➔ Biochem Equipment Procurement $
  - ➔ MTS Prototype Development $
  - ➔ PTS Prototype Development $

Questions?

Feel free to contact us:

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