# Organisms in Space/ECLSS

MAE 4160, 4161, 5160

V. Hunter Adams, PhD

# Today’s topics:

- Functions of environmental control and life support system (ECLSS)
- Main ECLSS technologies
- Coupling between ECLSS and other subsystems
- Brief history of organisms in space

A brief history of animals in space . . .

Fruit flies launched in
a captured German V2
rocket from White Sands
Missile Range, NM

**1947**

Mouse launched aboard
a V2. Rocket disintegrated.

**1950**

**1783**

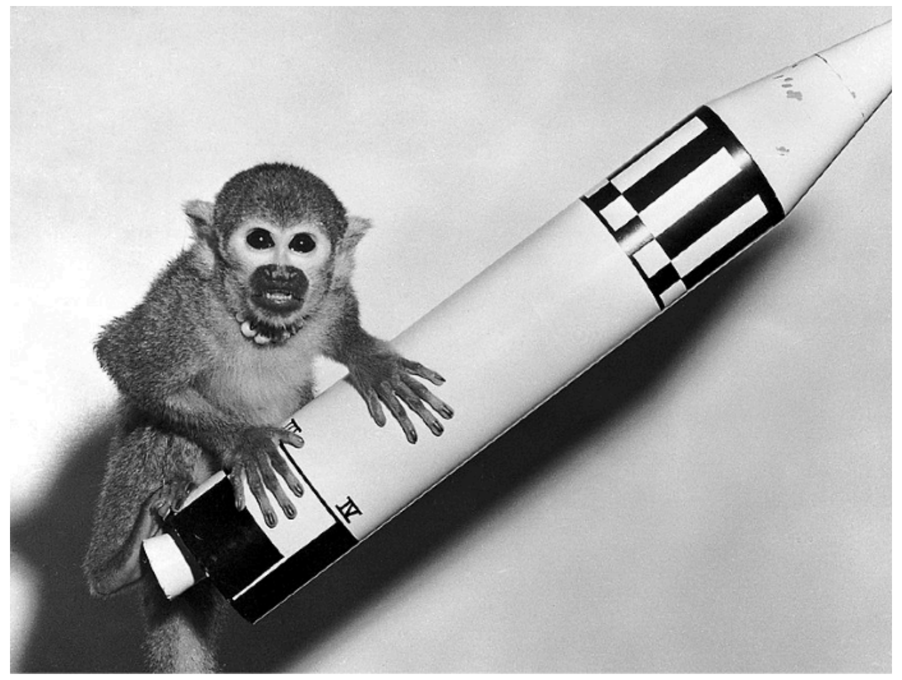
Sheep, duck, and rooster
sent aloft in a hot air balloon
to study if land-dwelling creatures
could survive at altitude
(the duck was the control)

**1949**

Albert II became the first
monkey in space (rhesus)
aboard US-launched V2 rocket
(RIP Albert I)

**1951**

Soviet launched R-1
carried two dogs
(Tsygan and Dezik) into space,
but not into orbit.



Able and Miss Baker
(rhesus and squirrel monkey)
became first monkeys to
survive spaceflight.

**1959**

Soviet Sputnik 5 carried
dogs Belka and Strelka,
a gray rabbit, 40 mice, 2
rats, 15 flasks of fruit flies
and plants to orbit and returned
them alive.

Strelka's pup was given to Caroline
Kennedy as a gift from Khruschev.

**1960**

**1957**

Soviet Sputnik 2
spacecraft carried Laika
the dog into orbit. Died during
flight, as intended. First animal
in orbit. Many dogs would follow.

**1959**

First rabbit in space.
Frogs, mice, more monkeys
and dogs.

**1961**

Ham the chimp goes
to space in a Mercury capsule
aboard a Redstone rocket.

Showed an ability to perform
tasks in space.

**1963**

Félicette launched into space by France - the first cat in space.


**1968**

Zond 5 (Soviet) sends two tortoises to orbit the moon with wine flies, meal worms, and other specimens. The first animals in deep space. Animals survived but lost some weight.

**1972**

Apollo 17 carried five pocket mice (Fe, Fi, Fo, Fum, and Phooey) who stayed in the command module.

**1973**

Skylab 3 carries first fish in space (a mummichog) and the first spiders (garden spiders named Arabella and Anita)

**1980's - today**

More monkeys, rats, insects, chicken embryos, guinea pigs, newt, tree frogs, sea urchins, brine shrimp, jellyfish, nematodes, carpenter bees, killifish, silkworms, quail eggs, cockroaches, ants, painted lady and monarch butterflies, geckos

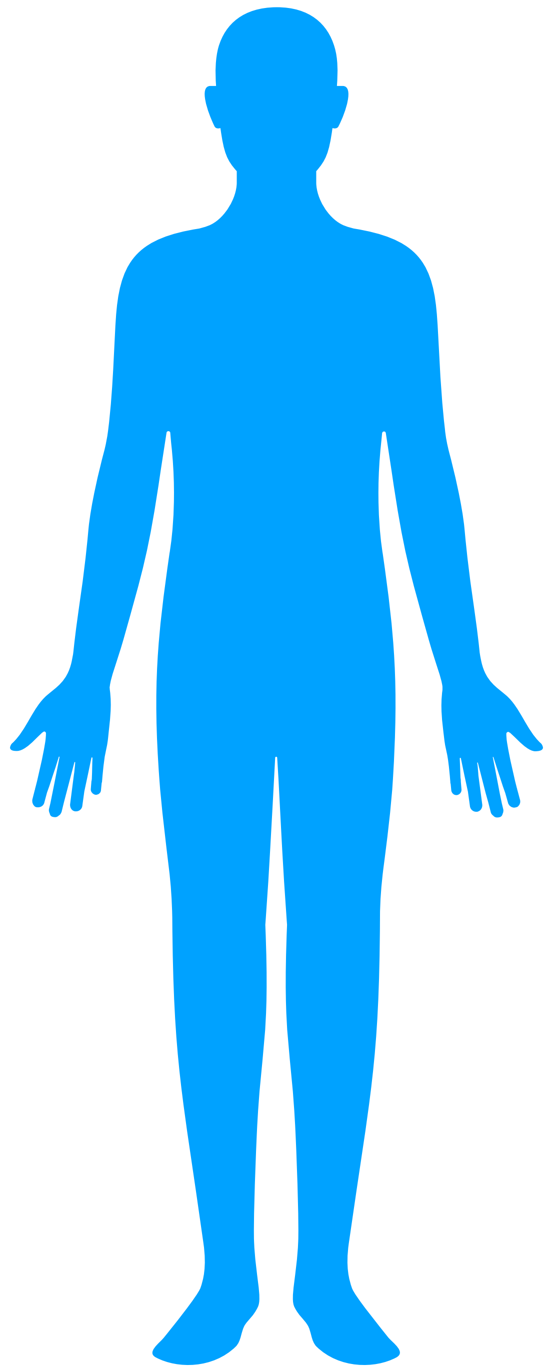
# Functions of ECLSS

- Controlling conditions of the atmosphere inside the spacecraft
  - Temperature
  - Humidity
  - Pressure
  - Oxygen concentration
  - CO2 concentration
  - Concentration of other contaminants
- Water recovery and management
- Food production and storage
- Waste management
- Fire detection and suppression
- Radiation shielding
- Physical and psychological support (hygiene, exercise, sleep, . . . )

# The human as a system

What are the **inputs** and **outputs** for a human?

Food
Water
Oxygen



$CO_2$
Solid waste
Urine
Wastewater
Heat (~100W)

# Human Needs and Effluents Mass Balance (per person per day)

## Needs

Oxygen = 0.84 kg (1.84 lb)

Food Solids = 0.62 kg (1.36 lb)

Water in Food = 1.15 kg (2.54 lb)

Food Prep Water = 0.76 kg (1.67 lb)

Drink = 1.62 kg (3.56 lb)

Metabolized Water = 0.35 kg (0.76 lb)

Hand/Face Wash Water = 4.09 kg (9.00 lb)

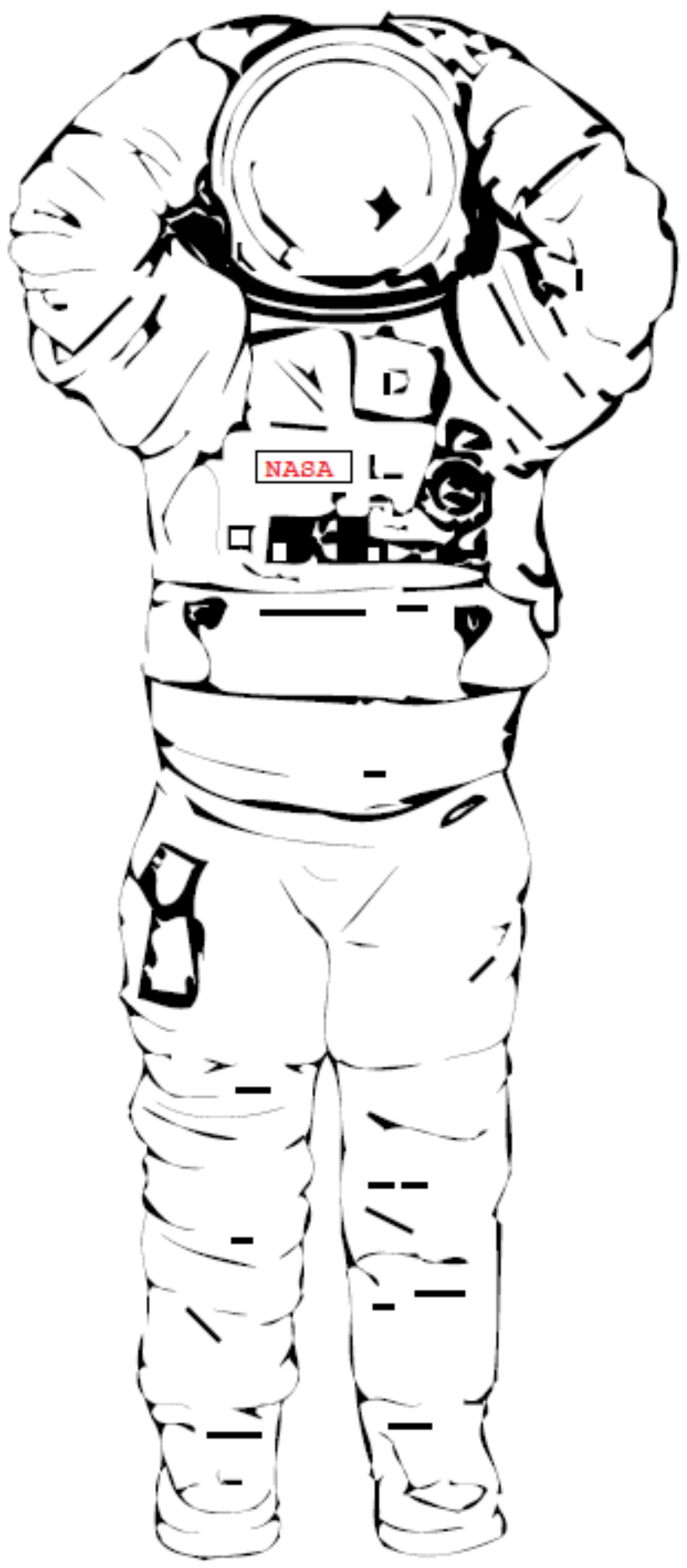
Shower Water = 2.73 kg (6.00 lb)

Urinal Flush = 0.49 kg (1.09 lb)

Clothes Wash Water = 12.50 kg (27.50 lb)

Dish Wash Water = 5.45 kg (12.00 lb)

Total = 30.60 kg (67.32 lb)




## Effluents

Carbon Dioxide = 1.00 kg (2.20 lb)

Respiration & Perspiration
Water = 2.28 kg (5.02 lb)

Food Preparation,
Latent Water = 0.036 kg (0.08 lb)

Urine = 1.50 kg (3.31 lb)

Urine Flush Water = 0.50 kg (1.09 lb)

Feces Water = 0.091 kg (0.20 lb)

Sweat Solids = 0.018 kg (0.04 lb)

Urine Solids = 0.059 kg (0.13 lb)

Feces Solids = 0.032 kg (0.07 lb)

Hygiene Water = 12.58 kg (27.68 lb)

Clothes Wash Water
Liquid = 11.90 kg (26.17 lb)
Latent = 0.60 kg (1.33 lb)
Total = 30.60 kg (67.32 lb)

Note: These values are based on an average metabolic rate of 136.7 W/person (11,200 BTU/person/day) and a respiration quotient of 0.87.
The values will be higher when activity levels are greater and for larger than average people. The respiration quotient is the molar ratio of $CO_2$ generated to $O_2$ consumed.

# Consumable needs

- Can’t live very long without oxygen, food, or water
- For survival . . .
  - 0.6kg of dehydrated food per person per day
  - 0.8kg of oxygen per person per day
  - 3.9kg of potable water per person per day
- Habitability (niceties) . . .
  - Add 1-25 more kg of water for personal hygiene

# Open vs. closed-loop ECLSS

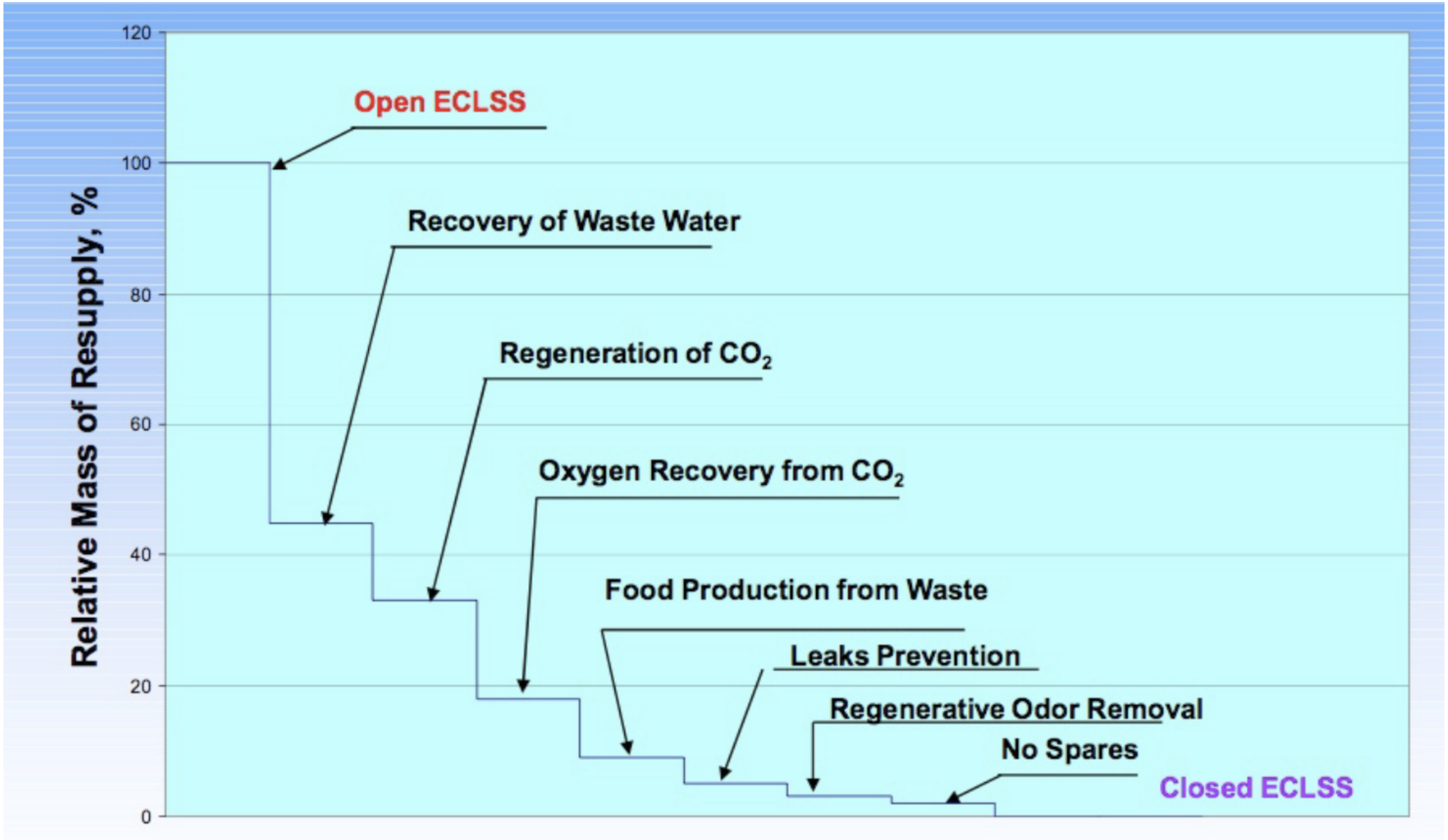
**Closed loop**

- More complex (equipment, mass, power, thermal requirements)
- Less resources brought from Earth
- Less resupply needed
- Lower reliability
- Lower TRL

**Open loop**

- Simple
- Reliable
- Required resources directly proportional to mission lifetime
- Need resupply for long missions

# Resupply reduction



# Short vs. long-term ECLSS

**Mission duration is a critical requirement for ECLSS**

- Very short duration (few hours)
- Short duration (few days)
- Long duration (few months)
- Expedition class (few years)

# Expedition class missions

**Atmosphere revitalization**

- $CO_2$ removal
- $O_2$ production
- Trace contaminant monitoring/control
- Microorganism control
- Atmosphere control/supply
- Monitoring major atmosphere constituents
- Atmosphere constituent storage
- Pressure control
- Temperature control
- Humidity control
- Ventilation
- Equipment cooling

**Water recovery and management**

- Water storage/distribution
- Water production
- Water recovery
- Water quality monitoring

**Waste management**

- Collection/stabilization
- Treatment/degradation
- Recycling of degradation products

**Fire detection and suppression**

- Detection of fires
- Suppression of fires
- Cleanup after fires

**Other functions**

- Food storage and preparation
- Plant growth facilities
- Nutritional control
- Radiation protection
- Dust removal
- Thermally conditioned storage
- Habitability

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## Entirely closed system.

# Long duration missions

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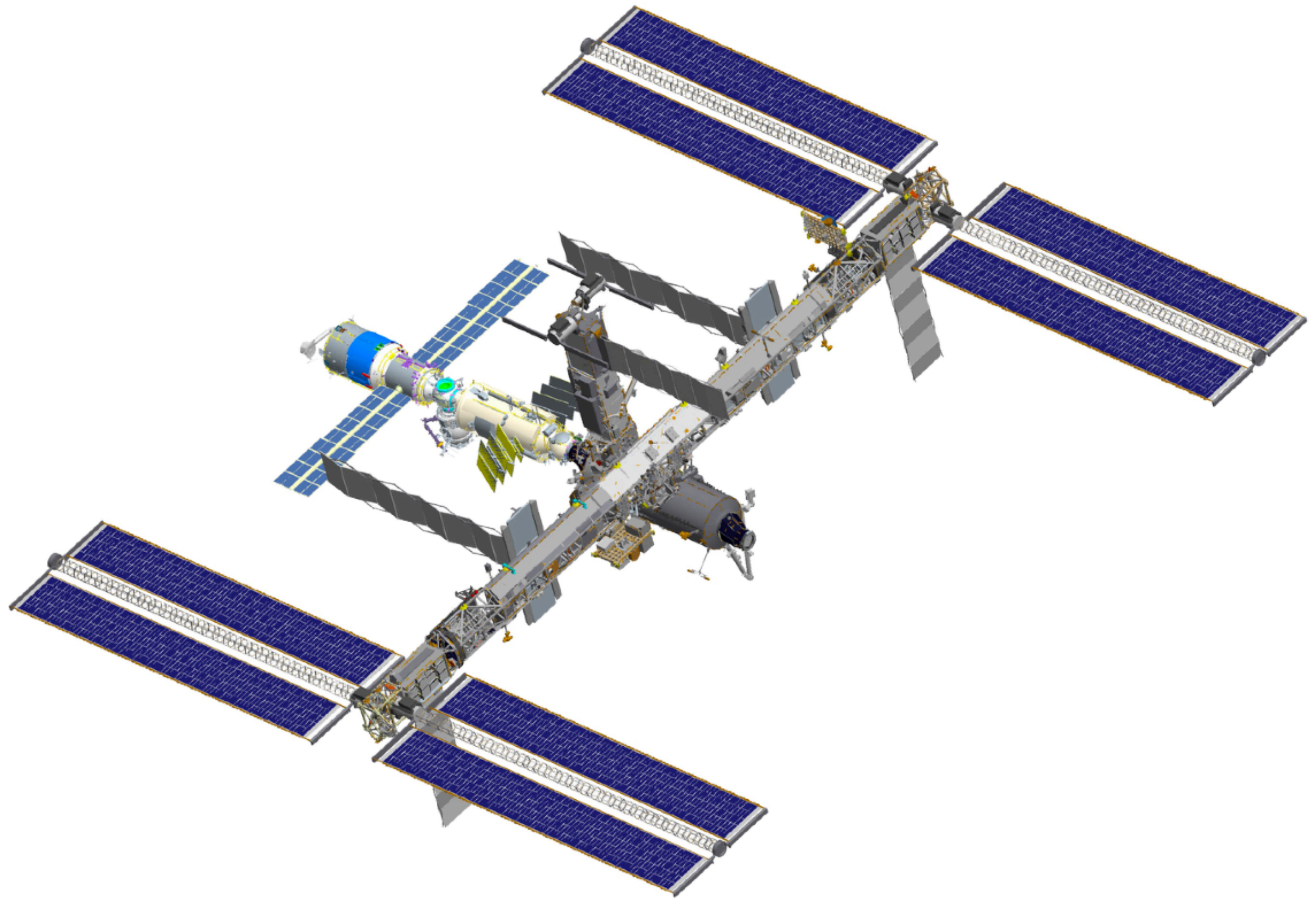

# Short duration missions

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**Water recovery and management**

- Water storage/distribution
- Water production
- ~~Water recovery~~
- ~~Water quality monitoring~~

**Waste management**

- Collection/stabilization
- ~~Treatment/degradation~~
- ~~Recycling of degradation products~~

**Fire detection and suppression**

- Detection of fires
- Suppression of fires
- ~~Cleanup after fires~~

**Other functions**

- Food storage and preparation
- ~~Plant growth facilities~~
- ~~Nutritional control~~
- Radiation protection
- Dust removal
- ~~Thermally conditioned storage~~
- ~~Habitability~~

# Very short duration missions

**Atmosphere revitalization**

- $CO_2$ removal
- $O_2$ production
- ~~Trace contaminant monitoring/control~~
- Microorganism control
- Atmosphere control/supply
- Monitoring major atmosphere constituents
- Atmosphere constituent storage
- Pressure control
- Temperature control
- Humidity control
- Ventilation
- Equipment cooling

**Water recovery and management**

- Water storage/distribution
- ~~Water production~~
- ~~Water recovery~~
- ~~Water quality monitoring~~

**Waste management**

- Collection/stabilization
- ~~Treatment/degradation~~
- ~~Recycling of degradation products~~

**Fire detection and suppression**

- ~~Detection of fires~~
- ~~Suppression of fires~~
- ~~Cleanup after fires~~

**Other functions**

- ~~Food storage and preparation~~
- ~~Plant growth facilities~~
- ~~Nutritional control~~
- ~~Radiation protection~~
- ~~Dust removal~~
- ~~Thermally conditioned storage~~
- ~~Habitability~~

# Temperature and humidity - heat index

Given a temperature T and a relative humidity RH, the heat index HI is the temperature such that HI at 20% relative humidity **“feels like”** T at RH. HI>T for RH>20% because humidity reduces perspiration rate (sweat evaporation)

**Air Humidity, %**

| Air Temperature, $^oC$ | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43 | 57 | | | | | | | | | | | | |
| 42 | 54 | 57 | | | | | | | | | | | |
| 41 | 51 | 54 | 57 | | | | | | | | | | |
| 40 | 48 | 51 | 54 | 57 | | | | | | | | | |
| 39 | 45 | 48 | 51 | 54 | 56 | | | | | | | | |
| 38 | 42 | 45 | 48 | 51 | 53 | 56 | | | | | | | |
| 37 | 41 | 42 | 46 | 48 | 50 | 53 | 55 | | | | | | |
| 36 | 39 | 40 | 44 | 46 | 48 | 50 | 52 | 54 | | | | | |
| 35 | 37 | 38 | 41 | 3 | 45 | 47 | 49 | 51 | 52 | 56 | | | |
| 34 | 34 | 36 | 38 | 40 | 42 | 44 | 46 | 47 | 49 | 52 | 53 | | |
| 33 | 33 | 34 | 35 | 37 | 39 | 41 | 43 | 44 | 46 | 48 | 50 | 52 | 55 |
| 32 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 41 | 43 | 45 | 47 | 49 |
| 31 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 40 | 41 | 42 | 42 | 44 |
| 30 | 30 | 31 | 31 | 32 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 38 | 40 |
| 29 | 29 | 29 | 29 | 30 | 30 | 31 | 31 | 32 | 32 | 33 | 34 | 35 | 35 |
| 28 | 28 | 28 | 28 | 29 | 29 | 30 | 30 | 30 | 31 | 32 | 32 | 32 | 33 |

**Extreme Danger**

**Danger**

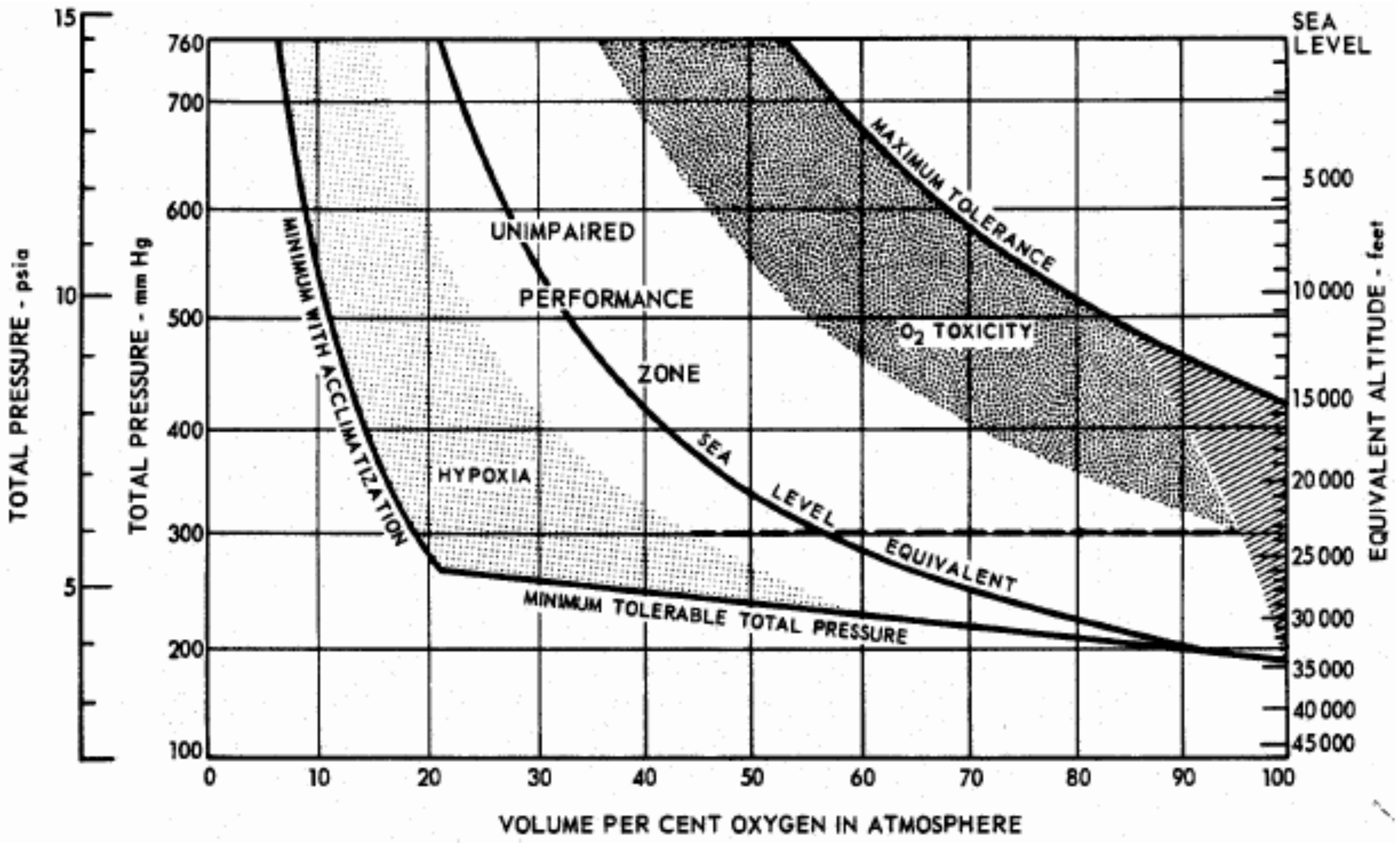
**Extreme Caution**

**Caution**

**Cabin Temperature** should range from ~18-27$^o$ C .

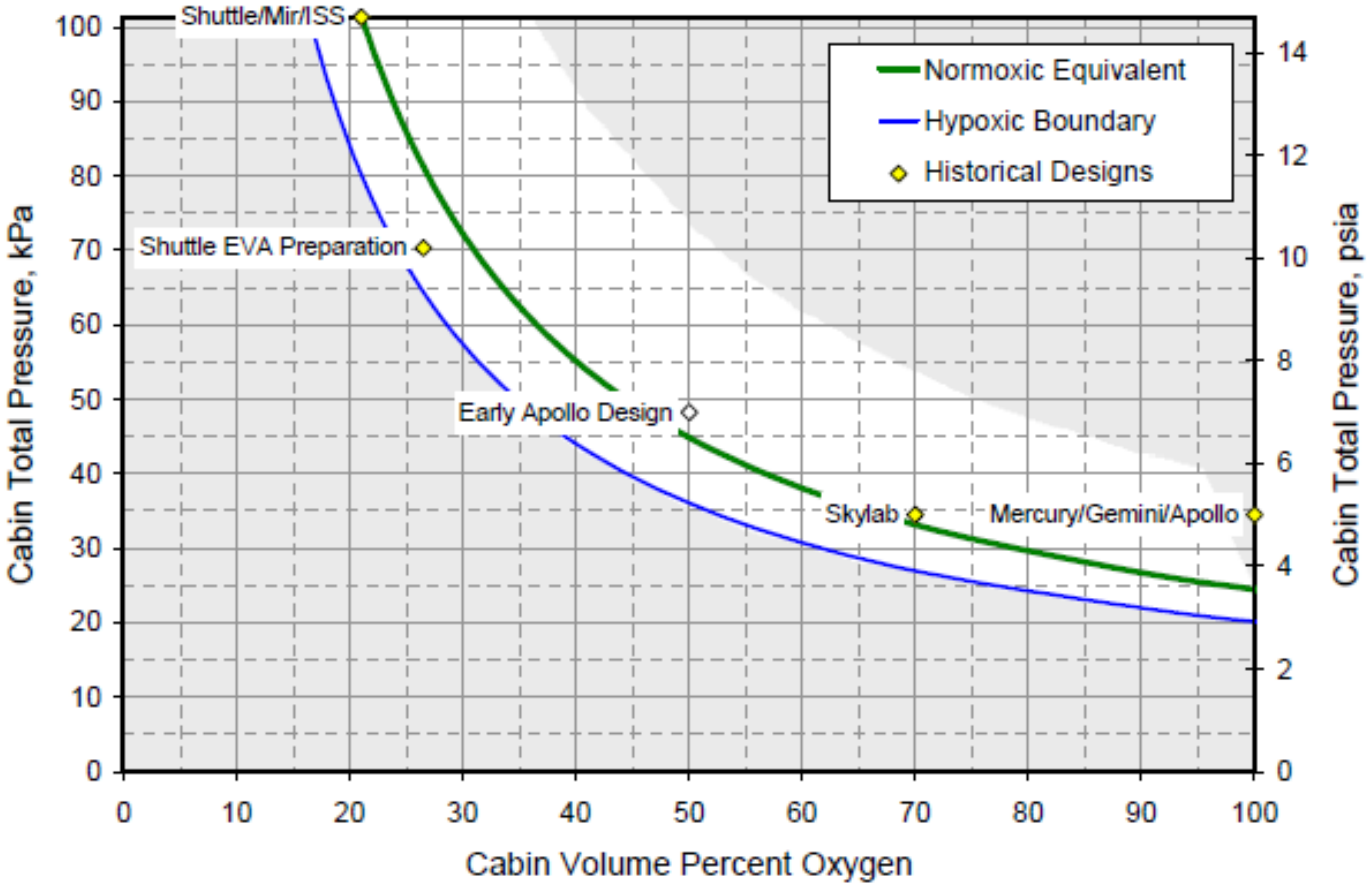
# Composition and pressure

- Choices for atmospheric pressure and composition are coupled
- Total pressure must be >6kPa to avoid vaporization of body fluids
- Oxygen partial pressure (O2 concentration x total pressure) must be high enough to avoid hypoxia, but low enough to avoid O2 toxicity
    - ~20kPa (between 17-35kPa)



# Design considerations

- Lower total pressure and higher oxygen concentration
  - Cheaper structure
  - Higher flammability (Apollo 1 disaster)
  - Decrease pre-breathing time for EVA
- Higher total pressure and lower oxygen concentration
  - More costly structure
  - Lower fire risk
  - Higher pre-breathe time



# Atmosphere - $CO_2$ removal

- Humans produce $CO_2$ through respiration

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{heat}$$

- High $CO_2$ levels increase respiration and heart rate, among other things
- Must be actively removed from the atmosphere (0.3% max)
- Can use expendable lithium hydroxide (LiOH) granules

$$2LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O + \text{heat}$$

(Need ~2kg of LiOH per person per day)

- Or absorption processes (e.g. molecular sieves, solid amines)

# $CO_2$ reduction: Sabatier reaction

$$4H_2 + CO_2 \longrightarrow 2H_2 + CH_4 + \text{heat}$$

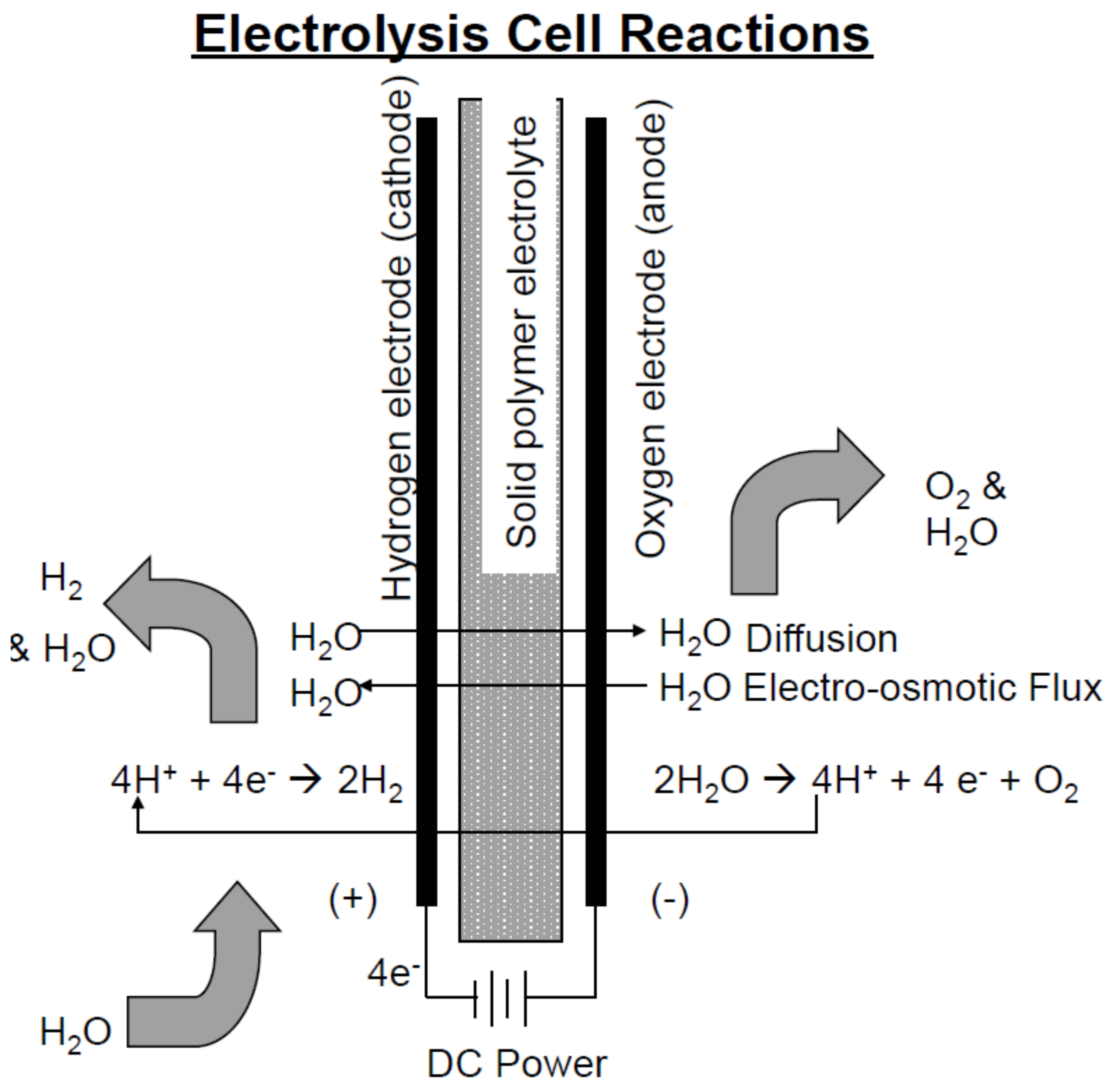
- Requires hydrogen to work
- Generates methane that is usually vented
- Perhaps the methane could be used as propellant in the future?

# Oxygen generation

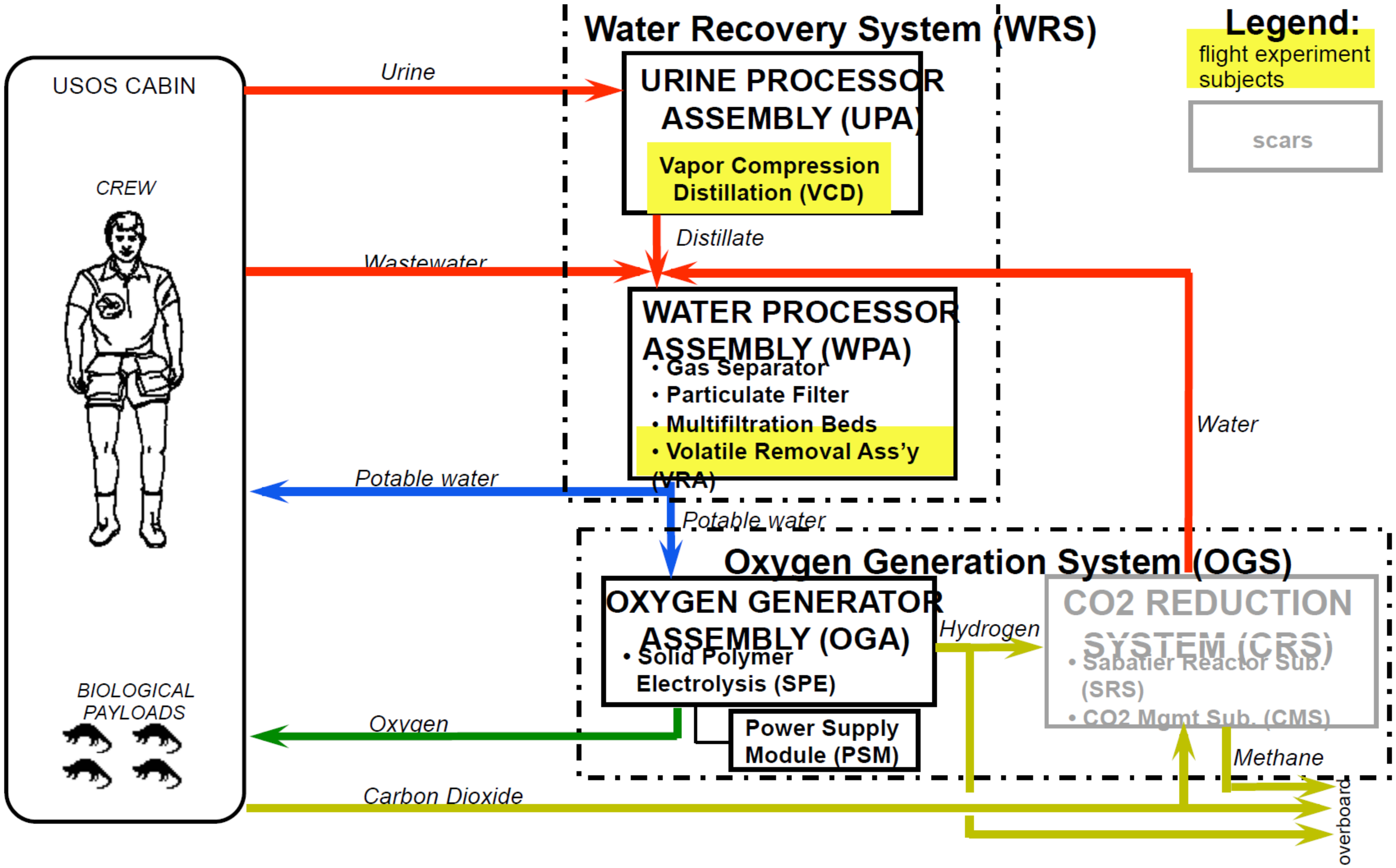
**Water electrolysis**

$$2H_2O + \text{energy} \longrightarrow 2H_2 + O_2$$

- Like fuel cells but the other way around (requires energy)
- Hydrogen can be vented or sent to a Sabatier reactor



# Closing the loop



# Trace contaminants - activated carbon

- Activated carbon or charcoal is a form of carbon processed to have small, low-volume pores that increase the surface area available for absorption or chemical reactions
- Can be made of wood, bamboo, etc.
- Activated physically (pyrolysis at 600-900C) or chemically (oxidation at high temperatures)
- Adsorption is when atoms/ions/molecules get stuck (adhere) to a surface due to
  - electrostatic forces
  - Van der Waals forces
  - Chemical (covalent) bonds

# Urine processing

- Remove water through distillation
- Distillation is the process of separating the components or substances from a liquid mixture by selective boiling and condensation
    - The process exploits differences in the volatility (boiling point) of the mixture’s components
    - Usually low pressure, ambient temperature
- Purge gases from distillation
- Brine is concentrated and ultimately removed in recycle filter tank
- Water is sent through to water processing assembly

# Water processing

- Filters to remove particulate
- Multifiltration beds to remove dissolved contaminants (salts, large organics) by adsorption
- Catalytic reactor to oxidize organics