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BIOSS: REGENERATIVE ECLSS SYSTEM BASED ON ACCELERATED PLANT GROWTH AND PROCESSING OF ORGANIC WASTE

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Abstract

Closed-loop RECLS system for long duration missions: It will be necessary to include all output elements back into the system for long-duration missions outside of our planet. The goal of having a greenhouse module attached to every kind of mission is to permit long duration missions without the need for cargo resupply.
Accelerated plant growth: The uniform repartition of auxins inside the plant body is realized by rotating the plants around a central axis, this will increase their growth rate. Installing those drums in a yet bigger centrifuge, in micro-gravity allows the plants to detect gravity and therefore increase their auxin repartition.
Worm composting of organic waste: Human waste and non-edible parts of plants will be used as compost for the plants, closing the loop on the system. After processing by the worms, the material will go through UV irradiation to become a growing medium for the plants.
Keywords: RECLSS, plant, gravitropism, compost, worm, deep space

Nomenclature

biological intensive oxygen and sustenance system (BIOSS)
environmental control life support system (*ECLSS)*
international space station (*ISS)*
regenerative environmental control life support system (*RECLSS)*
micro ecological life support system alternative (*MELISSA)*
organic light-emitting diode (OLED)
omega garden unit (OGU)
big omega centrifuge (BOC)
large omega centrifuge (LOC)
Bigelow 330 cubic meters (B330)
concept of operations (ConOps)

1.1 Introduction to the BIOSS Concept

In the future, long duration missions will require the production of some of the nutrients required by the crew. The volume required and the cost to carry all the dry food to orbit and then to destination will become impractical as the duration of the mission increases. The design of a highly efficient greenhouse is a necessity for the expansion of humankind into space. The food produced will be restricted to vegetables and fruits as producing other items such as nuts or meat would require too much space and time.

The future explorers will require the highest possible yield on the minimum area and an efficient yet harmless way to process the biological byproducts of the plant consumption and normal human biological reaction. Multiple solutions have been proposed to get rid or reuse human feces and urine but so far they have deliberately ignored the processes that naturally occur on planet Earth.

The BIOS system (biological intensive oxygen and sustenance) aims at achieving those goals of high efficiency while keeping the hardware to a minimum and providing solutions that don't rely on complicated systems but use state-of-the-art elements from Earth that will help partially close the loop of an ECLSS system. Those systems are increased gravitropism and vermicomposting. The first hasn't been studied for fully grown plants yet but the reaction of plants to gravity is extensively described in scientific literature [6]. The second has been studied many times and it proves to be the most efficient and safe way to process human waste.

The goal to have a fully closed-loop life support system is almost impossible to achieve but we can minimize the quantity of consumables to transport with each mission (mostly food) and reduce the amount of human waste that needs to be stored, this solution proposes to recycle most organic byproducts of human activity and plant consumption and use these products to enable and enhance plant growth.

Adding modules that contain that system to a spacecraft or to an off-the-earth base will be a necessity in the future and multiple evolutions of this concept are possible but we will limit the scope of this study to a maximum of 6 crew members and two different modules.

1.2 Design Parameters and Mission Requirements

To evaluate the size of the equipment needed for a crew of 6 we first need to establish what the inputs and outputs are. The crew size will be defined as 6 humans having the same characteristics, body size, training, sex etc. We will establish a baseline for one standard crew member and multiply the numbers by 6. Variation in size and therefore needs will not be discussed in this study but the results can be interpolated.

A human body requires every day, 2200 calories, 0.919 kg of oxygen and 3.85 kg of water, it produces, 0.13 kg of fecal matter, 1.083 kg of carbon dioxide and reject 1.957 kg of urine, perspiration and respiration also produces 1.9 kg of water [1]. With those numbers in mind we can start sizing the system, each chapter will detail the right amount of material and area for a crew of 6.

It is important to understand that all the material needed to grow and recycle the biomass will have a cost to launch, we can get the basic logistical principle for a BIOS system as follow:

- You need at least 2 BOCs per crew member
- We estimate the mission to have 6 crew members
- A normal mission without a RECLS system will recycle O_2 at a rate of 75%, H_2O at a rate of 90%

and of course no food could be recycled (with a state-of-the-shelf ECLSS system)

- A 6 person mission would need 1.2 kg of water, 1.23 kg of air and 10.9 kg of food per day
- The total weight of the equipment for 12 BOCs is 5909 kg (5808 kg with a 1.1 factor for spares) and 101.2 kg (92.1 kg with a 1.1 factor for spares) for 4 compost machines so total is 6010.2 kg to transport
- If you remove the need for an ECLSS system uniquely recycling the atmosphere you could save 657 kg
- Therefore if we aim to provide for 80% of the diet of the crew, we can calculate at what time such a system would make sense

$$(1.2+1.23+10.9)*525 \text{ days} = 6998.25 \text{ kg} \quad (1\text{-a})$$

$$1.2*520+ (10.9*520)*0.2+ (6010.2-657) = 7008 \text{ kg}. \quad (1\text{-b})$$

That means that right after 525 days, any mission could benefit of a BIOSS and keep benefiting from such a system for as long as the mission needs to be. In term of total weight the advantage of such a system is evident.

The urine will be processed by an equivalent system that is currently used on the ISS, too much urine in the compost can be harmful to the worms and will therefore be kept out of this system [10]. The toilet system will be similar to the one currently on the ISS, except for the shape and size of the feces container, this element will be detailed in chapter 3. On Earth, urine can be mixed to water by a ratio of 1 to 8 to nourish the plants but transport and mixing would be too dangerous in this situation. Therefore a new device will be needed to extract Nitrogen, Potassium and Phosphates and mix it back to the water used for the plants.

Different plants will have different needs and it is assumed that each rotating garden will have a different mix of growing medium, different watering schedules and finally different concentrations of Nitrogen, Phosphate and Potassium in the water, water PH will also be managed.

Temperature and humidity will be a little higher than the regular atmosphere of the station but pressure should be the same, 75 kpa 21% 0_2, 78% N, 1% CO_2 and never above 27° Celsius.

The greenhouse would benefit from a nuclear reactor that would provide continuous and plentiful energy but any other system that can provide a continuous supply of electricity would do. It is assumed that the mission has plentiful energy, those systems are not considered in that study.

1.3 Objectives

This model of greenhouse can be added to any mission and provide for a planned 80% of the crew's diet, this number is also backed by predictions made by the MELISSA project [2].

It is expected that water, oxygen and some amount of food will be shipped to the spacecraft and produced on site in the case of a base. The total closing of a pressure shell cannot be perfect and therefore oxygen and water will have to be resupplied periodically. Food will also have to be shipped but in much smaller quantities because of uncertainties in production and for the simple fact that crew members will want to fill the 20% left of their nutrient requirement with something else (meat, fish..).

We will also compare the different square meters necessary for atmosphere recycling and food production with the numbers obtained by the BIOS-3 experiment conducted in Russia [3].

Most of the production capabilities will be expressed in square meters, this experiment concluded that 63 m^2 of diverse crops (Wheat, Carrot, Onion etc.), would be enough to fully regenerate the atmosphere and also to provide for almost 75% of the food for a crew of 3. Which means that in theory, 21 m^2 of crops should be sufficient per crew. Multiplying that number by 1.07 (80% divided by 75%), we can deduct that 22.40 m^2 should be enough with classic growing methods to sustain 80% of the required food for one human.

Therefore we would need 134.40 m^2 of crops to sustain a crew of 6 but the goal of this study is to improve the growth yield and as a result reduce the required area. One garden unit or OGU should grow approximately 0.67 m^2 of vegetables, fruits and herbs. That number is based off the research done in BIOS-3 and extrapolated by the results that amateur rotating farmers are describing online. A formal research on that technology is planned at the University of Houston.

This paper will detail in the next chapters the two different systems used to improve that productivity.

1.4 Proposed Modules and Timeline

The envelope for the greenhouse will be dependent on the mission but it is assumed that inflatable modules will be used as the volume to house such a system is important.

As of 2018, the best example for such a technology is the B330. It is an independent spacecraft that can sustain 6 crew members for a period of time depending on the amount of storage that will be launched to the craft. You can find more information regarding its design and capability by contacting the Bigelow Aerospace Company.

To understand the general organization of one BIOSS using a B330 please refer to figure 1. For this system the most interesting aspect is that fully deployed, the interior space will be about 330 cubic meters, enough to house 6 LOC, which equates to 150 OGU or

$$1 \text{ LOC}*6=150 \text{ OGU and} \quad (2\text{-a})$$

$$150 \text{ OGU} * 0.67 \text{ m}^2=100.50 \text{ m}^2 \quad (2\text{-b})$$

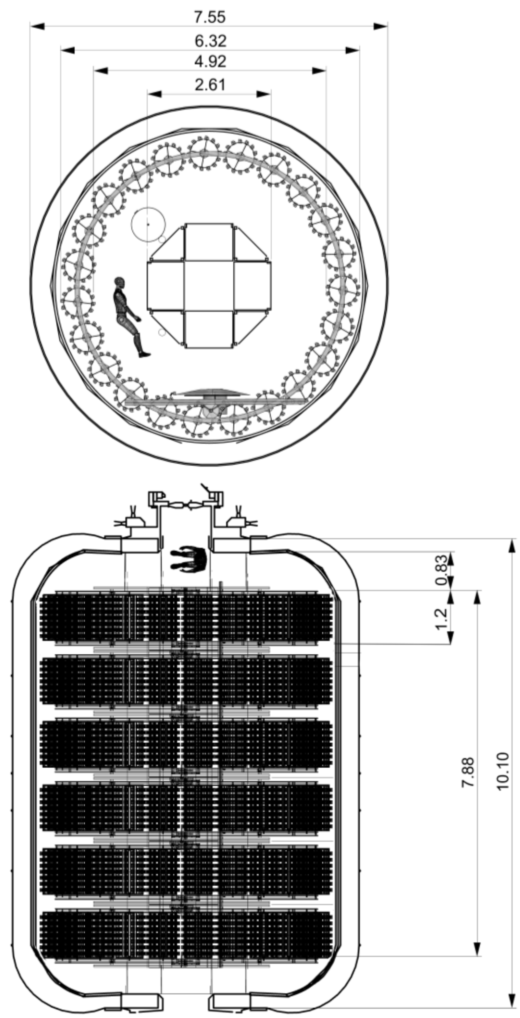


Figure 1. General dimensions and organization for LOC units in a B330 module (expressed in meters)

According to the previous equations, we will have 100.5 square meters of cultivable space, those numbers are to be correlated with the 134.40 square meters necessary for six crew members.

It seems insufficient but in the next chapters we will explain how this area is ample with the different optimization techniques employed.

The other configuration will be in the shape of a torus and will combine the advantages of a solid shell module and the ones of an inflatable. This kind of concept has already been studied in the past [4]. The technologies and dimensions for this module are taken from the Columbus module from the ISS and the inflatable technology from the B330. The advantages of such a system are numerous, first you can easily store the BOCs in the central area for launching and then transport them to the expanded volume after deployment. Secondly separation of the growing area and the living/working area allows for a more easily controllable environment. The connection of this module to the central part of a station or a spacecraft is therefore not a problem, we could fit inside

$$1\ \text{BOC}*12 = 144\ \text{OGU}. \qquad (3)$$

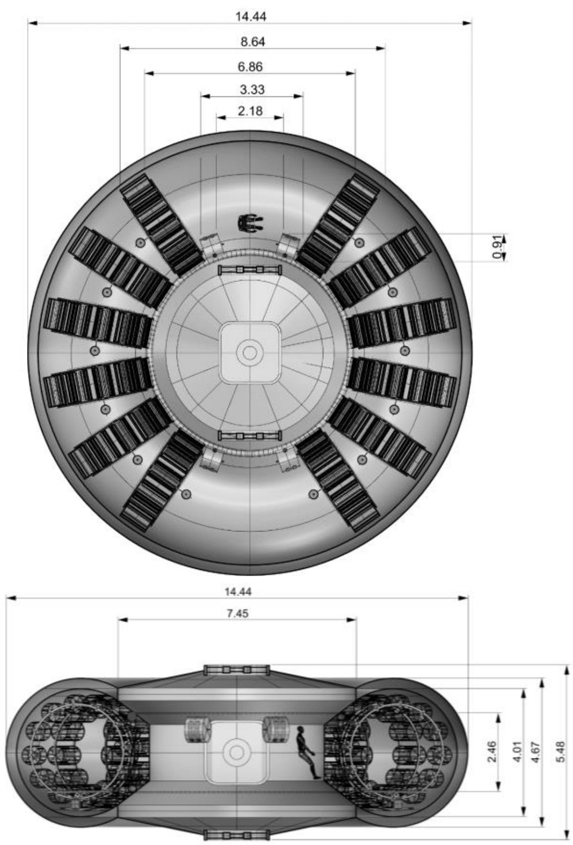


Figure 2. General dimensions and organization for BOC units in a torus module (expressed in meters)

The circulation of the atmosphere will need to be continuous and large ducts and fans will be necessary to circulate the “clean” air and the “dirty” one. The best option for that kind of situation would be to house the module centrally in the base or spacecraft to diminish the size of fans and ducts. The common berthing mechanism represents the best option for transferring gases as it is included in its baseline [5], the international port will evolve in time and should provide for air and fluid transfer in the future but for now it is not the best option.

Again we see that the total area for each crew member is 16.08, well under the 22.4 limit according to the BIOS-3 experiment, explanations will be provided in chapter 2 and 3.

ConOps are based on estimated working times and will need testing on the ground with a mockup to ensure that crew members will not spend too much time taking care of the plants and the compost, partly automated tasks will need to happen after an experimentation phase.

It is estimated that crew members will each have a turn at harvesting, planting and cleaning the OGU, each OGU should have a median growing time of 30 days. Every 30 days, one OGU will need to get serviced, each crew member needs 24 OGUs. Therefore with an estimate of 2 hours for servicing, each crew member will have to spend 48 hours each month in the BIOSS module to feed himself. This number represents only 7 % of the total number of hours in 1 month, it could be argued that maintaining some mechanical ECLSS system would take much more time. These operations will be detailed in chapter 2.

Regarding the volume that it will take to transport and store the BOC or LOC units, after rearranging the unit and all of its elements, it appears that a volume of 2 cubic meters would be enough for the packaged BOC as can be seen in figure 3, we can extrapolate and estimate that a LOC with almost twice as many garden units will be occupying twice the space so 4 cubic meters.

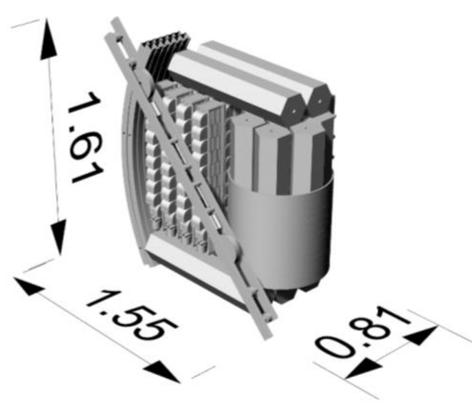


Figure 3. Dimensions of a compacted BOC unit (expressed in meters)

Therefore for 12 BOC units we will need 24 cubic meters, the torus module can accommodate for 125 cubic meters in its rigid center so transport and deployment in one launch should not a be a problem. The B330 in its rigid center will have the possibility to house 40 cubic meters, 6 LOC at 4 cubic meters will equal 24 cubic meters and will therefore easily fit into the central section of the module.

2.1 Introduction to Gravitropism and Augmented Growth Cycles

The augmented uniform repartition of auxin inside a plant body is realized by rotating the plants around a central axis, a centrifuge in its concept. This rotating drum alleviates the need to have a complicated watering system in presence of gravity forces. This system has shown great results on the ground, where amateur farmers increase by 2 their output (compared to regular aquaponic/aeroponic system) they also obtain stronger and more resilient plants. Research will soon begin at the University of Houston to study the effects of such a system but many farmers claim impressive yields using this technique.

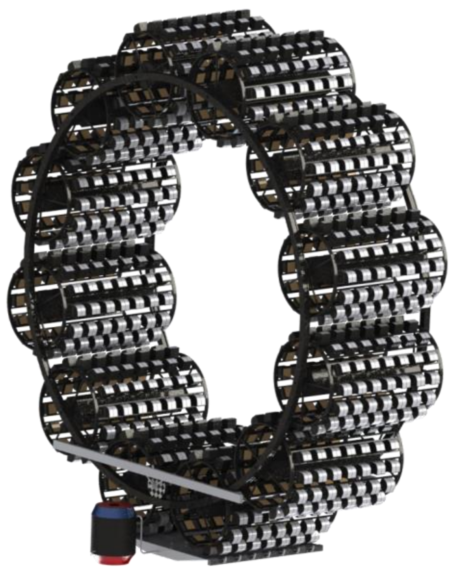


Figure 4. Rendering of a BOC unit

The effect of having mechanical stresses acted on them increases the plant growth and resistance to outside elements such as mushrooms or pest [6].

The growth cycle of the plant can be increased, this simple fact has been proven many times with the use of hydroponics or aeroponics. We can see that with the right combination of nutrients and of course the right growing conditions, plants are able to realize their full potential and thrive.

Another element that was added in recent time is the benefit of nutrients from feces and urine, in the case of aquaponics for example. Recycling of human feces by worms has proven to be reliable and efficient in the past. Worm composting is a natural process that happens every day on earth.

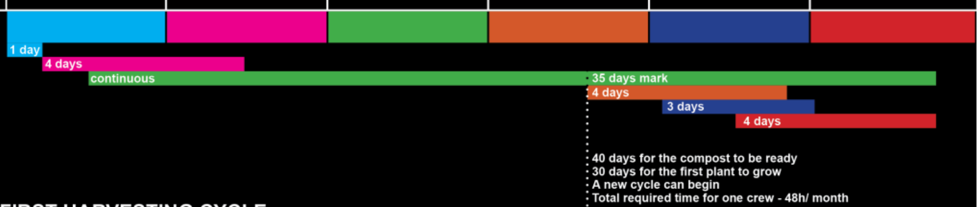
Converting that technique to microgravity and reduced gravity will involve artificial gravity at some point, a rotating apparatus will therefore be needed. A bigger centrifuge that will rotate constantly the smaller OGUs, more details will be furnished in the second part of this chapter.

The operation of the greenhouse will involve multiple parts and systems but the general timeline is described in table 1.

Table 1. Tentative schedule for the operation of the greenhouse

	INSTALLATION	PLANTING	GROWING AND COMPOSTING	HARVESTING AND PREPARATION	CLEAN UP AND MAINTENANCE	SEEDS TRANSFER AND TESTING
ACTIONS	Unpacking Mounting Dry-run Testing Fixing Calibrating	Planting of first germinated seeds Transfert of first organic bags	Routine check on plants growth Routine transfer of oragnic waste bags and monitoring of worms Germination of new seeds	Roots extraction and separation of edible biomass Shredding of first non-edible mass Preservation of worm eggs Preservation of seeds	Microwave processing of vermicast Washing of compost bags Burning of used vermicast	Transfer of germinated seeds in planters Replenishment of growing medium with compost Test of rotating garden
EQUIPMENT	General tools Power tools Sensors Motors	Plant container Base growing medium Germination machine Compost bags	Sensors Compost bags	Gardening tools Shredding machine Cold storage	Clean-up machine Microwave machine Gloves Furnace	Gardening tools Gloves Sensors Motors
DURATION	1 hour per rotating garden 3 hours for bigger centrifuge	3 hours/ crew	3 hours/ month/ crew	15 hours/ month/ crew	15 hours/ month/ crew	15 hours/ month/ crew
LOCATION	All areas	Germination machine Growing areas Compost machines Waste amangement area	Greenhouse module Waste compartment	Greenhouse module Storage module	Greenhouse module	Greenhouse module

DURATION



SCHEDULE FOR FIRST HARVESTING CYCLE

2.2 The Apparatus

Installing those drums in a yet bigger centrifuge, in micro-gravity, allows the plants to detect one angle of gravity force, and to have an opposed reaction to it, therefore activating a repartition of their auxin, experiments with different gravity forces applied on plants proved that plant require a minimum of g forces to develop harmoniously[7]. An OGU will be housed inside a bigger centrifuge (BOC or LOC) that will rotate at different speeds based on the gravity forces applied to the spacecraft at a certain time, figure 5 represents one OGU.

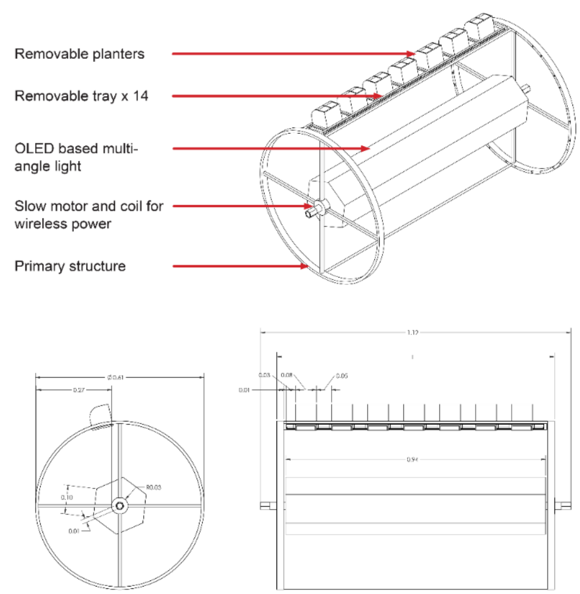


Figure 5. General dimensions and organization of an OGU (expressed in meters)

The rotation rate of the OGU in a 1g setting will be of 1 rotation every 45 minutes. The big centrifuge will rotate at 1 rotation every hour. Those numbers will change with each different situation. Based on recent research, the minimum gravity setting at which plants will react is approximately 0.08g (studies conducted on the ISS have proven that plants will react to a much lower gravity force but we will conserve this force as a measure of precaution) [12], the speed of rotation will then never be higher than 6 rpm for the big centrifuge (considering a 3.25 m diameter for the BOC), figure 6 represents one BOC unit.

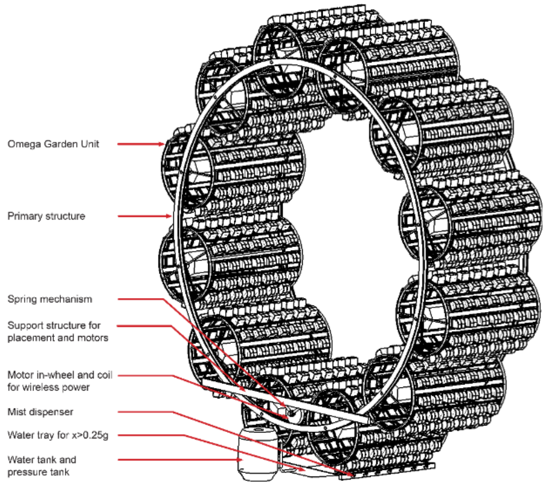


Figure 6. Diagram of a BOC unit and its multiple elements

The water distribution system will also be dependent on the gravity setting, since water acts differently with each situation, capillarity will be a stronger component in a micro-gravity setting and the choice of a wick system for the plant container is therefore an important design solution, please see figure 7 for the configuration of the planter.

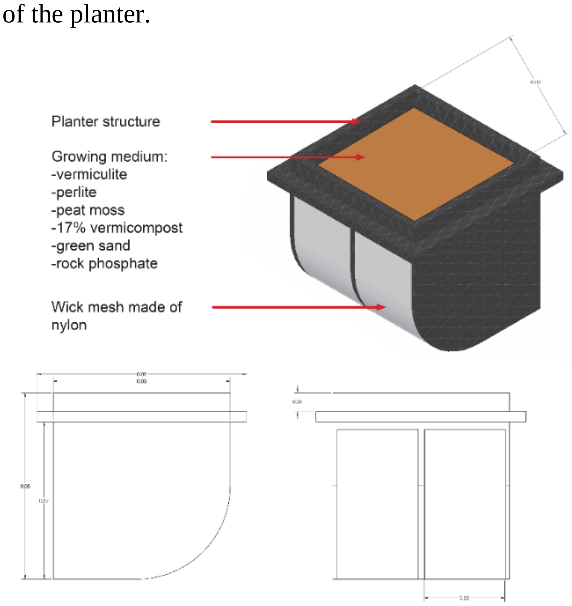


Figure 7. Diagram and dimensions of a planter unit (expressed in meters)

The wick system can be used for both situations as it retains the growing medium inside the container but easily transmit the water to all materials and finally to the plant roots. The wick system will be composed of Nylon or Rayon to prevent the development of mold or bacteria.

A simple system of pumps and tanks will be used in situations superior to 0.25 g and a mist dispenser will be used for every situation where gravity forces are lower.

The lighting system and the motors used in each OGU will rely on wireless transmission of electricity, each lamp and motor will be provided with a coil that will receive electricity from a transmitter, this technology has been in use on planet Earth for a long time and doesn't represent any danger for multicellular organisms. Regarding the different components and the outputs of the lamps, OLEDs will be used and a spectrum of blue and red lights is chosen. Research by Philips has proven that plants are more receptive to certain wavelengths [8]. The OLEDs will save energy, produce less heat and will be more durable than any other type of lamp, the orientation of the plants in a central axis around the device will also provide the best solution for an equal repartition of the light, figure 5 represents an available commercial item that represents the best option in terms of efficiency and size.

Figure 8. Example of a possible central OLED system for an OGU

2.3 Proposed Diet for the Crew

We will not be able to produce every kind of vegetables or fruits available right now on planet Earth but a good varied selection is possible with this system and some of those item have already been tested with the rotating garden system. For example, some items have proven to grow really fast, 35 days was the time needed to produce ripped tomatoes with that system on the ground.

The crew will have a choice regarding their diet but a plan and schedule will be proposed to satisfy all their requirements. Now, assuming that the BIOS-3 experiment needed 22.4 m^2 to provide for 80% of the crew diet, the 16.75 m^2 that we have seems insufficient. But with results provided by amateur farmers and the expected findings of the University of Houston Rotating Greenhouse study, we can expect growth to be speeded by a factor of 2. This would mean that compared with other systems used currently, the rotating apparatus would provide for double the harvest, 16.75 m^2 would represent 33.50 m^2. This area is therefore ample for 80% of the crew diet.

Please refer to table 2 for a complete list of human requirements and the resources provided by the best plants possible. Balance is almost achieved but there is at the moment a surplus of some elements, study of the perfect diet will need more time but this proposal will be enough to satisfy the crew's needs.

Table 2. Proposal for a stable diet containing plants that would fit into the OGU

	Quantity (cup)	Weight (g)	Calories	Protein (g)	Fat (g)	Carbs (g)	Time to grow (days)	Height (cm)
Goal			2200	56	61	390		
Lentil	1	198	230	18	0.8	40	90	40
Green pea	1	145	117.45	8	0.6	21	68	140
Tomato (1)	1	123	22.14	1.1	0.2	4.8	60	90
Strawberry	1	144	47	1	0.4	11	90	40
Soybeans	2	372	1660	136	74	112	97	91
Kale	1	67	33	2.9	0.6	6	110	30
Khorasan wheat	2	344	502	22	3.2	104	120	70
Red sweet pepper	1	92	28	0.9	0.3	6	119	60
Total		1485	2639.59	189.9	80.1	304.8		

2.4 Conclusions regarding the Outputs and Inputs of the System

The atmosphere regeneration can be easily described by figure 9, it is assumed that during the first 30 days of travel, carbon dioxide will be produced without being used by the plants, it is important then to understand that the beginning of the growth cycle and therefore the beginning of the regeneration cycle will only completely start after a certain amount of time (a value of 30 days seems reasonable). For the beginning of the first grow cycle, a mechanical ECLSS will be used.

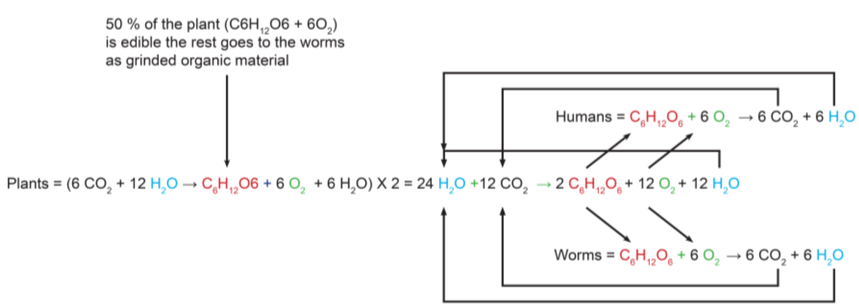


Figure 9. Closed loop for the atmosphere regeneration using the three elements (humans, worms, plants)

The growing cycles of the different LOC and BOC will require different starting times as young and old plants consume and produce CO^2 and O^2 at different rates. Further studies on the ground in closed environment will be necessary.

Some nutrients will eventually disappear from the system and the atmosphere and water will naturally decrease with different leakage rates, 20% of the food and some amount of oxygen and water will need to be produced/shipped depending on the mission, a total closed-loop system is impossible for the moment.

The power requirement for one OGU is 5844 watts per day, including OLED based lights for each unit (380 watts at an average rate of 15 hours per day), small motor (6 watts, continuous) and other components pumps, fans, grinder, microwave. For one crew member, two BOC will be necessary, that would equate to 24 OGU. The total power requirement for one crew-member are therefore 159 kilowatts per day, compared to the ISS with its 2160 kilowatts per day that figure is acceptable for the current solar panels technology or said previously for a nuclear reactor, please refer to table 3 for a better breakdown of all electricity requirements.

Table 3. Energy requirements for one crew member per day

	OLED	Motor big	Motor small	Pump	Fan 12" 2500 rpm
Electricity needs (watts)	380	75	6	16	310
lifespan (hours)	50000				
Voltage	120-240		120		120
Mass					1050 cf / minute
Noise					53 db
Use per day (hours)	15	24	24	2	24
Total (watts)	5700	1800	144	32	7440
	Omega unit		Big centrifuge		Requirement for 1 crew-member for 1 day
watts/day	5844		79752		159504
Square meter	0.67		8.04		16.08
Weight (kg)	38		456		912

With those details in mind we can now talk about the organic machines that will take care of the conversion of the organic byproducts.

3.1 Introduction to Composting and Eisenia Fetida

Human waste and non-edible parts of plants will be used as food for the worms, closing the loop on the system. Composting is a natural process that happens on earth and that helps to build the top part of the soil, contrary to what can be perceived, most soils are alive with multiple different species, such as pseudo-scorpions, bacterias etc. This natural process usually happens over a long period of time but if the right conditions and the right food is present, worms will multiply exponentially and their population will self-regulate reaching a certain density, this density is described in more details in the next parts.

Worms have multiple requirements, they need oxygen, water, food and above all a dark environment. The interior of the compost machine will always stay dark, fresh air will be coming from the circulating ducts coming from the rest of the station/base/craft, it will exit with more CO_2 to the growing area where plants will use it. Composting will then take place, worms will eat, cast, reproduce and move around the compost machine as long as oxygen, moisture and food is present.

Having a large population of worms will permit the processing of the human feces and will result in vermicast, a nutrient-rich casting that will provide an excellent growing medium for the plants. Dead worms will not be a problem as their decomposition rate is really high and their bodies will be assimilated by the organic mass present in the composting machine.

Regarding the movement of worms in microgravity, it has been studied that their behavior is not greatly affected by this change in their environment [9] and the composting machine provides for compression handles in order to permit a density sufficient enough for worms to thrive without g forces.

3.2 The apparatus and Protocol

The compost machine will be composed of 5 independent compost bags that can be easily moved. Two of them are feces bags and will be placed directly in front of the opening for ease-of access.

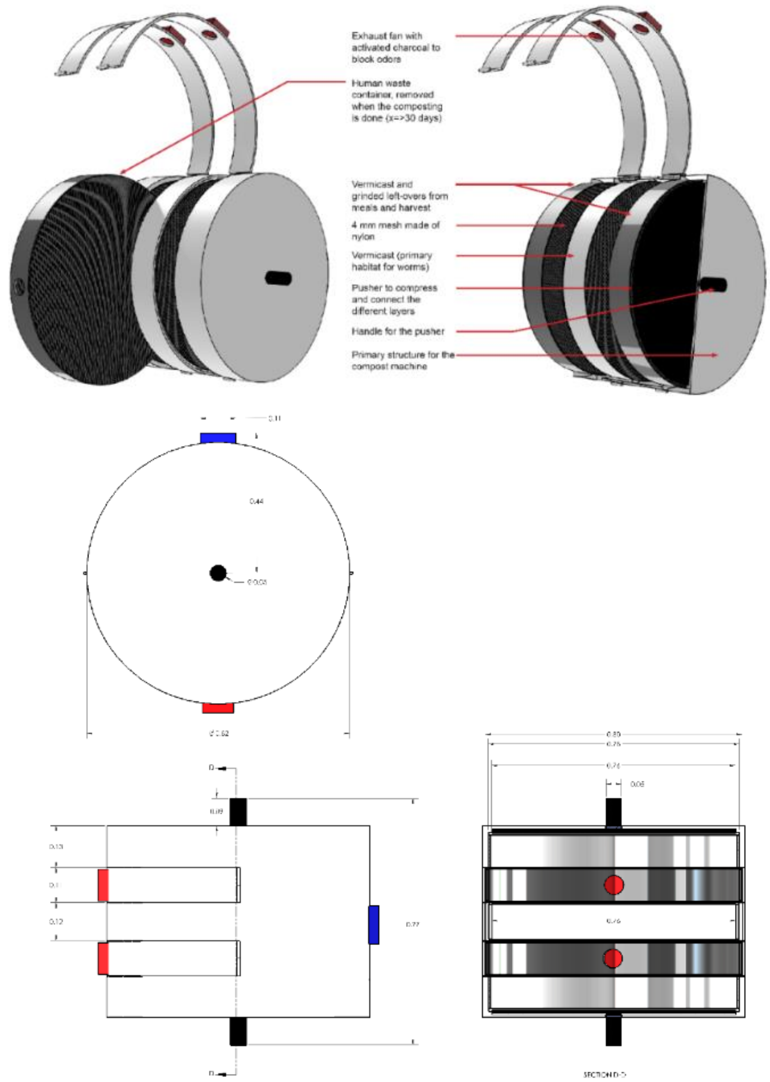


Figure 10. Diagram and General dimension of the Compost machine and its different elements, the blue part represents the air intake and the red part the exit (expressed in meters)

This machine will be both passive and active, the worms will work without any help but the circulation of air and the replacement of food/vermicast will be active parts. Air circulation will be done by 3 small fans located on the openings of the machine, two in front and one larger in the back. The flow of fresh air should be optimum with such an arrangement. Odor filters will be placed on the exit path. These machines will be placed along the “dirty” air supply line to the BIOSS module and will act as a CO_2 enrichment device.

Contingency rules obliged, worm eggs will be stored in freezers, in case of a catastrophic failure of the system and/or contamination by other agents. A collection of new eggs will happen every month, this collection will serve further studies to determine the evolution of worms in this specific habitat.

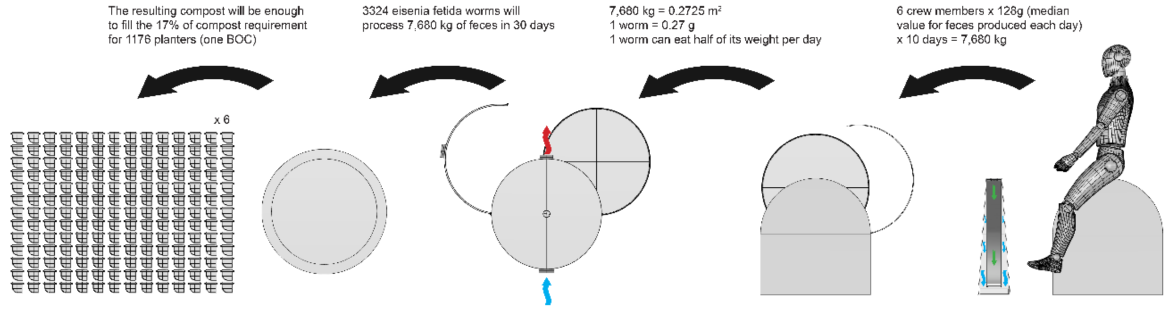


Figure 11. Protocol for using the compost machine and the compost bags

3.3 Closing the Loop

The worms require 75% of humidity in their food medium, human feces are composed of 75% of water, there won't be a need for watering the stock too often.

It is important to understand that the raw material has to be pre-composted before it can be assimilated [10], this precomposting phase will occur in the compost bag during the 10 days period of filling by the crew. Once the compost bag is closed, transported and sprayed with water to dissolve the individual plastic bags, it will have to sit in the composting machine for an extra 4 days before the worms can transfer from other compost bags present in the machine to this new feeding material.

After this initial resting phase, the worms already present in the machine will migrate through two 4mm screen pushed against each other and start their feeding process. It is estimated that one regular size Eisina Fetida worm can process ¾ of its weight every day. The optimal density of worms is 90,718 g per 0.092 m^2 [10]. The surface area of one compost bag is 0.275 m^2. To understand the number of worms required to perform the composting process for one filled compost beg we can refer to those equations

128 g of human feces per day [10] * 6 crew members * 10 days=7,680g, (4-a)
(0.275 m2/0.092m2)*90.718g= 272.15g of worms per unit (4-b)
7,680/((272.15*(3/4))=37.63 days. (4-c)

We can then conclude that with optimal growing pattern such as described in figure 12, just 4 compost bags should be enough to process all fecal elements in a 38 days rotation cycle.

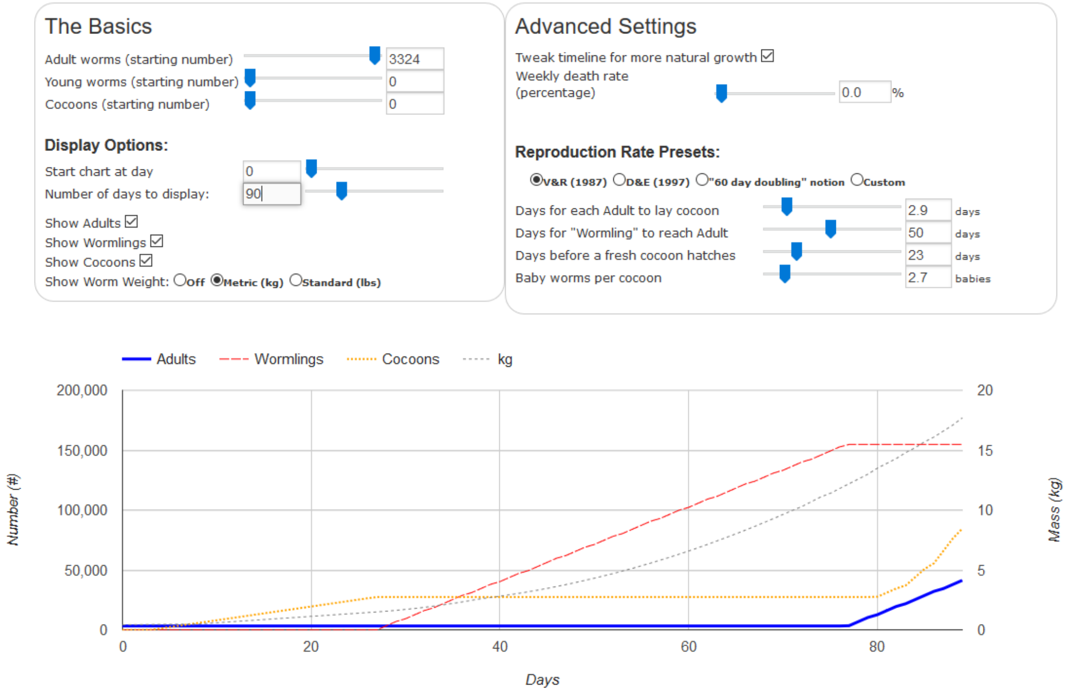


Figure 12. Eisina Fetida growth cycle to reach a sustainable population and maintain above 3324 the total number of worms

As a measure of safety and because non-edible parts of the plants will also have to be processed, it will be necessary to have 4 composting machines which means 8 primary compost bags and 12 secondary bags. After processing by the worms, the primary compost bags will be transferred to a microwave chamber to be irradiated, this action will kill all the elements that might contaminate the plants and will also improve the availability of nutrients in the compost [11].

Only 17% of the growing medium will have to be replaced as is it is dangerous to grow plants in pure compost. The composition of the growing medium has been described in figure 7.

The used compost could be burned to produce carbon dioxide or be used for other purposes but a certain part of it will be reused in the composting machine to serve as worm habitat, in the secondary compost bags. It has been proved that worms can thrive better and multiply if their habitat is composed of multiple layers of feces, vermicast and other components (grinded non-edible plants in this case)[10]

The cycle is complete and the humans will just have to keep eating, grinding the non-edible parts of the plants and transfer the compost bags between the waste management facilities to the growing area, this cycle can be better understood with figure 13.

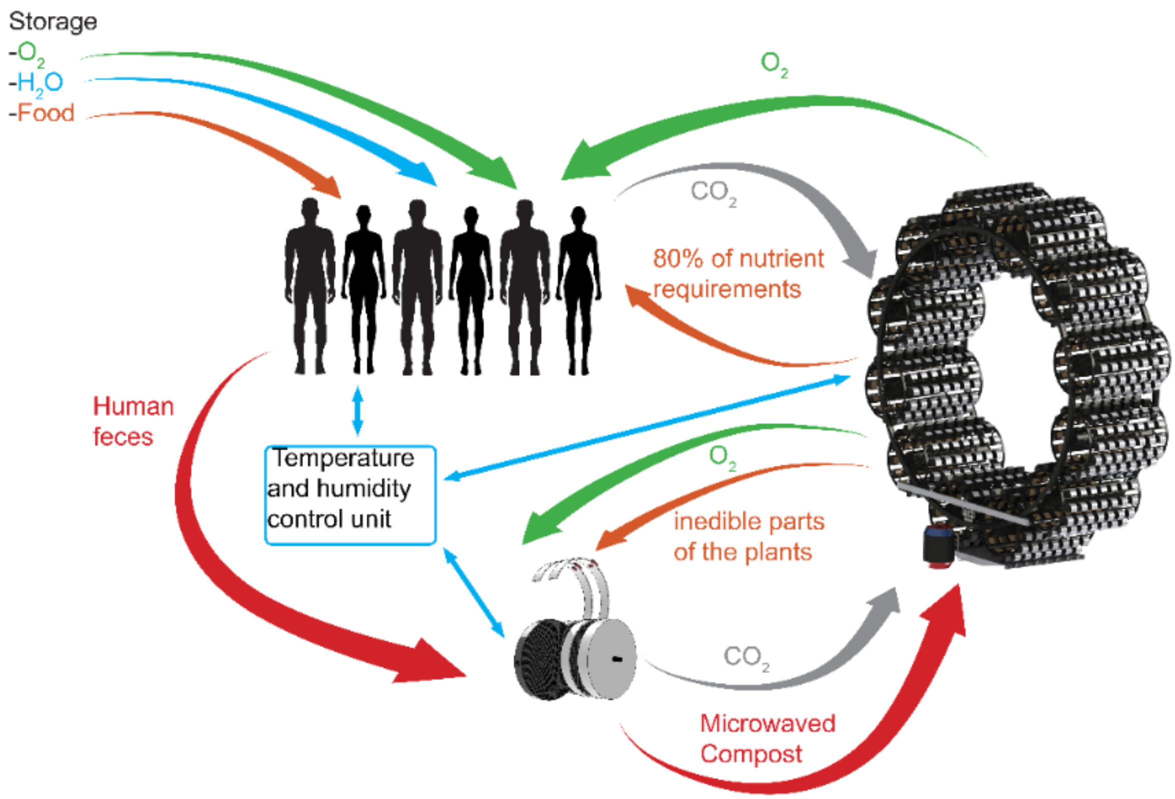


Figure 13. Closing the loop by using three different actors that exchange gas, nutrients and time

Summary and Conclusions

Resupply of long duration missions will be less numerous and the total stored mass of consumable at launch will be smaller for missions exceeding 525 days. The BIOSS module will be required for every mission in the future and the study of this particular system will continue but the preliminary assumptions is that this arrangement will provide more yield per square meter than traditional methods used currently and more safety regarding the recycling of human waste.

After studying all the different aspects of plant growth and composting, we can conclude that the combination of a rotating garden and a processing of organic products by worms will provide enough food and fresh air for a crew of 6 in a minimal space. Allowing this kind of RECLSS, the BIOS system is to be at the same time, cost-effective, safe, reliable and enjoyable for the crew.

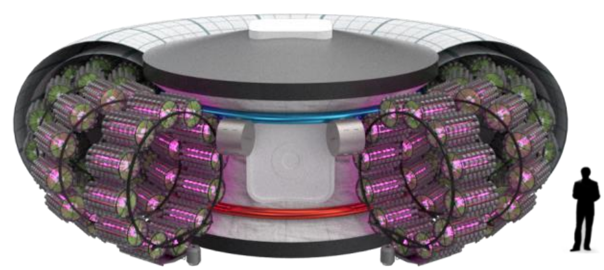


Figure 14. Rendering of the completed module with 12 large centrifuges and the 4 compost processing units

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Appendices

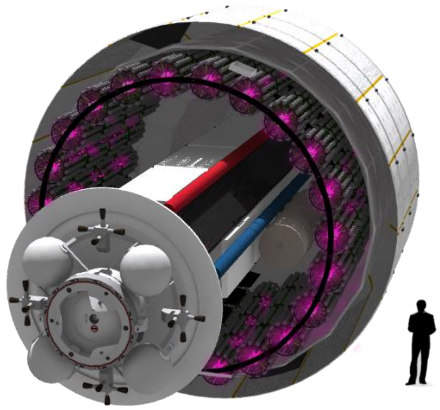

Figure 15. Rendering of the B330 with 6 very large centrifuges and the 4 compost processing units

Figure 16. The waste management installed on the ISS, the proposal is to simply modify the size and shape of the feces container but keep the rest of the design

Figure 17. Comparable system developed on planet Earth by Omega Garden incorporated

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