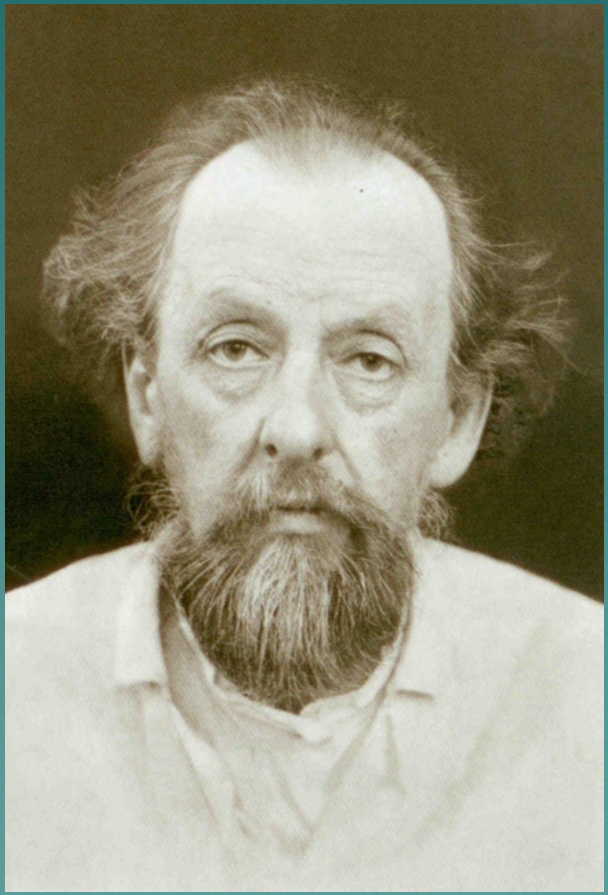
45th Scientific conference dedicated to the memory of

K.E. Tsiolkovsky

Kaluga-town, 2010 September



Conveyer-type cylindrical plant growth units in advanced biological life support systems for space crews

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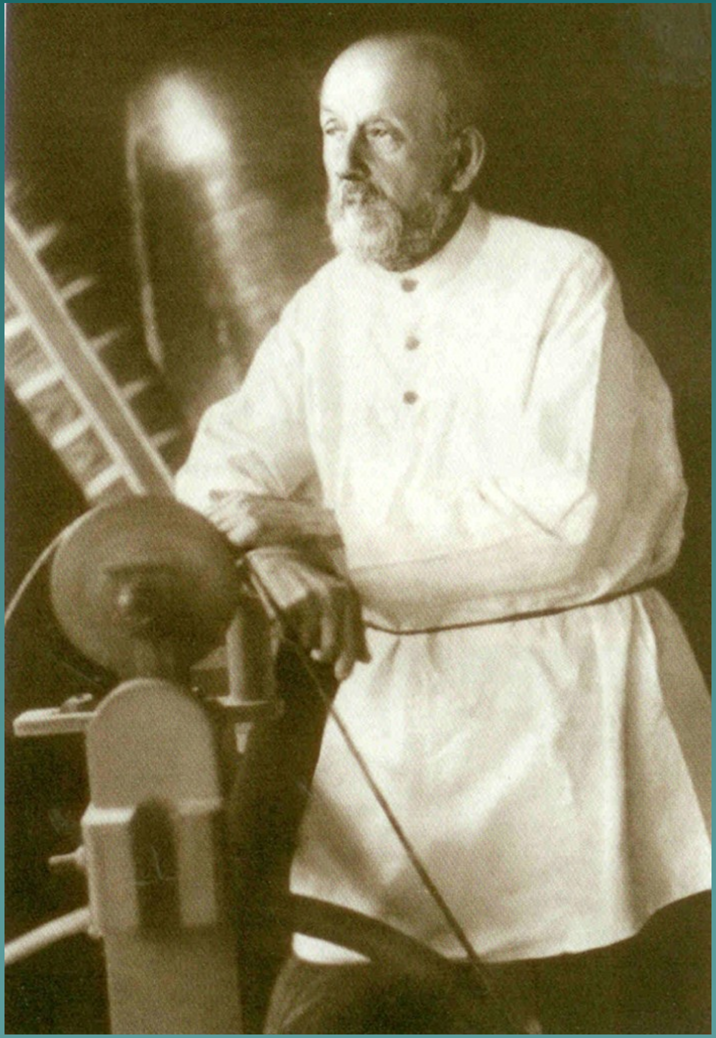
K.E. Tsiolkovsky(1857-1935)

K.E. Tsiolkovsky – a pioneer of Biological Life Support Theory for the Human in Space



1) The Dreams about Earth and Sky. 1895

2) Out of the Earth. 1918, 1920.

3) Goals of Space Flotation. 1929

4) A Life at Interplanetary Environment. 1964 г.

Main K. Tsiolkovsky's ideas in the field of BLSS

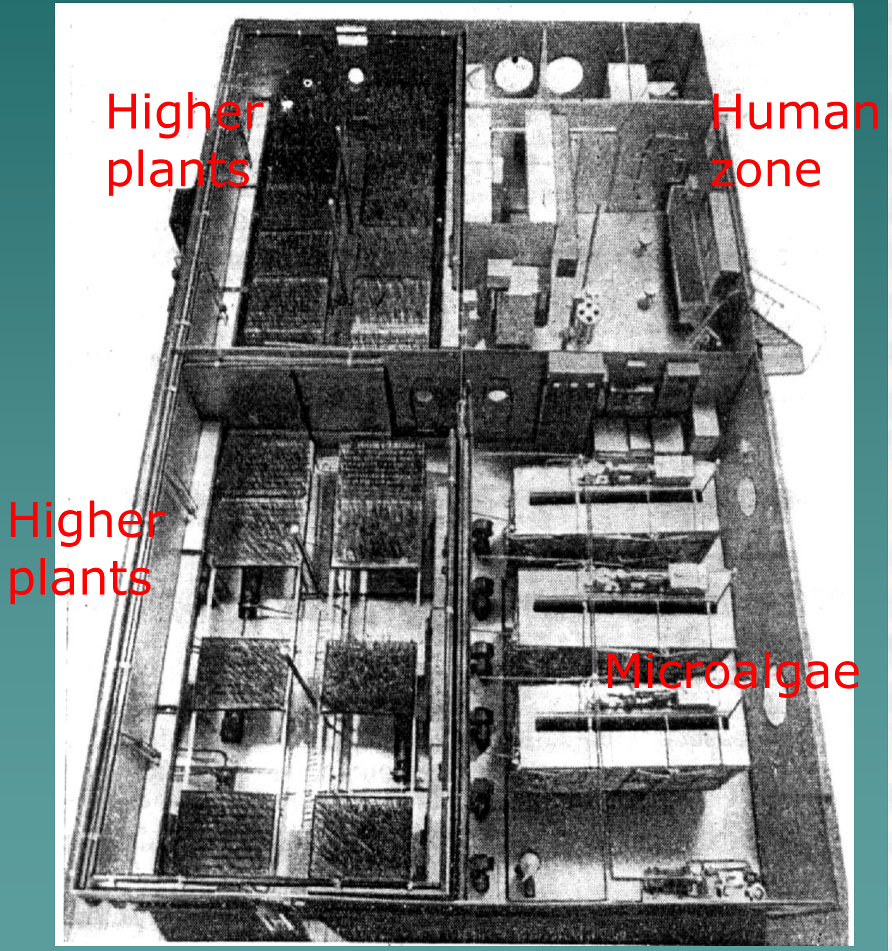
1. Use of plant growth facilities (PGF) for food, water and air regeneration during manned space flight
2. Arrange of the PGF like an outside lodgment connected by tubes with crew habitation
3. Use of spacesuit and lock-chamber for crewmembers visits to the PGF
4. Use of automatically controlled parabolic mirrors for sunlight concentration and delivery to crops through the PGF openings
5. Use of rarefied atmosphere (up to 20 mm Hg) inside the PGF
6. The PGF gas and liquids purification by means of pumping through the soil
7. Regeneration of the plant transpiration water by means of vapor cooling and condensate purification
8. Prevention of PGF soil particles fly away root modules in weightlessness with help of RM rotating
9. Use of cylindrical root modules like a tubes filled by artificial soil with perforations for plant stems which are pumped through by liquid fertilizer and air in the PGF
10. Use of rotating curvilinear conic planting surface with light flow from the cone bigger base for more uniform light distribution inside the crop

Scheme of the BLSS

(I. Gitelson et al., 1975)

(G. Meleshko, Ye. Shepelev, 1996)

Bios-3 structure



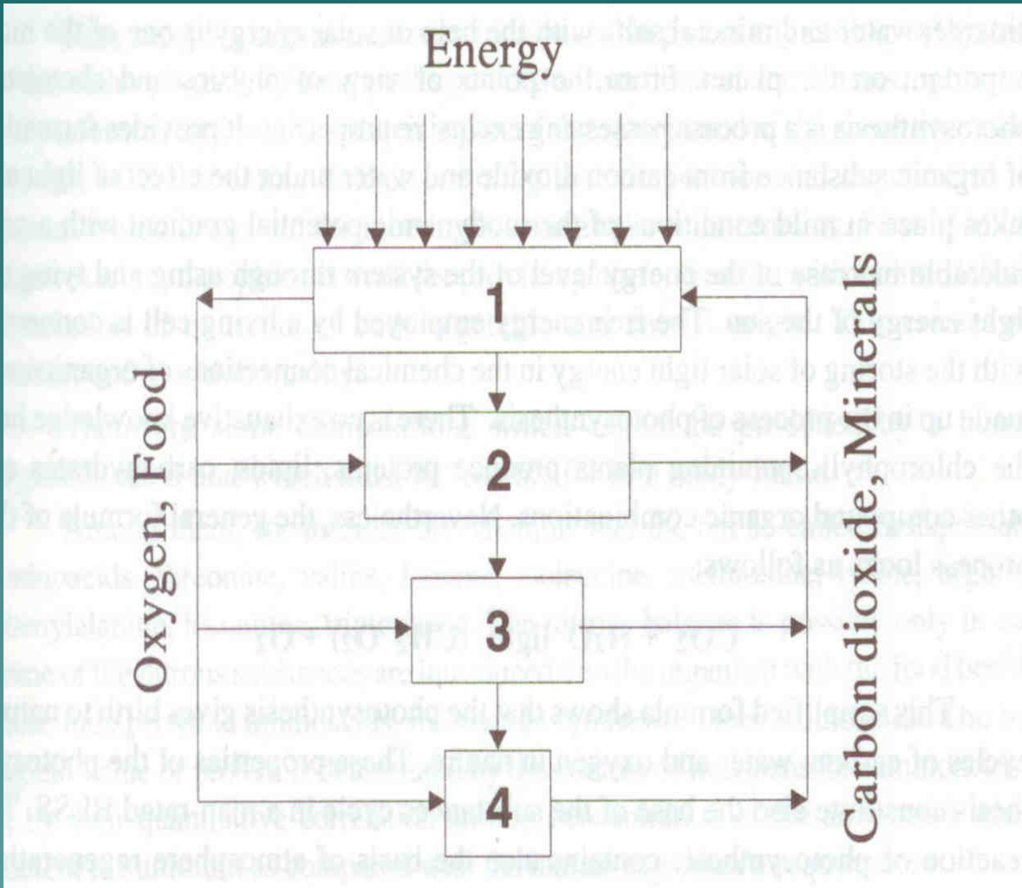
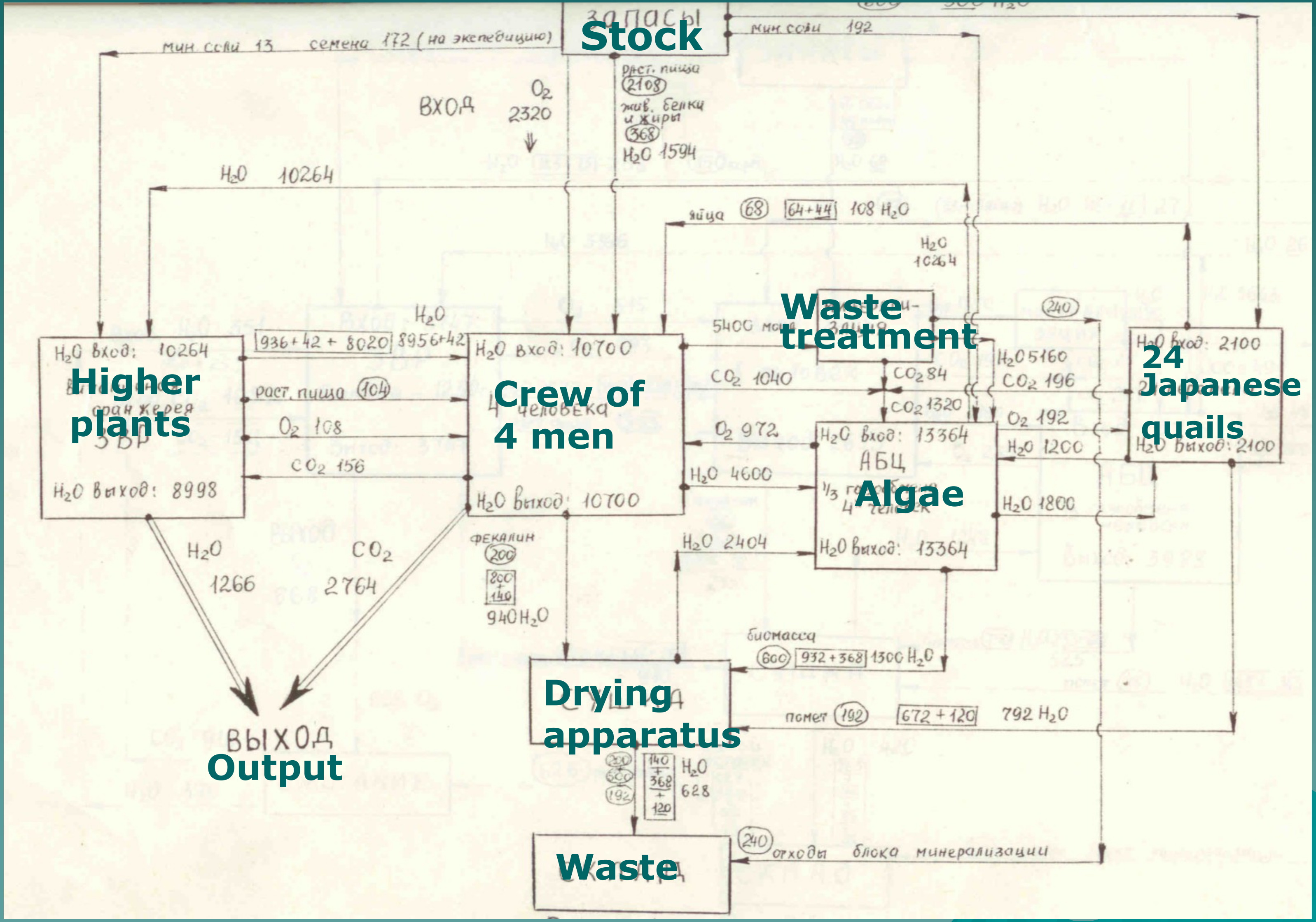
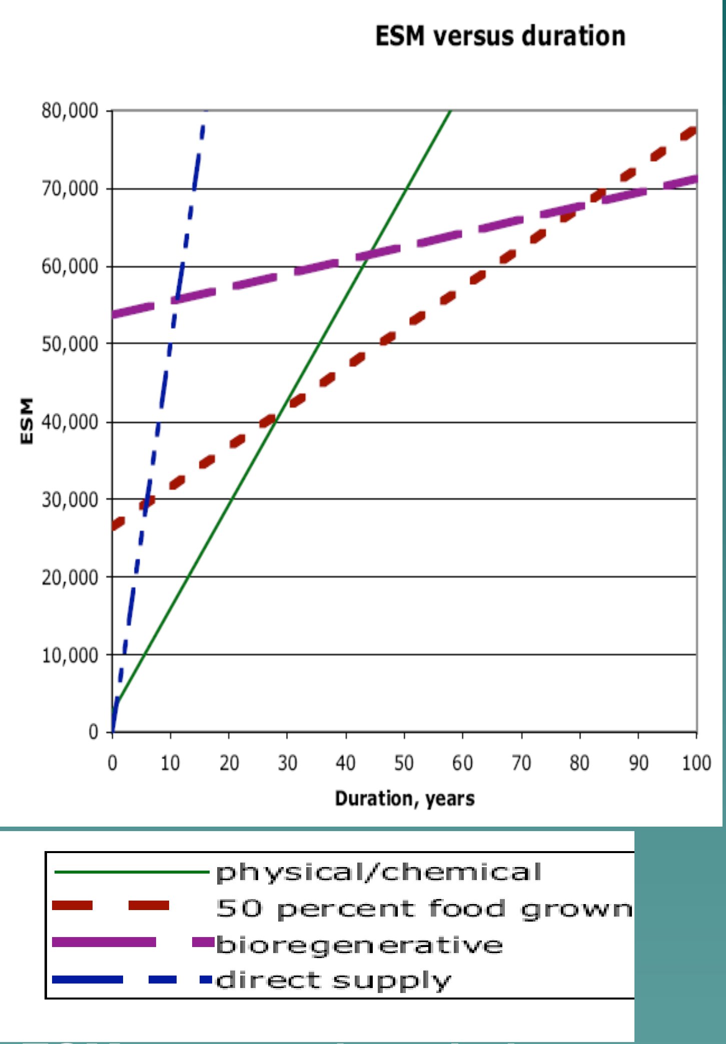


Fig.2. The scheme of autotrophic connections in an ecological system.
1. Photoautotrophic organisms; 2. Herbivorous animals;
3. Carnivorous animals; 4. Microorganisms - mineralizers.

One version of a scheme of Hybrid Bio-physical-chemical LSS with closure of 80% (IMBP, 1990)



Comparison of Bioregenerative and Physical/Chemical LSS (by H.Jones, 2006)



P/C vs. Direct supply, days	50% food vs. P/C, years	100% food vs. P/C, years	100% food vs. 50% food P/C, years	Author, date
		5-7		Choochkhin et al., (1975)
	6	7	10	Gustan et al. (1983)
		4		Gustavino (1991)
131		1.5		Drysdale et al. (1992)
		1,5		Bartsev et al. (1997)
	6	15	30	Hanford (1997)
256	29	44*	80*	Jones (2006)

ESM gauges the relative cost of hardware based on its mass, volume, power and cooling and labor requirements

LSS for Mars Transit Vehicle: how we can elect it?

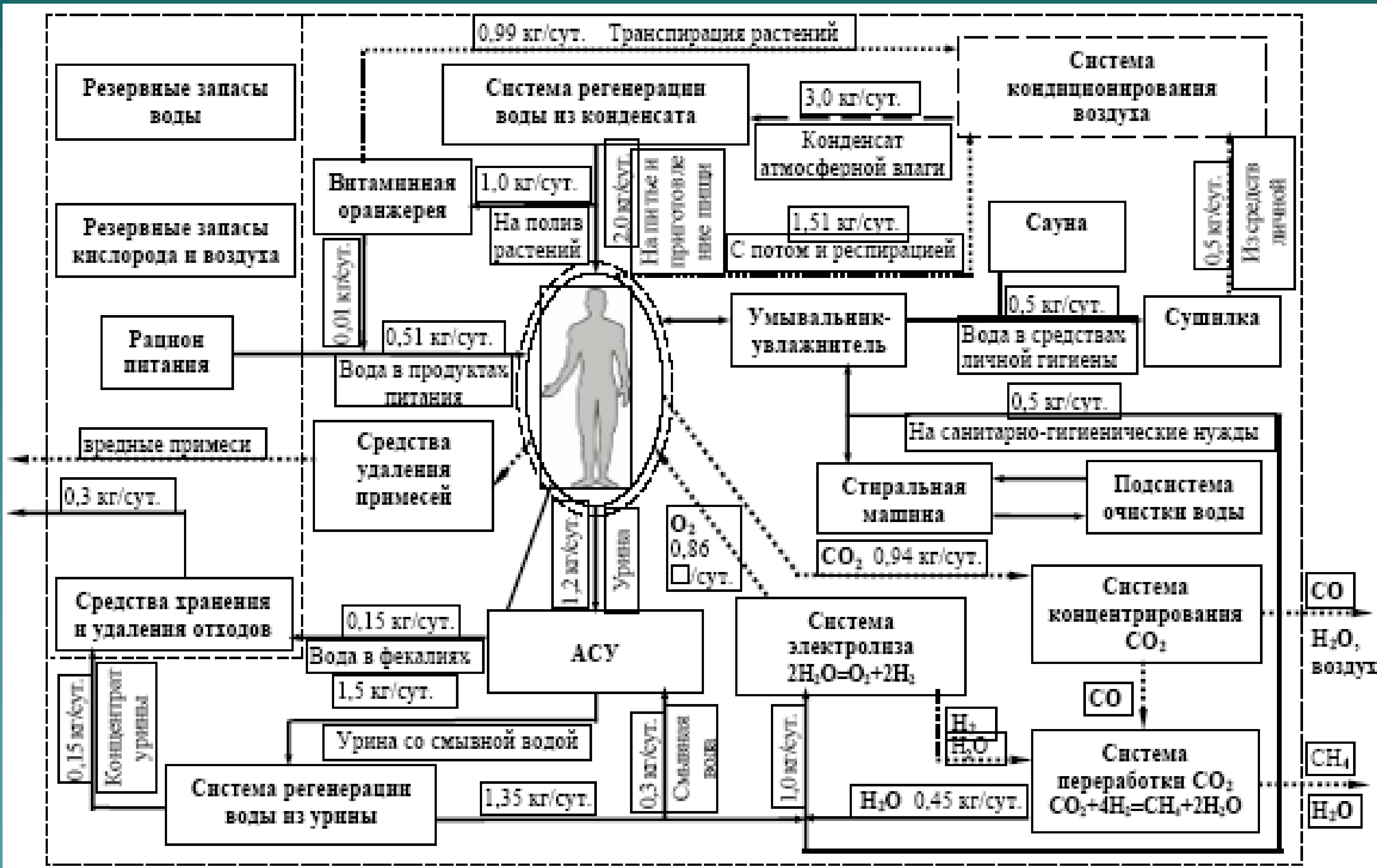
Advantages of open loop physical/chemical LSS with stored foods:

- the simplest design
- high readiness
- high reliability
- the lowest ESM for the first Martian mission

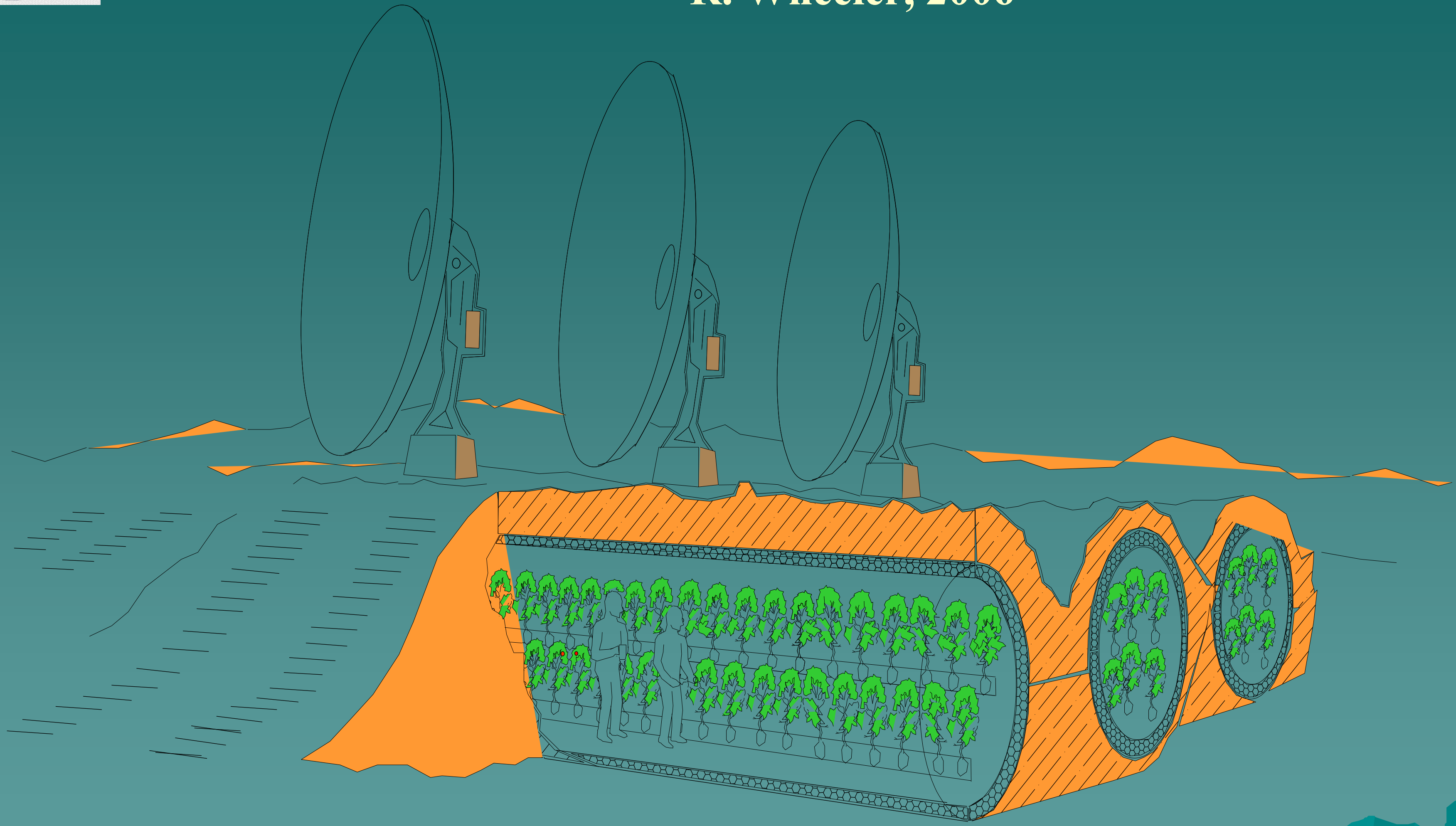
Advantages of physical/chemical LSS with Vitamin Plant Growth Facility:

- improvement of the crew diet with assumable vitamins and minerals
- enhancement of the diet with fresh vegetables
- emotional uphold to the crew
- reduce of free time surplus for crewmembers

Structural scheme of LSS for habitable module of interplanetary vehicle (Romanov et.al., 2007)



Use of PGF like an outside lodgment with spacesuit and lock-chamber for crewmembers visits
R. Wheeler, 2006



It had been investigated in NASA projects:

BIO-Plex and Advanced Life Support Systems Integrated Test Bed (ALSSITB), 2000-2005

Use of automatically controlled parabolic mirrors for sunlight concentration and delivery to crops through the PGF openings

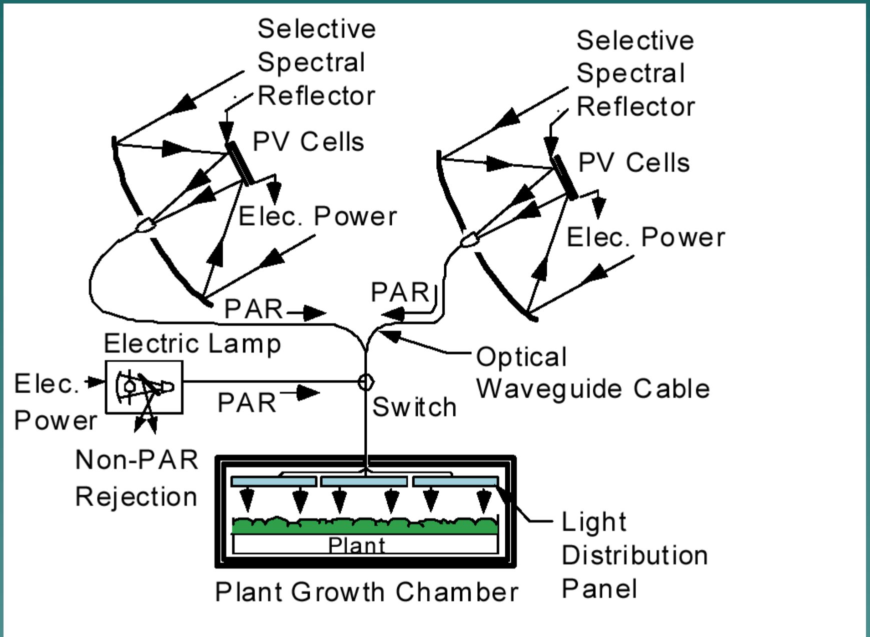


Figure 2. The optical waveguide (OW) solar plant lighting system for simultaneous PAR transmission and PV power generation.

Physical Sciences Inc.

(T. Nakamura et al., 1999-2002)

The University of Arizona, USA

(Cuello et al., 1998-2001)

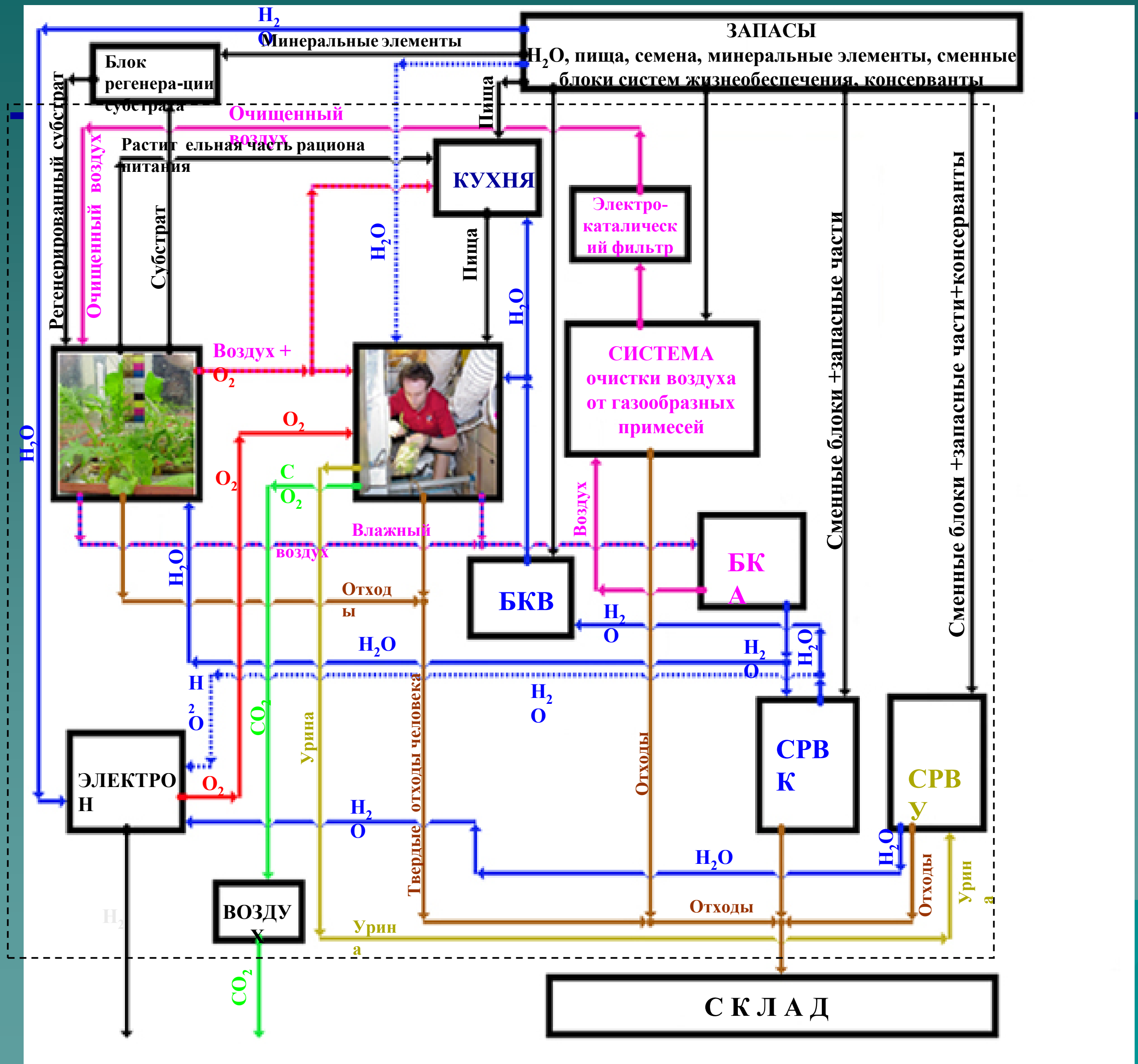
Use of rarefied atmosphere inside the PGF

1. Yu. Berkovich, B. Grishaenkov et al., 2 weeks wheat crop vegetation inside closed chamber with O_2+CO_2 atmosphere, pressure (CO_2 – 0,3 kPa, O_2 -20 kPa), without $\mathbf{N_2}$. USSR, IMBP and Dnepropetrovskiy Politechnical University, 1982.
2. H.J. Brinkjans et al.,7-days tomato crop vegetations inside closed chamber with air pressure of 40 kPa. Technical University Berlin, 1992.
3. V. Rygalov et al., full cabbage vegetation inside closed chamber with air pressure of 10 kPa (CO_2 – 1 kPa, O_2 -6 kPa, water vapor - 3 kPa). NASA Kennedy Space Center, 2000-2003

The PGF gas and liquids purification by means of pumping through the soil

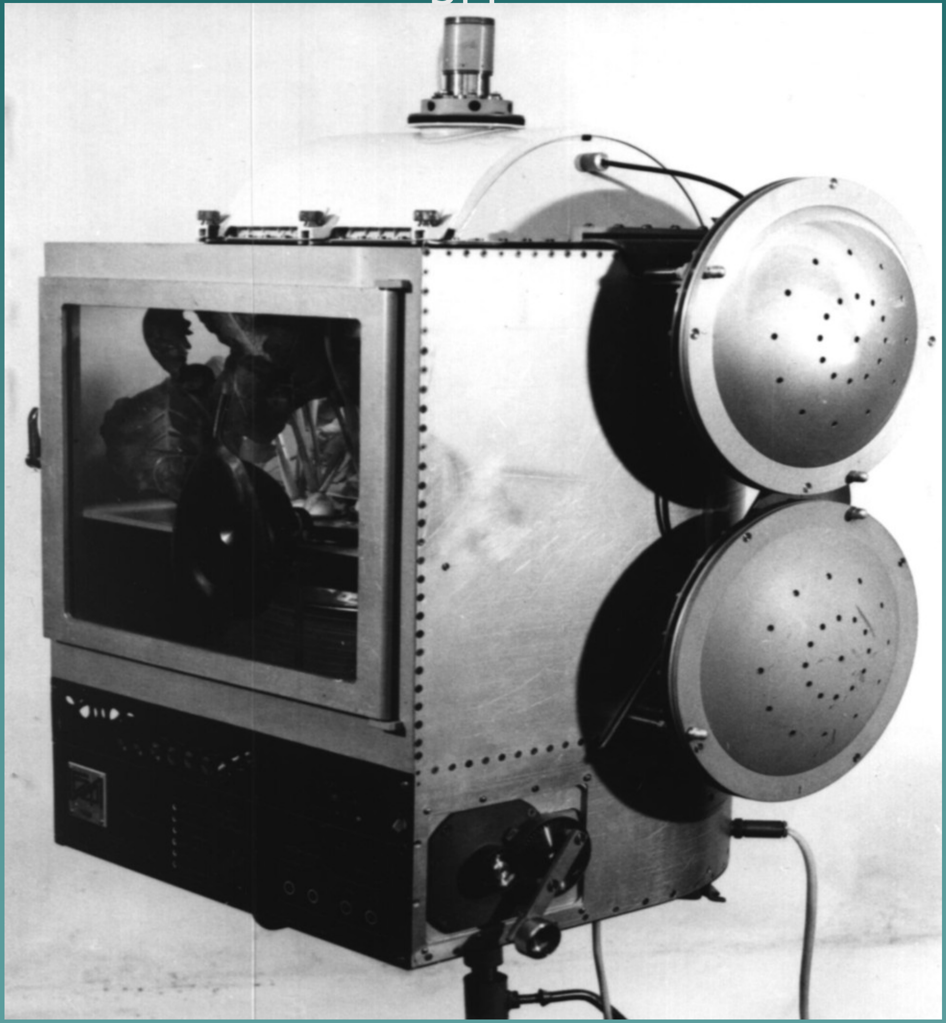
Biosphere-2

Regeneration of the plant transpiration water by means of vapor cooling and condensate purification



Prevention of PGF soil particles fly away root modules in weightlessness with help of RM rotating

Vitamin PGU prototype "Karusel 3M"



Made in

Institute of Biophysics,

Krasnojarsk-town,

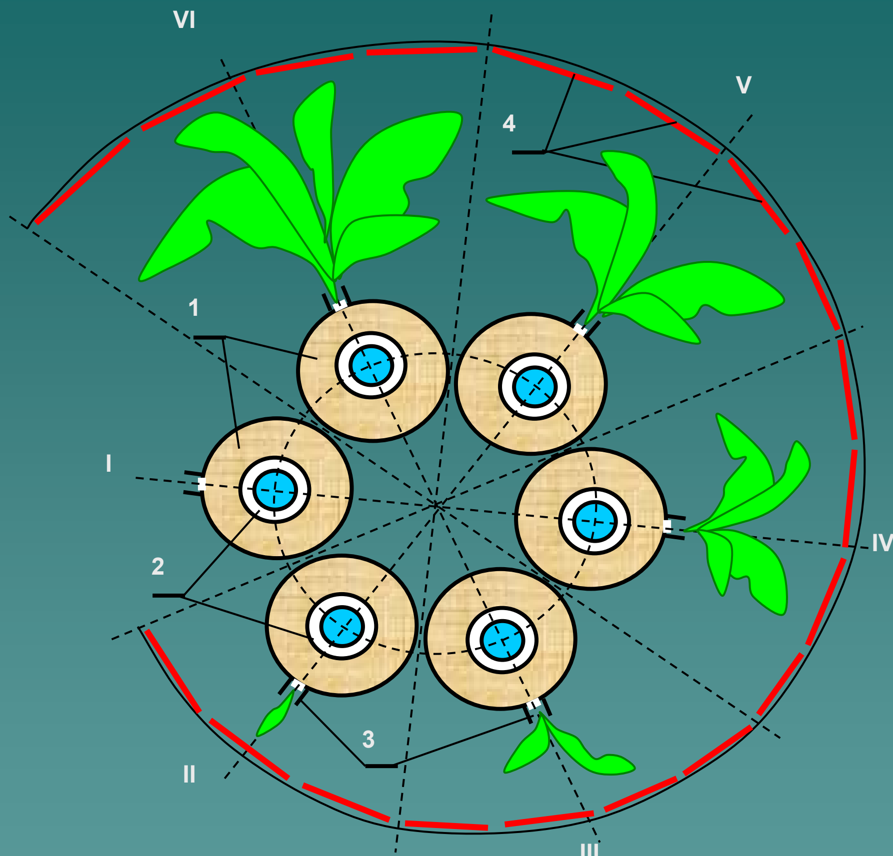
USSA, 1981

Use of cylindrical root modules like a tubes filled by artificial soil with perforations for plant stems which are pumped by liquid fertilizer and air through

Cylindrical root modules with a fibrous ion-exchange mineral-rich artificial substrate BIONA-B3

Use of curvilinear planting surface for more uniform light distribution inside the crop

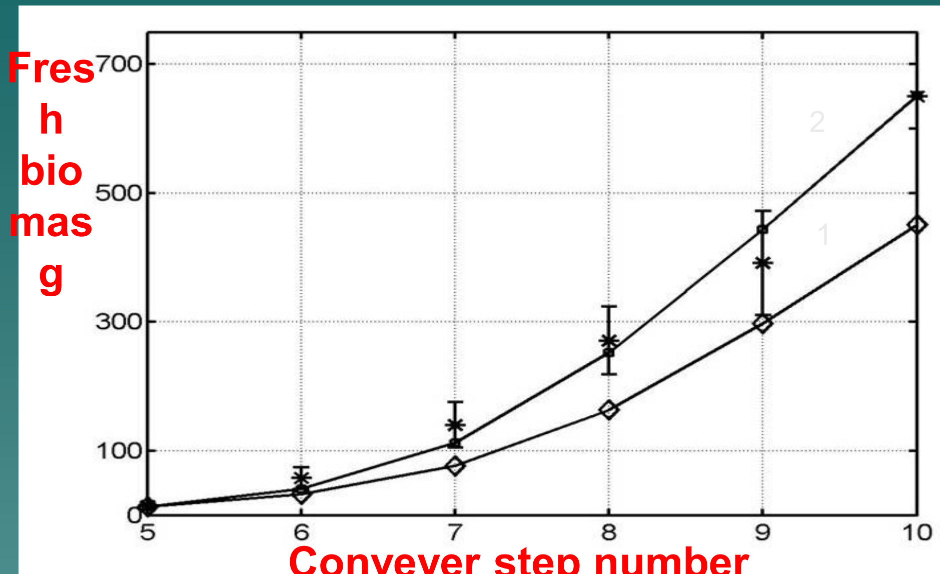
A Cylindrical Conveyor-Type PGF cross section schematic

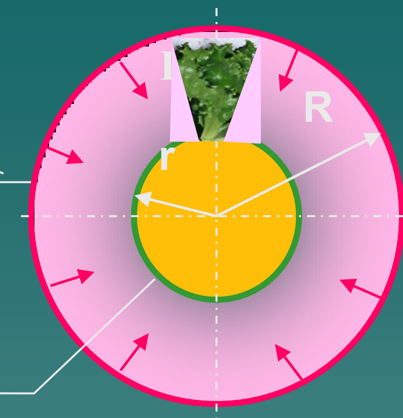


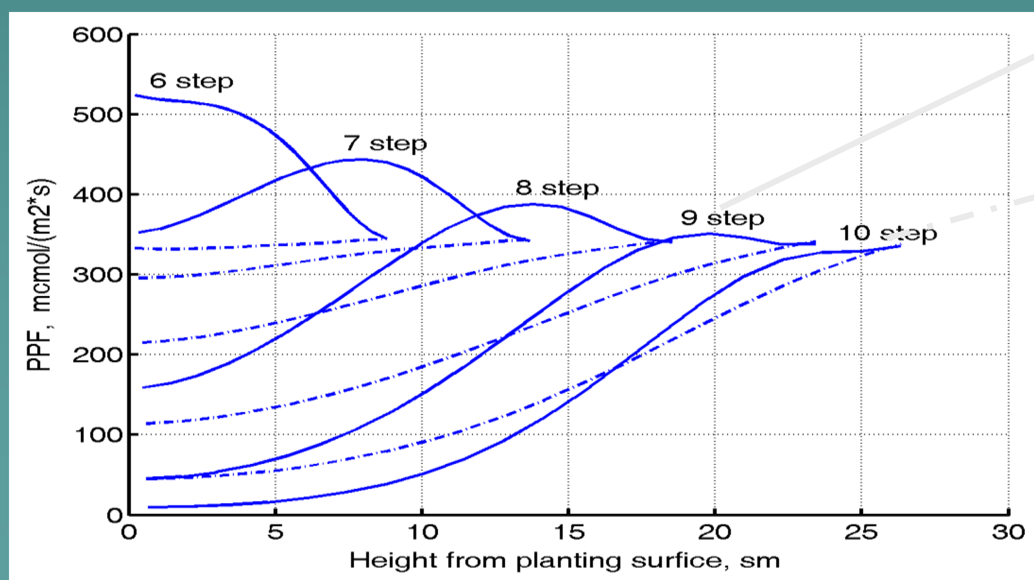
The system had been patented at IMBP in 1997

1 – root modules; 2 –porous tubes; 3 –planting slots; 4 –LEDs panels; I - VI – the conveyer steps.

Calculated light distribution inside the conveyer-type crops and productivity







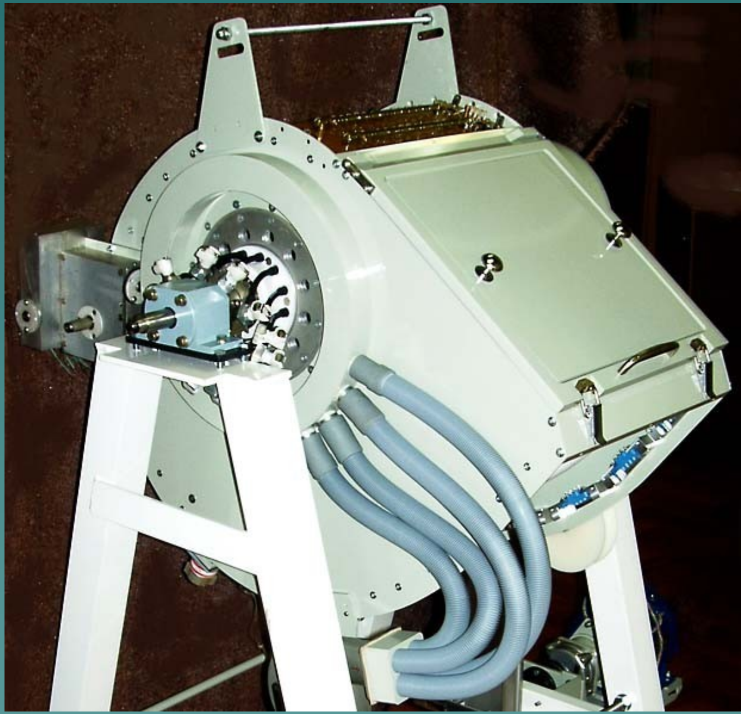
Advantages of Cylindrical Conveyor-Type PGFs

- Cylindrical form provides 50% more specific productivity per unit volume and approximately 30% more specific productivity per unit of energy consumption in comparison to other known space PGFs.
- This system provides fresh salad every few days, excluding power consumption to preserve biomass and vitamin degradation and therefore would be a advantageous source of vitamins for the crew.
- Planting and harvesting, and replacement of used root modules are performed in one and the same position at the salad machine window in order to reduce man-hours and mechanize, if necessary, these manipulations.
- Water and air handling units are compatible to ISS LSS units thereby decreasing maintenance and spare parts.
- Overall PGF dimensions conforms to ISS hatch openings allowing for easier transfer and movement through the cabins.

Phytoconveyer growth chamber

Components of the plant growth facility:

- plant growth chamber (PGC);
- root module unit (RMU) with seed strips;
- lighting unit (LU);
- substrate moistening and airing unit (MAU);
- monitoring and control system (MCS);
- base frame with a reverse drive.



The root module unit and the lighting unit are mounted inside PGC;

the substrate moistening and airing unit and the monitoring and control system are individual remote units connected to the PGC with electric cables and hoses with hydraulic bayonet connectors

PGF "Vitacycle" performance data

Parameter, unit	Value
Dimensions, m: length max diameter	 0.7 0.75
Planting surface, m^2	0.3
Lighting surface, m^2	0.8
Growth chamber volume, m^3	0.2
Root modules number	10
Lighting	LEDs: red (660nm) - 90%; blue (470 nm) – 10%
PPF at a distance of 4 cm away from LEDs, µmol/(m^2s)	350 45
Power consumption, kW	0.5
Average productivity, g/day	215 17

It is able to supply 80% vitamin C for 2 crewmembers and 100% vitamin A for 4 crewmembers

Conveyer-type cylindrical PGF "Vitacycle" inside Mars transportation vehicle model during MARS-500 experiment

Conclusions

1. K.E. Tsiolkovsky's ideas devoted to BLSS lead us to the practical use of PGF for space crews life support.

2. Similarly to the "Phytocycle-LED", the conveyor-type cylindrical PGF will raise by 30% the specific productivity per a unit of power consumption, almost twice per a volume unit, and will significantly reduce labor expenditure on maintenance as compared with the plant growth chambers with the flat planting surface.

3. It is important to continue efforts for application of Tsiolkovsky's ideas in the field of increase of space PGF subsystems effectiveness and competitive ability.

Thank you for attention!