

National Aeronautics and Space Administration



The Lunar Mars Life Support Test Project

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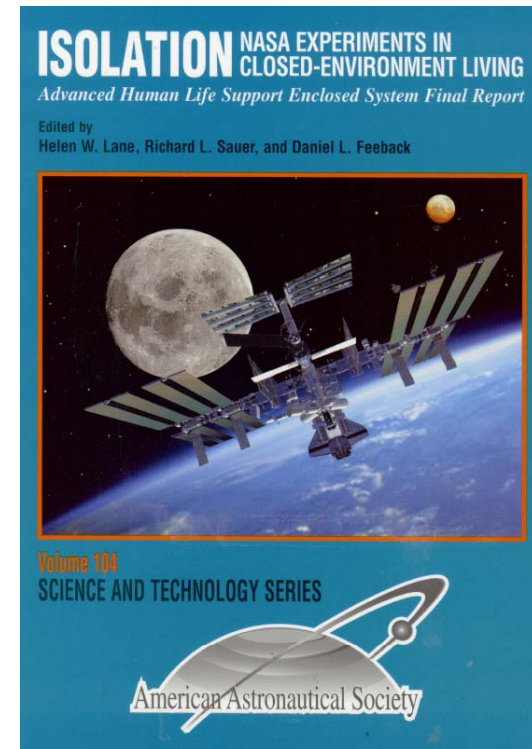
Background

NASA's Large Scale Bioregenerative Life Support Tests



KSC's Biomass Production Chamber

- Large-scale closed crop testing
- Control system development
- Evaluation of robotic arm (Florida State)
- Wastewater processing by crops
- Trace gas evolution & microbial ecology



JSC's Large Scale Human-In-The-Loop Testing

- Large-scale crop testing
- Human test subjects
- Closed atmosphere
- Integration of physicochemical and biological technologies

Lunar Mars Life Support Test Project (LMLSTP)

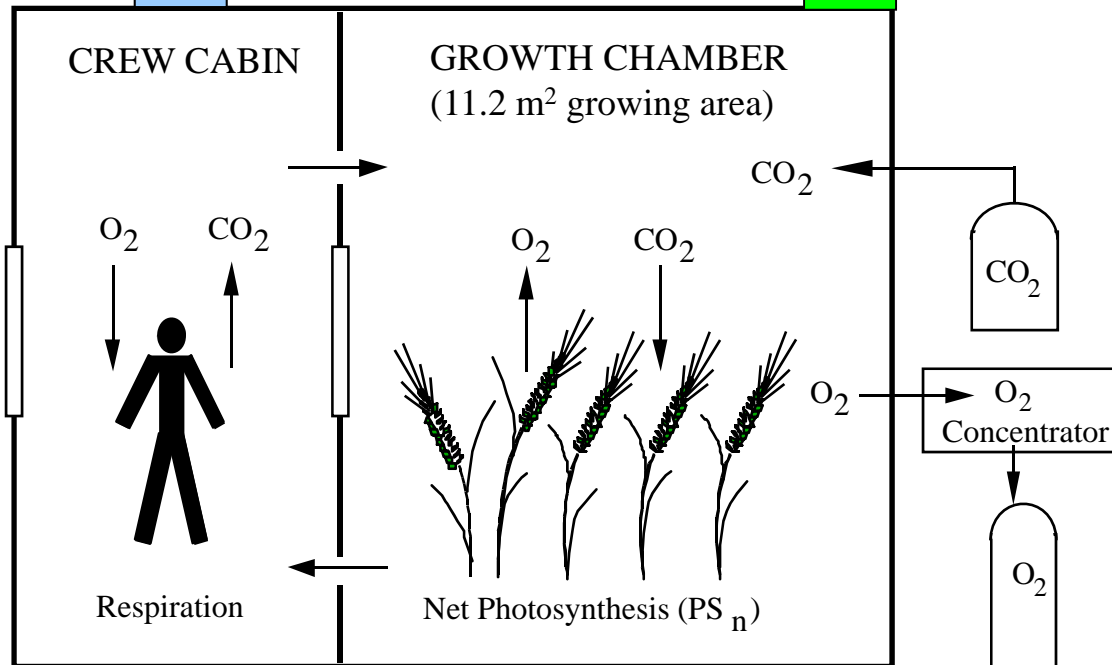


Four tests with human test subjects were performed between 1995 and 1998 at NASA's Johnson Space Center

Test	Phase I	Phase II	Phase IIA	Phase III
Duration	15 days	30 days	60 days	91 days
Crew	1	4	4	4
Types of Systems	Biological (Wheat)	Physicochemical (Advanced)	Physicochemical (ISS Regenerative ECLSS)	Integrated Physicochemical & Biological (Advanced)
Full Closure	Air	Air & Water	Air & Water	Air & Water
Partial Closure				Food & Waste
Open Loop	Water, Food & Waste	Food & Waste	Food & Waste	

Lunar Mars Life Support Test Project

Phase I: 15-day, 1-Person Test

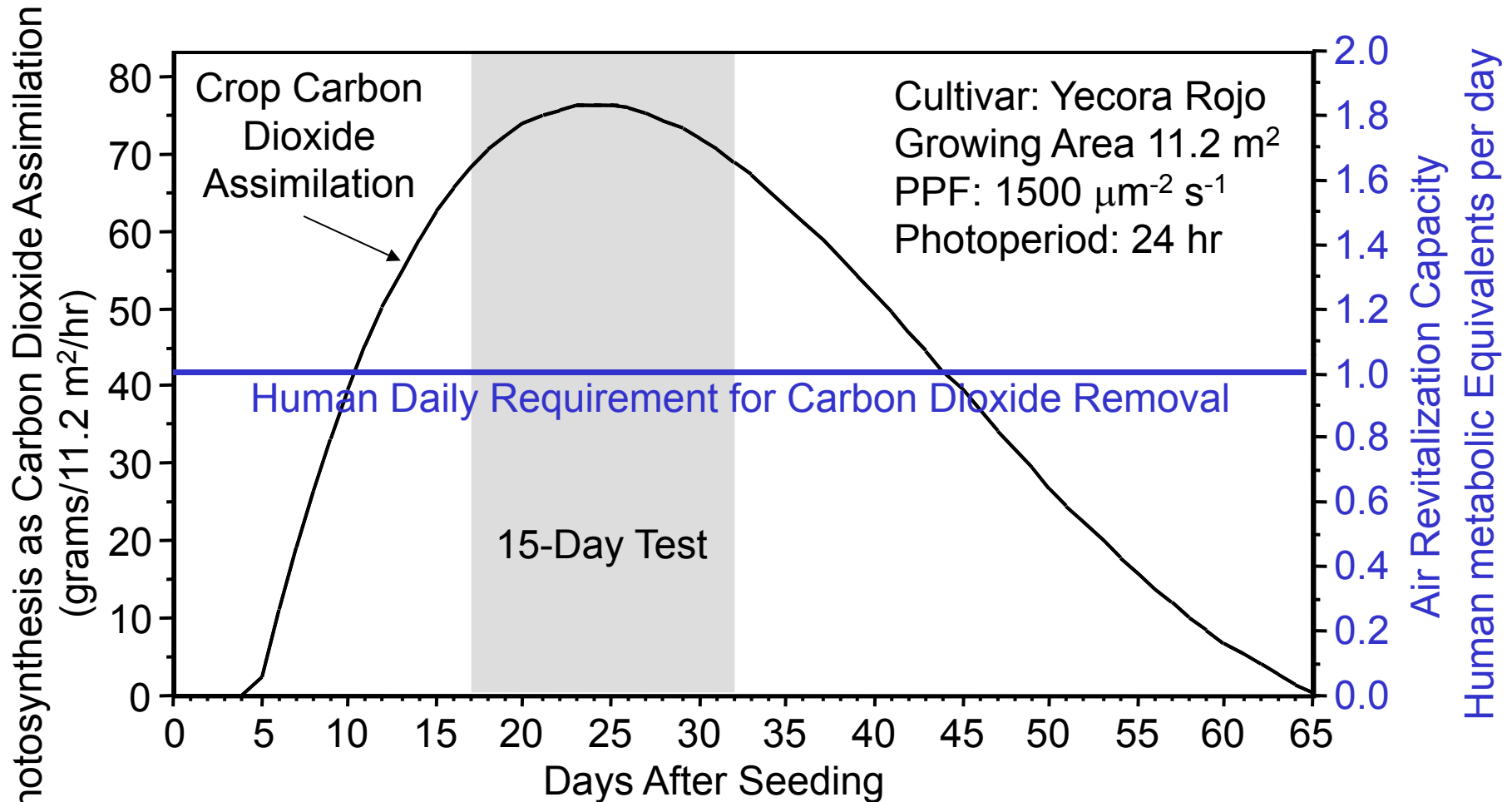


Test Facility

- 2.7 m wide by 2.4 m tall atmospherically sealed with 2 compartments – 19.2 m^3 (crew cabin) & 27 m^3 (growth chamber).
- Growth chamber section outfitted with a hydroponic growing system for wheat.
- Leak rate $<2\%$ volume per day

LMLSTP Phase I: 15-day, 1-Person Test

Expected rate of photosynthesis of a wheat crop



The growth chamber was expected to exceed the carbon dioxide removal capacity and oxygen production requirement for one person during the 15 day period selected for the test (shaded).

LMLSTP Phase I: 15-day, 1-Person Test

Control of Atmospheric Composition

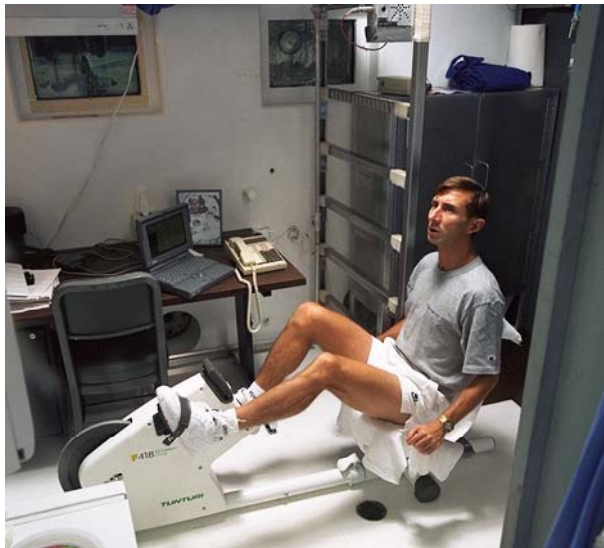


Three methods for controlling atmospheric CO₂ and O₂ were demonstrated. Physicochemical (P/C) systems were used to correct for imbalances between crew respiration and crop photosynthesis (PS_n) was regulated directly.

Method of Control	Integrated P/C & Biological	Environmental Regulation of PS _n	Environmental Regulation of PS _n
Days of Test	1-6	7-12	13-15
Photosynthesis	Maximum	Limited by Light Intensity	Limited by CO ₂ Availability
Description	P/C Systems Correct Imbalance	Crop CO ₂ Assimilation Matched to Crew CO ₂ Output Respiration	
Photosynthetic Photon Flux (Light Level)	Fixed Intensity	Intensity Adjusted Continuously to Maintain Cabin [CO ₂]	Fixed Intensity
Supplemental CO ₂ Injection	Inject to maintain cabin [CO ₂]	Contingency Only	
P/C O ₂ Scrubber	Remove O ₂ to maintain cabin [O ₂]	Contingency Only	

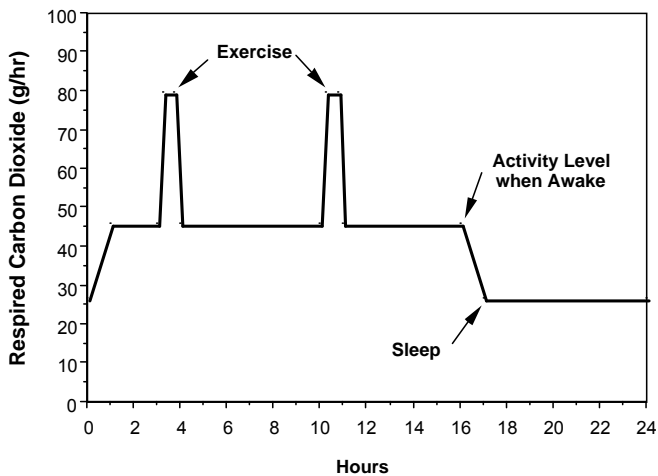
LMLSTP Phase I: 15-day, 1-Person Test

Control of Atmospheric Composition

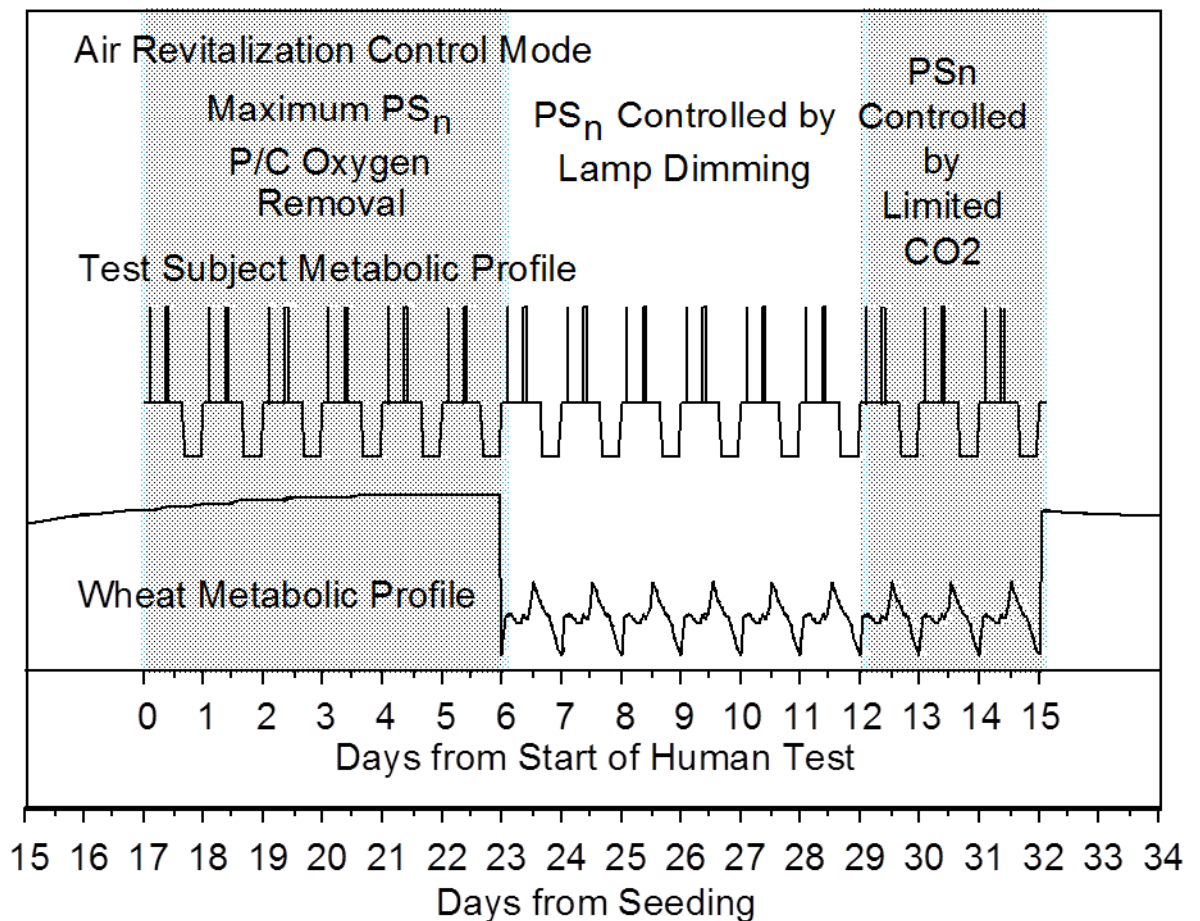


Demonstrated three control strategies

1. Full light, CO₂ injected to maintain [CO₂] setpoint
2. Light dimmed to maintain [CO₂] setpoint
3. No automated control; light at intermediate setpoint; CO₂ limited to crew member respiration



Test Subject Metabolic Profile

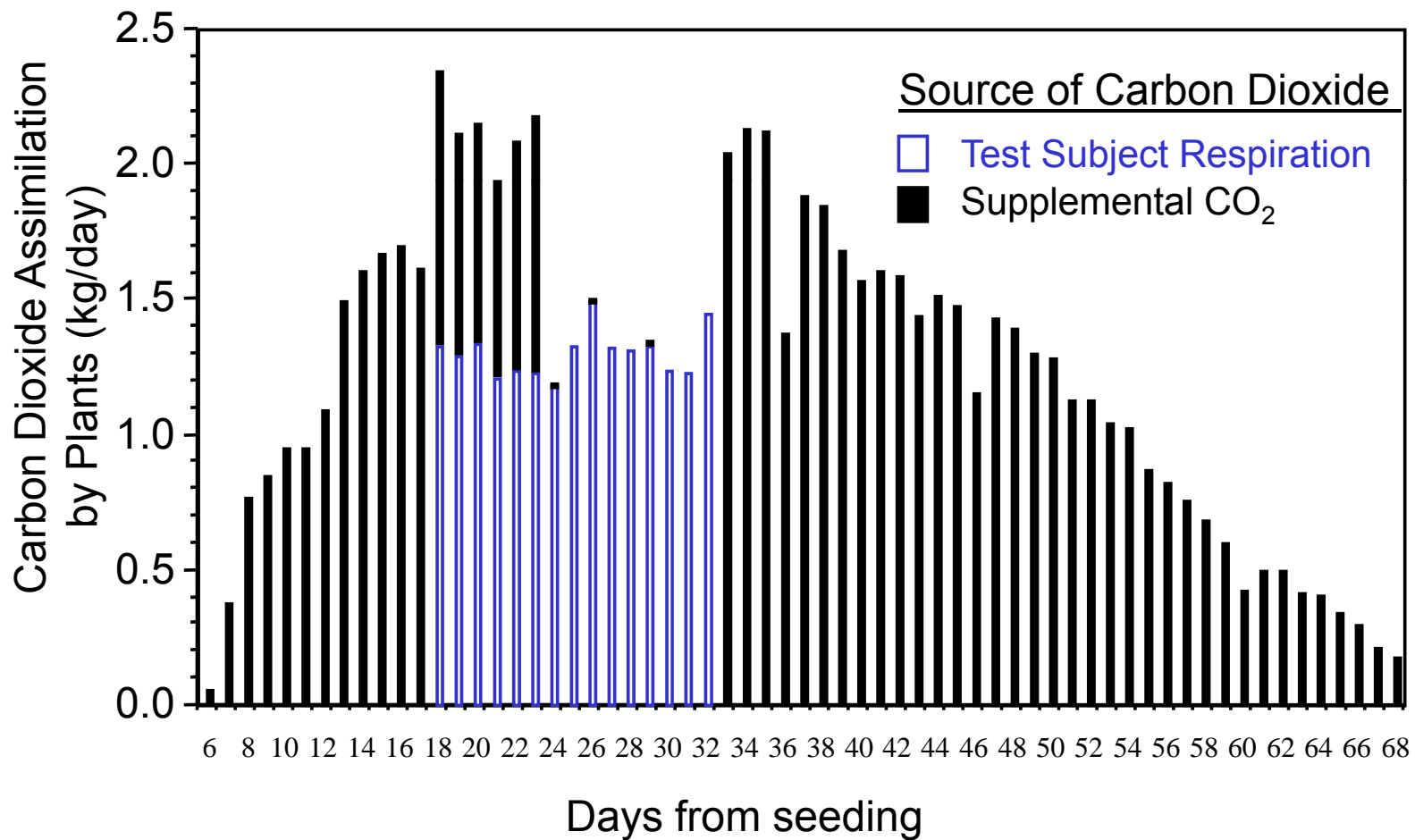


LMLSTP Phase I Test Results

Daily Removal of Carbon Dioxide from Cabin Atmosphere



Daily removal of atmospheric carbon dioxide by the wheat crop over its life cycle

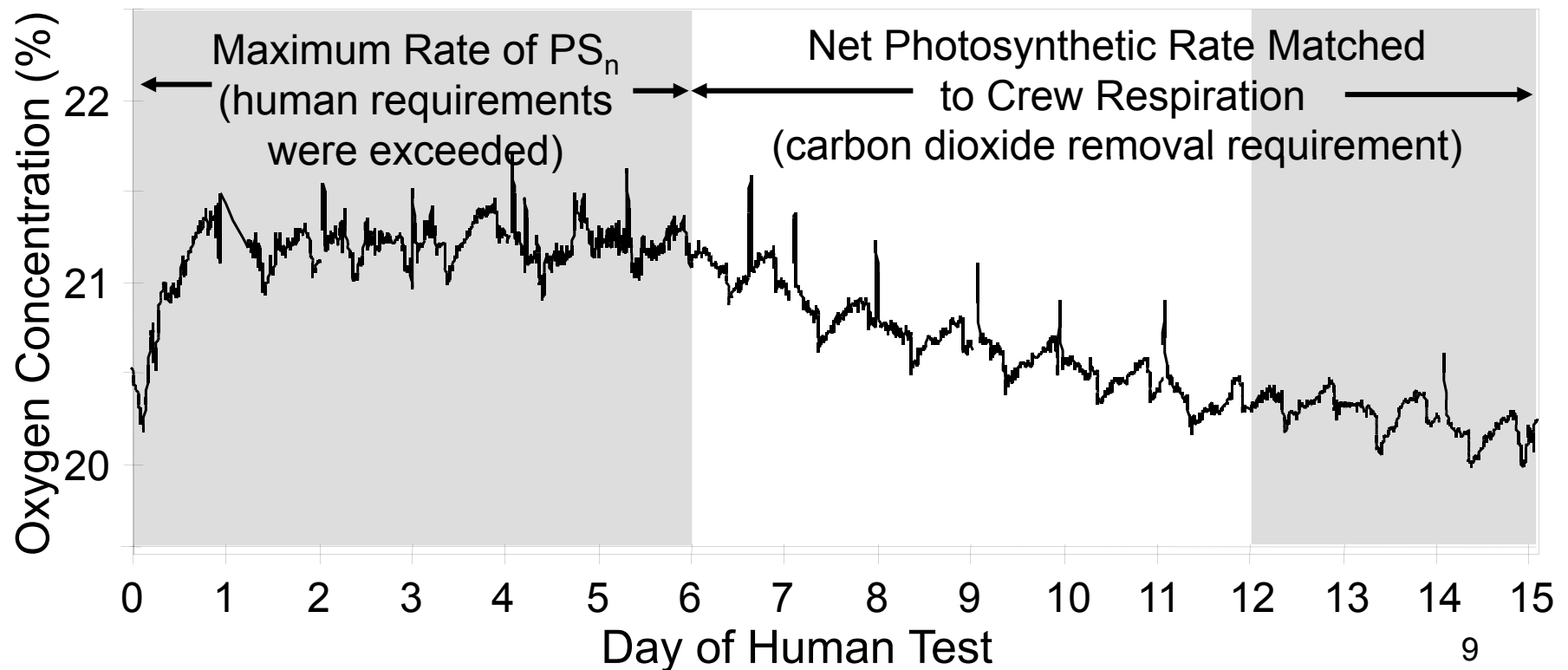


LMLSTP Phase I Test Results

Oxygen Concentration in the Cabin Atmosphere

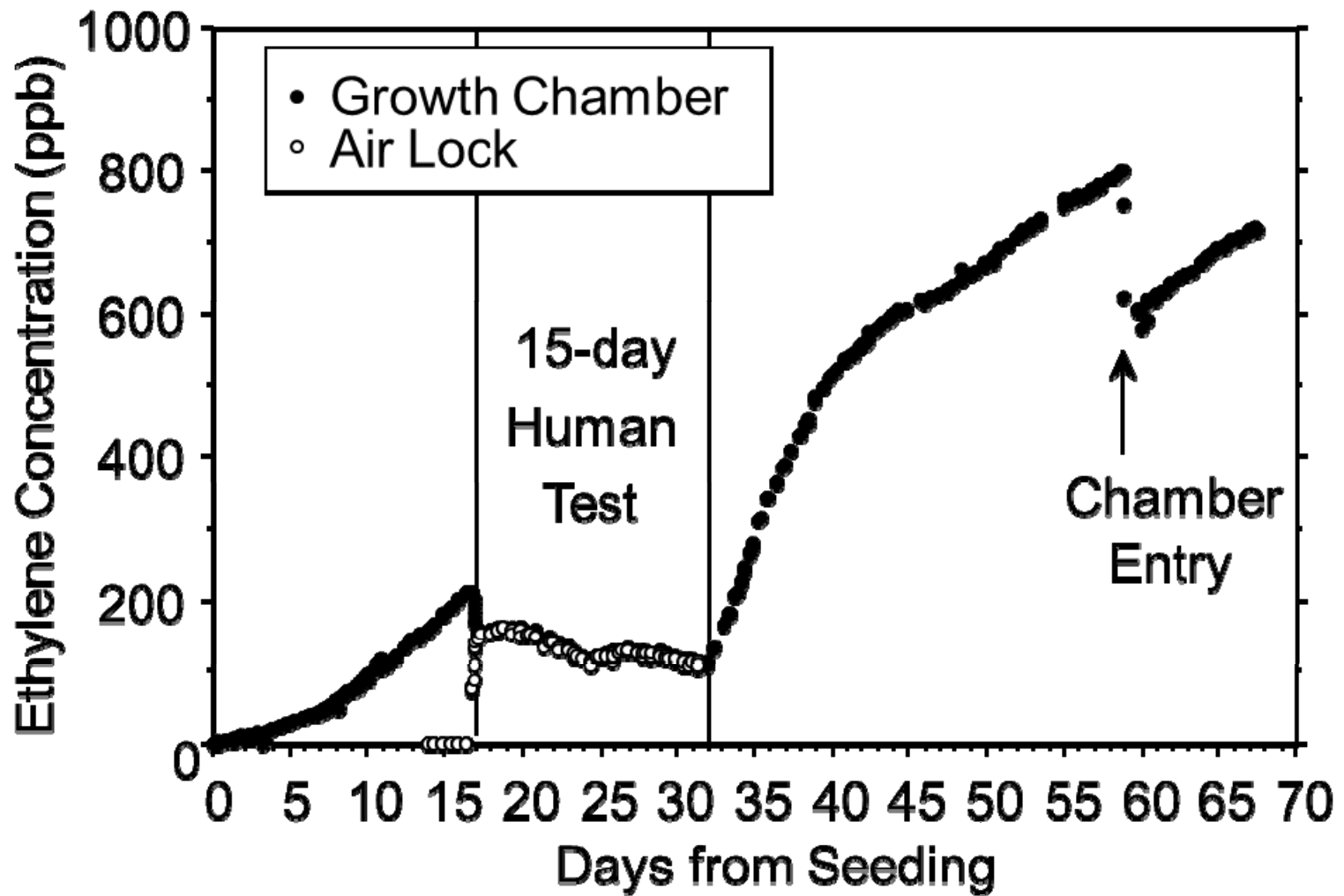


- During the first control period, O₂ production by the wheat exceeded the crew member's respiration requirement. Physicochemical (P/C) systems were used to remove excess O₂ and maintained concentrations below a critical level.
- During the 2nd and 3rd control periods, net photosynthesis (PS_n) was matched to the crew member's CO₂ output and cabin [O₂] slowly fell.



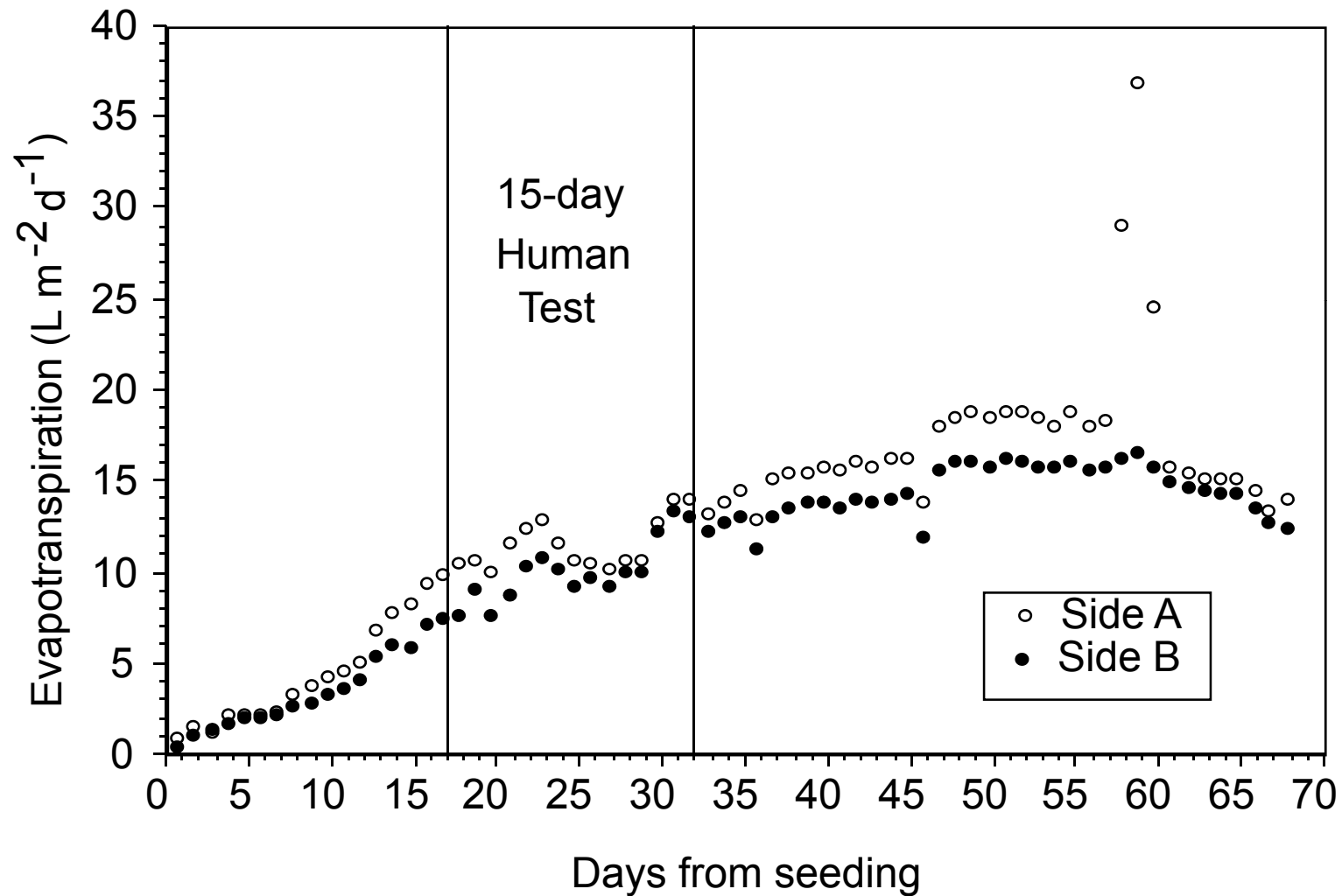
LMLSTP Phase I Test Results

Ethylene Concentration in the Cabin Atmosphere



LMLSTP Phase I Test Results

Evapotranspiration

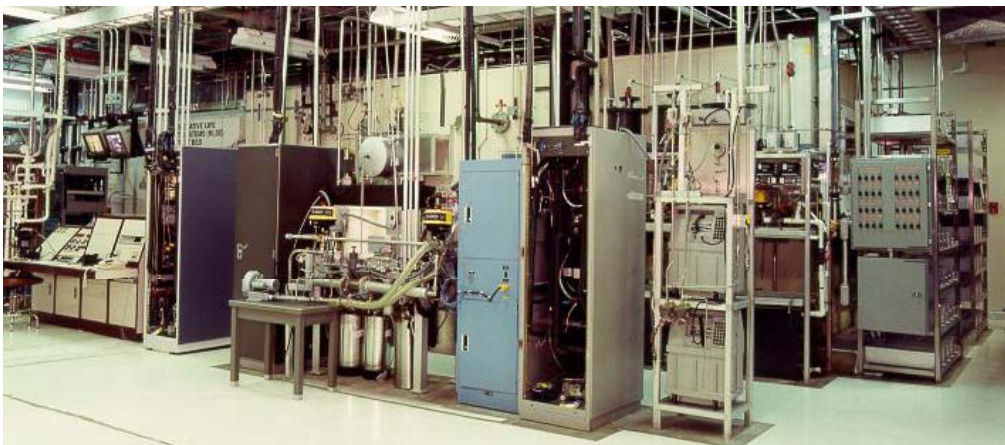


LMLSTP Phase III: Overview

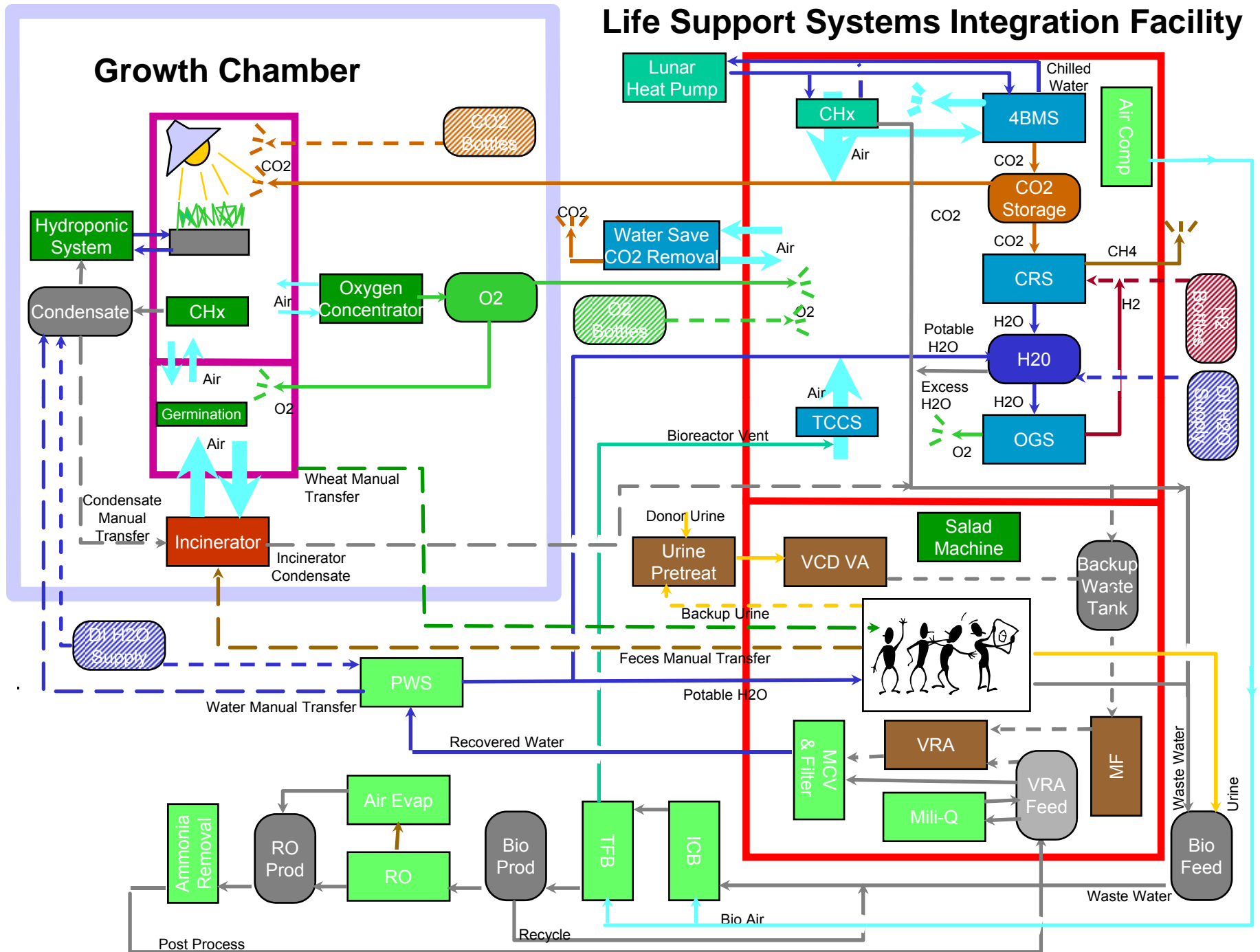


- 4 crew members for 91 days
- Demonstrated an integration of advanced regenerative biological and physicochemical (P/C) technologies for life support.
- Two chamber facilities were interconnected
- Air revitalization System
 - Higher plants compliment P/C systems
- Water Recovery System
 - Microbial cell bioreactors were used for the primary treatment step

- Food System
 - The stored food system was supplemented with wheat grain for bread and fresh lettuce grown *in situ*
- Waste Management System (Demonstrations)
 - Incineration of human feces
 - Biodegradation of plant inedible materials



Life Support Systems Integration Facility



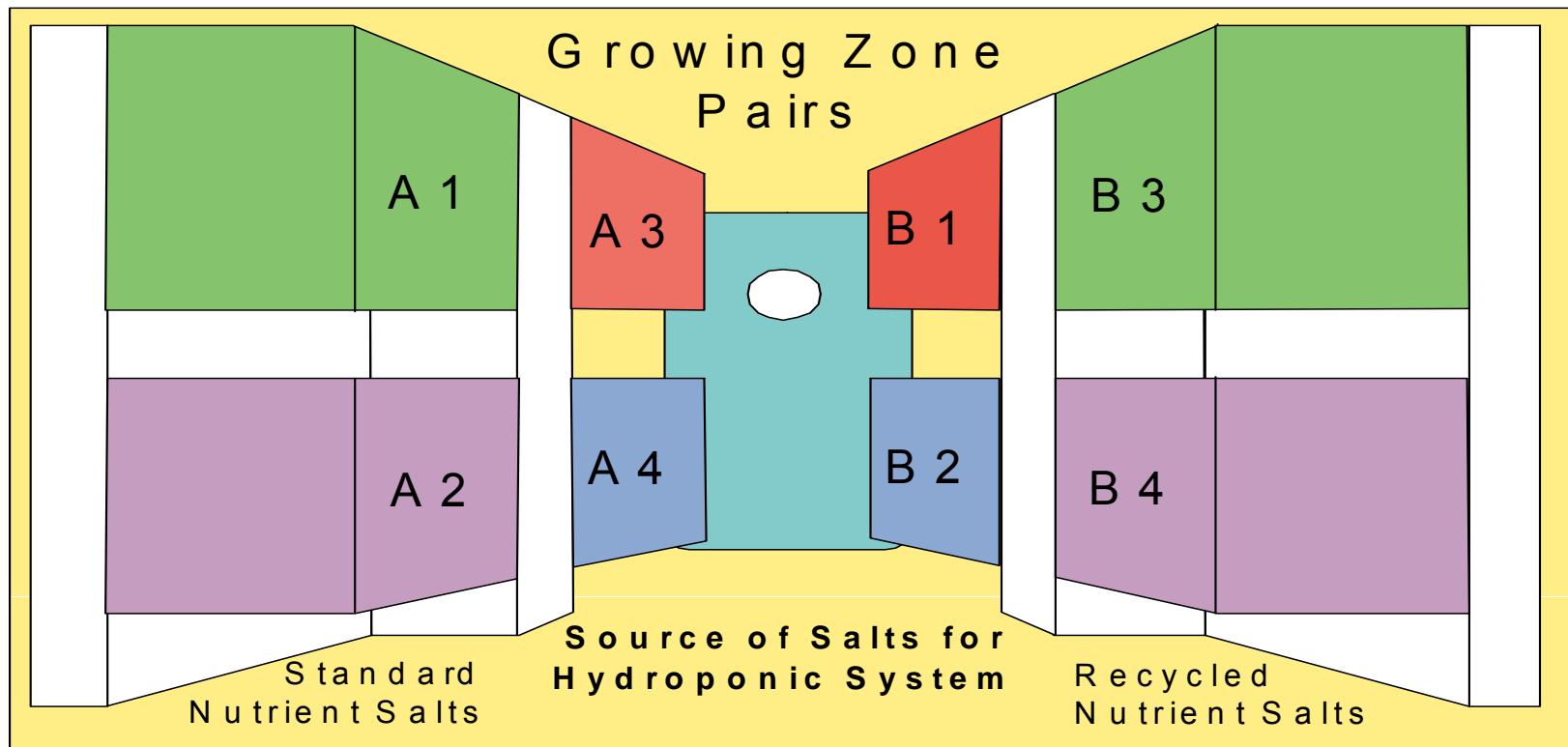


LMLSTP Phase III: Growth Chamber Configuration

The 11.2 m² growth chamber was divided into 2 sides, A and B, each with a separate hydroponic system.

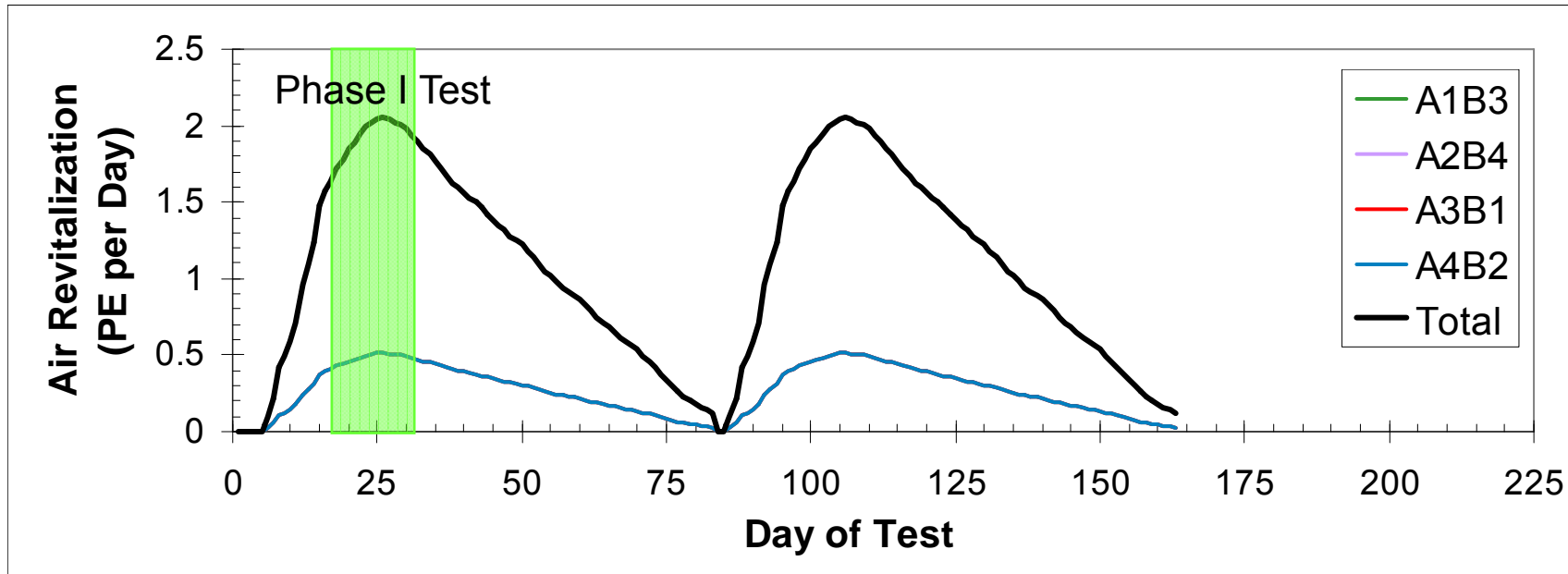
- Side A: standard hydroponic nutrient solution formula
- Side B: nutrients derived from inedible biomass

Each side had 4 growing zones. After the chamber was fully planted, wheat was harvested and re-planted in a staged, serial fashion, in increments of $\frac{1}{4}$ of the planted area, approximately every 20 days.



LMLSTP Phase III:

Predicted atmosphere revitalization with batch cropping

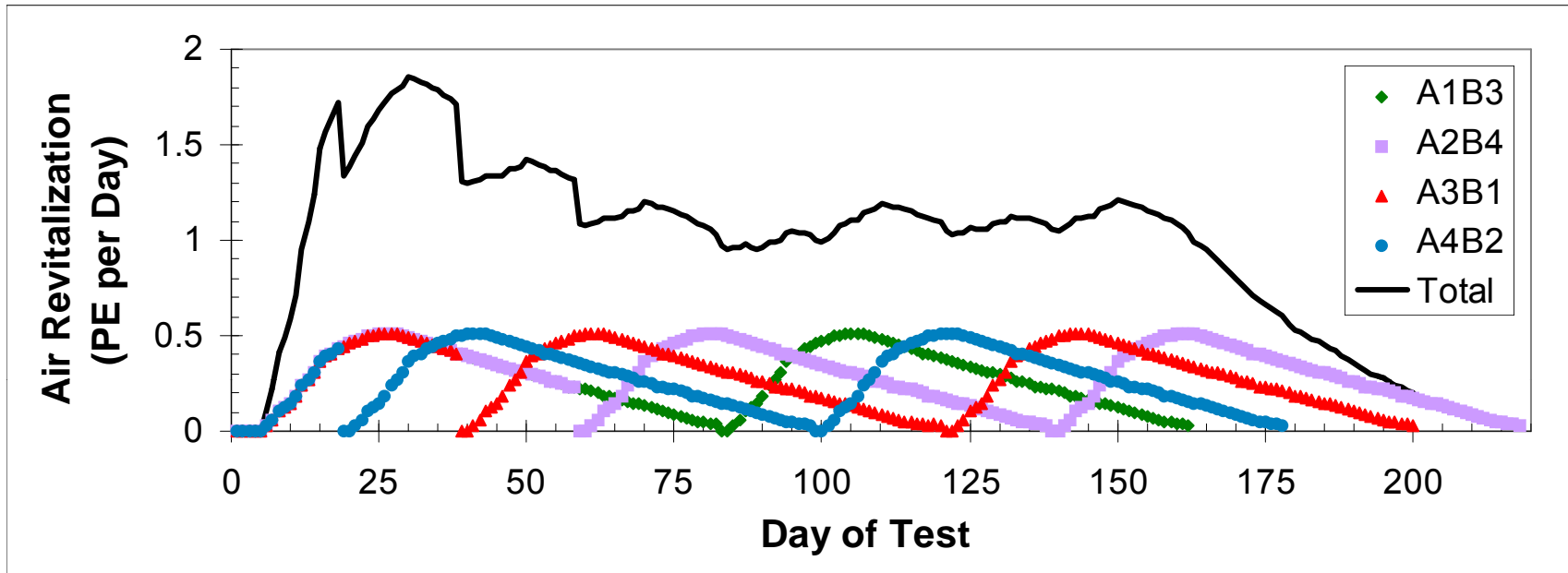


A4B2	83	83
A3B1	83	83
A2B4	83	83
A1B3	83	83

Atmosphere revitalization predicted from CO₂ assimilation from “Apogee” Wheat grown at a PAR level of 1500 $\mu\text{m}^{-2} \text{s}^{-1}$ and a 24 hr photoperiod, given that all four quarters of the growth chamber were planted and harvested sequentially at the same time.

LMLSTP Phase III:

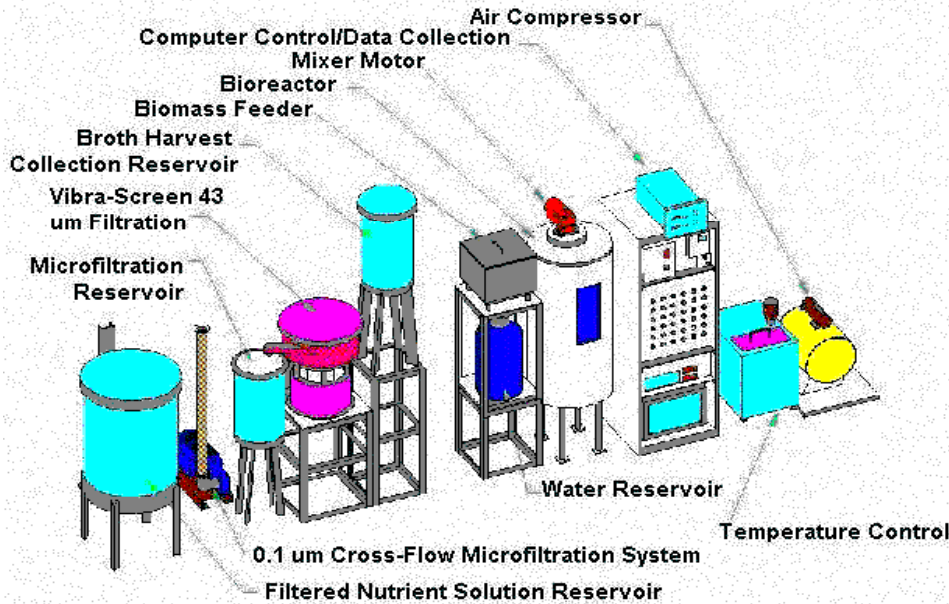
Predicted atmosphere revitalization with staged cropping



A4B2	18	83	83
A3B1	38	83	83
A2B4	58	83	83
A1B3	82	83	

Atmosphere revitalization predicted from CO₂ assimilation from “Apogee” Wheat grown at a PAR level of 1500 $\mu\text{m}^{-2} \text{s}^{-1}$ and a 24 hr photoperiod

LMLSTP Phase III: Waste Management System Demonstrations



Biological Degradation of Inedible Biomass and Recovery of Nutrient Salts

- 1/2 of the wheat's inedible biomass was mineralized using a stirred tank aerobic bioreactor.
- Recovered nutrient salts were returned to the plant growth systems.
- Average degradation of total solids: 45% (≈ 26 kg biomass was treated)
- Average salt recovery: 80%.

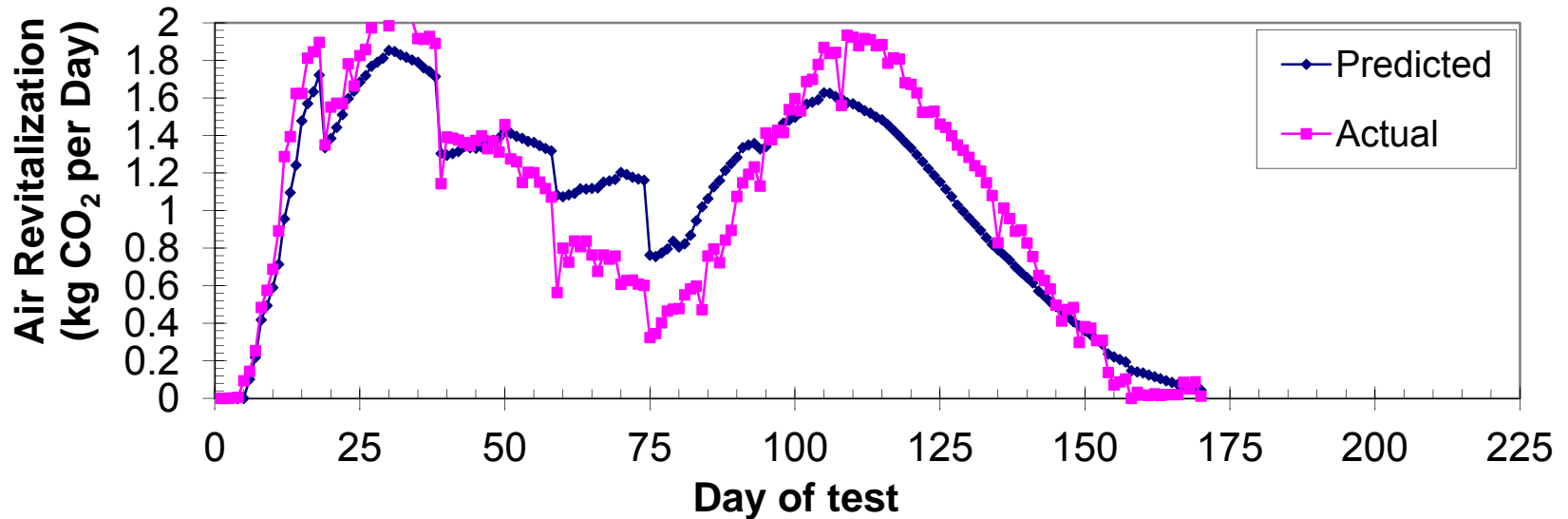


Incineration of Human Feces and Recovery of Carbon Dioxide

- Human feces (8.2 kg total) were incinerated in a fluidized bed incinerator.
- Carbon dioxide exhaust was injected into the wheat chamber after treatment for trace contaminants

LMLSTP Phase III Results:

Actual Air Revitalization (CO₂ Removal) vs Predicted



A4B2	18	78	80
A3B1	38	39	82
A2B4	58	86	
A1B3	79	81	

Actual Planting and Harvesting Schedule Performed

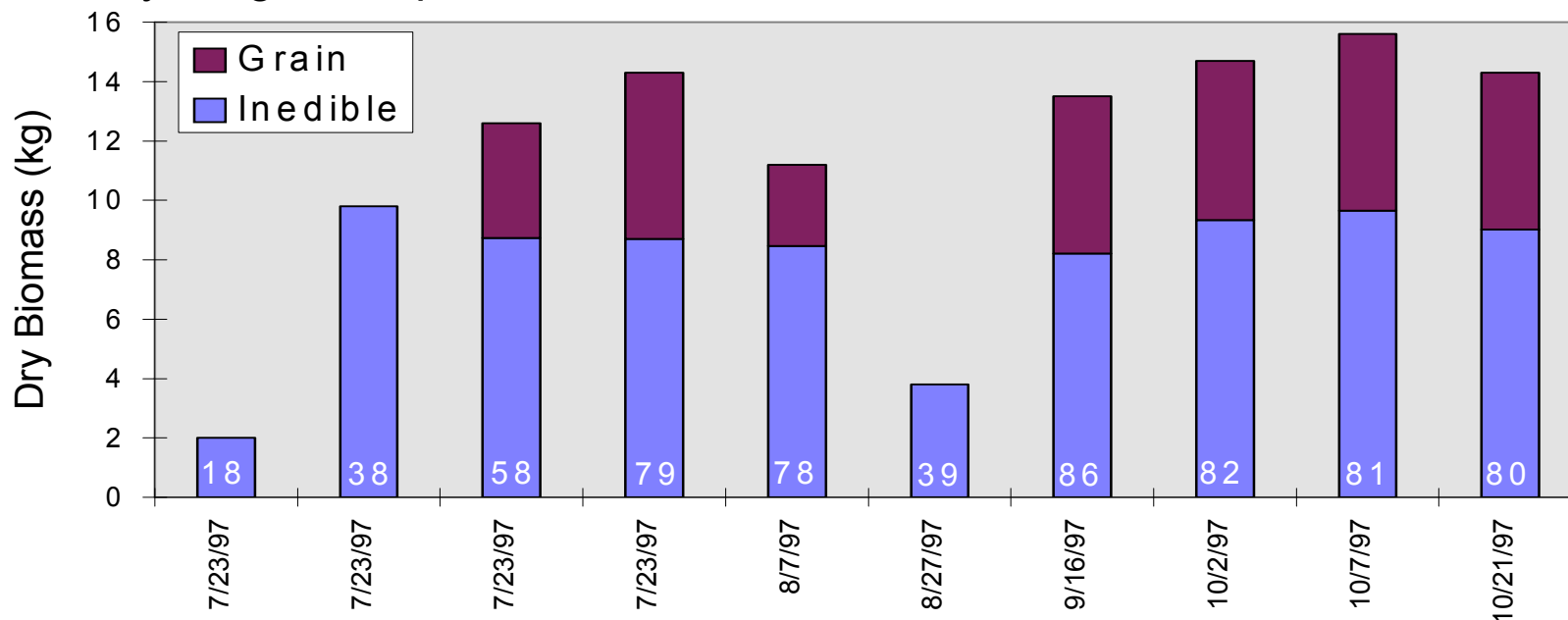
Test Deviations & Anomalies

- To reduce test costs, the last quarter of chamber (A2B4) was not replanted
- Crop nutrient management was inadequate
 - the first crops planted took up excessive amounts of K & P
 - this resulted in nutrient deficiency stress in later crops, with secondary affects on growth, yield and resistance to disease organisms
 - an opportunistic *Fusarium* infection was observed in stressed plants

LMLSTP Phase III Results: Wheat Yield



Yield By Staged Crop



White numbers in bars: Age at harvest Date Seeded

Yield By Nutrient Source	Mean Grain Yield		Harvest Index
	(kg)	(kg m ⁻²)	
Side A (Pure Salts)	10.48	1.87	36.5
Side B (Biologically Recovered Salts)	11.4	2.03	38.8
Total Chamber	21.88	1.95	37.7

Harvested grain was introduced into the Human Chamber to make bread. Fresh bread was baked every 5 days.

LMLSTP Phase III Results: Lettuce Production System



- Lettuce was grown in a small growth chamber located within the crew living space.
- The chamber contained a 0.22 m² growing area illuminated with light emitting diodes (LEDs) providing 189 $\mu\text{mol s}^{-1} \text{m}^{-2}$ photosynthetic photon flux.
- Sequentially planted every 11 days, with 8 harvests during the 91 day-test, 4 plants per harvest
- Average shoot fresh mass per plant was 157 g (5.5 oz) at an average of 31.5 days from seeding
- Average Harvest Index
 - 69% Amount Consumed/Total
 - 83% Shoot/Total
- Average daily rate of make-up water use was 3.18 L m⁻² d⁻¹ for 64.5 total liters



Prime Farmland?

