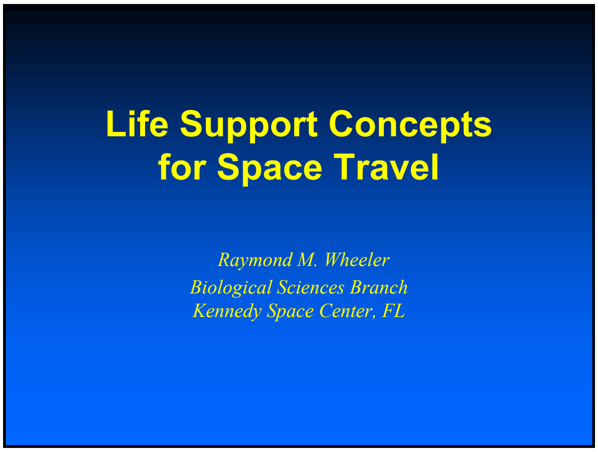
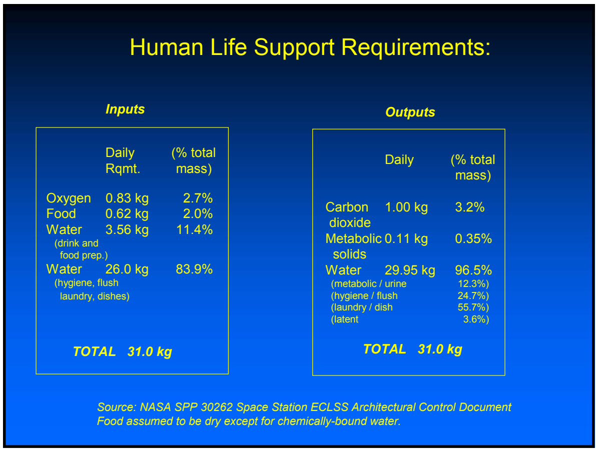


Life Support Concepts for Space Travel

Raymond M. Wheeler
Biological Sciences Branch
Kennedy Space Center, FL



Human Life Support Requirements:

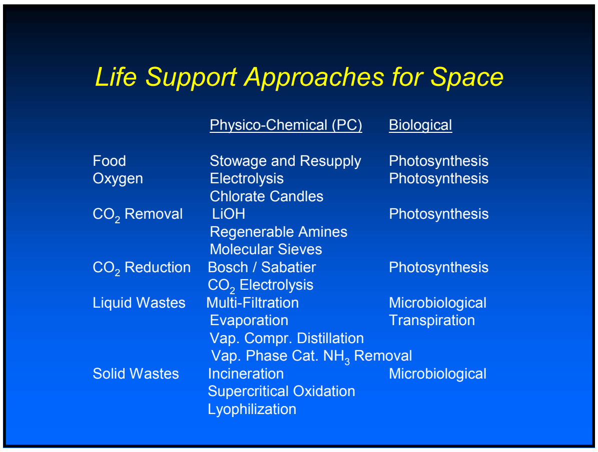
Inputs

	Daily Rqmt.	(% total mass)
Oxygen	0.83 kg	2.7%
Food	0.62 kg	2.0%
Water (drink and food prep.)	3.56 kg	11.4%
Water (hygiene, flush laundry, dishes)	26.0 kg	83.9%
TOTAL	***31.0 kg***	

Outputs

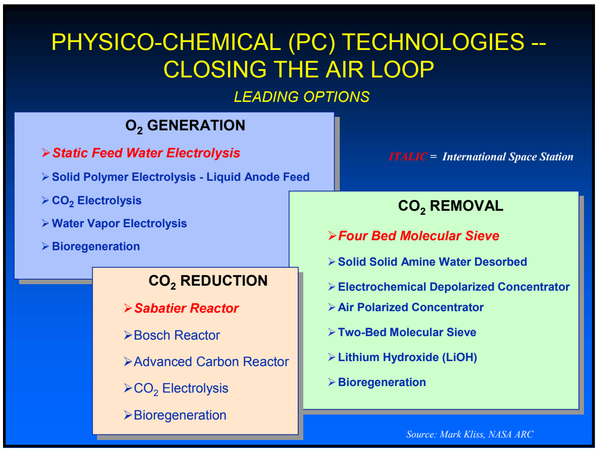
	Daily	(% total mass)
Carbon dioxide	1.00 kg	3.2%
Metabolic solids	0.11 kg	0.35%
Water	29.95 kg	96.5%
(metabolic / urine		12.3%)
(hygiene / flush		24.7%)
(laundry / dish		55.7%)
(latent		3.6%)
TOTAL	***31.0 kg***	

Source: NASA SPP 30262 Space Station ECLSS Architectural Control Document
Food assumed to be dry except for chemically-bound water.



Life Support Approaches for Space

	Physico-Chemical (PC)	Biological
Food	Stowage and Resupply	Photosynthesis
Oxygen	Electrolysis Chlorate Candles	Photosynthesis
CO_2 Removal	LiOH Regenerable Amines Molecular Sieves	Photosynthesis
CO_2 Reduction	Bosch / Sabatier CO_2 Electrolysis	Photosynthesis
Liquid Wastes	Multi-Filtration Evaporation Vap. Compr. Distillation Vap. Phase Cat. NH_3 Removal	Microbiological Transpiration
Solid Wastes	Incineration Supercritical Oxidation Lyophilization	Microbiological



PHYSICO-CHEMICAL (PC) TECHNOLOGIES -- CLOSING THE AIR LOOP

LEADING OPTIONS

O_2 GENERATION

- ➢ ***Static Feed Water Electrolysis***
- ➢ **Solid Polymer Electrolysis - Liquid Anode Feed**
- ➢ **CO_2 Electrolysis**
- ➢ **Water Vapor Electrolysis**
- ➢ **Bioregeneration**

ITALIC = ***International Space Station***

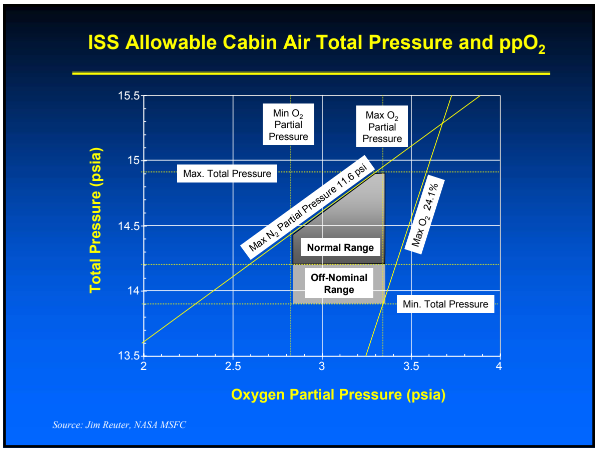
CO_2 REMOVAL

- ➢ ***Four Bed Molecular Sieve***
- ➢ **Solid Solid Amine Water Desorbed**
- ➢ **Electrochemical Depolarized Concentrator**
- ➢ **Air Polarized Concentrator**
- ➢ **Two-Bed Molecular Sieve**
- ➢ **Lithium Hydroxide (LiOH)**
- ➢ **Bioregeneration**

CO_2 REDUCTION

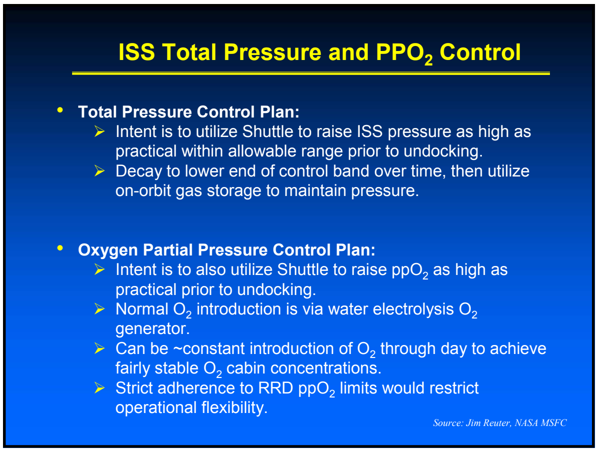
- ➢ ***Sabatier Reactor***
- ➢ Bosch Reactor
- ➢ Advanced Carbon Reactor
- ➢ CO_2 Electrolysis
- ➢ Bioregeneration

Source: Mark Kliss, NASA ARC



ISS Allowable Cabin Air Total Pressure and ppO_2

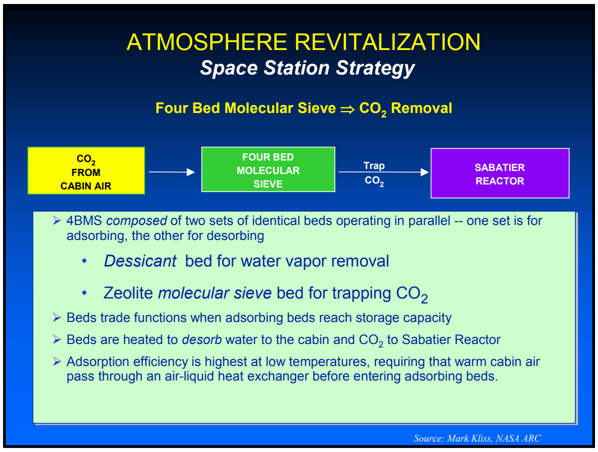
Source: Jim Reuter, NASA MSFC



ISS Total Pressure and PPO_2 Control

- **Total Pressure Control Plan:**
  - ➢ Intent is to utilize Shuttle to raise ISS pressure as high as practical within allowable range prior to undocking.
  - ➢ Decay to lower end of control band over time, then utilize on-orbit gas storage to maintain pressure.
- **Oxygen Partial Pressure Control Plan:**
  - ➢ Intent is to also utilize Shuttle to raise ppO_2 as high as practical prior to undocking.
  - ➢ Normal O_2 introduction is via water electrolysis O_2 generator.
  - ➢ Can be ~constant introduction of O_2 through day to achieve fairly stable O_2 cabin concentrations.
  - ➢ Strict adherence to RRD ppO_2 limits would restrict operational flexibility.

Source: Jim Reuter, NASA MSFC



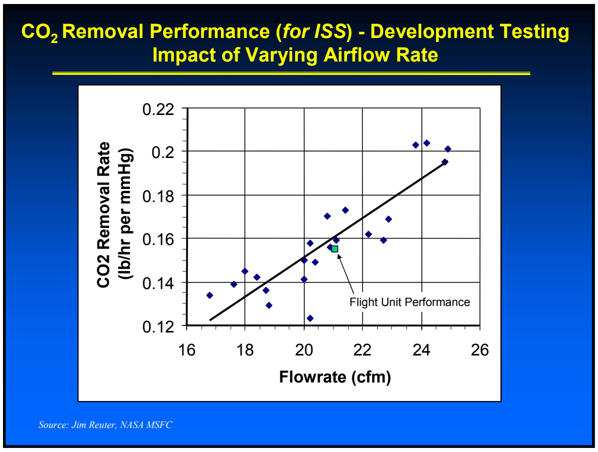
ATMOSPHERE REVITALIZATION

Space Station Strategy

Four Bed Molecular Sieve ⇒ CO_2 Removal

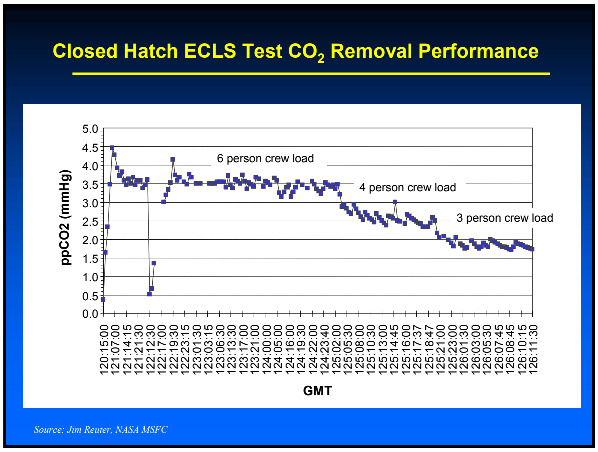
- 4BMS *composed* of two sets of identical beds operating in parallel -- one set is for adsorbing, the other for desorbing
  - *Dessicant* bed for water vapor removal
  - Zeolite *molecular sieve* bed for trapping CO_2
- Beds trade functions when adsorbing beds reach storage capacity
- Beds are heated to *desorb* water to the cabin and CO_2 to Sabatier Reactor
- Adsorption efficiency is highest at low temperatures, requiring that warm cabin air pass through an air-liquid heat exchanger before entering adsorbing beds.

Source: Mark Kliss, NASA ARC



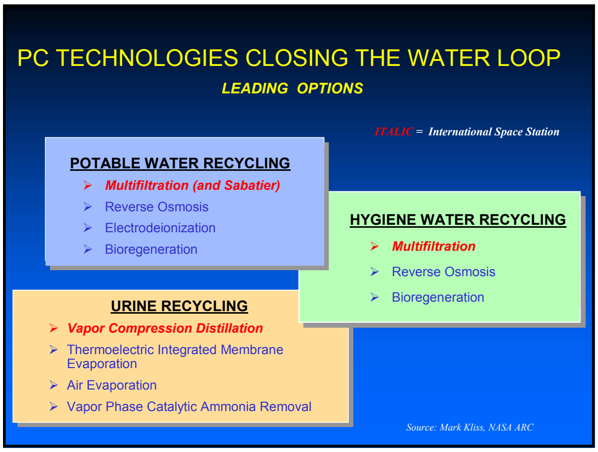
CO_2 Removal Performance (*for ISS*) - Development Testing Impact of Varying Airflow Rate

Source: Jim Reuter, NASA MSFC



Closed Hatch ECLS Test CO_2 Removal Performance

Source: Jim Reuter, NASA MSFC



PC TECHNOLOGIES CLOSING THE WATER LOOP

LEADING OPTIONS

***ITALIC* = International Space Station**

POTABLE WATER RECYCLING

- ***Multifiltration (and Sabatier)***
- Reverse Osmosis
- Electrodeionization
- Bioregeneration

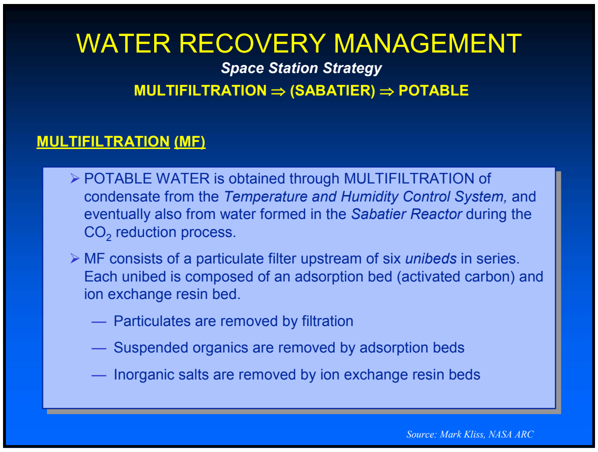
HYGIENE WATER RECYCLING

- ***Multifiltration***
- Reverse Osmosis
- Bioregeneration

URINE RECYCLING

- ***Vapor Compression Distillation***
- Thermoelectric Integrated Membrane Evaporation
- Air Evaporation
- Vapor Phase Catalytic Ammonia Removal

Source: Mark Kliss, NASA ARC



WATER RECOVERY MANAGEMENT

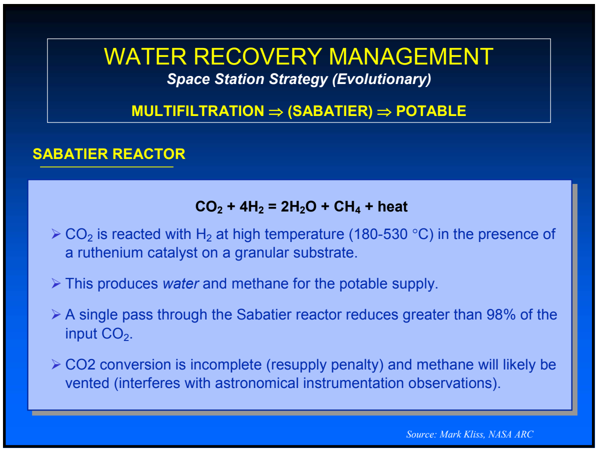
Space Station Strategy

MULTIFILTRATION ⇒ (SABATIER) ⇒ POTABLE

MULTIFILTRATION (MF)

- POTABLE WATER is obtained through MULTIFILTRATION of condensate from the *Temperature and Humidity Control System*, and eventually also from water formed in the *Sabatier Reactor* during the CO_2 reduction process.
- MF consists of a particulate filter upstream of six *unibeds* in series. Each unibed is composed of an adsorption bed (activated carbon) and ion exchange resin bed.
  - Particulates are removed by filtration
  - Suspended organics are removed by adsorption beds
  - Inorganic salts are removed by ion exchange resin beds

Source: Mark Kliss, NASA ARC



WATER RECOVERY MANAGEMENT

Space Station Strategy (Evolutionary)

MULTIFILTRATION ⇒ (SABATIER) ⇒ POTABLE

SABATIER REACTOR

$$CO_2 + 4H_2 = 2H_2O + CH_4 + heat$$

- CO_2 is reacted with H_2 at high temperature (180-530 °C) in the presence of a ruthenium catalyst on a granular substrate.
- This produces *water* and methane for the potable supply.
- A single pass through the Sabatier reactor reduces greater than 98% of the input CO_2.
- CO2 conversion is incomplete (resupply penalty) and methane will likely be vented (interferes with astronomical instrumentation observations).

Source: Mark Kliss, NASA ARC

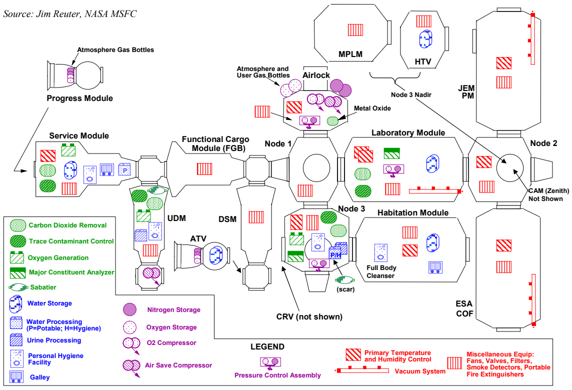
ISS Atmospheric Contaminant Control Methods

- **Passive Control**
  - Materials selection and control process
  - Payload materials and processes screening
  - Hardware design
- **Active Control**
  - **Mir:** Expendable and regenerable charcoal for volatile trace gas control and ambient temperature catalyst for CO control
  - **ISS U.S. Segment:** Expendable charcoal for volatile trace gas control and high temperature catalytic oxidation for CO and methane control
  - **ISS Russian Segment:** Same system used onboard Mir
- **Incidental Control**
  - Overboard leakage
  - Absorption by humidity condensate
  - Human respiration
  - Dilution via atmosphere replenishment
  - Carbon dioxide removal assembly

Source: Jim Reuter, NASA MSFC

Principal Life Support Hardware Distribution

Source: Jim Reuter, NASA MSFC

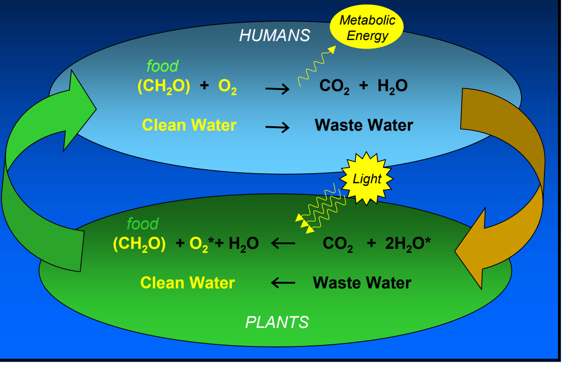


Constraints ("Economics") of Life Support in Space:

- Energy Requirements
- System Mass
- System Volume
- Crew Time
- System Reliability

These apply for all Life Support Technologies

Plants and Bioregenerative Life Support



HUMANS

Metabolic Energy

food

(CH_2O) + O_2 → CO_2 + H_2O

Clean Water → Waste Water

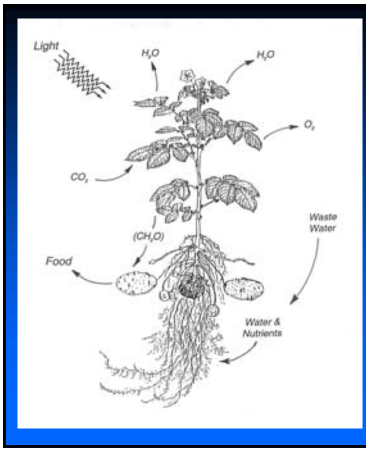
Light

food

(CH_2O) + O_2* + H_2O ← CO_2 + $2H_2O$*

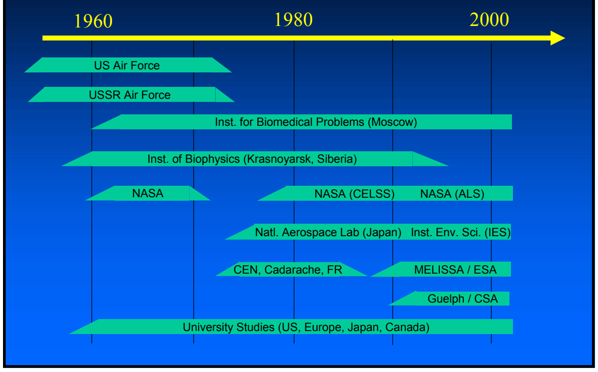
Clean Water ← Waste Water

PLANTS



Plants as a "Life Support Machines"

Testing with Plants and Algae for Life Support



1960 1980 2000

US Air Force

USSR Air Force

Inst. for Biomedical Problems (Moscow)

Inst. of Biophysics (Krasnoyarsk, Siberia)

NASA

NASA (CELSS) NASA (ALS)

Natl. Aerospace Lab (Japan) Inst. Env. Sci. (IES)

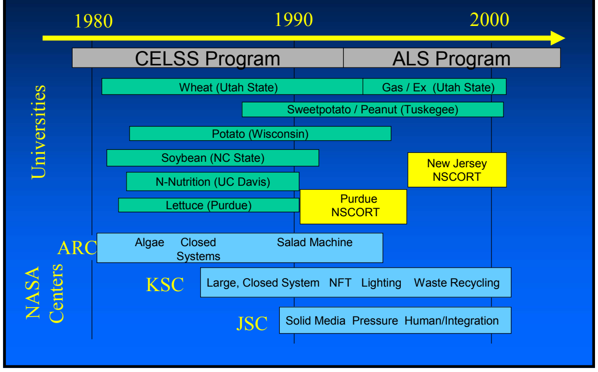
CEN, Cadarache, FR

MELISSA / ESA

Guelph / CSA

University Studies (US, Europe, Japan, Canada)

NASA Testing with Plants for Life Support



Plants and Life Support: Some Background

*Joseph Priestley (1772) **

- "…a sprig of mint in a glass jar continued growing for some months, I found that the air would neither extinguish a candle, nor was it at all inconvenient to a mouse"
- "plants thrive particularly well in air made obnoxious by the exhalations of animals (and humans)"

** Abstracted from E.I. Rabinowitch. 1945. Photosynthesis and Related Processes. Interscience Publ. Inc. NY.*

Early Bioregenerative Studies Focused on Algae and Cyanobacteria *(1950s and 1960s)*

- *Chlorella pyrenoidosa* TX71105 (thermotolerant 39°C)
- Other species of *Chlorella*, *Anacystis, Synechocystis*, *Scenedesmus*, *Synechococcus, Spirulina* were studied
- Development of culture systems (chemostats, turbidostats)
- Studies with animals (e.g., mice, monkeys) and humans
- Interest in Assimilation and Respiration Quotients (AQ and RQ)

➢"…a general misconception in the scientific community is that success of the bioregenerative approach depends on development of a biologically and chemically closed ecology with complete material balance. While this may be the ultimate goal, few consider it possible if indeed necessary" (Miller and Ward, 1966)

Observations from Algae Studies:

- Positives
  - high photosynthetic efficiency
  - good volume efficiency
  - good energy efficiency--minimum wastage of light
- Negatives
  - difficulties with food processing / palatability
  - long-term, sustained production challenges
  - gas / liquid phase issues for μ-gravity
  - no transpiration advantage for water purification
  - not convenient for point source lamps

Photosynthesis in Space

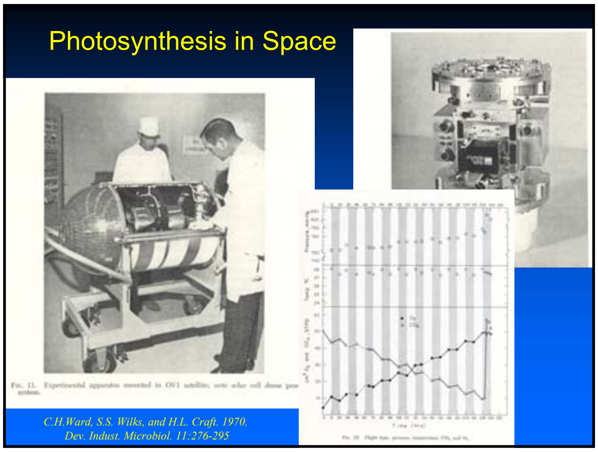


Fig. 11. Experimental apparatus mounted in OV1 satellite; note solar cell dome pow system.

C.H.Ward, S.S. Wilks, and H.L. Craft. 1970. Dev. Indust. Microbiol. 11:276-295

Bioregenerative Life Support for Space:

Reviews of Work in 1950s and 1960s:

- Eley, J.H. and J. Myers. 1963. A study of a photosynthetic gas exchanger. A quantitative repetition of the Priestley Experiment. Texas J. Sci. 16:296-333.
- Miller, R.L. and C.H. Ward. 1966. Algal bioregenerative systems. In K. Kammermeyer (*ed.*) Atmosphere in Space Cabins and Closed Environments. Appleton-Century-Croft, NY.
- Taub, F.B. 1974. Closed ecological systems. *In*: R.F. Johnston, P.W. Frank, and C.D. Michener (*eds.*) Annual review of Ecology and Systematics. 5; 139-160.