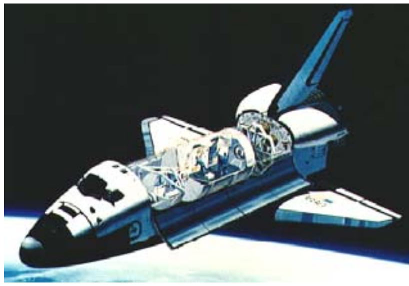

Long Duration Orbiter Environmental Control and Life Support System

December 6, 2005

16.885 Aircraft Systems Engineering

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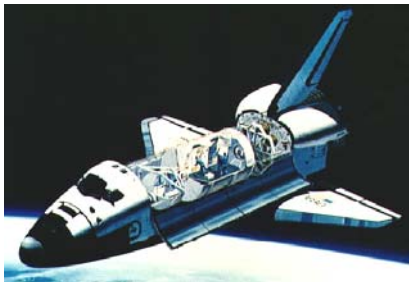
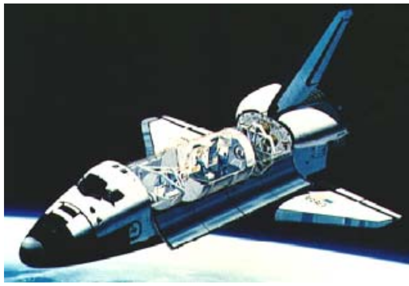


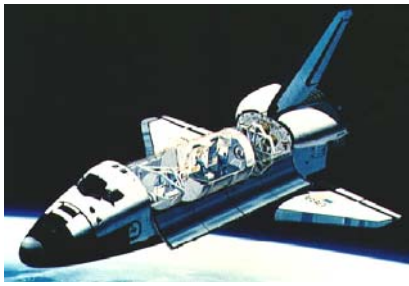
Outline

- NASA’s Extended Duration Orbiter (EDO) concept
- Long Duration Orbiter (LDO) proposal
  - Power Extension Package (PEP)
  - Regenerative Fuel Cells
  - Water Reclamation
  - Air Revitalization
- Conclusions



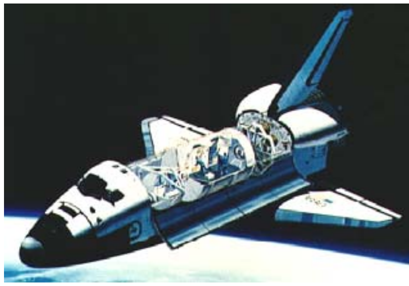
Consider STS-61

- Launched Dec. 2nd, 1993
- Spacewalk-intensive mission (5 in 5 days) to service Hubble Space Telescope
- 11 days total
- Mission profile had very low “free-time” margin
- Fortunately no serious delays jeopardized mission objectives

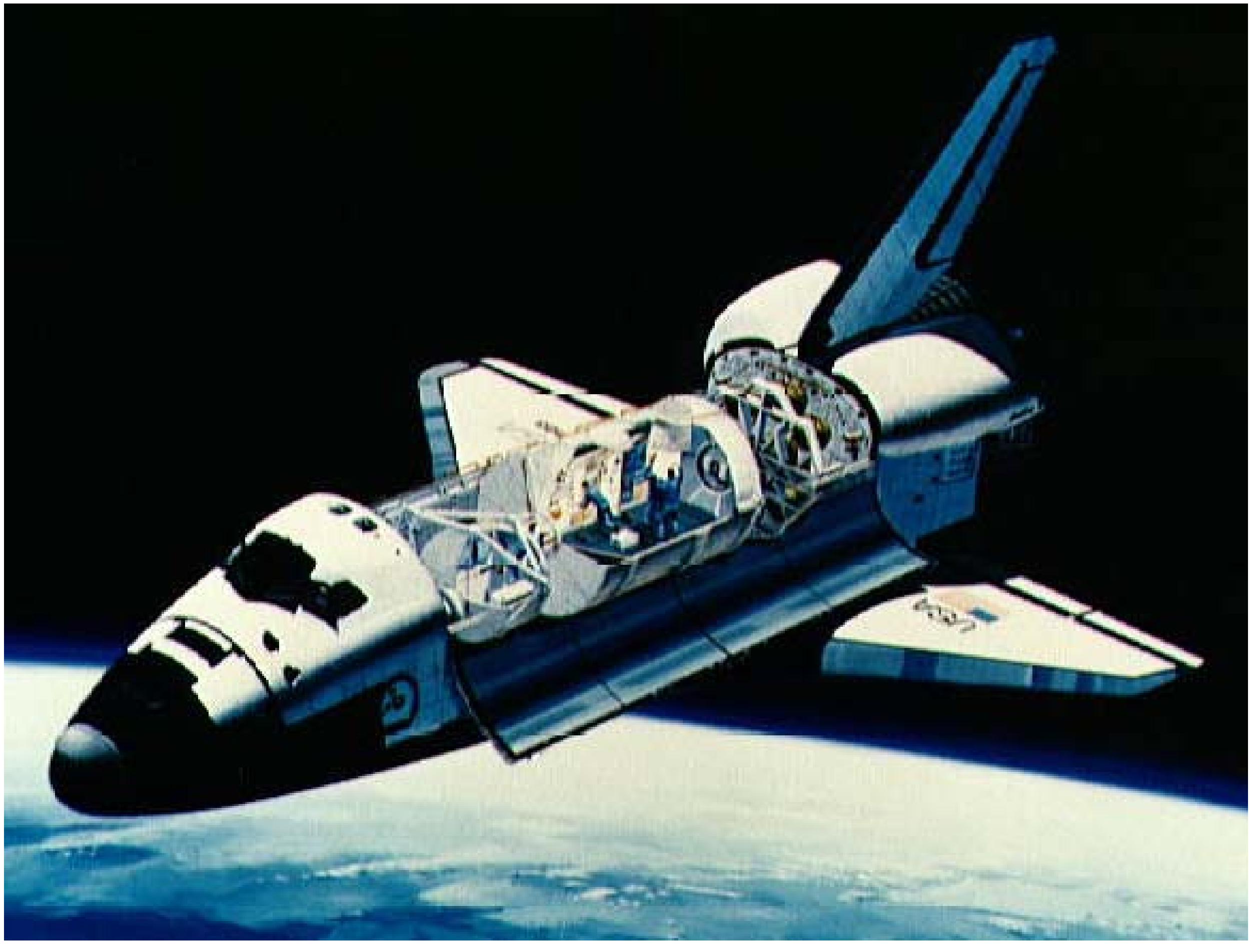


Long Duration Missions

- Suppose the mission had run into significant unforseen delays
- What if the task was just too demanding for one mission?
- What about longer durations?
  - Missions with multiple objectives (launch, service, recover)
  - Missions that use the shuttle to expand the capabilities of the International Space Station
  - Extend orbital endurance in order to perform repairs before re-entry
- How should NASA address longer-duration missions?

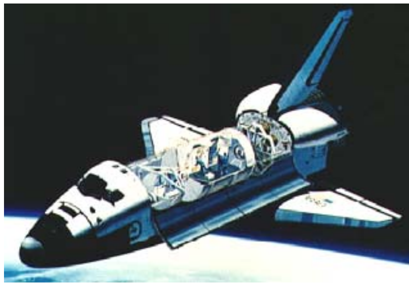


NASA's Solution



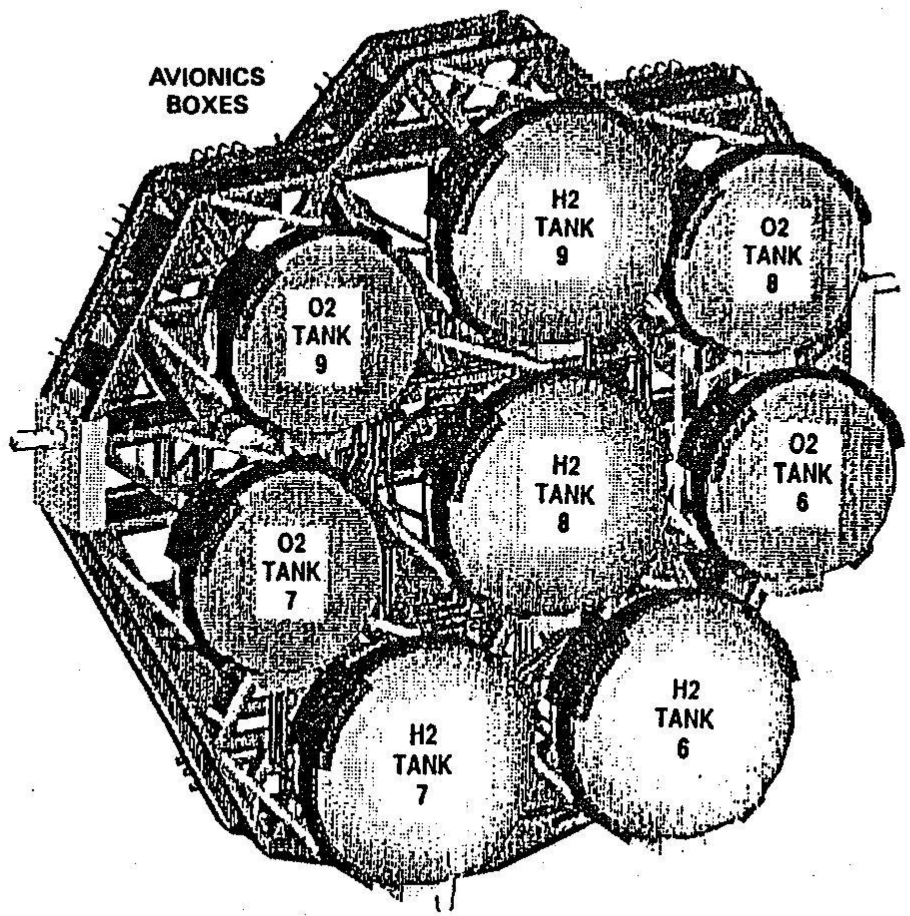
NASA's EDO with Cryogen Pallet and SpaceLab

NASA's Extended Duration Orbiter (EDO) concept was developed to extend endurance up to 18 days (payload dependent)

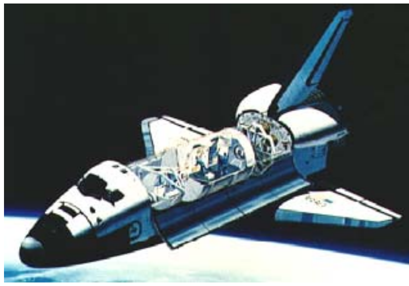


NASA EDO Specifics

- NASA's EDO concept incorporated:
  - Additional cryogenic oxygen and hydrogen to extend fuel cell operations
  - Regenerable CO_2 removal system with an emergency LiOH backup system
  - Extra tanks of gaseous nitrogen for ECLSS operation
  - An improved waste collection system

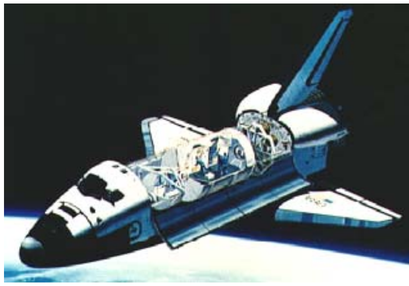


Cryogen Pallet in EDO



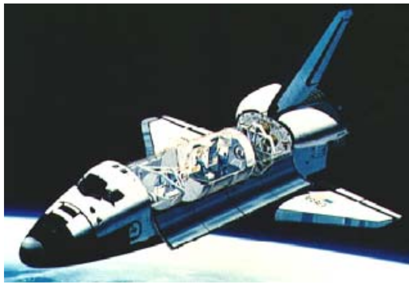
Pallet-Based EDO Limitations

- NASA's EDO "cryogen pallet" strategy extends endurance by launching additional cryogens to orbit
- Cryogenic stores are the primary limiting factor to mission duration
  - More fuel cell substrate = More energy
  - More oxygen = Longer life support capability
- NASA's EDO extends endurance at significant weight and volume penalty



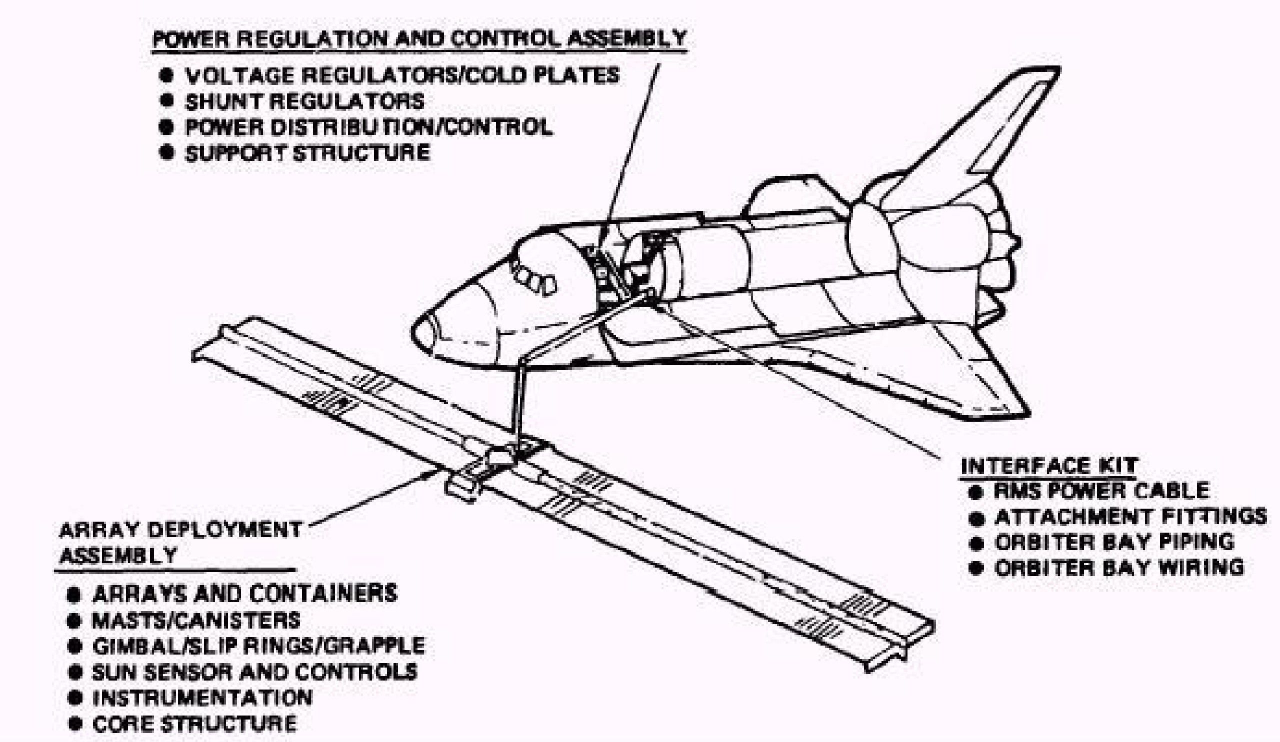
Alternative Approach: Long Duration Orbiter (LDO)

- More efficient approach would be to *decrease cryogen depletion rate* rather than simply increase cryogen stores
- Method 1: Augment power-generating capability of orbiter
  - Implement alternative power source to reduce cryogen demand for electrical energy generation
- Method 2: Recover and reuse consumables
  - For example, excess water could be converted back into oxygen and hydrogen for further power generation instead of being jettisoned

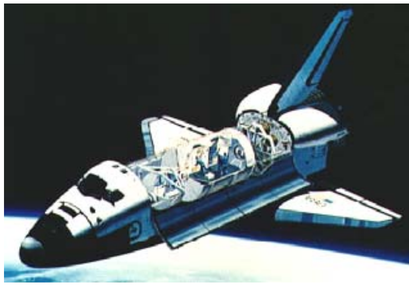


Power Extension Package (PEP)

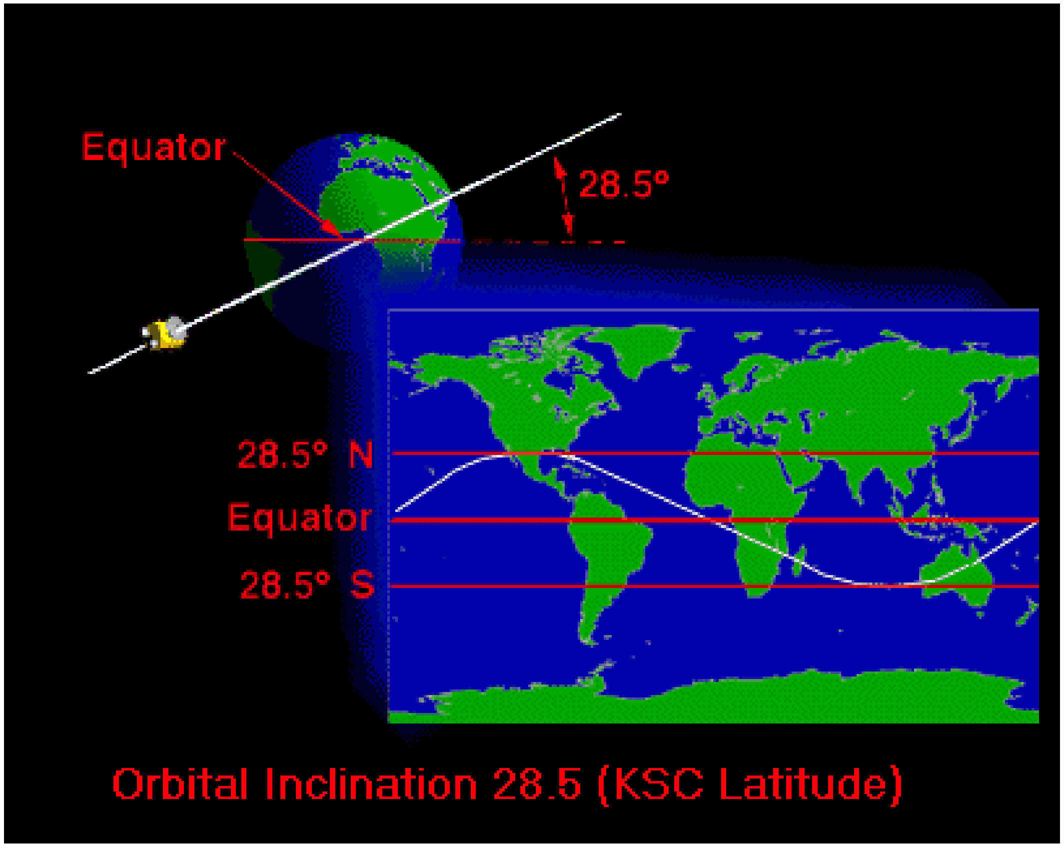
- PEP proposed in 1970s to increase peak orbiter power generation from 21kW to 30kW
- PEP potentially suitable for LDO
- Performance depends on orbital inclination and solar cell efficiency



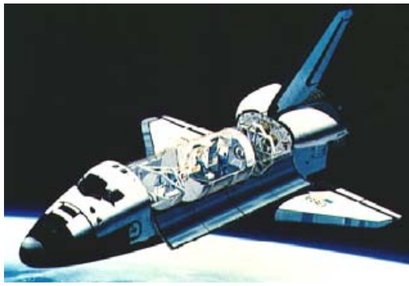
Orbiter with PEP Deployed



PEP

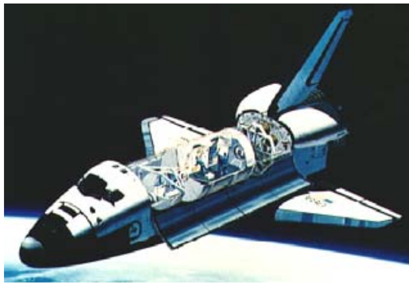


- Sunlight exposure increases with inclination (60% of time at 28.5º
- Greater exposure means less dependence on cryogens for power generation
- PEP incurs *fixed* weight and volume penalties compared to the *linearly increasing* penalties of the pallet-based solution



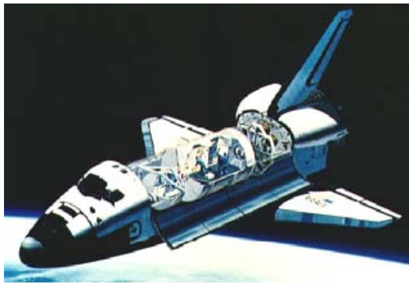
PEP Operational Summary

- PEP provides 30kW of power for ~60% of mission, assuming a conservative 28.5º orbital inclination
- Fuel cells typically generate 14-21kW of power, depending on mission-specific demand
- This leaves ~9-15kW of surplus power during "daytime" portions of the mission
- Excess power could be harnessed via storage mechanism for "nighttime" operations



Regenerative Fuel Cells (RFCs)

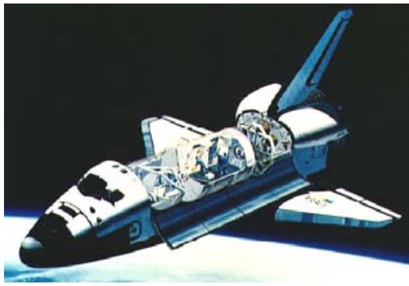
- RFCs allow for “reversal” of the normal fuel cell reaction via electrolysis
- Excess power generated by the PEP can drive electrolysis subunits of the RFCs
- RFCs represent small weight and volume penalty over current fuel cell design
- Assuming a very conservative 50% RFC electrolysis efficiency, the PEP/RFC combination yields the following results:



Combined Performance Gains

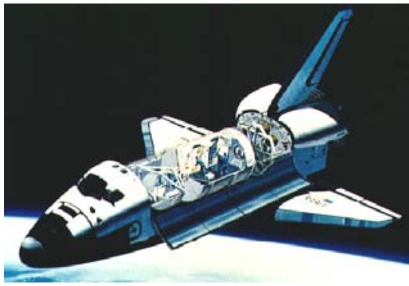
Configuration	Mission duration (7 man crew)	10 days	20 days	30 days	45 days
Existing EDO	Weight of cryogens and hardware (lb)	6,028	14,760	21,760	28,760
	Volume (Payload Bay penalty)	0	1/10th	2/10th	3/10th
PEP LDO	Weight of cryogens and hardware (lb)	7,007*	10,111*	13,111	17,111
	Volume (Payload Bay penalty)	1/10th	1/10th	2/10th	2/10th
PEP/RFC LDO	Weight of cryogens and hardware (lb)	7,916*	9,468*	10,588*	12,572*
	Volume (Payload Bay penalty)	1/10th	1/10th	1/10th	1/10th

**EDO Pallet unnecessary*



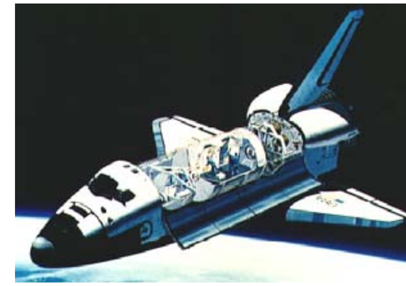
Water Reclamation

- Current orbiter produces excess water
- PEP means less water produced by fuel cells
- RFCs allow unused water to be converted back into fuel
- Therefore, water reclamation system would greatly extend duration



Water Uses on Orbiter

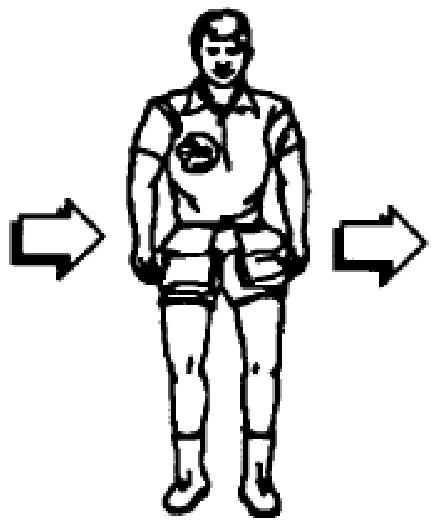
- Active thermal control through flash vaporization
- Food preparation
- Drink
- Wash
- Launch and contingency return
- EVA



Crew Water Balance

U.S Crewmember Water Balance, kg/person-day (lb/person-day)

Drinking	1.62 (3.56)
Food Water Content	1.15 (2.54)
Metabolized Water	0.35 (0.76)
Food Preparation	0.76 (1.67)
Total	3.88 (8.53)



Urine	1.5 (3.31)
Sweat and Respiration	2.3 (5.02)
Fecal Water	0.08 (0.20)
Total	3.88 (8.53)

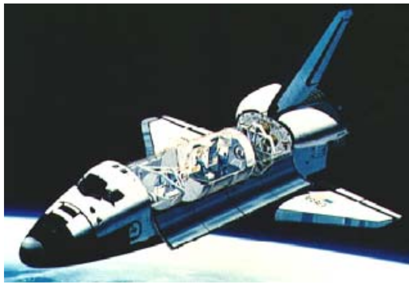
(source: NASA TM-108441)

U.S Cabin Water Balance, kg/person-day (lb/person-day)

Shower	2.7 (6.00)
Handwash	4.1 (9.00)
Laundry	12.5 (27.5)
Urinal Flush Water	0.5 (1.09)
Total	19.8 (43.59)

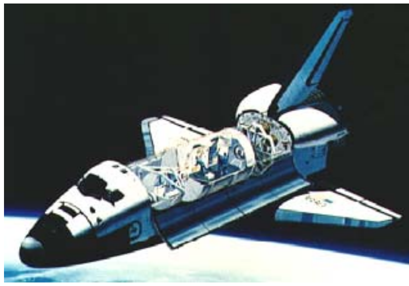
→ SHOWER / HANDWASH / LAUNDRY / URINAL →

Waste Shower & H'wash	6.51 (14.33)
Waste Laundry	11.90 (26.17)
Urinal Flush Water	0.5 (1.09)
Latent	0.91 (2.0)
Total	19.8 (43.59)



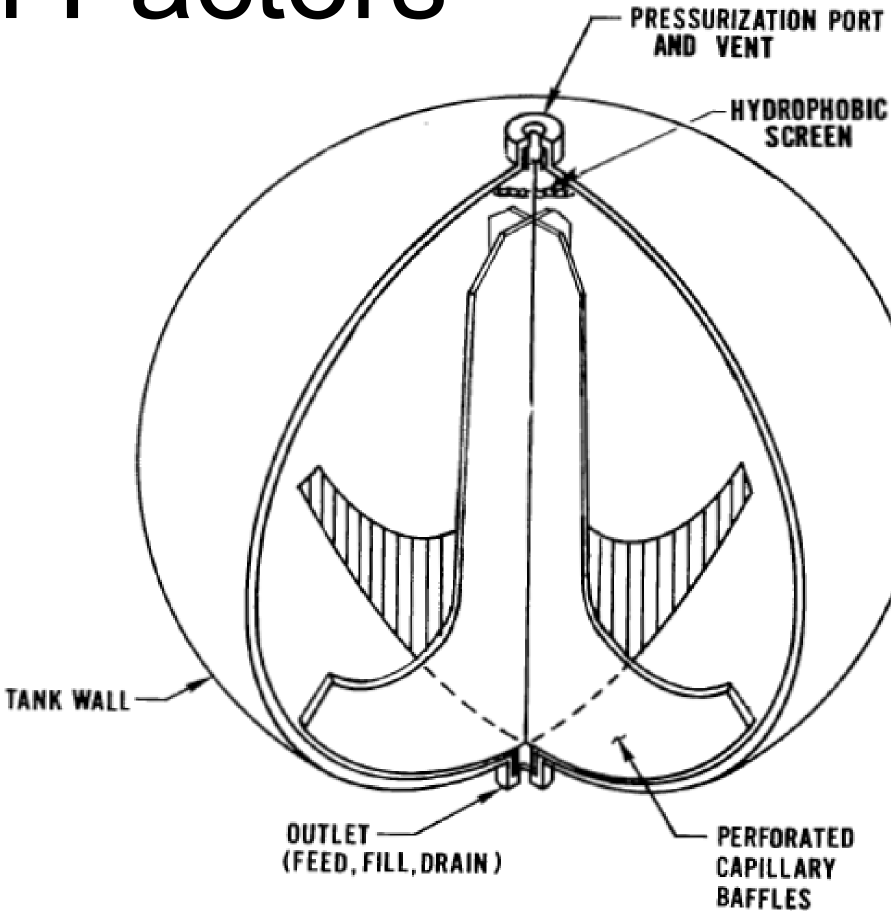
Methods of Reclamation

- Five types examined:
  - Vapor compression distillation (VCD)
  - Air evaporation
  - Thermoelectrically integrated membrane evaporation
  - Reverse osmosis
  - Multifiltration
- Selection: multifiltration with additional air evaporation for urine

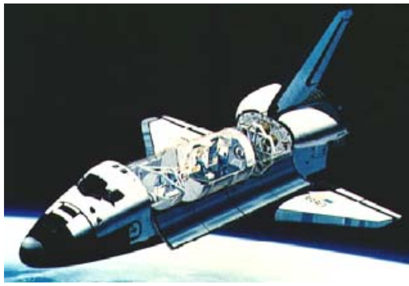


Water Reclamation Additional Factors

- Mechanical and chemical filtration
- Sterilization (chemical treatment and pasteurization)
- Taste testing
- Pumps
- Storage tanks

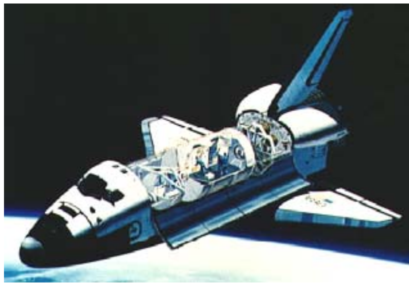


Spherical bladderless tank



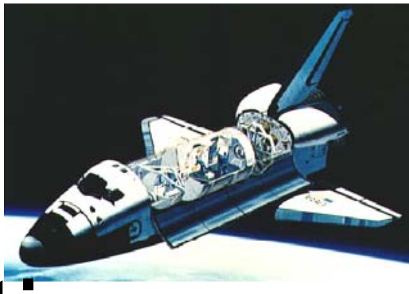
Achievable Reclamation Percentages

- Humidity condensate (99%)
- Shower (95%)
- Laundry (95%)
- Urine (95%)
- Oral hygiene (95%)



Air Revitalization System (ARS)

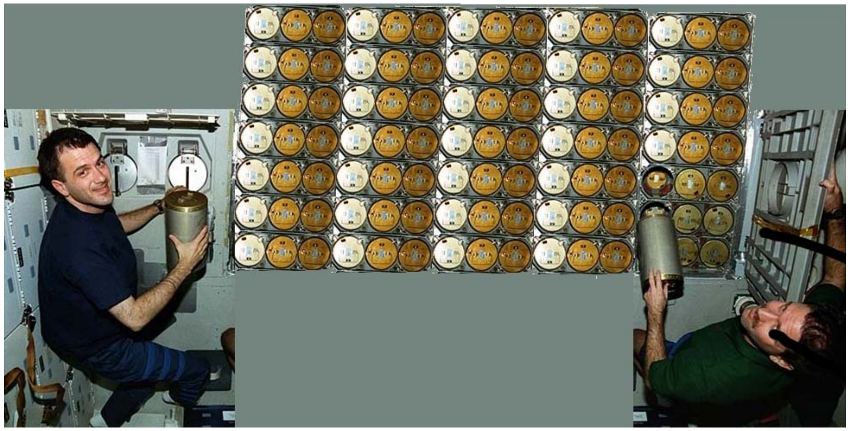
- Air temperature control
- Air circulation
- Humidity control
- Odor, bacteria, trace contaminant control
- CO_2 removal (improvement required for LDO)



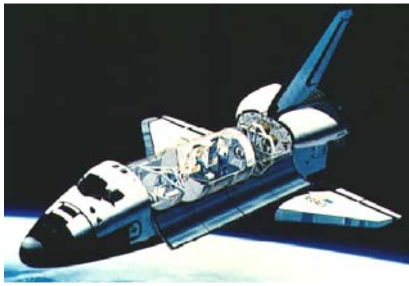
CO_2 Removal: Current Limitations

***LiOH Canisters** (crew = 7)*

- 10 day mission:
  - 35 canisters (+7 contingency)
  - 270 lb (+ 12.7 lb installed unit)
  - 10.5 ft^3 (+36 ft^3 installed unit)

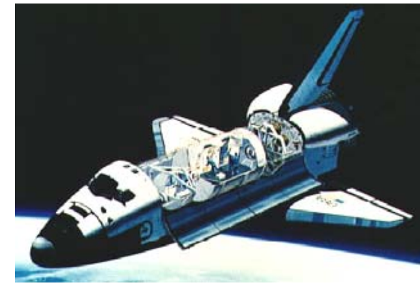


- 30 day mission:
  - 105 canisters (+7 contingency)
  - 717 lb (+ 12.7 lb installed unit)
  - 28 ft^3 (+36 ft^3 installed unit)



Solution Concept

- A *Regenerative CO_2 Removal Subsystem* is needed with the following characteristics:
  - almost no expendables
  - volume reduction
  - weight reduction
- The consequences are:
  - additional power consumption
  - additional heat generation (radiator weight penalty)



Proposed subsystem

- CO_2 Concentration: *Electrochemical Depolarized Concentrator (EDC)*

$$CO_2+\tfrac{1}{2}O_2+H_2=CO_2+H_2O+\text{Electrical Energy}+\text{Heat}$$

- CO_2 Reduction: *Sabatier Reactor*

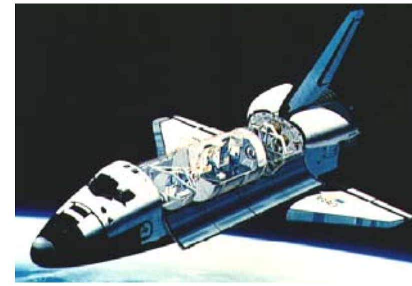
$$CO_2+4H_2=CH_4+2H_2O+\text{Heat}$$

- Overall process:

CO_2
Oxygen
Hydrogen

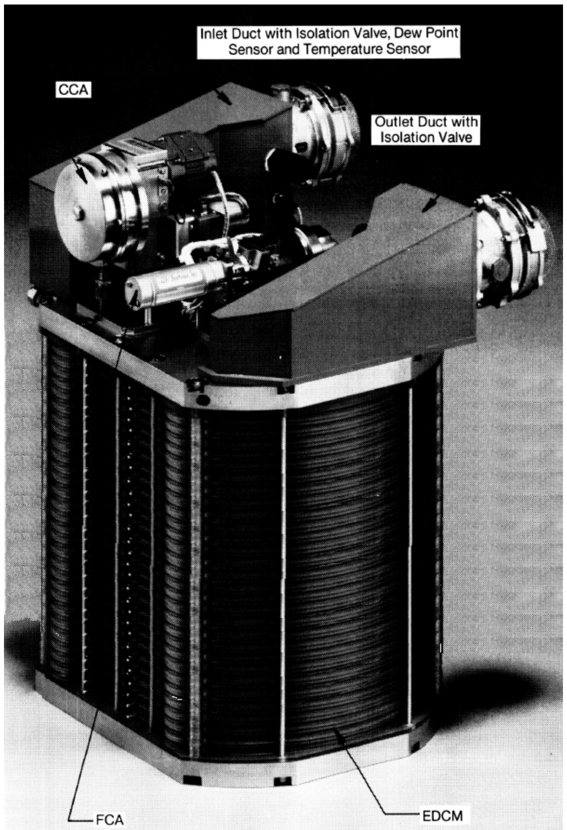
→

Methane (dumped or converted)
Water (used, dumped or electrolyzed)
Electrical Energy (used)
Heat (removed by additional cooling)



Long Duration Orbiter

Electrochemical Depolarized Concentrator (EDC)



Number of cells: 28

Power Generated: 123 W (DC)

Power Consumed: 50 W (AC)

Heat Generated: 424 W

Weight: 100 lb

Dimensions: 19x17x15 in

CO_2 Removed: 14.8 lb/day

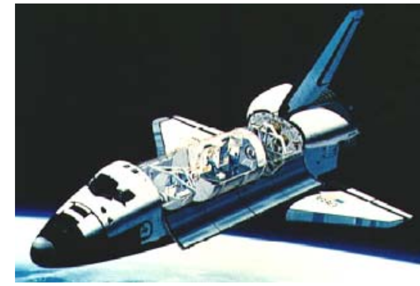
O_2 Consumed: 6.28 lb/day

H_2 Consumed: 0.78 lb/day

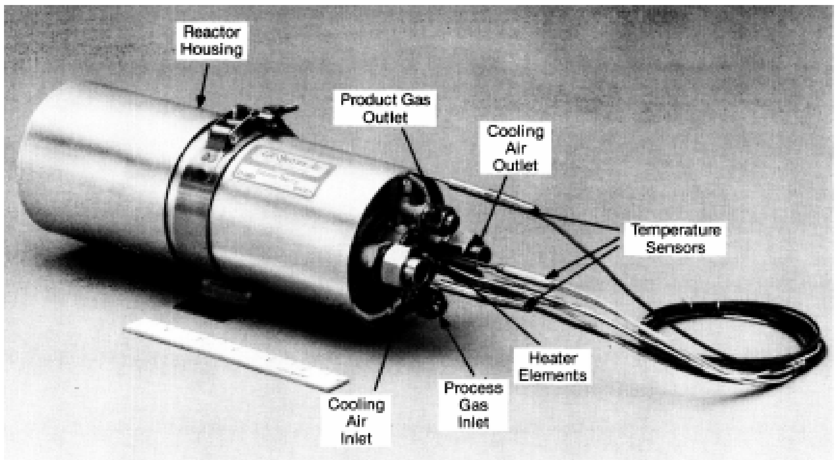
H_2O Generated: 7.06 lb/day

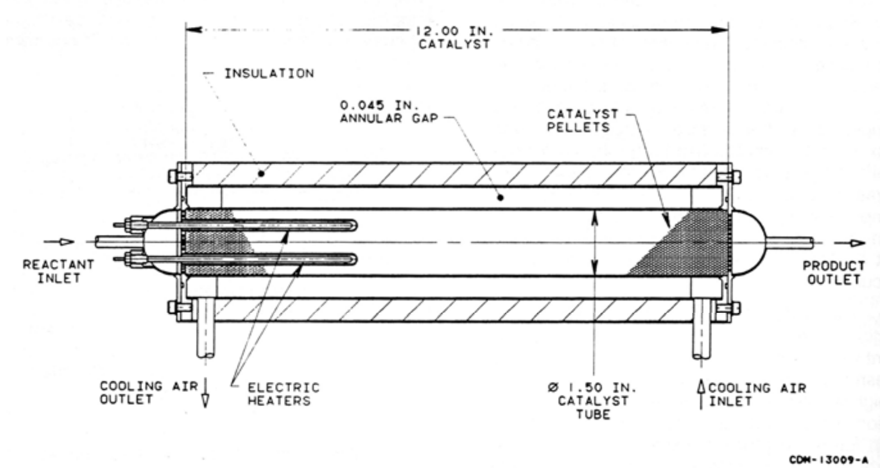
Massachusetts Institute of Technology

Long Duration Orbiter



Sabatier Reactor





Power Consumed: 350 W

Heat Generated: 420 W

Weight: 231 lb + 0.2 lb/day

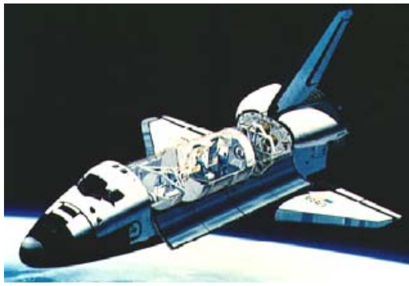
Volume: 4.9 ft^3

CO_2 Consumed: 15.4 lb/day

H_2 Consumed: 3.09 lb/day

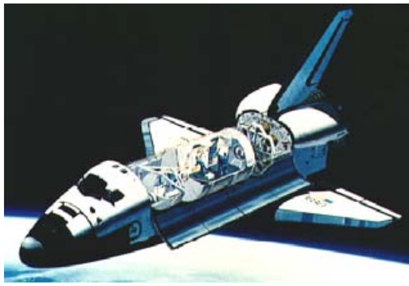
H_2O Generated: 12.3 lb/day

CH_4 Generated: 6.2 lb/day



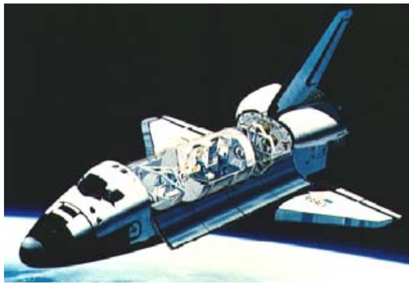
LiOH vs. EDC+Sabatier

Mission duration (crew = 7)	10 days	20 days	30 days	45 days
Power Consumption, W	445			
Heat Generation, W	621			
Volume, ft^3	-38.8	-47.55	-56.3	-69.425
Weight, lb	51.5	-170.5	-392.5	-725.5
O_2 Consumption, lb	62.8	125.61	188.42	282.6
H_2 Consumption, lb	38.7	77.4	116.1	174.15
H_2O Generation, lb	193.6	387.2	580.8	871.2
CH_4 Generation, lb	62	124	186	279



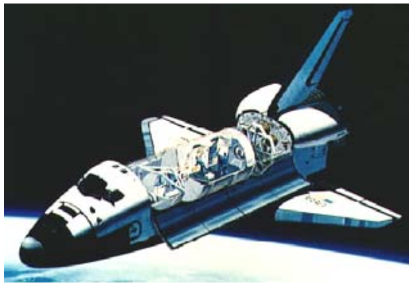
EDC + Sabatier Reactor

- is lighter than LiOH for missions longer than 10 days
- is much smaller than LiOH subsystem
- fits in the space destined to LiOH canisters
- doesn't have expendables
- can work on a fail safe mode
- generates methane and water, which can be used or reduced
- generates heat that has to be taken care of by the ATCS
- consumes power that is provided by regenerative fuel cells



Conclusions

- Proposed LDO allows operation for up to 45 days with the same weight and volume penalties as 20 days of operation of the EDO, by:
  - Increasing power generation with PEP
  - Converting excess water back into fuel with RFCs
  - Reclaiming water through air evaporation and multifiltration
  - Improving CO_2 removal process with EDC and Sabatier reactor



Questions?