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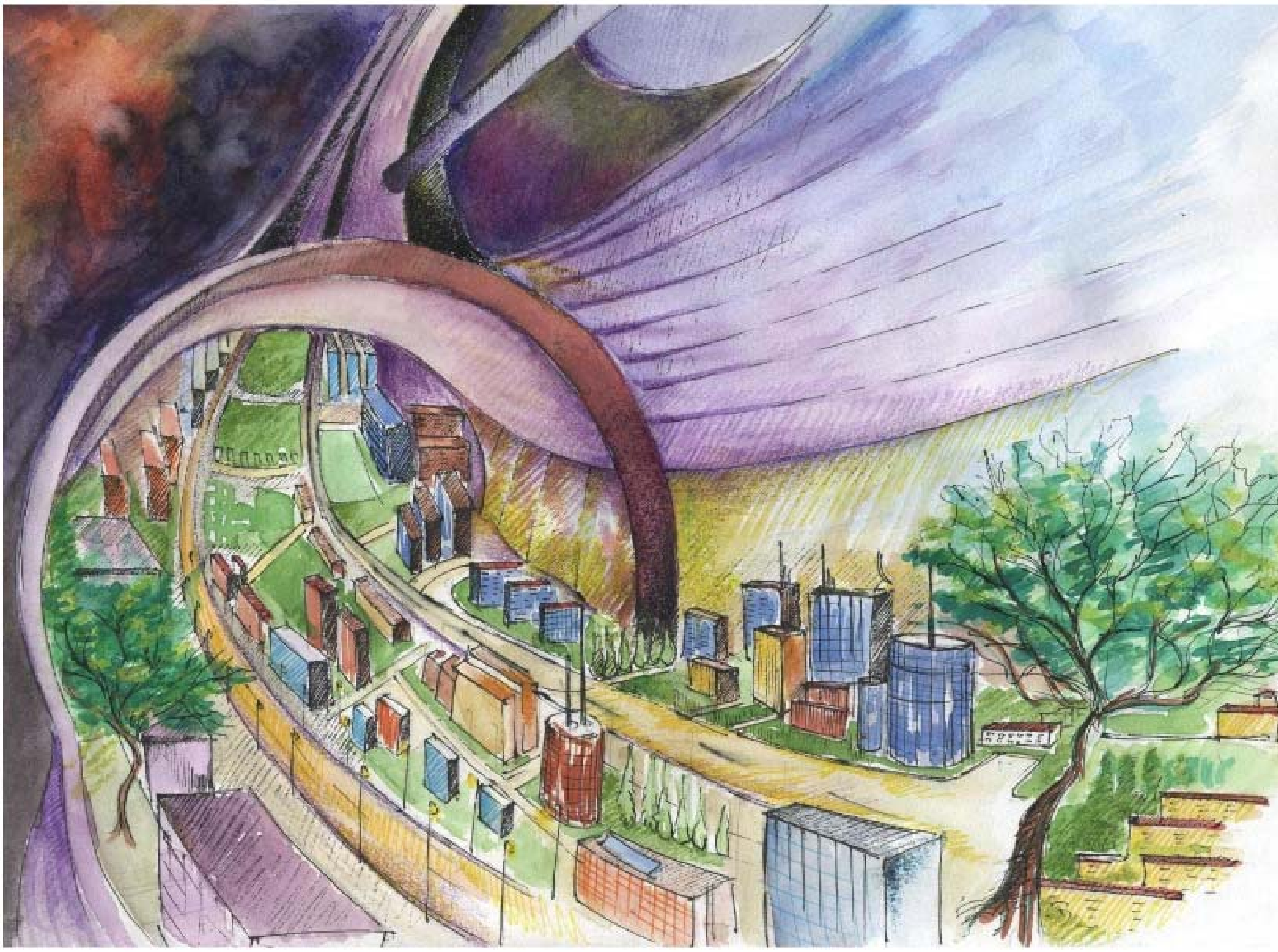
LEDA



NASA Ames Research Center Annual Space Settlement Contest

2004

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L.E.D.A.

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Acknowledgements

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We gratefully thank God for guiding us through the difficult still chalenging conceiving of this project.

FOREWORD

1. Why is the construction of a space settlement necessary?

L.E.D.A comes from **L**ife sustaining **E**nvironment **D**esigned for **A**rtificial habitats. In Greek mythology Leda was a nymphy which metamorphosed herself into a beautiful swan. As the shape of the Settlement somehow resembles with that of a swan we have chosen Leda to be the name of the settlement.

It seems a futuristic, almost science fiction idea to build an orbital space settlement. Actually it is possible for humans to survive in outer space with the appropriate technical and social support. The main purpose of LEDA is conquering space and building Earth like places for humans to inhabit.

We had to analyze a variety of aspects…from the shape of LEDA to the coloring of the rooms, from the food sources to the entertainment activities.

The opening words of the popular TV Show "Star Trek – The Next Generation" are: "space, the final frontier". Our theory is that the final frontier is not the space, it is solving the problems that humans will encounters by living in a new environment. The first true challenge is changing the way we think, in order for us to create a self sustaining orbital settlement, to create an ecosystem and to balance it.

We believe that space settlements are the future "residences" of human beings. They prove humans' capacity to adapt to new ways of life, to explore the boundaries of space, giving a boost to human civilization.

2. General impact of LEDA on the development of human society

Civilization signifies the totality of means with the help of which man adapts himself to his environment (physical and social), succeeds in subduing, transforming and organizing it. All that belongs to the horizon regarding the satisfying of material necessities such as commodities and security means "civilization". The latter's , pre-eminently of a utilitarian nature, comprises: alimentation, housing, clothes, public constructions, communication means, technology in general, economic and administrative activities, social, political, military and juridical organization, education in general and higher education – yet only as far as there processes comply with the exigencies of practical life.

The implications of building the settlement are great, because it opens a new gateway to space and breaks one of the greatest boundaries known to man: human life in space. The psychologists will have a lot to think about; new conditions of life bring new ways of life and new ways of thought… new ideas generated by a new type of mind: the mind of one who is not limited by terrestrial mentalities, who understands the possibilities of space itself. A new type of environment is created and as such, a new type of human: the human born and raised in space: a human who understands the concept of gravity and life sustaining mechanisms from the moment he is born, because his life depends on it. He will understand at an early age the importance of air and water, and why is it so important to preserve and to try to maintain equilibrium in the artificially created geo-ecological system.

Human history will note that the orbital settlement is the first attempt of conquering space, and overcoming the barriers of Earth's surface. Geography will also note that the new settlement is in fact a new part of Earth, a space colony, a new human territory, the inhabitants being pioneers in space life.

3. The economical and political importance of LEDA

Another important aspect concerning the space settlement is its economical importance, involving both investments and profits. The investors will be governments and organizations interested in obtaining all kind of profit from the extracting spatial industry, solar wind traps, solar energy scientific breakthroughs and spatial tourism, the profit creating a large economical variation between the participants at this project, and the non participating governments and organizations. A fight for the manipulation of the space station will begin, because of its role in the worldwide economy… Space is an unexploited source of profit, and its exploration and exploiting will change monetary values as we know them. Lunar minerals will become important merchandise, new materials will be manufactured (from the titanium ore which is scarcely found on the Earth's crust), and electricity will be cheaper.

The political importance of this settlement is strongly related to the economical factor. That is why the station's leaders will have to be impartial and incorruptible, understanding that an equality must be kept in order not to bring forward any of the investors in the process of sharing the profit that the station creates.

CHAPTER I

Topography, geology and physical properties of space

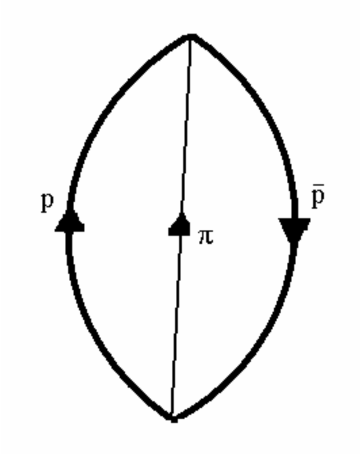
The universe is made of 70% vacuum energy, 26% exotic dark matter, 4% ordinary matter (e.g. planets, stars, asteroids) and 0.005% radiation (light, cosmic and gamma rays, X-rays).

The existence and properties of empty space can be determined by experiment. Most of the physical properties of space are paradoxical: space is supposed to be empty, but not an absolute vacuum, containing sizeable amounts of matter, energy and radiation; space is an unwelcoming environment, but it offers endless possibilities for life beyond our world.

"Nothing" is a philosophical concept, accessible to logical analysis. Philosophers have been trying to define it since ancient times (Aristotle). We have come to understand that truly empty space cannot exist (that would mean that no matter would be present and gravitational and electromagnetic fields would be exactly zero). Still, the concept needs further clarification for us to fully understand it.

The nineteenth-century Scottish physicist James Clerk Maxwell gave the following definition for vacuum: "The vacuum is that which is left in a vessel after we have removed everything from it". This definition still leaves us with an unanswered question: what can't we remove and how do we know we have removed "everything we can remove"?

The distinction between matter and void had to be abandoned when it was proved that particles can spontaneously appear or disappear in the void without the presence of any particles causing powerful interaction.



Three particles: a proton (p), an antiproton (p⁻) and a pion (ð) form out of nothing and then disappear in the void. According to the theory of fields, this type of event occurs all the time. Vacuum is far from being "empty". It contains an unlimited number of particles that are constantly formed and destroyed.

In physics, "something" is quantified by energy. An enclosed space is empty in a physical sense if it has released all the energy it can. According to Einstein's formula "$E=mc^2$", air molecules (with the mass "m") stand for an amount of energy, and the energy from an enclosed space is removed when the air is pumped out. Any system left alone will release all the energy that the surroundings can absorb, assuming a state of minimum energy (e.g. a pendulum will eventually slow to a stop and hang motionless whatever its initial state; it gives off its energy through friction). In some cases, the physical definition of emptiness may lead to surprising results. For example, a physical system represented by a glass filled with water at 0° Celsius (32° Fahrenheit) will surrender energy in the form of heat when the water passed from liquid state to solid (frozen) state. When it melts, it absorbs energy (the heat of melting), which means that the water in its lowest state of energy is solid. According to Einstein's formula $E=mc^2$, taking the ice out of the system would further lower its energy. Is there something that we cannot take away from any system without raising its energy?

Fully removing matter and energy from a system is, at the present time, impossible.

Since pure vacuum contains no matter, temperature does not exist, as temperature is a measure of the kinetic energy of particles in a substance.

Space is not a perfect vacuum, and temperatures in space vary from just above 0 K (-459,66 Fahrenheit) to millions of degrees at the center of stars.

Gravity gives shape to apparently featureless space. The hills and valleys it creates will be as important to space settlers as geographical features are to terrestrial settlers. For a relatively small body to escape from the surface of a massive body (a planet or moon), it must be lifted through a gravitational well (the more massive the body, the deeper the well). The Earth's gravity is 22 times more powerful than that of the Moon. This will be of importance to space colonists. In deciding where to get their resources they will have to take into account that matter can be more easily lifted from the Moon than from the Earth. Lagrangian liberation points can also be fount in the Earth-Moon system. These are points where gravitational forces from the two bodies cancel each other out.

The primary criteria for choosing the site of the colony are ease of access to resources, communication and low transportation costs. Satisfactory balances among them can be achieved by efficiently exploiting the topography of space.

One of the most important sources of energy in space is solar radiation. It consists of charged particles (protons) emitted from the sun and its intensity decreases as distance from the sun increases (as the square of distance from the sun). Another, more constant energy source is cosmic radiation, consisting of heavier particles (e.g. iron nuclei) from other galaxies. Radiation on the surface of a planet consists of solar winds or cosmic radiation that reaches the surface and neutrons and gamma-ray photons released when space radiation particles interact with the planet's atmosphere and crust.

Outside Earth's atmosphere, the energy flow from the sun is more steady and intense. 1390W of sunlight pass through every square meter of space directly exposed to the sun, while the maximum amount of light reaching the Earth's surface is 745W/m^2. A square meter of space receives 7.5 times more energy from the sun than an average square meter on Earth because of the day-night alternation on Earth and because sunlight doesn't fall perpendicularly on the surface of the planet.

The intensity and wavelength of unfiltered sunlight is deadly for humans, but it is, at the same time, one of the most valuable energy sources in space.
The earth's surface is protected from solar winds and cosmic radiation by the atmosphere and magnetic field. The atmosphere absorbs both space radiation and the gamma rays that are produced by the Earth's crust. The magnetic field diverts most charged particles to the poles, creating aurora borealis.

Mars has little atmosphere and no magnetic field, so the flow of charged particles anywhere on the surface greatly exceeds that on Earth. There is enough atmosphere to create a neutron field (from the interaction of charged particles with the atmosphere and with the crust), but it isn't thick enough to absorb the neutrons before they reach the surface. Some neutrons are reflected back toward the surface after interacting with the planet's crust.

Planets, moons and asteroids make up the main material sources in space. Comets could also be considered material sources, but they are hard to exploit because of their high velocity. Accessibility to these sources is determined by distance and the depth of the gravitational field. The Earth would be an important source of material for a colony situated in the vicinity, especially of hydrogen, nitrogen and carbon, which are not found in sufficient amounts anywhere near our planet. The moons of planets usually have shallow gravitational wells, so they offer an attractive source of materials. The Moon can be a good source of aluminum, iron, titanium, oxygen and silicon. These resources, supplemented with small amounts of a few elements from Earth, can supply a colony with all the materials it needs to sustain life.

Asteroids also have shallow gravitational wells and move in regular orbits. They may contain sizeable amounts of hydrogen, carbon and nitrogen, as well as other minerals and frozen water.

Recent studies revealed that the Universe is expanding at an increasing rate. This discovery seems to confirm Einstein's idea of "dark matter", the vacuum energy, which is forcing the expansion of the Universe. After studying this dark energy, proffesors Andrei Linde and Renata Kallosh of Stanford University say that the Universe will stop expanding in 10 to 20 billion years and the influence of dark energy will become neutral and then negative, causing a collapse.

In the 1930s, Paul Dirac, an English physicist, proposed that vacuum contained electromagnetic waves called "zero point energy", contained in "virtual photons", which appear out of nothing and the energy to create them is taken from the vacuum until the virtual photon disappears. According to this theory, there is an infinite number of possible photon modes, so the total zero point energy in the vacuum is infinite.

It was suggested that there is a substance called "ether", present everywhere, even in "empty" space. Energy residing in the ether would be the source for the random emerging and disappearance of particles in the, but there is nothing that permits the growth of large objects. When the energy increases, the number of participating particles increases, but they cannot be joined together, because they disappear as randomly as they appear.

Because an object is uniformly bombarded under most circumstances, the effects of zero point energy in space are not obvious.

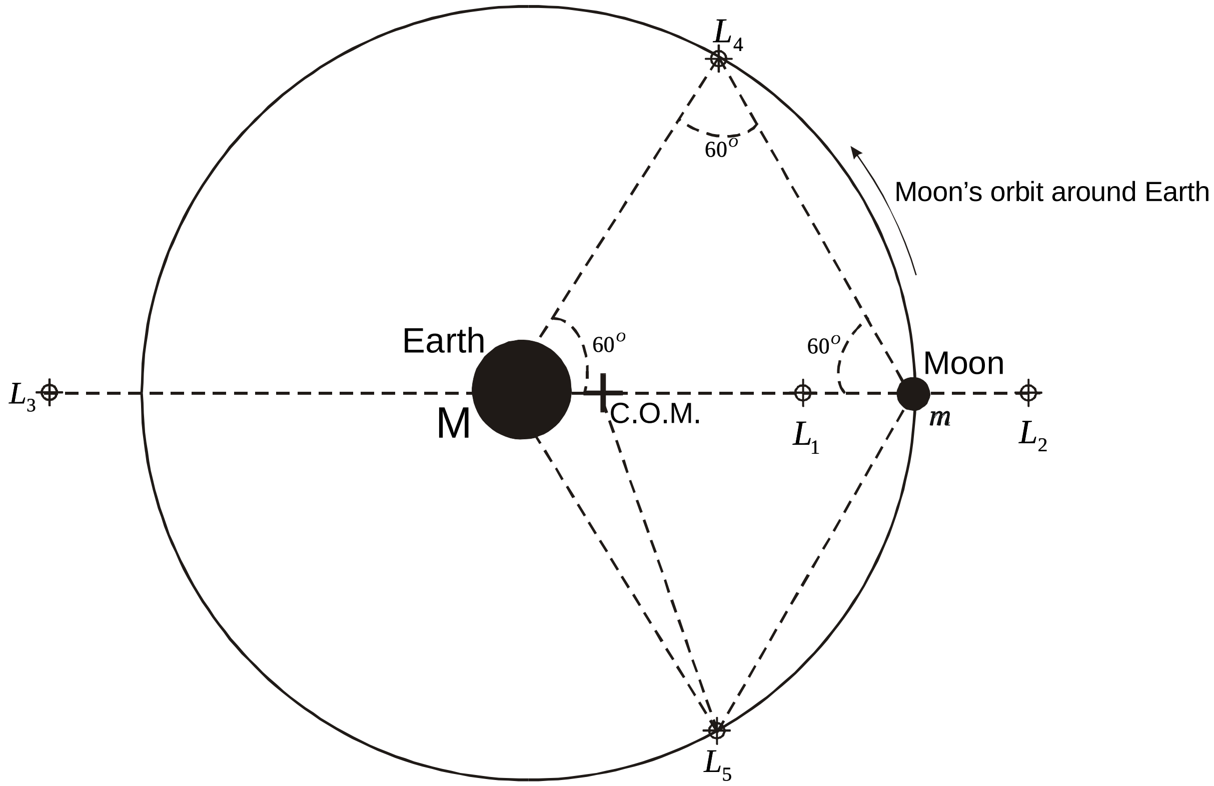
CHAPTER II

Placement of the space settlement

II.1. Choosing the space settlement's location

The best solution for placing the space settlement would be one of the Lagrange points (or Libration points), which are locations in space where gravitational forces and the orbital motion of a body balance each other. They were discovered in 1772 by French mathematician Louis Lagrange in his gravitational studies about the 3-body problem consisting in how a third, small body would orbit around two orbiting large bodies.

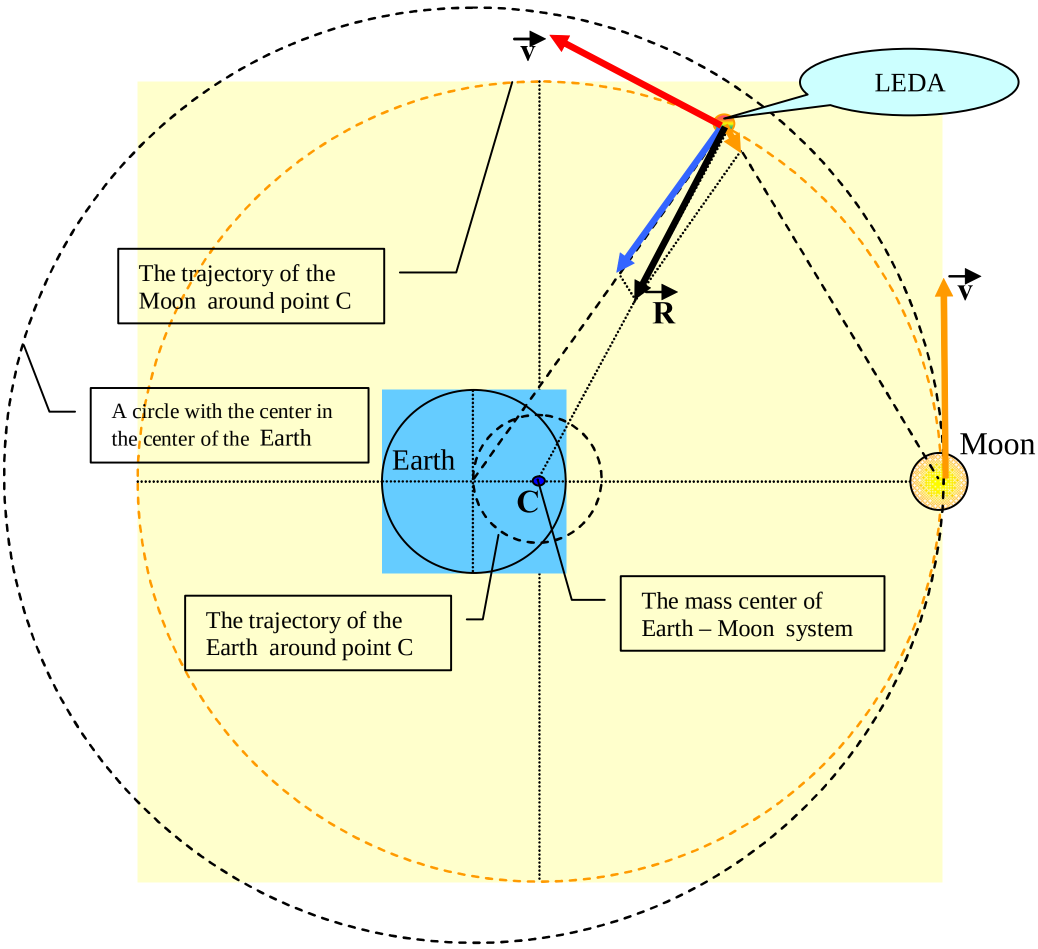
The solution found by Lagrange was astronomically confirmed in 1906, when the Trojan asteroids orbiting the Sun- Jupiter L4 and L5 points were discovered. To find the Lagrange points you must adopt a frame of reference that rotates with the system. The forces exerted on a body at rest in this frame can be derived from an effective potential in much the same way that wind speeds can be inferred from a weather map. The forces are strongest when the contours of the effective potential are closest together and weakest when the contours are far apart.



Of the five Lagrange points, three are unstable and two are stable. The unstable Lagrange points, labeled L1, L2, and L3 lie along the line connecting the two large masses. An object at L1, L2 and L3 is meta-stable, like a sphere placed in top of a hill. A little impulse is enough to make it move away. If the space settlement would be situated in one of these points, it would frequently have to use its small rocket firings to remain in the area, process in which part of the fuel and stored energy will be lost. The L1 and L2 points are unstable on a time scale of approximately 23 days, which will require the space settlement parked at these positions to undergo regular course and attitude corrections. Another inconvenient of the Earth-Sun L1 and L2 points, situated at approximately 1000000 miles from Earth in opposite directions, would be that both already shelter satellites. The L1 point of the Earth-Sun system affords an uninterrupted view of the sun and is currently home to the Solar and Heliospheric Observatory Satellite, also known as SOHO. The Microwave Anisotropy Probe (M.A.P.) is in a halo orbit around the Sun–Earth L2 position, about a million miles in the opposite direction. The L2 point will also be home of the Next Generation Space Telescope. There are, however, orbits around the L1, L2 and L3 points of the Earth-Moon system, in the planes perpendicular to the axis connecting the two major bodies, which are almost stable, requiring only small occasional corrections. The orbit around L1 would be a suitable location for the temporary parking of shuttles, crews and materials during the construction phase. It could also serve as waiting point for the space ships demanding permission to anchor the colony's cosmodrome. As the International agreement has set aside the far side of the Moon for being the only place in our Solar system shielded from terrestrial electronic transmissions, the Lagrangian L2 is not suitable for building space colonies or temporary "work camps".

That is why the L1, L2 and L3 points of both the Earth-Moon and Earth-Sun systems are not a reliable option for the space settlement's placement, although the Earth-Moon L1, L2 points are the Lagrange points closest to the Moon.

The L4 and L5 points are home to stable orbits so long as the mass ratio between the two large masses exceeds 0.0385 (M1/M2 < 0.0385). The condition is satisfied for both the Earth-Sun and Earth-Moon systems, and for many other pairs of bodies in the Solar system. An object at L4 or L5 is truly stable, like a sphere in a bowl: when gently pushed away, it orbits the Lagrange point without moving away farther and farther, and without the frequent use of rocket propulsion. Another reason why we should consider the L4 or L5 points as the most suitable for placing a space



The figure above shows the forces which appear in the movement of our Space Settlement. The gravitational force between the Space Settlement and Earth (Blue) and the gravitational force between the Space Settlement and Moon (orange) are vector summing the resultant force ($\vec{R}$, the black one), being oriented to the Earth's center of mass.

settlement is that the Sun's pull makes any object in Earth-Moon L4 and L5 locations "orbit" the Lagrange points in 89 days, which demonstrates the high stability of these areas. We must also consider the L4 and L5 points' proximity to the Moon which represents a great advantage due to the satellite's exploiting potential. Despite their stability, the L4 and L5 points of the Earth-Sun system are not a considerable solution because of the large, inefficient distance which separates them from a constant source of raw materials.

Finding the positions of the 5 points requires only simple math skills. L1, L2, and L3 are referred to as the collinear points because they lie on the line connecting the centers of mass of M and m. L4 and L5 are called the equilateral points because they lie at the tips of equilateral triangles with M and m at the other two vertices.

Let's first define the distance between M and m as a dimensionless value of 1. Next we will define A and

$$A = \frac{M}{M+m}$$
$$B = \frac{m}{M+m}$$
$$A + B = 1$$

B as the distances from the center of mass to m and M, respectively.

$$L_1 = \frac{A}{(B+L_1)^2} - \frac{B}{(A-L_1)^2}$$
$$L_2 = \frac{A}{(L_2+B)^2} + \frac{B}{(L_2-A)^2}$$
$$L_3 = \frac{A}{(L_3-B)^2} + \frac{B}{(L_3+A)^2}$$

The distances from center of mass to the first 3 equilibrium points are:

$$x_1 = A - L_1$$
$$x_2 = L_2 - A$$
$$x_3 = L_3 - B$$

Now we define:

x_1 and x_2 being the distances from m to L_1 and L_2, respectively, and x_3 being the distance from M to L_3. Substituting x's into the L formulas produces the following:

$$x_1^{\,3} = \frac{B(1-x_1)^2}{3-2B-x_1(3-B-x_1)}$$
$$x_2^{\,3} = \frac{B(1+x_2)^2}{3-2B+x_2(3-B+x_2)}$$
$$x_3^{\,3} = \frac{(1-B)(1+x_3)^2}{1+2B+x_3(2+B+x_3)}$$

Solutions to these equations must be found by iteration. That means coming up with an initial guess for a value for each x then plugging that guess into the equation to see what value of x it produces. We take the new x-value and plug it back into the equation and solve. We repeat this process until our guess and answer match to the level of accuracy we need.

Start with an x-value of $x = \left(\frac{B}{3(1-B)}\right)^{\frac{1}{3}}$ for x_1 and x_2. For x_3 start with $x = 1 - \left(\frac{7B}{12}\right)$. Some values of B, x_1, x_2, and x_3 are shown in the Collinear Values Table.

Collinear Values Table								
System	**B**	**X_1**	**X_2**	**X_3**	**R (mi)**	**X_1 x R**	**X_2 x R**	**X_3 x R**
Earth-Moon	**.01214**	**.1509**	**.1678**	**.9929**	**239,000**	**36,042**	**40,076**	**237,165**
Sun-Earth	**3.0359E-06**	**.010006**	**.010073**	**.999998**	**$93x10^6$**	**930,560**	**936,810**	**92,998,000**

L4 and L5 are easier to calculate. They are exactly the same distance from M and m as M and m are from each other, which puts the points 60 degrees ahead of and behind m, respectively, on its orbital path.

Due to the edifying facts above, we come to the conclusion that the space settlement should be placed in the L4 or L5 points of the Earth-Moon system.

The rotation axis of the space settlement must be parallel with its revolution axis. It must not change its direction during the revolution motion around Earth as the Space Station tends to keep its kinetically momentum and would easily leave its orbit, losing the needed mechanical equilibrium. Maintaining the rotating space settlement in an orbit parallel with its spinning axis will also imply, in time, a considerable use of fuel. This aspect is discussed in the next chapter.

II.2. Rotation and kinetic momentum

The basic condition for generating pseudo-gravity inside the space settlement is rotating the colony around its vertical axis (transversal axis). Therefore, the spin motion of the settlement is essential for the development of human activities in space. For a more realistic approach of the problem, we must first lay down the exact rules of the settlement's spinning motion.

Let's assume the colony is built in the position shown in the figure below, with maximum exposure to the Sun, with the intention of keeping it in this position during all its evolution on Earth's orbit. The settlement's orbital kinetic momentum (L), the orbital speed ($\vec{v}_0$) and the angular speed of the colony towards its rotation centre (Ω) are also represented in the figure.

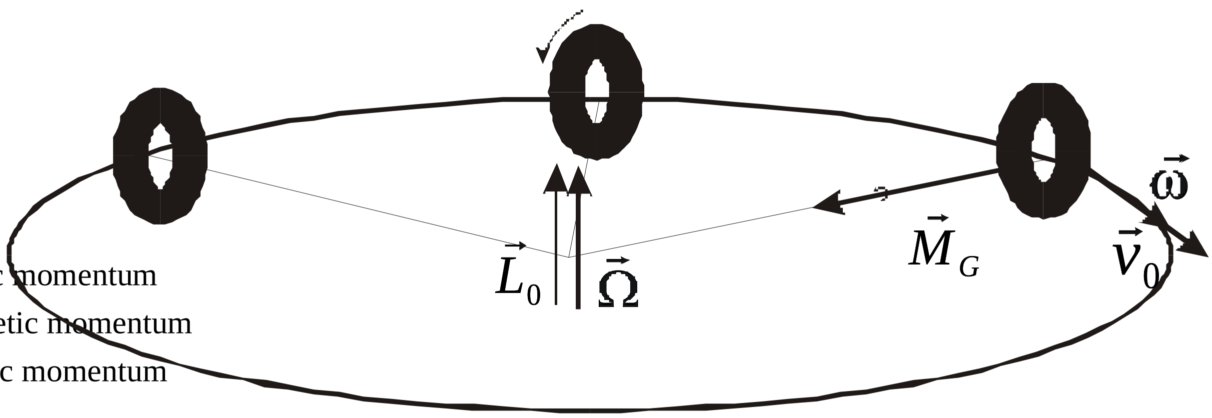
The stability of the movement involves the constancy of the orbital kinetic momentum L in time. The constancy of the rotation radius and the flatness of the trajectory derive from the first basic condition.

Now let’s assume the colony begins to rotate with the angular speed of around its symmetry axis. The laws of mechanics for solid and rigid bodies show that in this kind of situations a gyroscopic couple appears, characterized by the M_G momentum.

$$\vec{M}_G = I\vec{\omega} \times \vec{\Omega}$$; I - the inertial momentum of the settlement

The figure below shows the changes intervening along with the rotation of the settlement around its axis. The momentum of the gyroscopic couple leads to the rotation of the settlement around the direction which connects the center of the colony with the center of rotation. Therefore, the settlement can not keep its initial orientation towards the Sun. We can easily see that the total kinetic momentum is prone towards the ecliptic of the Moon, which involves the changing of the ecliptic plan orientation.

For maintaining the trajectory and the total kinetic momentum of the settlement it is necessary for the



L_t - total kinetic momentum

L_O - orbital kinetic momentum

L_S - spin kinetic momentum

kinetic momentum of the spin to be parallel with the orbital momentum. The momentum of the gyroscopic couple becomes:

As a result, the settlement will orientate its axis perpendicularly on the ecliptic plan of the Moon. Its

$$M_G = I\omega\Omega \sin 0^0 = 0$$

$$\vec{L}_t = \vec{L}_O + \vec{L}_S$$

$$L_t = L_O + L_S$$

rotation plan will be $5^o9'$ prone towards the ecliptic of the Earth. The solar rays will be incident on the surface of the settlement at an angle of approximately 84^o from the rotation axis of the colony.

CHAPTER III

External and internal structure of the space settlement

III.1. Shape

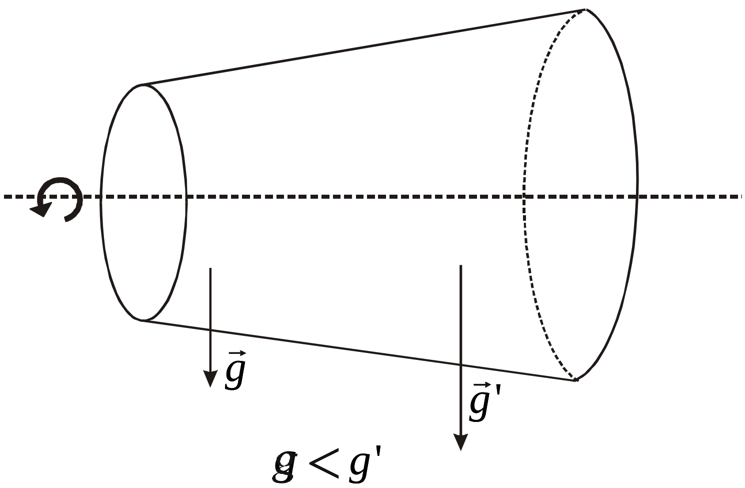
We have studied the advantages and disadvantages of different shapes for the space settlement. While choosing the most suitable shape we considered more shapes like the sphere, the cylinder, the dumbbell, the belly cone, the cylinder with spherical endcaps and the torus.

The biggest disadvantage of the sphere is producing only a small strip of habitable land at the expensive of a gargantuan volume. Another disadvantage of the sphere shape is that it can be very hard compartmented and administered.

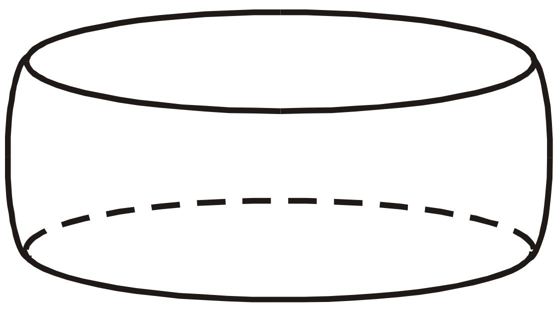
The cylinder has a very large living area but a very important disadvantage is the psychological one, because it is very unusual too see persons up your head. Another disadvantage is the too large amount of material used to create the necessary radius for the pseudogravity creation. Rotating cylinders also require too much atmosphere, of which 78% needed to be shipped up from earth in the form of nitrogen.

The dumbbell has the advantage of creating the necessary radius with saving material but it has very little volume for living in comparison with the material quantity needed.

The belly cone it is not a suitable shape because of the variable pseudogravitational illustrated in the figure below.

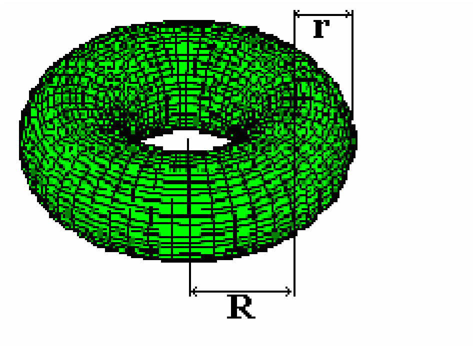


A cylinder with spherical endcaps has many advantages but for little dimensions, that‘s why we will user this shape for the 0 gravity center. We have the advantage of strict 0 gravity in the center of the cylinder, and constant pseudogravity on the endcaps. It can be easy segmented and it can contain a big amount of atmosphere, thus it can be also a temporary location for the colonists in case of the torus evacuation.

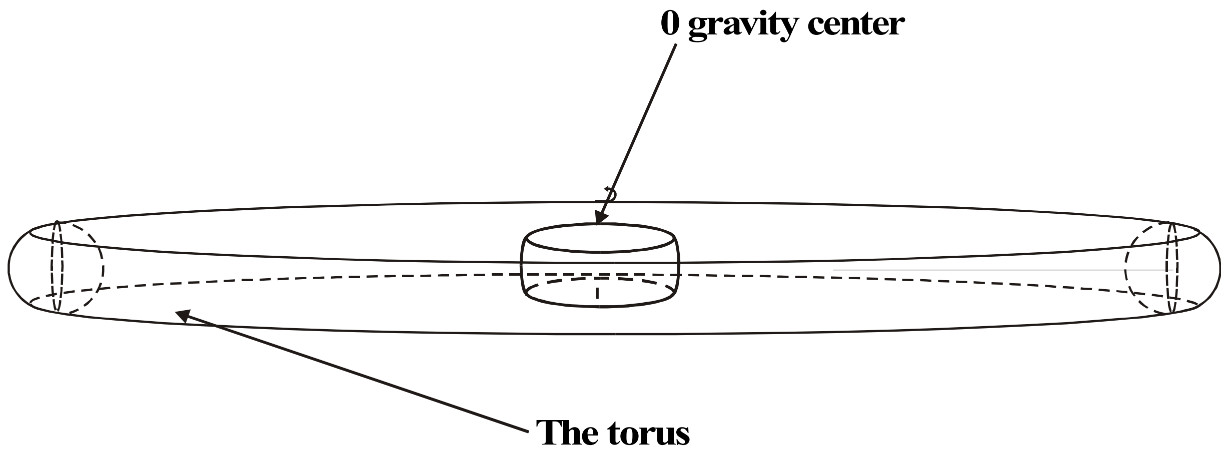


Cylinder with spherical endcaps

Studying all the possible shapes for the colony, we found that the torus is the most suitable shape for the space settlement habitat. It allows to control the radius which generates the atmosphere volume separately from the radius of rotation which is a very important element in the creation of pseudogravity in good biological conditions. Moreover, the torus can distribute its habitable area in a large ring. Moreover a well rounded shape distributes equally and radially all the pressure forces. Another advantage of the torus is that it assures maximum habitable area requiring minimum amounts of materials. The torus also provides the largest habitable area per ton of nitrogen.



$$\text{Volume of the torus} = 2 \cdot \Pi^2 \cdot R \cdot r^2$$



LEDA will have a composite shape containing both a torus and a cylinder with spherical endcaps. The torus will house the habitat of the colonists, while the cylinder with spherical endcaps will house docking facilities, industries, and research.

III.2. Dimensions

The dimensions of the settlement must be certainly calculated according with the assumed number of occupants, their average habitat needs and the requirements of the different activities they will develop onboard the orbital colony. Therefore, all estimations regarding the scale of the Settlement must be made by equally balancing comfort with maximum efficiency of the artificial habitat. We can allow no waste of space and materials, thus errors occurring within the design phase can severely affect the later development of the colony. Of course, we must also take into account the esthetical and homelike needs of the colonists, but efficiency in using, exploiting and distributing space inside the torus must overlook the less vital aspects.

As said, we must assure a comfortable and pleasant habitat for orbital colonists, considering their average needs and combining them with maximum efficiency in distributing space. The following calculations indicate the habitable volume of the torus according to a person's average needs and to the minimum dead space (unused space) inside the torus.

We consider: ΔV_0 - the average inhabitable volume needed by a person

N - the total number of persons onboard the settlement

$V_{residential}$ - the total residential volume inside the torus

f - the fraction of volume representing unusable space (related to the total residential volume)

V_u - the uninhabitable volume part of the total residential volume (occupied by walls, buildings etc.)

V_{th} - the volume of the torus;

T - the rotation period

R- the large radius of the torus

r- the small radius of the torus

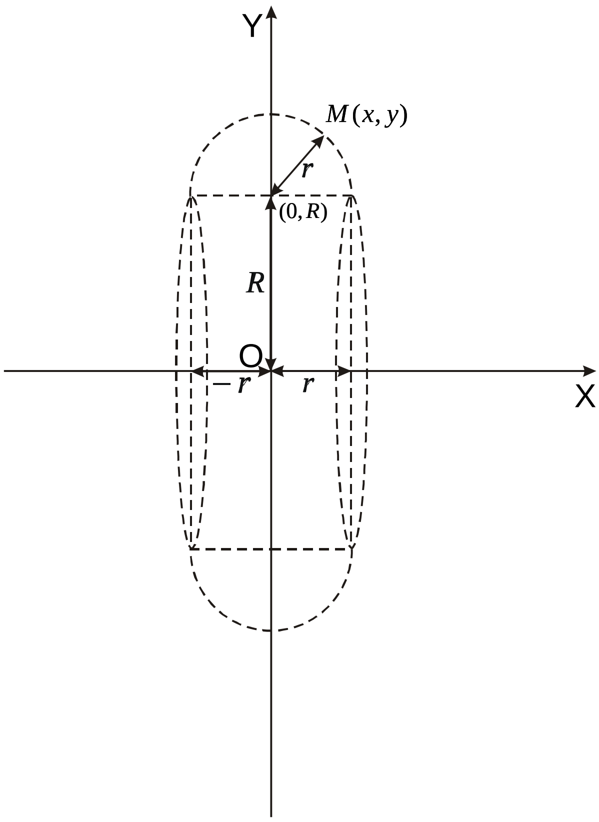
ω - the angular speed of the torus

L- the outer circumference of the torus

A_h – the habitable area

ΔA_0 - the habitable area per person

$$V_{residential} = \frac{N\Delta V_0}{1-f} \qquad [1]$$



$x^2 + (y-R)^2 = r^2$ – the equation for the circle C(O,R)

$$f:[0,r] \to \Re$$

$$f(x) = R + \sqrt{r^2 - x^2}$$

$V_{rotation}$ – the volume of the rotation body obtained by rotating the graphic representation of the function around Ox
$V_{cylinder}$ – the volume of the cylinder having R as radius of the base and r as height
$V_{difference} = V_{rotation} - V_{cylinder}$

$V_{cylinder} = \Pi R^2 r$

$$V_{rotation} = \Pi\int_0^r f^2(x)dx = \Pi\int_0^r (R + \sqrt{r^2 - x^2})dx = \Pi\left(\int_0^r (R^2 + 2R\sqrt{r^2 - x^2} + r^2 - x^2)dx\right) =$$

$$= \Pi(\int_0^r R^2 dx + 2R\int_0^r \sqrt{r^2 - x^2}dx + \int_0^r \left(r^2 dx - \int_0^r x^2 dx\right) = \Pi\left(R^2 r + 2R\frac{\Pi r^2}{4} + r^3 - \frac{r^3}{3}\right) =$$

$$= \Pi\left(R^2 r + \frac{\Pi R r^2}{2} + \frac{2r^3}{3}\right)$$

We also know that

$$\int_0^r \sqrt{r^2 - x^2}dx = r^2\int_0^{\frac{\Pi}{2}} \cos^2 t \cdot dt = r^2\,\frac{\Pi}{4} = \frac{\Pi r^2}{4}$$
$$x = r \cdot \sin t$$
$$dx = r \cdot \cos t \cdot dt$$

$$V_{difference} = \Pi\left(R^2 r + \frac{2r^3}{3} + \frac{\Pi R r^2}{2} + 2R\frac{\Pi r^2}{4}\right) - \Pi R^2 r = \Pi\left(\frac{2r^3}{3} + \frac{\Pi r^2 R}{2}\right) = \Pi r^2\left(\frac{2r}{3} + \frac{\Pi R}{2}\right)$$

$$V_{utilitarian} = 2\Pi r^2\left(\frac{2r}{3} + \frac{\Pi R}{2}\right) = \Pi^2 r^2 R + \frac{4\Pi r^3}{3}$$
$$V_{residential} = 2\Pi r^2\left(\frac{\Pi R}{2} - \frac{2r}{3}\right) = \Pi^2 r^2 R - \frac{4\Pi r^3}{3}$$

We can observe an interesting fact about the volumes:

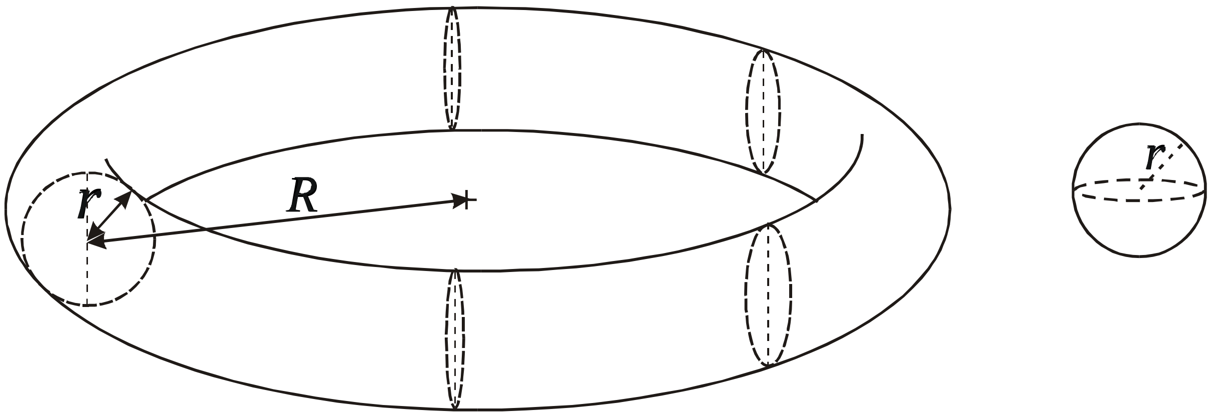
$$V_{th} = 2\Pi^2 r^2 R$$

$$V_{sphere} = \frac{4\Pi r^3}{3}$$

$$V_{utilitaria} = \frac{1}{2}V_{th} + V_{sphere}$$

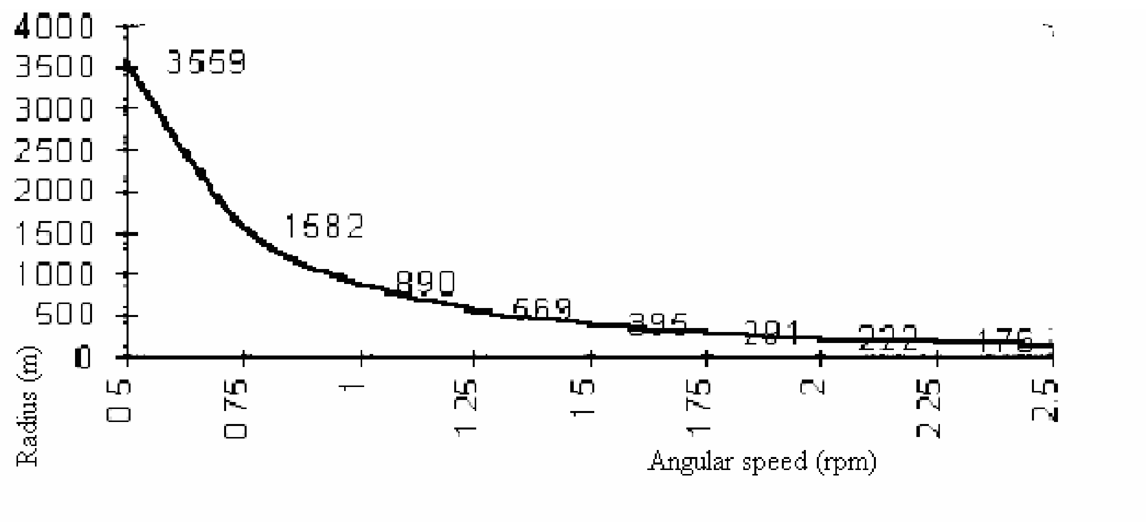
$$V_{re\sin dential} = \frac{1}{2}V_{th} - V_{sphere}$$

$$V_{residential} = \Pi^2 r^2 R - \frac{4\Pi r^3}{3} \quad [2]$$



Taking into account the rotation motion of the orbital colony, we must determine the radius (R) for which the simulated gravitational constant along the residential area is optimum ($g = 9.8\frac{m}{s^2}$).

$$\left.\begin{array}{l} a = \omega^2 R = \dfrac{4\Pi^2}{T^2}R \\ a = g \end{array}\right\} \Rightarrow \qquad R = \frac{gT^2}{4\Pi^2} \quad [3]$$



The graphic representation above shows the relation between the radius and the angular speed of the torus for which the simulated gravitational constant along the inhabited circumference is $9.8\frac{m}{s^2}$.

Considering the reaction of the human body to different angular speeds, we have chosen a rotation period of 127 s to be most suitable for the Space Colony. Therefore we can now determine the major radius (R) of the torus.

$$R = \frac{9.8 \cdot 127^2}{4 \cdot 9.85}$$

$$\boxed{R \cong 4011m \quad [4]}$$

As the feasibility of the Space Settlement strictly depends on the available technological possibilities, its structure and dimensions must well accord to precise construction and engineering norms. The most economical solution would be building a torus in which the ratio between the major radius and the minor radius allows the minimum residential area and volume per person. Still we have to consider the psychological needs of colonists; as in this case the minor radius will be too small to simulate a realistic sky and to minimize the sensation of an enclosure we must choose another option. Respecting the different proportion laws we reached the conclusion that the minor radius of the torus (r) should be 1/8 of its major radius. That means about 500m, a distance large enough to prevent the colonists from feeling somehow secluded.

$$\boxed{r = 500m \quad [5]}$$

Therefore we can now determine the residential volume inside the torus ($V_{residential}$)

$$V_{residential} = \Pi^2 r^2 R - \frac{4\Pi r^3}{3} = 9.85 \cdot 250000 \cdot 4011 - \frac{4 \cdot 3.14 \cdot 125000000}{3}$$

$$\boxed{V_{residential} = 9353754167m^3 = 9.35Km^3 \quad [6]}$$

We consider a minimum habitable volume per colonist of about 2000m^3. For creating superior life conditions and better reproducing the demographic density on Earth and for avoiding possible overcrowding due to the population growth we must supplement this volume with an average of 28000m^3 per person. In this case, the residential area per person will be of about 100m^2.

$$\boxed{\Delta V_0 \approx 30000m^3 \text{ / person} \quad [7]}$$

$$\boxed{\Delta A_0 \approx 100m^2 \text{ / person} \quad [8]}$$

By combining relations [1] and [6] we can estimate the initial number of colonists.

$$V_{residential} = \frac{N \Delta V_0}{1-f} \Rightarrow N = \frac{(1-f)V_{residential}}{\Delta V_0}$$

$$\boxed{N = \frac{0.8 \cdot 9353754167}{30000} \approx 250000 \, persons \quad [9]}$$

We can now determine the other numeric dimensions of the torus:

$$L = 2\Pi R \approx 25Km$$

$$V_{th} = 2\Pi^2 R r^2 = 19754175000m^3$$

$$A_h = 2\Pi R \cdot 2r = 4\Pi R r = 4\Pi \cdot 4011 \cdot 500 = 25189080m^2 \approx 25Km^2$$

All calculations are made in the perspective of a dynamic demography which could lead to the doubling of the population in less than ten years.

Because of its industrial use, the central body of the torus (or the 0 gravity center) has a larger fraction of inaccessibility (f'=60%). As the 0 gravity center is the main industrial core of the settlement, providing it with all required goods, it must dispose of sufficient space for efficiently carrying its activity. With the development of different technologies, the need for new industrial facilities will surely appear; wherefore we must provide enough space for the future expansion of industry onboard the Settlement. Concurrently, the 0 gravity center will be the only sheltering place in case of emergency evacuations caused by the different damages that can occur in the structure of the ring. Its life sustaining system will be independent and it will be able to temporary accommodate more than 250000 people; still, it must maintain the current industrial production to ensure life onboard the undamaged part of the settlement. Therefore, its dimensions must consider both its industrial and emergency use.

Taking into account the eventuality of a considerable population growth and that of a future industrial expansion we designed an initial volume of about 1304m^3/person inside the central body (considering both functional and emergency aspects). As the residential norms assure1740 m^3/person, this space is enough to be efficiently used in constantly developing industrial activities and in recreating all conditions, facilities, even commodities in case the habitable ring of the Space Settlement becomes unavailable for a longer period of time. In normal circumstances, this space could use as extra-storage room for goods produced inside the industrial core or even as leisure site.

We consider:
f'- the fraction of inaccessibility
r' – the larger radius of the central body
V_{cb} – the volume of the central body
A_{sp1} – the surface of the solar panels on the 0 gravity center
A_{sp2} – the surface of the solar panels around the 0 gravity center
A_{spt}- the total surface of the solar panels
ΔV_e - initially, the functional and emergency volume / person should be of about 1304m^3
R_{sp} – the radius of the solar panels around the central body

$$V_{cb} = \frac{N\Delta V_e}{1-f'} = 815125000m^3$$

$$V_{cb} \approx \Pi r'^2 \cdot 2r \Rightarrow r' = \sqrt{\frac{V_{cb}}{2\Pi r}} = \sqrt{\frac{815125000m^3}{3.14 \cdot 1000}} \approx 509.5m$$

$$A_{sp1} = 2\Pi r'^2 \approx 1630226m^2 \approx 1.6Km^2$$

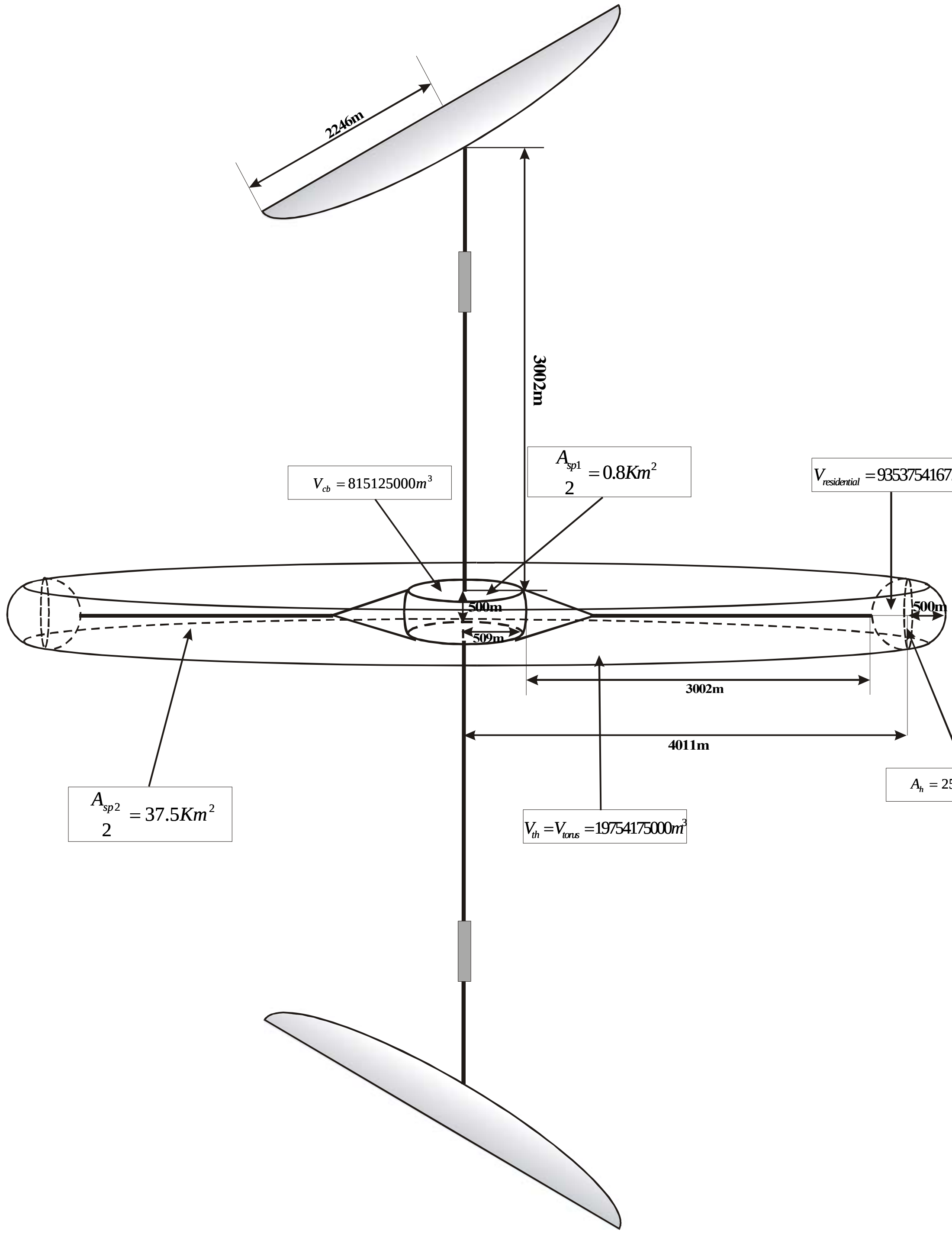
$$A_{sp2} = 2\Pi\left[(R-r)^2 - r'^2\right] = 2\Pi(R-r-r')(R-r+r') = 2 \cdot 37893645m^2 = 75Km^2$$

$$A_{spt} = 1.6 + 75 = 76.6Km^2$$

$$R_{sp} = R - r - r' = 3002m$$

Small evacuation modules must also be provided in case the 0 gravity center is damaged and can not sustain life anymore. We studied the spacecraft habitats which have been already used in different space missions and reached the conclusion that the average minimum volume required by a person is 2.5m^3. Therefore the dimensions of the evacuation modules must afford at least 2.5m^3/person; the chemical composition inside must be 72% O2 / 28% N2 at 5psi. A Spacecraft habitat summary is listed below:

	Summary of spacecraft habitats	**Effective volume (m3)**	**Pressure**	**Chemical composition / Pressure of the gaseous environment**	**Number of crew members**
	Vostock	2 m^3	sea level pressure	21% O2, 79% N2	1
	Voskhod / Soyuz	5 m^3	13.7-16.4 psia	2.7-3.9 psi ppO2	3
	Salyut Space Station	81 m^3	13.5-18.5 psia	3.1-4.6 psi ppO2	
	MIR Space Station - Base block, Kvant 1, Kvant 2, Kristall, Spektr, Priroda	~90 m^3 ea.	sea level pressure	6.8 psia ppO2 (21-40%)	
Russian spacecrafts	Mercury	1 m^3	5 psi	100% O2	1
	Gemini	3 m^3	5 psi	100% O2	2
	Apollo	7 m^3	5 psi	100% O2 on orbit	3
				60% O2 / 40% N2 during launch	
	Lunar Module	5 m^3			2
	Command and Servicing Module	7 m^3			
	Skylab Orbital Workshop	approx. 300 m^3	5 psi	72% O2 / 28% N2	
US Spacecrafts	Orbiter	71 m^3	sea level pressure	3.1 psi ppO2 (21%)	
				10.2 psia pre-EVA, 30% O2	
	Spacelab	~70 m^3			
	SPACEHAB	~31 m^3			
	ISS	~1200 m^3			



2246m
3002m
$\frac{A_{sp1}}{2} = 0.8Km^2$
$V_{cb} = 815125000m^3$
$V_{residential} = 9353754167m^3$
500m
509m
500m
3002m
4011m
$A_h = 25189080m^2$
$\frac{A_{sp2}}{2} = 37.5Km^2$
$V_{th} = V_{torus} = 19754175000m^3$

III.3. General structure

The internal structure of the settlement must serve both as residential and productive environment. As it should maintain life for very long periods of time there must be tight relations between the different structural parts of the artificial environment.

The two main components of the space settlement must assure appropriate conditions of life within their exterior walls. Therefore the interior of the torus must be properly divided to ensure an efficient use of space and materials. In the perspective of population growth and industrial expansion enough space space must be set apart for future developments inside the Settlement.

As we said the interior of both torus and central body must be used for two main purposes: the building of spaces designed for living and spaces designed for life maintaining activities. Therefore, the ring of the torus will be divided into two main volumes. The volume closest to the center will be the one designed for residential purposes, while the one in the exterior will serve for industrial, agricultural and transportation purposes, as shown in Annex a.

For main elevators carrying a maximum of 100 persons each will permanently connect the extreme points of the Colony: the lower floors of the exterior volume with the 0 gravity center. For maximum efficiency, they will be situated symmetrically towards the 0 gravity center, at approximately equal distances from the main residential and utilitarian areas. The inner residential volume will shelter a detailed inventory of facilities and structures required for individual and community activities: residences, schools, shops, libraries, administrative offices, recreational areas, work places etc.

The outer volume will also be divided into 12 floors attending different purposes. The first floor (I), situated right between the residential areas, will shelter all pipe lines providing houses with water. The next floor (II) will accommodate the different storage facilities, the interior transportation system and two Gravitational Cosmodromes.

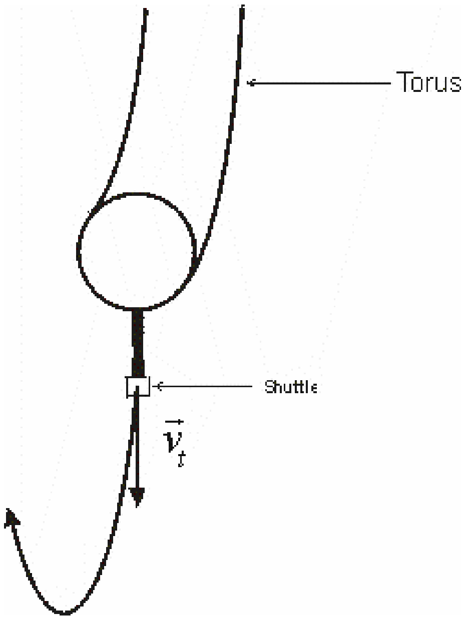
As the tangential speed reaches its maximum on the exterior circumference of the torus, the outer side of the Settlement ring can be used for launching space modules and shuttles on orbit without having to ignite their motors and thus using energy. They will burst forth from the torus with a speed equal to the tangential speed on the outer circumference of the settlement. The launching moment will be determined depending on the direction in which the modules must be headed. Therefore, the two Gravitational Cosmodromes on the exterior ring will be the basic launching facilities onboard the Settlement. Still, they will be less sutiable for docking maneuvers because of the high rotation speed of the exterior ring. The principle is detailed below:

$$v_t = \omega R$$

$$\omega = \frac{2\Pi}{T} = \frac{2 \cdot 3.14}{127} \approx 0.05 \frac{rad}{s}$$

$$v_t = 0.05 \cdot 4011 \approx 200 \frac{m}{s} = 720 \frac{Km}{h}$$

$\vec{v}_t$ - the tangential speed on the outer circumference of the torus equal to the launching speed



Levels III, IV, V, VI, and IX, X, XI will serve exclusively for agricultural purposes. Providing the specific formula for the area of a level is $A_{level} = 2\Pi(R + 70 + x)\cdot 2\sqrt{r^2 - x^2}$ (where R is the major radius of the torus, r is the minor radius of the torus, x is the hight of the floor) we can determine the approximate value of the total agricultural surface, which is 26.7 Km^2.

Plant growing will take place according to the different plant metabolisms and needs. Therefore, the temperature, the light intensity and specter and the CO_2 concentration inside the different "flats" will vary depending on the different crop types.

The livestock growing facilities and some of the primary food production installations will be found on floors VII and VIII. The main reason why they are situated between plant growing floors is that the livestock growing facilities cannot be placed in the immediate proximity of human residences because they could represent a serious factor of discomfort (source of odor and noise). On the other hand, livestock cannot be placed near the High-Gravitational Industry because of the noise produced by the different industrial facilities there. Being near the main sources of vegetal food, it will be very easy to supply the livestock growing facilities with the needed forage.

The main water pumping station , as well as the High-Gravitational Industry will be found on floor XII. The pumping station will resend water reaching the lower floors towards the central body of the Settlement, where it will be treated and reintroduced in the water supplying system.

The simulated gravitational constant on this floor can easily be determined.

$$g' = \omega^2 R = \left(\frac{2\Pi}{T}\right)^2 (R + r - 10) = \left(\frac{2\cdot 3.14}{127}\right)^2 (4011 + 500 - 10) = 0.0024\cdot 4501 \approx 11\frac{m}{s^2}$$

The high gravitation environment can be exploited by using it in different industrial activities, such as the intensification of the chemical processes, the recovery of diluted components from large aqueous streams, the crystal growth by solidification or the different adsorption systems.

A small empty space will be maintained in the extreme point of the torus; the reason why no installation or device can be used within this last floor (XIII) is that it is too close to the electro-magnetic coils.

Most of the floors are disserved by emergency and utilitarian elevators to ensure a rapid and fluent transit inside the industrial part of the torus.

The central body of the torus (Annex b) will shelter the industrial core of the Space Settlement. As it ensures a low gravity environment, it would be an ideal place to develop all industrial activities requiring the lifting of heavy or dense materials. The absence of wind and the 0 gravity conditions will allow the handling and assembling of huge components. Zero gravity also means the absence of convection currents in the different molten materials. Therefore, the material separation process, the crystallization progress and the mixing of materials will become much easier to achieve. Creating new types of alloys and crystal forms inexistent on Earth will surely be possible within 0 gravity conditions. The main water tank used in supplying the rest of the Colony with fresh water and the main water treatment station will be situated in the center of the central body, so that they will be evenly distant from all points inside the torus. 95% of the industries onboard the Space Settlement will develop their activity within the 0 gravity center (chemical compounds, solar power plants, ore smelting and metal processing facilities etc.)

Recreational areas will also be placed inside the central body of the Settlement, providing colonists with the chance to experience different entertainment activities in microgravity conditions (sports fields, small amusement parks)

Considering the diversity of activities taking place within the central body of the colony, the space inside it must be efficiently compartmented and isolated, so that the industrial processes would not interfere with the recreational ones. In the same time, industrial designers must provide efficient solutions for creating a rapid and fluent circuit of materials throughout the processing phase involving minimum amounts of energy.

Another important part of the central structure consists in the main docking facility of the Colony, situated below the inferior surface of the 0 gravity center. As the tangential speed near the center of the torus is null, the docking procedures will be safe and will not entail complicated maneuvers. From here, the space modules will be transported using a rail system to the Gravitational Cosmodromes outside the ring for further launching.

CHAPTER IV

Important functional elements of the Settlement

IV.1. Thermal stress

Considering the rotation movement of the Settlement it is easy to imagine that the position of a certain point of the torus towards the Sun is permanently changing. Therefore we can assume the temperatures of the different parts of the torus suffer constant variation depending on their position towards the Sun. The temperature of a certain surface will naturally tend to rise when facing the Sun and will tend to drop as soon as it begins to face the opposite direction.

According to Stefan's law, the power radiated by a black body in space is $P = \sigma \cdot A \cdot T^4; [P] = W(\frac{J}{s})$, where σ is Stefan's Constant ($\sigma = 5.67 \cdot 10^{-8} Wm^{-2}K^{-4}$), A is the surface area of the body ([A]= m^2) and T is the temperature of the body ([T]=K). Therefore the power radiated is directly proportional to T^4 for an identical body, which explains why the total energy under a black body increases so much for a relatively small increase in temperature.

We can also expect some dilation and contraction phenomena to occur during a complete rotation of the torus, although its exterior surface (the side facing the sun) will be covered with the solar panels supplying the electromagnetic coils. The solar panels will absorb 15% of the total solar energy; the rest of it will be transformed into heat. As the exterior solar panels are somehow isolated from the ring, only small amounts of heat will be transmitted to it. Moreover, the rotation period of 127s will not allow great temerature differences between the different parts of the torus. Therefore, the heat reaching the metallic exterior of the Settlement will not have considerable effects upon its shape and dimensions.

Still we must consider the three possible types of dilation: in length, surface and volume.

$$\boxed{l = l_0(1 + \alpha \cdot \Delta T) \quad [1]}$$

, where α is the linear dilation coefficient ($\alpha = \frac{l - l_0}{l_0 \cdot t^o}$)

$$\left.\begin{aligned} l &= l_0(1 + \alpha \cdot \Delta T) \\ L &= L_0(1 + \alpha \cdot \Delta T) \end{aligned}\right\} \Rightarrow S = S_0(1 + \alpha \cdot \Delta T)^2$$

By disregarding the terms containing $\alpha^2 \approx 10^{-10}$, we obtain:

$$\boxed{S = S_0(1 + 2\alpha \cdot \Delta T) \quad [2]}$$

$$\left.\begin{aligned} l &= l_0(1 + \alpha \cdot \Delta T) \\ L &= L_0(1 + \alpha \cdot \Delta T) \\ d &= d_0(1 + \alpha \cdot \Delta T) \end{aligned}\right\} \Rightarrow V = V_0(1 + \alpha \cdot \Delta T)^3$$

By disregarding the terms containing α^3, we obtain:

$$\boxed{V = V_0(1 + 3\alpha \cdot \Delta T) \quad [3]}$$

Relations [1], [2] and [3] represent the expressions of the three dilation laws.

l_0, S_0 and V_0 are the initial dimensions corresponding to the temperature T_0=273.15K (t_0=0°C)

We can now determine the final dimensions by considering an intermediary phase:

$$\left.\begin{array}{l} l_1 = l_0(1+\alpha \cdot t_1) \\ l_2 = l_0(1+\alpha \cdot t_2) \\ \Delta t = t_2 - t_1 \end{array}\right\} \Rightarrow \frac{l_1}{l_2} = \frac{1+\alpha \cdot t_1}{1+\alpha \cdot t_2} \Rightarrow l_2 = l_1 \frac{1+\alpha \cdot t_1}{1+\alpha \cdot t_2}$$

$$l_2 = l_1 \frac{(1+\alpha \cdot t_2)(1-\alpha \cdot t_1)}{1-\alpha^2 \cdot t_1^{\,2}} = l_1 \frac{1-\alpha \cdot t_1 + \alpha \cdot t_2 - \alpha^2 t_1 t_2}{1-\alpha^2 t_1^{\,2}}$$

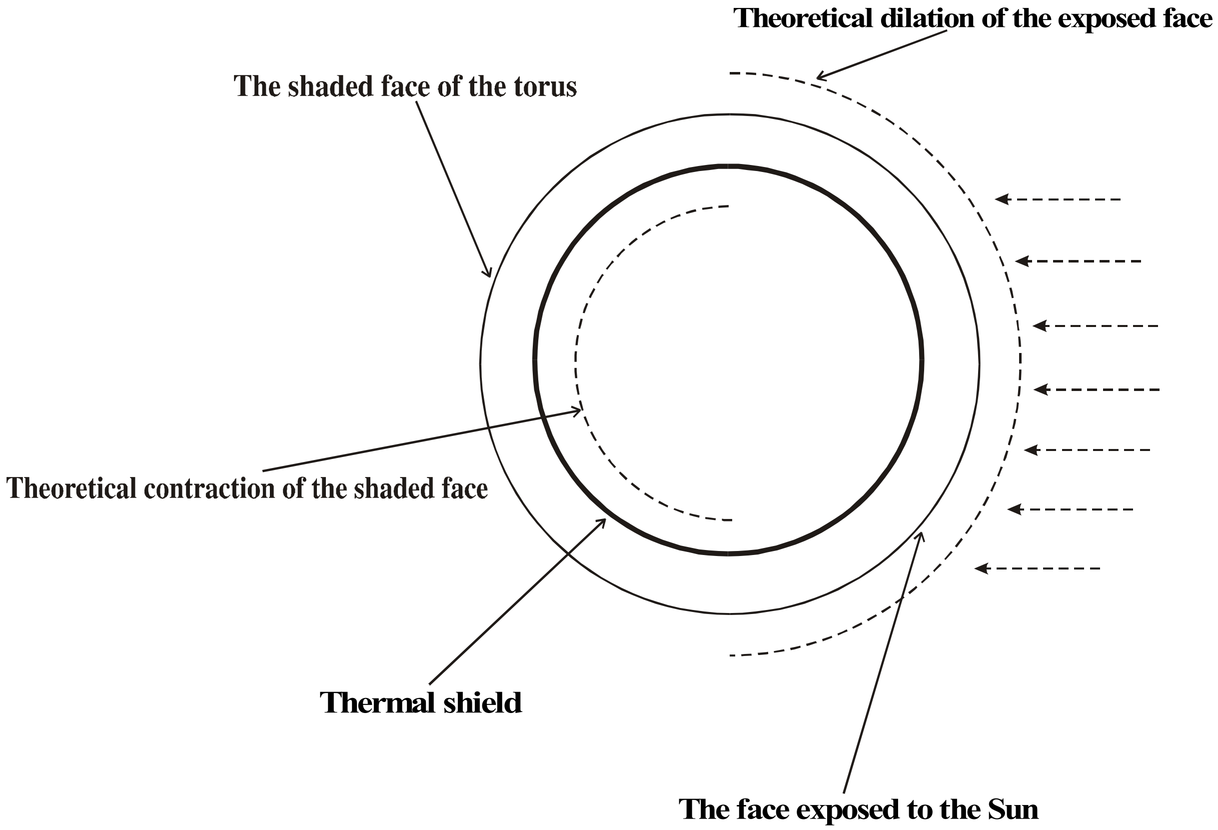
As $\alpha^2 \approx 10^{-10}$ we can disregard the terms containing it. Therefore,

$$l_2 = l_1(1+\alpha \cdot \Delta t) \quad [4]$$

$$S_2 = S_1(1+\beta \cdot \Delta t) \quad [5]$$

$$V_2 = V_1(1+\gamma \cdot \Delta t) \quad [6]$$

, where $\beta = 2\alpha = \frac{\Delta S}{S_0 \cdot \Delta T}$ and $\gamma = 3\alpha = \frac{\Delta V}{V_0 \cdot \Delta T}$



The temperature variations will cause small deformation forces to act upon the exterior of the torus. The deformation forces can be assimilated to forces caused by the dilation phenomena. According to Hooke's law,

$$\left.\begin{aligned} F_{def} &= \frac{SE}{l_0} \cdot \Delta l \\ \Delta l &= l_0 \alpha \cdot \Delta T \end{aligned}\right\} \Rightarrow F_{def} = \frac{SE}{l_0} \cdot l_0 \alpha \cdot \Delta T = SE\alpha \cdot \Delta T$$

$$\boxed{F_{dil} = F_{def} = SE\alpha \cdot \Delta T \quad [7]}$$

Δl - the dilation effect
l_0 - the initial length
ΔT - the time elapsed
F_{def} - the deformation force
F_{dil} - the dilation force
S- the surface area of the transversal section of the body
E- the module of eleasticity

As $SE\alpha$ is a constant, the dilation force varies according to time: $F_{dil} = f_{(time)}$

The dilation force can also be assimilated to an elastic force:

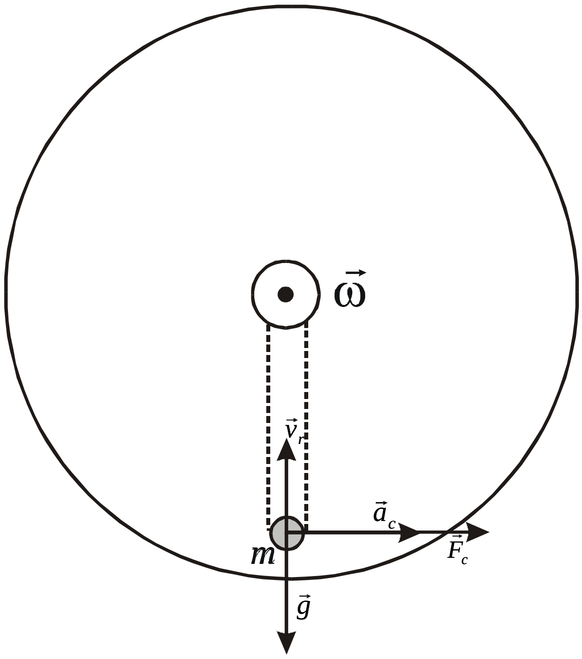
$$\left.\begin{aligned} F_{dil} &= \frac{SE}{l_0} \cdot \Delta l \\ \frac{SE}{l_0} &= k \end{aligned}\right\} \Rightarrow F_{dil} = k \cdot \Delta l$$

Therefore, the dilation force can theoretically cause harmonic vibrations to occur within the body of the torus. But practically the ring suffers chaotic vibrations. Therefore we must provide the inner circumference of the torus with a thermal shield to minimize the thermal stress and thus the chaotic vibrations.

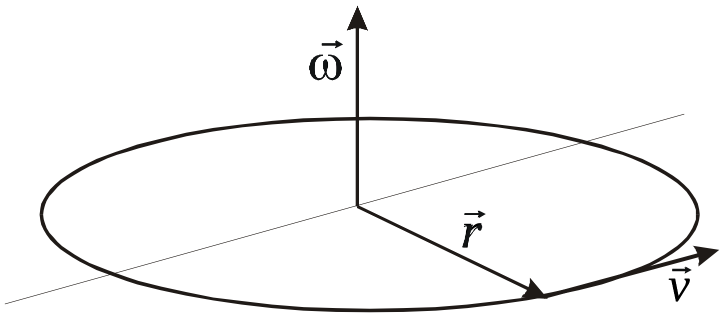
IV.2. The Coriolis force and its effects

As the Coriolis force is a force which acts upon any moving body in an independently rotating system, its effects can also be felt by colonists onboard the space settlement. The effect of the Coriolis force is an apparent deflection of the path of an object that moves within the rotating coordinate system. The object does not actually deviate from its path, but it appears to do so because of the motion of the coordinate system. The coriolis force is larger for parcels moving at faster speeds, it's zero if a parcel is not moving and is not that large for slow-moving objects or for those moving over short distances. That is why the Coriolis force will not represent a major inconvenient for colonists moving along the torus, as it is only felt by those traveling towards the center of the settlement.

Therefore, the four elevators connecting the main residential areas with the 0 gravity center must integrate special mechanical systems to ensure that travelers will not feel the effects of the Coriolis force. For achieving this, the composite force acting on the traveler must pass through its symmetry axis. One option would be providing the elevators with mobile floors which will change their angulations according to speed, total acceleration and distance towards the 0 gravity center. As the Coriolis force is larger for objects moving at faster speeds, it will certainly reach its maximum in points situated on the extreme circumference of the torus. In this case, the Coriolis force will reach its utmost at the base of the elevators, where the floor angulations will be maximum. While getting closer to the center of the torus, the angulations of the floors will slowly decrease, reaching 0^o at destination.



Knowing the angular velocity of the space settlement ($\vec{\omega}$) and the elevator's time of travel (t) we can determine the floors' angulations depending on these two data.



Assuming the relative speed of the elevator, implicitly that of the traveler is $v_r = 10\frac{m}{s}$, the acceleration associated to the Coriolis force is:

$$a_c = 2 \cdot \frac{2\Pi}{T} \cdot v_r = \frac{4 \cdot 3.14 \cdot 10}{127} \approx 1\frac{m}{s^2}$$

$$a_g = \omega^2 r = \omega^2 v_r t$$

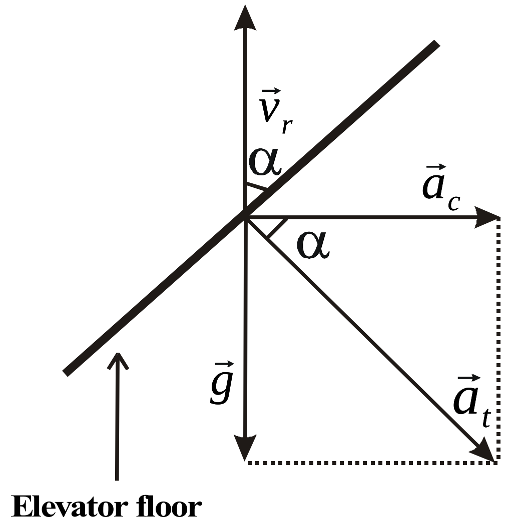
$$r = v_r t$$

$$a_c = 2\omega \cdot v_r$$

$\vec{a}_g$ - the gravitational acceleration

$\vec{r}$ – the position vector

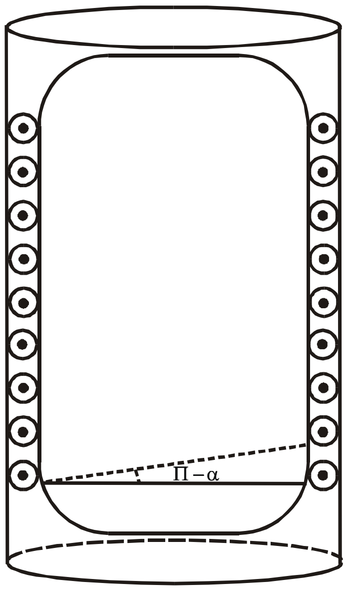
t - the time of travel of the elevator



$$tg\alpha = \frac{a_c}{a_g} = \frac{2\omega v_r \sin 90^o}{\omega^2 v_r t}$$

$$\boxed{tg\alpha = \frac{2}{\omega t}}$$

For reducing the friction between the elevator room and its tube caused by the Coriolis force (which changes its direction accordingly to the direction of movement) the elevator must be fitted with small lateral bearings or wheals.



Elevator towards the center of the settlement

IV.3. Radiators

This chapter consists of a few points about the role of radiators in the temperature regulation of the space colony.

Any habitat needs light. This may be provided as sunlight or artificial light, but whichever; it will introduce energy will end up as heat, thus tending to increase the temperature of the habitat. The activities of the colonists and their artifacts may add to the heat generated, particularly if they rely on further imported energy.

The main type of heating and cooling will be electric radiators and coolers with intelligent centralized thermostat.

They would be mounted under the 'floor' of the habitat and would obviously require active pumping of the transfer medium. Still there would be no need for a rotating connection.

The "Thermic Valve" Principle with applicability in non-electric radiators and coolers

The temperature of an object suspended in space, in this case the space settlement, will be hot or cold depending upon the amount of radiation that it absorbs. So in shadows it gets very cold, and in the sunlight it gets very hot. This is the main idea for our non-electrical radiator and cooler.

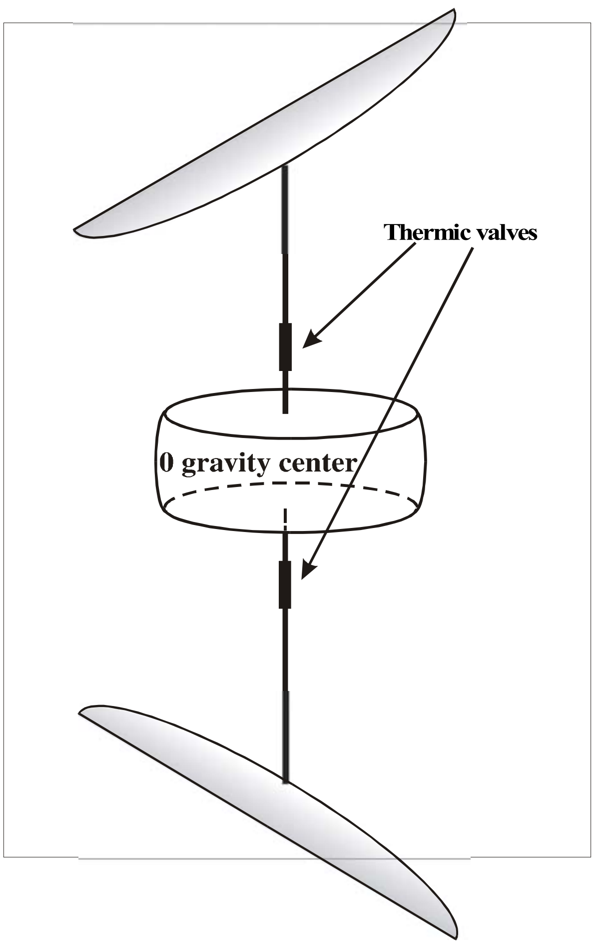
$E = K \cdot T^4$ (Thermo equilibrium)

We must put a thermoconductor material up and under the 0 gravity zone, as shown in the image below for maintaining this zone to a normal temperature without electric heaters powered from the photovoltaic cells. The thermoconductor material can have a circulating caloric agent like water or any other.

This makes two advantages:

- This is a secondary source of power
- In case the electric system failures the colonists can use the 0 gravity center as a "life boat"

The position of the rectangular thin panel will be auto orientated by a thermo sensible material located inside the 0 gravity zone thus its angle with the sun rays will be controlled.
If its angle with the solar rays is 90^o the panel will receive the maximum amount of radiation thus it will heat the interior of the torus, and if its angle is 0^o it will cool the 0 gravity zone.
In an intermediary angle (between 0^o and 90^o) ,the luminous flux will decrease ,hence, the energy absorbed by the heat conducting material will be the appropriate for maintaining the 0 gravity zone temperature to 20^o C.

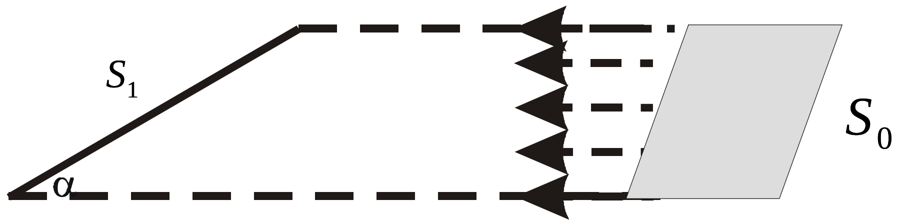


The heat conducting material will have one black side for better taking the beam energy.
The Wiedemann-Franz law says that the boundary resistances of heat and electricity are proportional. We must use a resistant material because of the great difference between high and low temperatures of the thermo conductor. These are some good heat conductors materials but not resistant to such big radiation and temperature.

Material	Thermal conductivity (cal/sec)/(cm^2 C/cm)	Thermal conductivity (W/m K)*
Silver	1.01	406.0
Copper	0.99	385.0
Aluminum	0.50	205.0
Lead	0.083	34.7

Studying the table below we find out that the most suitable material for the radiator panel will be the carbon foam.

Carbon Foam Properties	
Density	0.2 - 0.6 g/cm3
Thermal Conductivity	50 - 150 W/m·K
Specific Conductivity	258
Compressive Strength	3.4 MPa
Compressive Modulus	144 MPa
Specific Surface Area	4 - 34 m^2/g



$$E = \frac{\Phi}{S}\left(\frac{W}{m^2}\right)$$

$$E_0 = 1380\frac{W}{m^2}$$

For determining the amount of solar energy (E_S) absorbed by one of the panels, we will consider a flat thermo conductor panel of surface S_1 and a surface S_0.

$$\Phi_i = ES_0$$

$$S_0 = l^2\frac{\sqrt{2}}{2}$$

$$\Phi = E_0 S_0 \cong E_S l^2$$

The solar energy absorbed on the panel will be:

$E_S = \frac{E_0 S_0}{l^2} = \frac{E_0 l^2 \sqrt{2}}{2l^2} = E_0\frac{\sqrt{2}}{2} = 0.707E_0$, for a panel inclination of 45^o

The small temperature differences between different areas of the torus will generate little breezes which will improve the air circulation.

IV.4. The light factor

a. The benefits of natural Sunlight

Light is one of the most important elements which contribute to the development of natural life and human activities. It is known that the absence of light or the insufficient amount of light can cause severe damage to living organisms, including human beings, leading to biological extinction. Light plays also a major role by influencing people's morale and mentality. Therefore, we can not imagine long-term life on the orbital colony without light. This chapter will discuss the distinction between the light we receive from natural sources and that provided by human technology. Most of the direct and indirect effects of artificial lighting will be debated in detail.

The importance of adequate sunshine on the body, on exposed skin, on a regular basis is important for human health. Without adequate sunshine, we cannot expect to achieve superior health onboard the space settlement. Also, there are definite negative health effects from artificial lighting. For optimum well-being on the colony, it is necessary to be aware of any influence which upsets the natural order of life.

Natural sunlight is needed by all the more highly developed forms of life in all conditions of health and ill-health and throughout their existence. It is a valuable factor in all states and conditions of the human body. As artificial light does not produce a complete spectrum of light, its influence tends to change the natural body rhythms especially accustomed to the light of nature. The only way we may avoid these negative effects is to avoid their causes. Natural sunlight enhances bodily nutritive processes overall. Also, it specifically facilitates phosphorus and calcium absorption and catalyzes the production of vitamin D in the skin.

Sunlight is of value in all states and conditions of the body and in all stages of development.
Its role in proper bone development is due to the fact that only through the aid of natural sunlight, particularly the ultraviolet rays, may the laying down and fixation of the calcium and phosphorus salts be accomplished in an ideal fashion as to make for the transformation of cartilage into bone. When insufficient sunlight is obtained, the result is defective, misshapen, brittle and easily broken bones. Sunlight also proves invaluable in cases of glandular inactivity and aids in increasing the coagulating power of the blood, being of inestimable value to sufferers from hemorrhage disorders. The influence of sunlight is also directly related to the number of red cells and hemoglobin in the blood. An insufficiency of light will cause an increase in the serum or watery portion of the blood and a corresponding decrease in the quantity of blood fibrin and red corpuscles, resulting in anemia. But with sufficient sunlight, the oxygen-carrying power of the blood is increased, the circulation of the blood is improved, and consequently the blood's power to repair and build tissue is increased. Sunlight's influence on the muscles is to add to their size and quality and to enhance their contractile powers by improving the condition of the entire body, including the nerves that control the muscles. Regarding the pregnant mother and her unborn child onboard the orbital colony, it must be noted that the benefits to be derived from sunlight are greatest during periods of development and rapid gains in flesh. Sunshine, again, by improving overall health and vitality, aids in the skeletal development of the baby and helps preserve the normal alkalinity of his blood. Another benefit is that pregnant mothers who get sufficient sunlight experience little if any tiredness, backaches and loss of appetite. All anabolic activities in the body ultimately depend on sunlight for most effective function.

As human activity is very important onboard the settlement, full-spectrum lighting in closed work places will create significantly lower stress on the nervous system than standard cool-white lighting and will reduce the number of absences due to illness. Full-spectrum lighting will act to boost the immune system in the same way as natural sunlight and will also be used in open-door spaces during orbital nights.

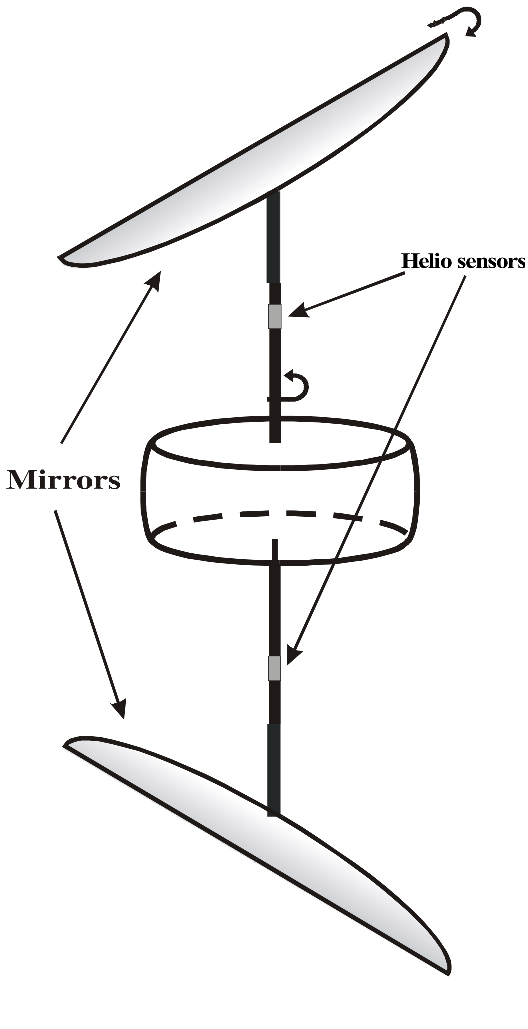
Still the effects of artificial lighting have been noticed in both plants and animals. For example, plants grown in artificial light lack the rugged constitution of plants grown under natural lighting conditions. Their growth may be stimulated by subjecting them to longer hours of light, as compared to the natural light cycle of the revolving earth. But this forced growth produces plants bearing flowers and fruit of lesser quality and color appeal than those grown in sunlight. The animal world is also adversely affected by variance of light wavelengths. Fluorescent lighting can cause genetic mutations, cancer and death in the cells of many life forms, including humans.

Aside from the facts concerning the direct negative effects of unnatural lighting, we must also consider their more indirect effect on our body rhythms. Their presence, by turning night into day, tend to imbalance the circadian rhythms- the regular cycles of rising and falling body temperature, variations in body chemicals that naturally occur approximately once every 24 hours. The result may be 'light stress." All plants and animals require alternating periods of light and dark so that some vital processes may rest while others become activated. The anabolic activities during the night can take place efficiently only when not interfered with by lighting, which continues to stimulate activity in the living cells.

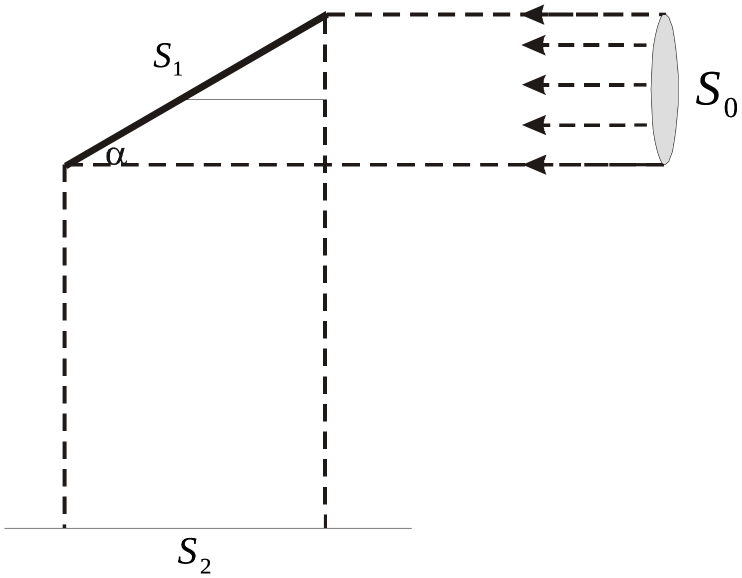
That is why the space settlement must dispose of artificial 14-hour days and 10-hour nights. Open spaces inside the torus will have natural sunlight during day time and full-spectrum illumination during the night.

b. Mirrors and light generation

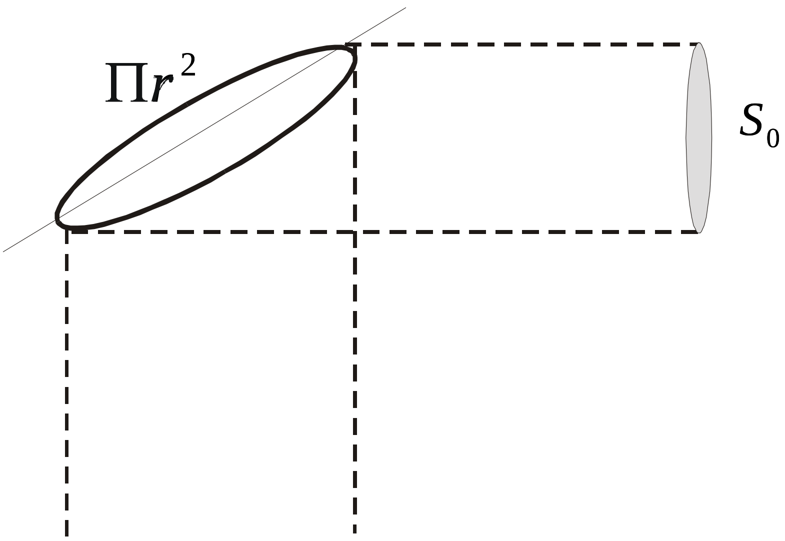
The only feasible option for illuming the residential and recreation areas inside the torus using natural sunlight is to dispose of two large mirrors to reflect the solar rays in the desired location of the colony. The two mirrors will be placed symmetrically towards the center of the ring (or the 0 gravity center), being directly connected to the central body by two long cylindrical bars made of titanium. Taking into account that the angle between the apparent orbit of the Moon and Earth's ecliptic is $5^{o}9^{'}$, the two mirrors have to be slightly prone towards the main ring of the torus, as shown in the diagram below. We will consider a mirror inclination of 45^{o}.



The two Helio sensors containing photoreceptor cells will permanently determine the position of the Sun towards the mirrors. By connecting them to the rotating system of the mirrors, they will always keep them face to the Sun, so that the amount of light reflected onto the surface of the torus will be maximum.



For determining the amount of solar energy (E_S) reflected by one of the mirrors, we will consider a flat mirror of surface S_1 and a light source of surface S_0.



$$E = \frac{\Phi}{S} (\frac{W}{m^2})$$

$$E_0 = 1380 \frac{W}{m^2}$$

$$\Phi_i = E S_0$$

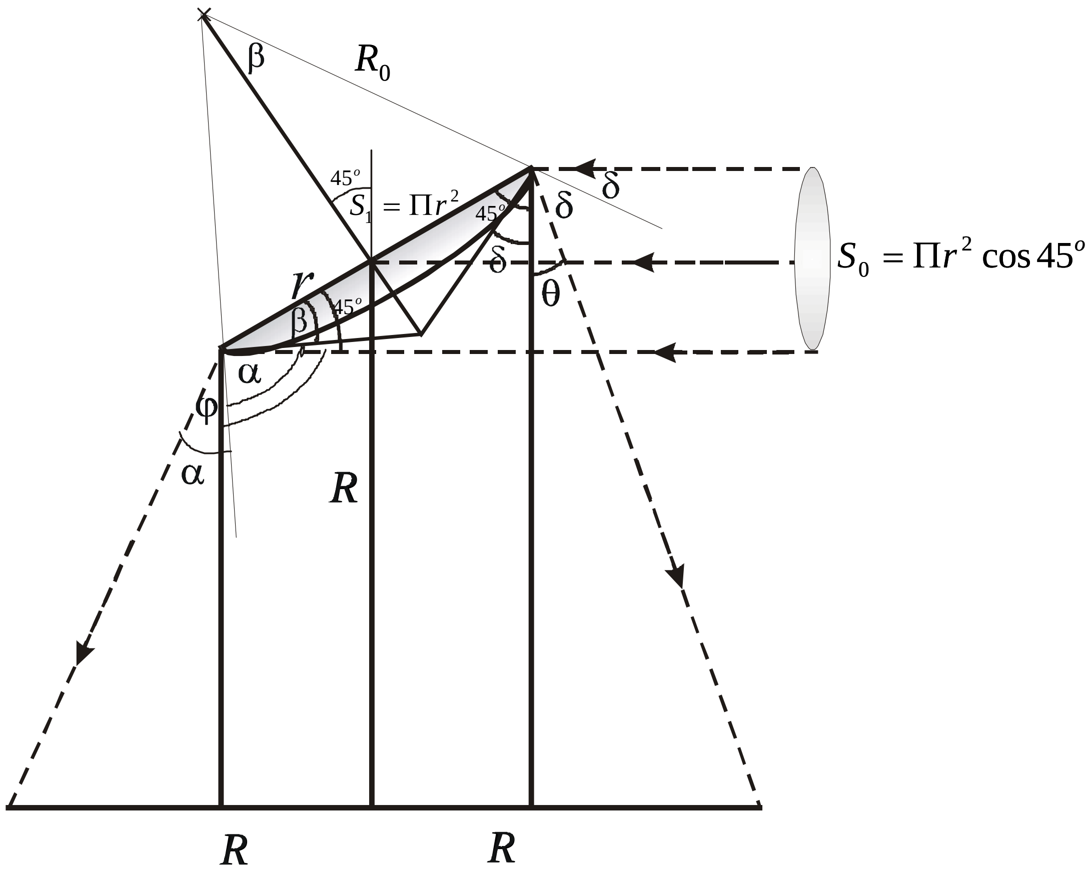
$$S_0 = \Pi r^2 \frac{\sqrt{2}}{2}$$

$$\Phi = E_0 S_0 \cong E_S \Pi r^2$$

The solar energy reflected on the ring will be:

$$E_S = \frac{E_0 S_0}{\Pi r^2} = \frac{E_0 \Pi r^2 \sqrt{2}}{2 \Pi r^2} = E_0 \frac{\sqrt{2}}{2} = 0.707 E_0$$, for a mirror angulation of 45^o

If the mirrors are slightly curved, then their convex shape will allow the reflection of the light on a wider area. In this case, we can determine the convexity of the mirrors by calculating their radius:



$\alpha = \varphi + 45^o - \beta$

$2(\varphi + 45^o - \beta) - 2\varphi = 90^o$ $\quad 2\delta + \theta = 90^o$

$2\varphi + 90^o - 2\beta - 2\varphi = 90^o$ $\quad \varphi = 90^o$

$\beta + \delta = 45^o$

$\varphi = 2\beta \quad [2]$

$45 - \beta = \alpha - \varphi$

$\theta = \varphi \quad [3]$

$\delta = 45^o - \beta$

$2(45^o - \beta) + \theta = 90^o$

$90^o - 2\beta + \theta = 90^o$

$\theta = 2\beta \quad [1]$

$2\delta + \varphi = 2\alpha - \varphi = 90^o$

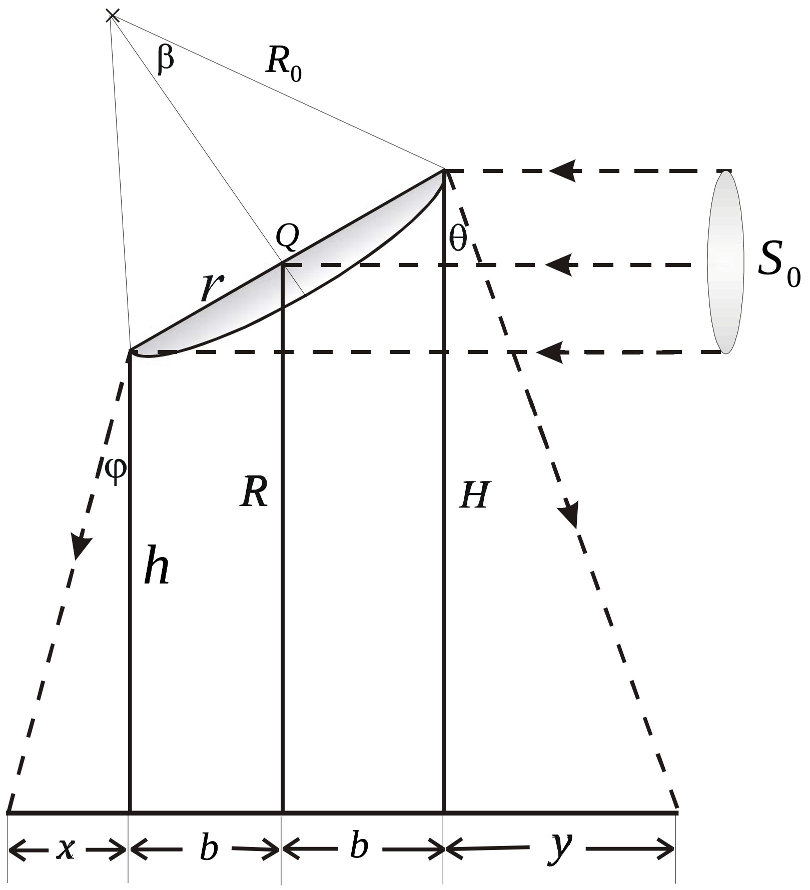
$45^o + \delta = 45^o + \alpha - \varphi$

$\delta = \alpha - \varphi$

$2\alpha - 2\delta = 2\varphi$

$\alpha - \delta = \varphi$

$\alpha = \delta + \varphi \quad [4]$



$$b = r\frac{\sqrt{2}}{2}$$

$$h = R - r\frac{\sqrt{2}}{2}$$

$$H = R + r\frac{\sqrt{2}}{2}$$

$$\tan\varphi = \frac{x}{h}$$

$$\tan\varphi = \frac{y}{H}$$

$$2b + x + y = 2R$$

$H + h = 2R \quad [5]$

$$x = h \cdot \tan\varphi$$

$$y = H \cdot \tan\varphi$$

$$x + y = (H + h)\tan\varphi$$

$$2r\frac{\sqrt{2}}{2} + (H + h)\tan\varphi = 2R$$

$$r\sqrt{2} + 2R\tan\varphi = 2R$$

$$\boxed{r\sqrt{2} = 2R(1 - \tan\varphi) \quad [6]}$$

If $r = \frac{R}{\sqrt{2}}$, then:

$$R = 2R(1 - \tan\varphi)$$

$$\frac{1}{2} = 1 - \tan\varphi$$

$$\boxed{\tan\varphi = \frac{1}{2} \quad [7]}$$

$$\boxed{\varphi = 26^o \quad [8]}$$

$$\beta = \frac{\varphi}{2} = 13^o \quad [9]$$

$$\alpha = \frac{90^o + \varphi}{2}$$

$$\delta = \frac{90^o - \varphi}{2} = 45^o - \beta$$

$$\sin\beta = \frac{r}{R_0} = \frac{R}{R_0\sqrt{2}}$$

$$R_0 = \frac{R}{\sqrt{2}\sin\beta}$$

$$R_0 = \frac{R}{1.41 \cdot \sin 13^o} = \frac{R}{1.41 \cdot 0.22}$$

$$\boxed{R_0 = 3.22R \quad [10]}$$

R_0 - the radius of curvature of the convex mirror

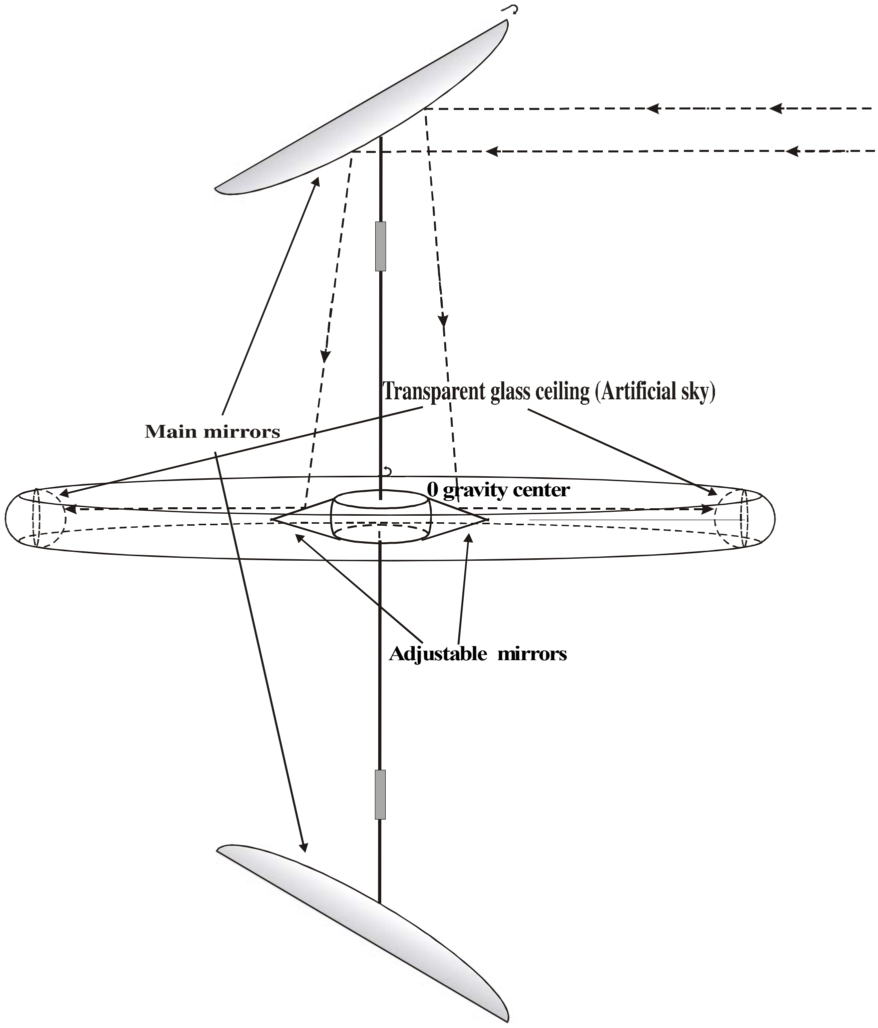
$R = R_{sp}$ - the distance between the mirror and the 0 gravity zone (the length of the bars which connect the central body with the mirrors)

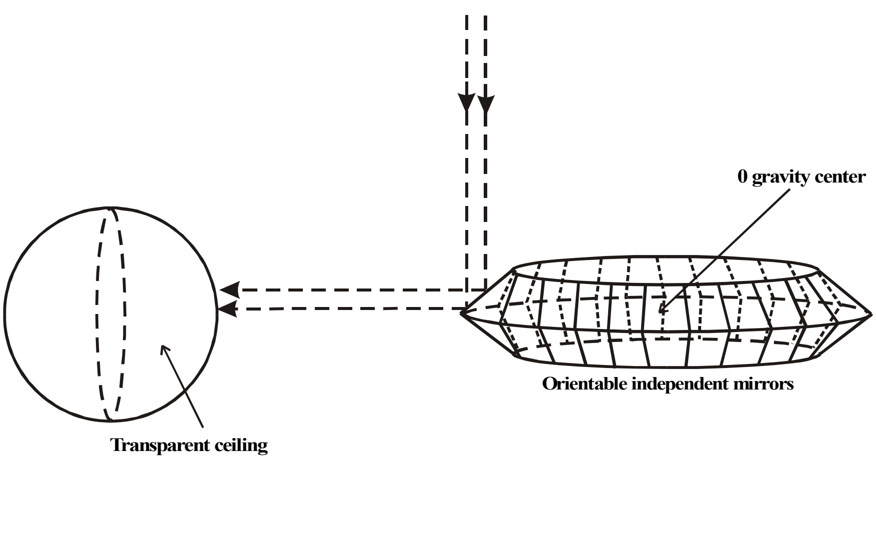
$$R_0 = 3.22 \cdot R_{sp} = 3.22 \cdot 3002 \cong 9730m$$

$$r = R_0 \cdot tg\beta \Rightarrow r = 9730 \cdot tg13^o = 9730 \cdot 0.2 \cong 2246m$$

c. Simulating the circadian cycle

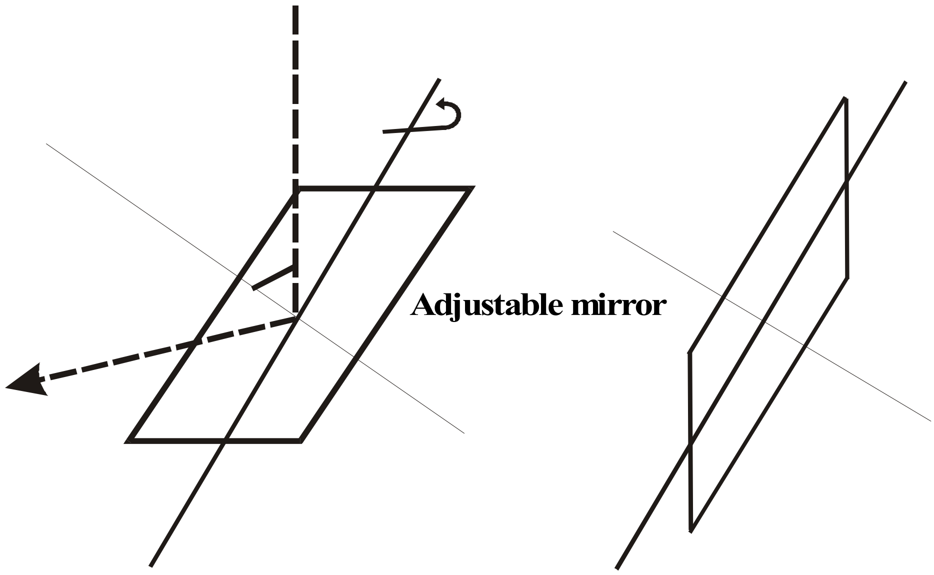
For an easier, less stressful and more rapid accommodation of people in space, creating an artificial "sky" seems to be an imperative condition. Therefore, we will generate the illusion of having a sky by using a transparent ceiling made of special glass, which will not allow the passing of UV radiations. To achieve this, Pb^{2+} ions will be introduced in the process of clear glass fabrication. The solar light reflected by the two main mirrors will be subsequently reflected by smaller, independent mirrors situated around the 0 gravity center of the torus. Each of them will reflect light onto a well defined sector of the ceiling. To properly illumine the interior of the torus, the solar rays must be reflected perpendicularly on its transparent glass ceiling. Hereby, the illusion of a lightsome sky will be produced. The principle is shown in the drawings below.





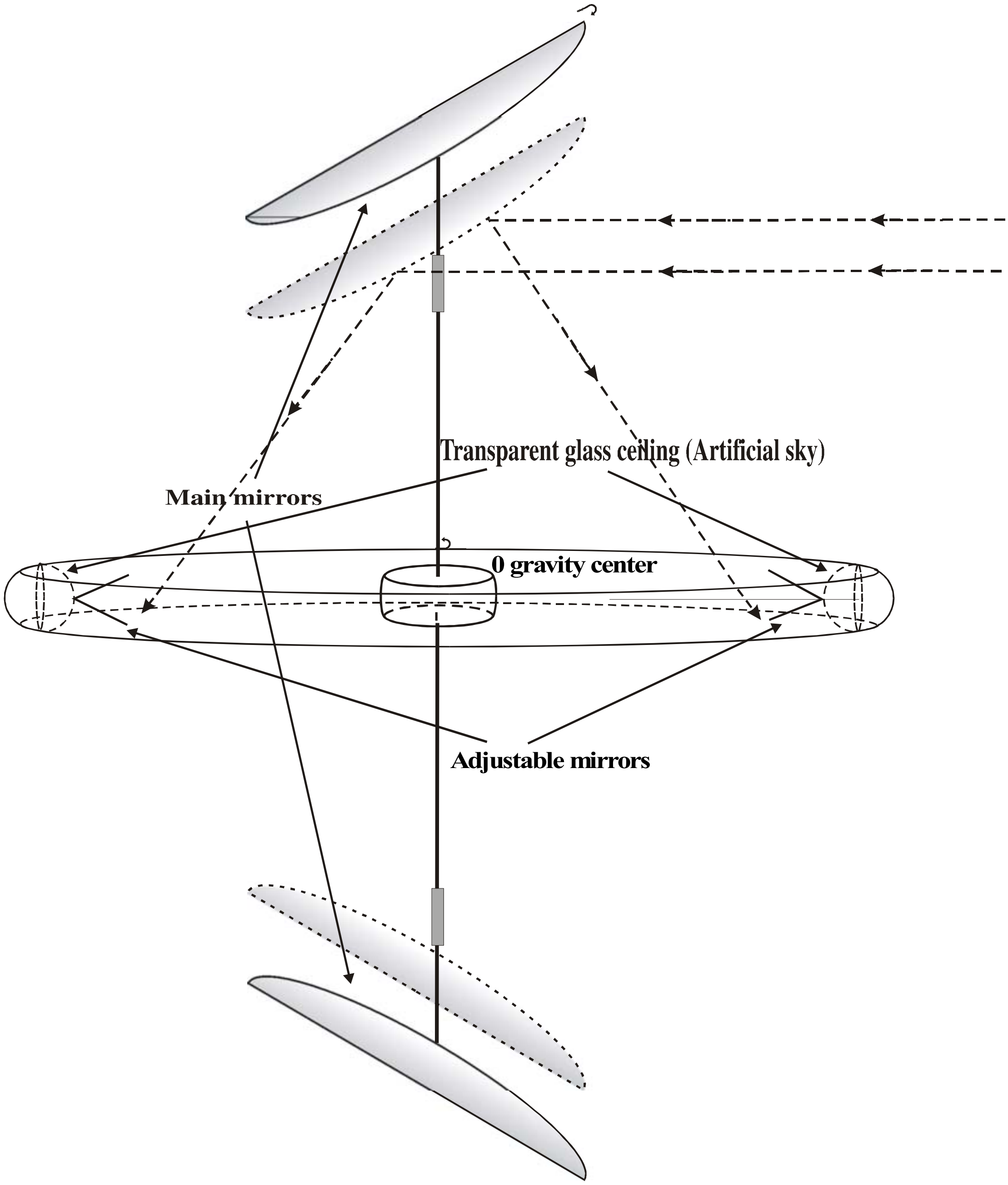
As we said, the regular sequence of days and nights plays a major role in the proper development of human beings, affecting both metabolism and social activity. There are three possibilities for simulating the circadian cycle.

1.The first and most efficient, involving only small amounts of energy and simple technological means, is the independent rotation of the adjustable mirrors, so that the reflection angle will not allow light to reach the transparent ceiling of the torus. It can be achieved by using common rotating mechanisms which will orientate the mirrors at an angle of 0^o towards the solar rays, so that the reflection angle will become null. The 0^o angulations will accord with the night periods inside the torus. The principle is shown in the diagram below.



2.Another way of simulating Terrestrial nights inside the orbital colony will imply a different positioning of the adjustable mirrors. In this case, they should be placed on the inner circumference of the torus, in the immediate vicinity of its ceiling. The idea is lowering the main mirrors so that the light reflected by them will cover a more limited area, avoiding the adjustable mirrors, thence avoiding being reflected inside the torus.
The lowering of the two large mirrors will imply the use of complex technology and considerable amounts of energy. Disposing the adjustable mirrors along the inner contour of the ring will require much more material than disposing them near its center. Therefore, this option is too uneconomical to be considered.

3. The third solution consists in covering the ceiling of the torus with two superposed titanium “nets”. During the day period, the light reflected by the adjustable mirrors would pass through the nets’ empty spaces. For simulating night periods and even crepuscules, these empty spaces will be slowly narrowed by shifting the exterior net over the interior one, until the surface of the ceiling will be completely covered. Still this option would entail the use of large quantities of titanium thence a considerable amount of economic resources.



Method No.2 - Lowering of the two main mirrors

CHAPTER V

Construction

V.A. Ground procedures

1. Launching site

Carrying materials from Earth is very expensive, thus we must build in space a whole industry for bringing the material we need for the Space Settlement's construction. The ground procedures will consist in preparing all the materials necessary for the Moon base and the L1 temporary base. We will also need to carry in space materials which can not be found on the Moon, Mars or appropriate asteroids. We will need powerful shuttles for carrying the crew, the engineers and the needed robots for the Space Settlement's construction. The materials and the space shuttles will be launched from a site in India near the geomagnetic equator because workforce is less expensive and the gravity constant is minimal.

2. Launching techniques and automatic procedures

All the tools, robots and materials will be sent to the lunar base which was built before especially for this purpose. After the programmed robots extend the lunar base for living, the crew consisting in workers, engineers and doctors will arrive to the lunar base.

3. Means of transportation

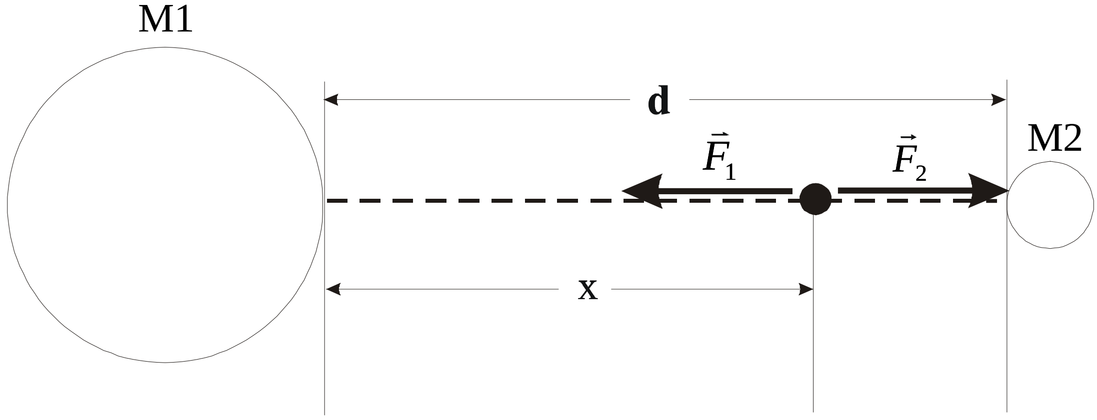
In the early times, the astronauts were constrained to very difficult exercises, but nowadays almost any normal person can become an astronaut. The crew will be transported from the Earth to the Moon exactly like astronauts in common Space Shuttles.

V.B. On-orbit procedures

1. Using L1 as temporary deployment site

The building of the orbital settlement in L5 will involve the existence of a temporary "work camp" somewhere near the main construction site. This transit platform will function as anchorage zone for all materials and crews arriving both from the Moon and the Earth. For maximum efficiency, it must be placed between the two major bodies. As we said before, the orbit around L1 would be ideal for the temporary parking of shuttles, workers and materials during the construction of the space settlement, as it is relatively close to the Moon, the main source of materials (58200 Km). For better understanding its positioning, let's consider the following example.

Two cosmic bodies of masses M_1 and M_2 respectively are situated at a distance (d) one from the other. On the line connecting the two bodies there is a point in which the gravitational field is null.



Therefore, the composite force resulting from the attraction forces of the two large bodies on another body of mass m situated in this point is null.

$F_1 = F_2$

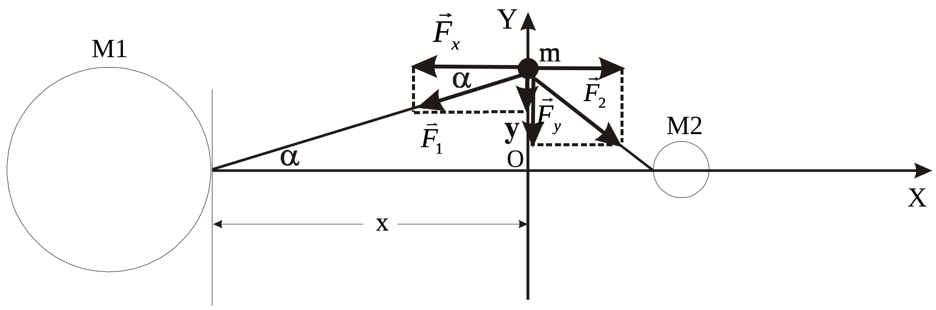
$$\frac{kM_1 m}{x^2} = \frac{kM_2 m}{(d-x)^2}$$

$$\frac{\sqrt{M_1}}{x} = \frac{\sqrt{M_2}}{d-x}$$

$$d\sqrt{M_1} - x\sqrt{M_1} = x\sqrt{M_2}$$

$$x = \frac{d\sqrt{M_1}}{\sqrt{M_1} + \sqrt{M_2}} \quad [1]$$

Let's assume that the body of mass m situated between M_1 and M_2 is moved by y, perpendicular to the direction determined by the two cosmic bodies:



$$F_x = F\cos\alpha \approx F \; (\alpha \text{ is very small, and } \cos\alpha \approx 1)$$

The gravitational forces have both horizontal components (on the OX axis),

$$F_{1y} = F\sin\alpha \approx F\alpha = F\frac{y}{x}.$$

and vertical components (on the OY axis),
The composite force of gravitational interaction along the OY axis is an elastic force:

$$F_y = -\frac{2F}{x}y = -ky \quad [2]$$

Therefore, the body will oscillate in respect with the law of linear harmonic oscillation. The equivalent constant of elasticity (k) is:

$$F = -2kM_1\left(1+\sqrt{\frac{M_2}{M_1}}\right)^3 my \quad [3]$$

By matching this relation with the standard relation for the force of elasticity:

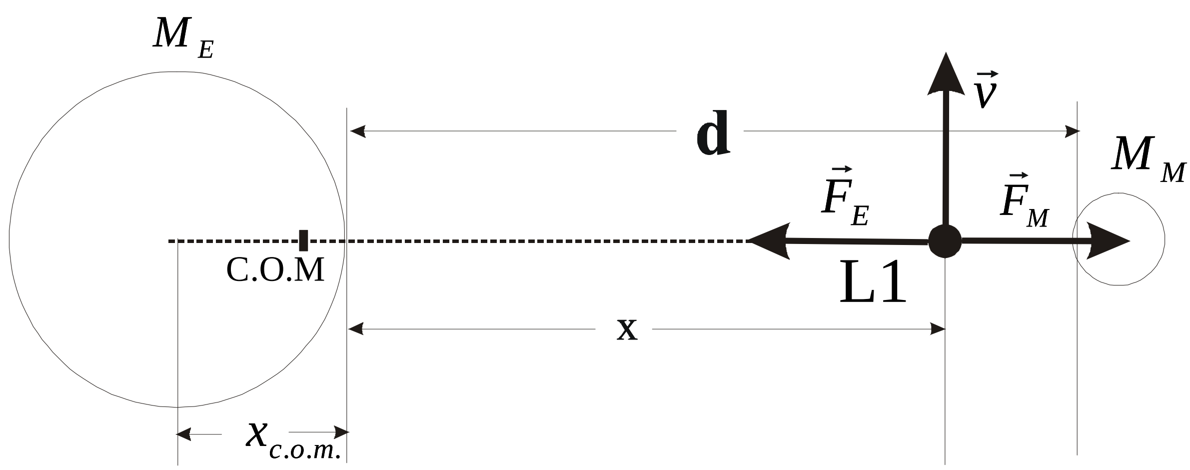
$F = -\omega^2 my$, we can determine the oscillation period of the body of mass m.

$$m\omega^2 = m2kM_1\left(1+\sqrt{\frac{M_2}{M_1}}\right)^3$$

$$\omega = \sqrt{2kM_1\left(1+\sqrt{\frac{M_2}{M_1}}\right)^3} = \frac{2\Pi}{T} \quad [4]$$

$$T = \frac{2\Pi}{\sqrt{2kM_1\left(1+\sqrt{\frac{M_2}{M_1}}\right)^3}} \quad [5]$$

In the case of our temporary transit platform between the Earth and the Moon, the equilibrium point is a little different from that in the situation above, as the body describes a circular motion around the center of mass of the Earth-Moon system.



$$F_E - F_M = \frac{mv^2}{r};$$

F_E - the gravitational force of the Earth; F_M - the gravitational force of the Moon

$$\frac{kM_E m}{(x_{c.o.m.}+r)^2} - \frac{kM_M m}{(d-r-x_{c.o.m.})^2} = \frac{mv^2}{r} \quad [5]$$

The speed of the deployment area in L1 must have a certain value, so that the Earth, the Moon, the transit platform and the center of mass of the Earth-Moon system will be permanently collinear. This can be accomplished only if the angular speed of the body in L1 is the same with that of the Earth and that of the Moon,

$$\omega = \frac{v}{r} = \frac{v_{OM}}{d - x_{c.o.m.}} \quad [7]$$

where v_{OM} is the orbital speed of the Moon around the center of mass of the Earth-Moon system (v_{OM} =1Km/s). The distance between the center of mass and the Moon is $d - x_{c.o.m.}$. Therefore,

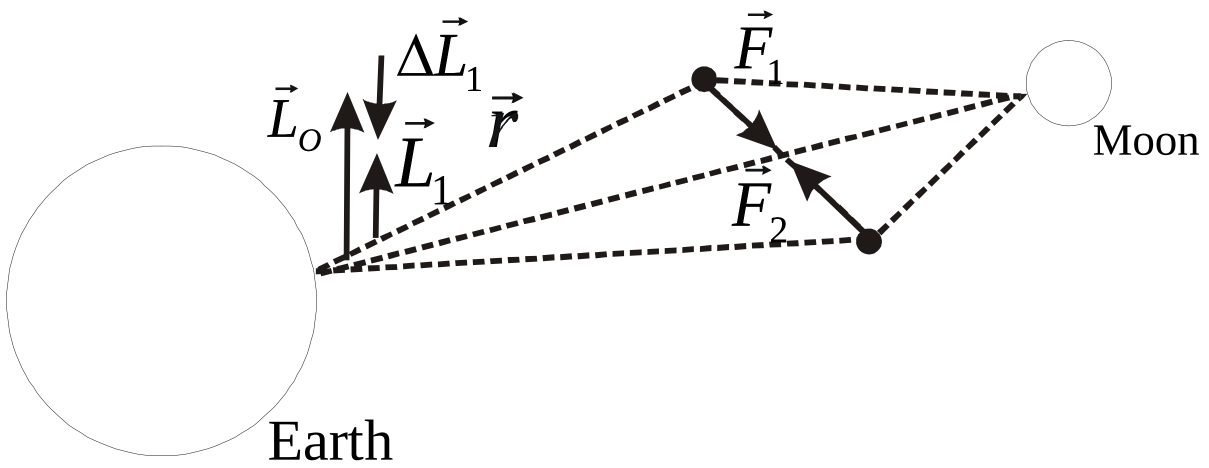
$$v = \frac{rv_{OM}}{d - x_{c.o.m.}} \quad [8]$$

By combining relations [5] and [8], the general relation becomes

$$\frac{kM_E m}{(x_{c.o.m.} + r)^2} - \frac{kM_M m}{(d - r - x_{c.o.m.})^2} = \frac{m}{r}\frac{r^2 {v_{OM}}^2}{(d - x_{c.o.m.})^2}$$

$$\frac{kM_E m}{(x_{c.o.m.} + r)^2} - \frac{kM_M m}{(d - r - x_{c.o.m.})^2} = m\frac{r {v_{OM}}^2}{(d - x_{c.o.m.})^2} \quad [9]$$

We can determine r from relation [9] by using numeric examples.
The temporary station in L1 is then moved with the desired y in the direction of movement on its trajectory. The transit platform will still have two superimposed motions: a uniform circular motion around the center of mass of the Earth-Moon system and an oscillating movement along its trajectory, with the amplitude of y. The orbital kinetic momentum of the transit station will suffer small variations in module, but its orientation will remain constant. Therefore, the trajectory of the deployment platform will remain plan.



2. Automatic and robotic devices

Extreme conditions in space and on the Moon, including heat and cold, radiation, and rough terrain, require robots that are mobile; have competent motion in hard or soft terrain; remain upright or are self-righting; and that are physically self-contained, durable, and autonomous. To accomplish our objectives the robots must be controlled by radio waves and hey must have intelligent algorithms having raised degree of autonomy. The robots operating with minimal Earth communication are essential for such a complex process of building the Space Settlement. Robots will pack the ore and this will be "launched" in the L1 zone, for temporary assembling. We have chosen this solution because it is hard to launch from the Moon big and heavy assembled parts of the Space Settlement.

For fuel saving we won't use Shuttles for carrying components from Moon in space. We will launch the component parts of the Space Settlement with a "Moon Canon" thereby the energy used for lifting the Shuttle's mass won't be used.
This is an acceptable speed calculating that we save a lot of fuel not using Space Shuttles for carrying the materials. If the parts of the Space Settlement produced on the Moon base are launched with 868km/h on

$$\frac{-k\cdot m\cdot M}{R}+\frac{m\cdot v^2}{2}=-\frac{k\cdot m\cdot M}{R+h}$$

$$\frac{m\cdot v^2}{2}=\frac{k\cdot m\cdot M}{R}-\frac{k\cdot m\cdot M}{R+h}=g_0R^2\cdot(\frac{1}{R}-\frac{1}{R+h})=g_0R^2\frac{R+h-R}{R(R+h)}=\frac{g_0\cdot R^2\cdot h}{R(R+h)}=\frac{g_0\cdot R\cdot h}{R+h}$$

$$v=2\cdot\sqrt{\frac{g_0\cdot R\cdot h}{R+h}}\cong 2\cdot\sqrt{\frac{1{,}62\cdot 176\cdot 10^4\cdot 6\cdot R}{7\cdot R}}\cong 2\cdot 1563 m/s\cong 868 km/h$$

$$v=868 km/h$$

the direction Moon-Earth they will stop exactly in the L1 point which will be used for temporary base for assembling the Space Settlement.

3. Assembling procedures and facilities

As we said before, the robots will assemble the Space Settlement in the L1 zone. First of all they will assemble the central body (The 0 gravity body) ,then the "pipes" which connect central body with the torus, then the torus and then finally the mirrors and the Photo Voltaic cells.

4. Temporary life sustaining

Keeping many people in good conditions for a long period of time is very difficult. The numerous numbers of robots is very important thus a little number of people will be needed for the construction.

The Shuttle carrying persons who must stay in space for supervising the robots activity will be located in the L1 zone and it will have a revolution motion around the L1 point which will need a small amount of fuel for trajectory corrections.

V.C. Building and life-sustaining materials

1. Material properties

Titanium
The most important material for the construction of the space settlement will be the Titanium Oxide. For the construction of the torus, the 0 gravity center and the annexes we will use an amount of 88980425100 kg of TiO_2. In the table below we will enumerate some of the Titanium Oxide properties.We will also use silicium, aluminium, lead and other metals for the functional completeness of

the Space Settlement.

Aluminium

Pure aluminium is a silvery-white metal with many useful characteristics. Alloys with small amounts of

Properties		
Property	**Value**	**Conditions**
Hardness,Knoop(KH) or Vickers(VH)	713 .. 1121 kg/mm/mm	Ceramic
Modulus of Rupture	0.06897 .. 0.1028 GPa	Ceramic, at room temperature
Poisson's Ratio	0.28	Ceramic
Thermal conductivity	6.69 W/m/K	Ceramic,at temp=100 C,porosity=0%
Thermal conductivity	5.02 W/m/K	Ceramic,at temp=200 C,porosity=0%
Thermal conductivity	3.76 W/m/K	Ceramic,at temp=400 C,porosity=0%
Thermal conductivity	3.34 W/m/K	Ceramic,at temp=600 C,porosity=0%
Thermal conductivity	3.34 W/m/K	Ceramic,at temp=800 C,porosity=0%
Thermal conductivity	3.34 W/m/K	Ceramic,at temp=1000 C,porosity=0%
Molecular Weight (g/mol.)	80	-
Density (g/cm^3)	4.23	-
Specific Gravity	3.9- 4.2	-
Boiling Point (°C)	2500- 3000	-
Melting Point (°C)	1830- 1850	-

copper, magnesium, silicon, manganese, and other elements have very useful properties. Strength on pure aluminium has a tensile strength of between 49 MPa and 700 MPa depending of alloying type and the heat treatment. Aluminium is a very good conductor of electricity, also being non-magnetic and non-combustible.

Copper

Properties	
Density / Specific Gravity (g.cm^{-3} at 20 °C)	2.70
Specific heat at 100 °C, cal.g^{-1}K^{-1} (Jkg^{-1}K^{-1})	0.2241 (938)
Melting Point (°C)	660
Electrical conductivity at 20°C (% of international copper standard)	64.94
Thermal conductivity (cal.sec^{-1}cm^{-1}K^{-1})	0.5
Reflectivity for light	90.0
Totally recyclable	Aluminium is 100% recyclable with no downgrading of its qualities.
Completely impermeable and odourless	Aluminium foil, even when it is rolled to only 0,007 mm thickness, is still completely impermeable and lets neither light aroma nor taste substances out.

Copper is an excellent electrical conductor. Most of its uses will be based on this property or the fact that it is also a good thermal conductor.

Nickel

Nickel is silvery white and takes on a high polish. It is hard, malleable, ductile, and a fair conductor of heat and electricity. Nickel gives glass a greenish color. Nickel plating is often used to provide a protective coating for other metals, and finely divided nickel is a catalyst for hydrogenating vegetable oils.

In the building of the electromagnetic coils we will use supermalloy for its high magnetic permeability properties.

Properties	
Atomic number	29
Atomic radius - Goldschmidt (nm)	0.128
Atomic weight (amu)	63.546
Temperature coefficient at 0-100C (K-1)	0.0043
Electrical resistivity at 20C (µOhmcm)	1.69
Boiling point (C)	2567
Density at 20C (g cm-3)	8.96
Melting point (C)	1083
Coefficient of thermal expansion at 0-100C (x10-6 K-1)	17.0
Latent heat of evaporation (J g-1)	4796
Latent heat of fusion (J g-1)	205
Specific heat at 25C (J K-1 kg-1)	385
Thermal conductivity at 0-100C (W m-1 K-1)	401
Photo-electric work function (eV)	4.5
Corrosion resistant	Copper is low in the reactivity series, thus it doesn't tend to corrode. Again, this is important for its use for pipes, electrical cables, saucepans and radiators.
Antibacterial	Copper is effective at stopping the growth of many micro-organisms. This is important for its use in water systems.
Non magnetic	Copper is non magnetic and non sparking. Because of this, it is used in special tools

Properties	
Name, Symbol, Number	Nickel, Ni, 28
Density, Hardness	8908 kg/m^3, 4.0
Appearance	lustrous, metallic
Atomic weight	58.6934 amu
State of matter	solid (ferromagnetic)
Melting point	1728 K (2651 °F)
Boiling point	3186 K (5275 °F)
Molar volume	6.59 ×10^{-6} m^3/mol
Heat of vaporization	370.4 kJ/mol
Velocity of sound	4970 m/s at 293.15 K
Electronegativity	1.91 (Pauling scale)
Specific heat capacity	440 J/(kg*K)
Electrical conductivity	14.3 10^6/m ohm
Thermal conductivity	90.7 W/(m*K)

2. Material sources

a. Terrestrial resources

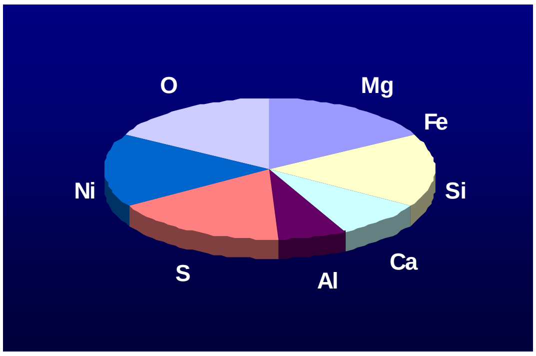
Approximate maximum permeability		
Material	**μ/H m^{-1}**	**μ_r**
Ferrite M33	9.42E-04	750
Nickel (99% pure)	7.54E-04	600
Iron (99.8% pure)	6.28E-03	5000
Silicon GO steel	5.03E-02	40000
Supermalloy	1.26	1000000

Earth is a very good source of materials, but taking objects in space from Earth requires a large amount of energy. Any material which is already in space has an enormous potential value relative to the same material that needs to be brought up from Earth. It is more than 10 times easier and cheaper to bring an object into low Earth orbit from the surface of the Moon than from the surface of the Earth. This is why we will take only the strictly necessary resources from Earth, as oxygen, water and construction materials for the lunar and orbital temporary base.

b. Lunar resources

The Moon is another potential source of materials. The Lunar regolith contains some useful ores,

Earth Composition			
Mantle + Crust		Core	
Substance	Concentation (%)	Substance	Concentration (%)
MgO	36.8	Fe	83
Al_2O_3	4.2	Ni	6
SiO_2	46.0	Si	~10
CaO	3.5	S	<5
TiO_2	0.23	O	~10
FeO	7.6		
Na_2O	0.39		
P_3O_5	0.02		
Cr_2O_3	0.44		
MnO	0.13		
K (ppm)	230		
Rb	0.74		
Cs	0.02		
F	19		
Cl (ppm)	12		
Br (ppb)	46		
I	13		
Co (ppm)	105		
Ni	2100		
Cu	28		
Zn	49		
Gu	3.8		
Mo (ppb)	44		
In	18.5		
Tl	5.7		
W	11		
Th	74		
U	21		



Principal Substance Composition

in particular TiO2 and FeO. However, the ore quality is not as high as that of some asteroids, and the moon is almost totally without volatiles. Water ice has been discovered on the moon, but its precise quantity is unknown, and the moon is still without any known good supplies of carbon, nitrogen, and helium.

The first resources which will need to be extracted from the Moon are discussed below:

Aluminium

Aluminium is one of the moon's resources. It's a light, good electrical conductor, the most widely used conductor material on Earth, even more than copper. Being light, it helps building large structures rotating for creating artificial gravity.
It can also be used as material for building mirrors, because aluminium mirrors are good reflectors, being able to compete even with those made out of asteroidal nickel. Atomized aluminium can also be used as a good fuel, when burned in oxygen.
Aluminum mirrors are good reflectors and could compete with those plated from asteroidal nickel. Atomized aluminum powder also makes a good fuel when burned with oxygen. Indeed, it's the fuel source of the Space Shuttle's solid boosters. On the Moon, it could become the primary fuel source for chemical rock-

etry of material to and from orbit (though we would need a different kind of rocket since the Space Shuttle solid boosters use aluminum in a kind of rocket we can't make from lunar materials).

There is also a disadvantage. This metal expands and contracts with temperature much more than ordinary metals, creating a problem in creating large structures on the moon made out of aluminum, which would be exposed to extreme day/ night temperatures. That is also why the equipment used in lunar extraction of minerals is not made out of aluminum, and steel (an iron and carbon alloy) is better used for any metal structure.Iron (steel) is better used on the Moon and other such places for metal structures.

The Moon has concentrations of aluminum in an easy to process mineral form: anorthiteEven if on Earth the main aluminum ore is the bauxite (containing 25% aluminum), on the moon the most occurring mineral containing aluminum is the anorthite(20% aluminum) and it is possible and feasible to process it(the procent of anorthite in the lunar crust is important from 78% to 80% on the landsites of the Appolo16 mission).

Calcium

The extraction of aluminum anorthite, would make calcium look only as a byproduct, the anorthite being a calcium-aluminum silicate $CaAl_2Si_2O_8$.Calcium is one of the most abundant elements in the lunar soil. Calcium and calcium oxides are useful in the production of ceramics, but calcium is also an excellent electrical conductor(it's not used un Earth as such because it burns in contact with the atmospheric oxygen as all the metals found in his group of elements e.g. Magnesium in flashbulbs) in vacuum environments.

At [20C, 68F], calcium will conduct 16.7% more electricity than aluminum, and at [100C, 212F] it will conduct 21.6% more electricity through one centimeter length and one gram mass of the respective metal. Compared to copper, calcium will conduct two and a half times as much electricity at 20C, 68F, and 297% as much at 100C, 212F."

Like copper, the calcium metal is easy to manipulate. It has half of aluminum's density, but it's not good as a construction material because it is not strong at all. Calcium slowly sublimates in vacuum. Calcium doesn't melt until 845C (1553F).

Titanium

Titanium is a high strength metal. It offers more strength per unit weight than aluminium and it is used for military aircraft and missiles.

Titanium mineral, ilmenite, FeTiO3 (iron titanium oxide) is one of the most attractive economical resources available on the lunar surface. Ilmenite grains of high purity found in the lunar soil make the separation process easier. These ilmenite grains average 53% TiO2, 44% FeO, 2% MgO and 1% of impurities.

Although utile: TiO2(titanium dioxide) is more desirable, ilmenite is also considered to be a commercial ore for producing titanium which we consider to use in the process of building the space settlement. Ilmenite minerals also trap solar wind hydrogen very well, so that processing of ilmenite will also produce hydrogen, a rare element on the Moon which can be used on the space station in the combustion cells.

Ilmenite is not found in large quantities on Earth's crust, but in lunar soil the purity and quantity of this mineral is significant.

Iron

Iron is an often encountered metal source on the Moon. It is obtained in the processing of ilmenite (see titanium above). Free iron grains also exist, and they can be extracted in an easy manner, by using magnets.

The Lunar mineral composition is shown below:
Lunar Ice

Sunlight doesn't reach the lunar poles, because of the moon's inclination of the rotation axis, almost 1.6 degrees. The temperatures inside these craters are around 50K(-223 Centigrade or -370 Fahrenheit). The south pole is a lot poorer in water than the north one(50% more than in the south pole).

Lunar Mineral Composition	
Mineral	**Avg. Abundance from Eight Samples**
SiO_2	44.60%
Al_2O_3	16.49%
TiO_2	0.036%
Cr_2O_3	0.30%
FeO	13.47%
MnO	0.18%
MgO	9.04%
CaO	11.97%
Na_2O	0.43%
K_2O	0.18%
P_2O_5	0.11%
S	10.63%

The first estimative figures of hydrogen, which existed in water ice: 0.3 to1% in 5000 to 20000 square kilometers at the south pole and 10000 to 50000 square kilometers at the north pole. After looking deeper into this problem, a theoretical quantity of six billion metric tons of water is concentrated in a small number of lunar polar craters.

Of course almost pure water is expected to be found at a very low temperature, this giving an extremely interesting problem: mining ice water. The material must be resistant in this cold situation, but the properties of the material must be exceptional. The mining surface must be heated before starting the mining. The mining of the material must be slow, and the vehicle and its attachments must be warmed also. Another option is to enclose an area and to heat the water there, bring it to the state of vapor, and then collect it into pipes and transport it into tanks. The south pole is permanently kept in shadow, but the north one isn't. It has shadowed areas, and the options of mining sites (sunlit rims of a polar crater) are many.

c. Near Earth Asteroid resources

While the Moon's gravity field is one-sixth that of Earth's, it is still enormously higher than that of an asteroid. This will make taking materials from asteroids a lot cheaper than launching them from the Moon. Still we must consider only bodies that have been nudged by the gravitational pull of nearby planets into orbits that cause them to enter the Earth's vicinity (Near-Earth Objects (NEOs)). In terms of orbital elements, NEOs are asteroids and comets with a perihelion distance less than 1.3 times the Earth-Sun distance. However, the vast majority of NEOs are asteroids, called Near-Earth Asteroids (NEAs). NEAs are subdivided into the Aten, Apollo, and Amor groups. The ones of interest for the construction of the orbital colony are those that have a high metal content and a high volatile content. The carbonaceous chondrites fit this description. These asteroids can contain sizable amounts of high quality metal ore, and significant deposits of volatile compounds, particularly water and carbon. The C1 and C2 types of carbonaceous chondrites are particularly suitable for our purposes and will be one of the main sources of building materials. The composition of the C1 and C2 types are summarized below.

C.3. Material exploiting and processing

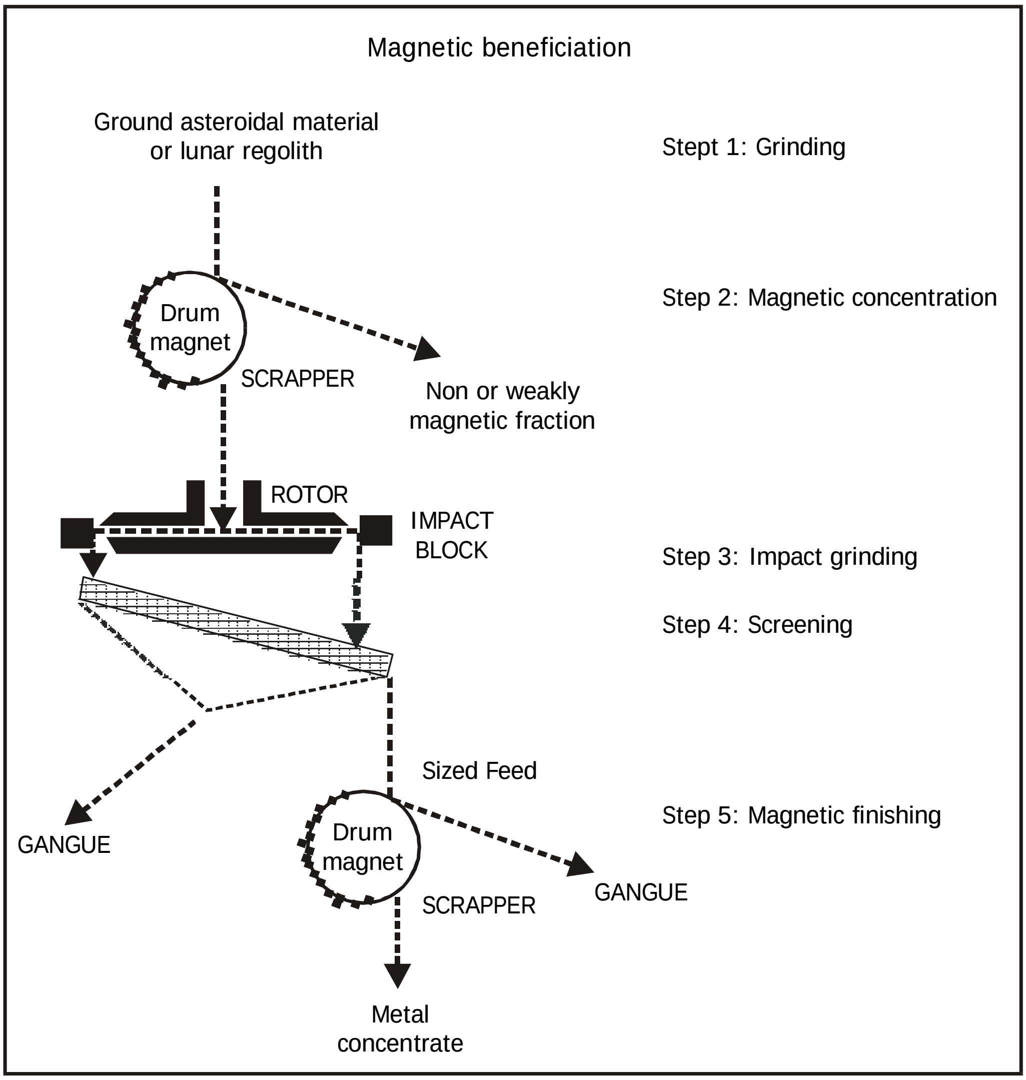
The different kinds of raw materials needed for building the space settlement will have to be efficiently exploited and processed with minimum effort and energy consume. That is why we must consider only the most reliable technologies for obtaining metals from lunar and asteroid ores.

Asteroid composition		
Mineral	**C Chondrite Class C1**	**Carbonaceous Chondrite Class C2**
Fe	.1	10.Jul
Ni	0	01.Apr
Co	0	.11
C	1.9-3.0	01.Apr
H_20	12	05.Jul
S	2	01.Mar
FeO	22	15.Apr
SiO_2	28	33.8
MgO	20	23.Aug
AlO_3	02.Jan	02.Apr
Na_20	0.3	0.55
K_2O	0.04	0.04
P_2O_5	0.23	0.28

a. Magnetic separation

Magnetic separation is a procedure used to obtain free metals from the ores found on asteroids and other celestial bodies. Asteroids are rich in free nickel-iron rocks, which are also found on the surface of the Moon but in smaller quantities (which are traces of old asteroid impacts).

The process is approximately the same on both sources (moon and asteroid):
The first step is the grinding of the rock, and then the smaller particles are put through magnetic fields to separate de silicates from the nickel-iron grains. This last procedure, after repeating this last process the nickel iron grains achieves a high percentage of purity. Material is dropped onto magnetic drums. The silicates and weakly magnetic particles don't stick to the drums, but the magnetic ones do until they are scraped off the magnet. The centrifugal grinder consists of a very rapidly spinning wheel that accelerates material down its spikes against an impact surface. The impurities remaining on the magnet surface are eliminated from the metal particles stuck on the magnets' surface.



An efficient detail is that of giving the drums a high speed, high enough to flatten metal granules on impact. The centrifugal grinding must be used again before advancing and repeating the process of magnetic separation. Most of the shattered impurities will be small quantities of little silicate granules which could be sieved out.

This method can also be used to separate minerals with weak magnetic proprieties. This is an adaptation of the process used on Earth, the difference being that a lower gravity found in space could determine a greater magnetic beneficiation.

Magnetic permeability
There are three types of magnetic proprieties.

Paramagnetic materials are those who attract the lines of a magnetic field, become polarized, and in consequence attracted. Those who repel the lines are called diamagnetic, and the third type of substance is the one who isn't affected by magnetic lines. Paramagnetic materials can also be Ferro-magnetic or feebly magnetic.

In conclusion, the main principle of magnetic separation is the different magnetic permeability of minerals.

b. Thermal separation

This process is used in extracting volatiles elements and compounds from asteroids, where they are often found.

The solar oven is a chamber heated by means of solar heat. At high temperatures, the volatiles leave the material. In space conditions (windless space and no gravity), the oven mirrors can be made out of aluminum foil. The gasses are captured and guided into pipes who take them into chambers situated in low temperatures (space shadow, no sun). The chambers are put in a series, the farthest being the coldest one. In this manner water is able to condense in the first one, and the other gasses float and condense in the next ones.

In this way, we can obtain rocket fuel, in the form of oxygen and hydrogen separated from the gaseous mixture. It is also possible to obtain a hydrogen-carbon compound which is used as fuel, methane gas (CH_4): $C + 2H_2 => CH_4$.

The chambers used for the storage of low temperature solid gasses can be manufactured from the free nickel iron metal. The solar oven can be used to melt the metals in space. The tanks don't need a high pressure, because the gasses are frozen solid in space.

c. Electrostatic separation

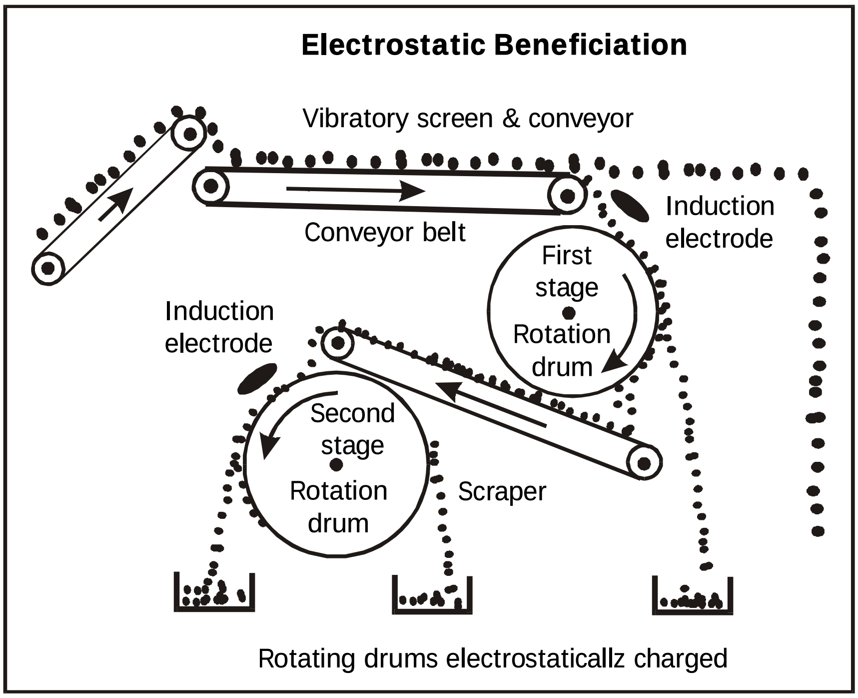
The first step in this type of separation is the separation of material pieces of the same size. This separation can be done by sieving by screens, and consequently passed through grinders, and sieved for a second time, in order to achieve uniformity.

The second step is using static electricity, charging the mineral grains and separating them by passing them through an electric field. This separation method is using the principle that different minerals have different electrostatic affinities, more exactly each mineral absorbs a different quantity of charge, depending on structure and composition. The material must pass this process for a few times, for obtaining a better separation of the minerals. This process doesn't alter the mineral in any way. It offers only separation.
The electrical charge can be made in several methods:

- Charging the sieving screen
- Charging any surface that they come in contact to
- Using an electron beam as they fall

This choice must be made depending on what type on mineral we wish to separate, each mineral having a different response to different methods and working conditions.

The separated material is put aside in special compartments. It is called the “concentrate”, and the output is called “tailing”.



This type of separation is used in obtaining the separation of not only one mineral. We can use more than one compartment, and the streaming material will split in multiple streams, depending on the charge they possess and the type on interaction with the magnetic field.

Space vacuum increases the speed and rate of this process, lacking wind, and giving the possibility of creating stronger energetic fields (10 times stronger) than in Earth’s Atmosphere. Also the lack of moisture is a factor that speeds up this process. Water makes the grains stick together, and also changes the minerals’ electrical properties (conductivity), reducing differences between minerals (This process on Earth is preceded by roasting the mineral probe). The low gravity on the Moon (1/6 of Earth’s gravity) also helps the separation process by decreasing the speed of the separated grains’ fall and as such, increasing the speed of the separation.

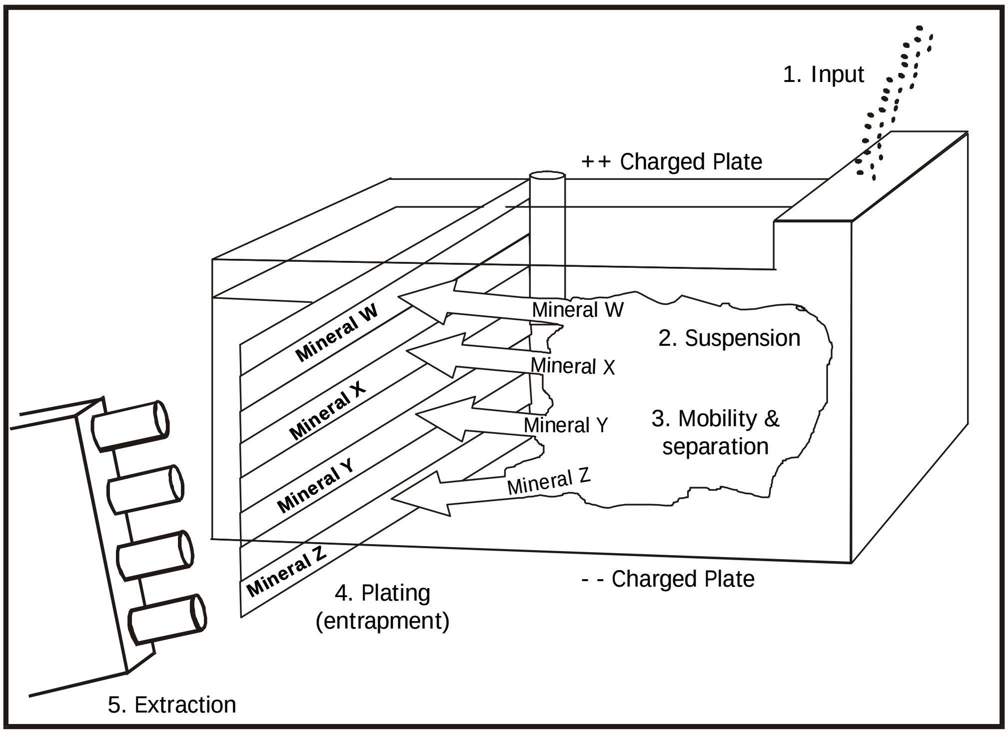
For the Solar Power Satellite (SPS), the General Dynamics report states: “The presence of large quantities of fine glass particles in lunar regolith is particularly relevant to the recommended use of foamed glass as primary structure for the SPS solar array and antennas. Foamed glass is commercially manufactured from fine particles of ground glass by the addition of small quantities of foaming agents and the application of heat. Thus, beneficiation of lunar regolith to recover the large amounts of fine glass particles may permit the direct production of all of the foamed glass needed for the SPS with few or no intermediate steps required to prepare the glass for foaming.”
This method can also be applied building the space settlement.

d. Electrophoresis

Electrophoresis for the separation of minerals can be achieved only in no gravity conditions. It is a simple process, but it's performances are better than the electrostatic one, but also a much slower one.

The schematic shown below explains how the process works.
There is a chamber filled with a fluid. An electric field is created between the two opposite walls by charging them with different charges: one positive, and one negative. The mineral probe is put into the fluid. The probe's grains will float facing the no gravity conditions. The electric charges created by the electric field passing through the two opposite walls are collected by the minerals' molecules. In this manner the minerals will migrate through the fluid to the position between other types of minerals (two isoelectric materials a higher and a lower one). Each mineral forms a plane of substance parallel to the walls and to the other minerals' planes.

Earth's gravity creates a large disadvantage, because it creates convection currents, and at the same time, gravitational settling. This was the reason why some electrophoretic experiments which were unsuccesful on Earth have been succeded in space, thanks to the lack of gravity.



One of the most exploitable properties of lunar soil is the wide range of isoelectric points of the minerals. No two minerals have the same isoelectric point or, in practically all cases, even similar isoelectric points. This property of lunar soil makes it an ideal candidate for electrophoretic separation; it means that for a given suspension material each mineral phase will separate and form a discrete band within the electrophoretic chamber.

e. Electrolysis of minerals

Electrolysis is the procedure decomposing a material in compounds, using a voltage. Electrolysis of minerals separated metal, oxygen, and/or their oxides. There are two electrodes: the anode (+) where the oxidation reaction occurs, and the cathode (-),
where the reduction reaction occurs.
The selection of electrodes and voltages and even additives are extremely important in order to achieve the wanted result. The ore is melted. The electrodes are put in. The metals go to the nega-

tive electrode (cathode) and oxygen to the anode (+).
The process can be written in the following way for ilmenite.

Total electrolysis of ilmenite: $FeTiO_3$

3* | anode (+) $O^{2-} \Rightarrow O^0$ (gas)+$2e^-$ [oxidation]

cathode (-) $Fe^{2+} + 2e^- \Rightarrow Fe^0$ (liquid)[reduction]

$Ti^{4+} + 4e^- \Rightarrow Ti^0$ (solid)[reduction]

Total process:

$$3O^{2-} + Fe^{2+} + Ti^{4+} \Rightarrow 3O^0 + Fe^0 + Ti^0$$

Aluminum, calcium, sodium , potassium and manganese will be liberated in vapor form, iron and silicium may be liquid or solid depending on the bath's temperature, and titanium will be deposited under a solid form.

f. Vacuum distillation

This is a process strongly related to the electrolysis. The resultant metals in the process of electrolysis are heated to the different liquefaction or boiling point to extract each one separately.

By means of the last two processes oxygen can be extracted from lunar soil.

g. Glass fabrication

Lunar and asteroidal materials can be used in the process of obtaining a great variety of glass structures: fiberglass, foamed glass, clear glass, and also materials used for the fabrication of walls, pipes and other construction materials.

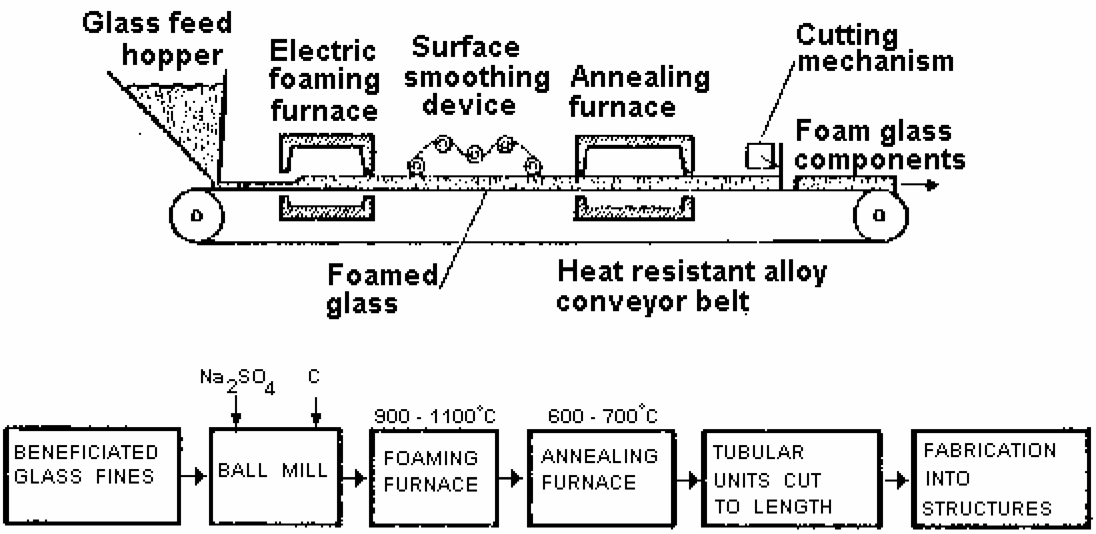
On the lunar surface natural glass particles are more often found than on Earth's surface, because of the lack of water (H_2O) existing on our planet's satellite. Lunar glass can be separated from other minerals by using electrostatic beneficiation.

Glass produced on earth is heavily contaminated by water vapor in the atmosphere, this contributing to the low mechanical proprieties (britteling material, weak, and non resistant to shocks). This fact has lead to research concerning "anhydrous glass", manufactured in the absence of water and which can be used in structures thanks to it's improved mechanical proprieties.

Foamed glass is the highest resistant glass manufactured yet, and whose mechanical proprieties make it usable in space construction.
It's fabrication scheme can be seen below:
Strong mechanically glass-ceramics can be manufactured by using FeO(from the lunar soils rich in this substance). The glass has a dark colour. Colourless glass can be manufactured by using anorthite ($CaTiO_3$), with small additions of CaO or SiO_2. This kind of glass is resistant to large changes of temperature, the expansion coefficient is a lot less than in other types of glasses.

Glasses, will be produced in the process of high speed cooling of melted material, to create a different crystalline structure. In order to obtain a higher resistant glass foamed glass will be reinforced with nickel-iron steel, so that structures made out of this material could support a wider range of tension and compression. To withstand radiation, Pb^{2+} ions must be introduced in the process of glass fabrication.

h. Generating plastic and rubber



Native lunar glass employed for making foamed glass

Continuous automated process for structural and waveguide components

Source: General Dynamics/Convair report for NASA and US Dept. of Energy on making solar power satellites from lunar materials.

Laminates and rubber are essential building materials, without which the interior layout of the Settlement will be impossible to achieve. Both plastics and rubber are light, flexible and durable, improving the functionality and esthetics of the different compartments of the Colony.

There are two possibilities for generating rubber and plastic. The first one is using Carbon to create carbochain polymers; the second involves the processing of Silicon. Both methods have their advantages and disadvantages.

The Carbon based products are much more durable and flexible than those based on Silicon. Transforming Carbon and Carbon composites into plastic entails a long row of chemical processes, each of them with its own coefficient of efficiency. The major impediment is the lack of organic matter (which is known to contain great amounts of Carbon) on both Moon and NEOs. The insignificant amounts of Carbon found on the Carbonaceous Chondrite Class C2 asteroids are not a reliable source of raw materials for this kind of composites. As carrying organic matter from Earth isn't an economically feasible option, we must consider creating rubber and plastic from Silicon based composites. Still small amounts of Carbon and water vapors can be used in generating the strictly needed high endurance rubbers. The process is shown below:
We can resume the whole chemical process to a more simple form:
The separation of the different hydrocarbons contained in the raw composite can be achieved by liquefying the initial mixture and than distilling it.

As we said, the most efficient way of creating plastic and rubber is obtaining them from Silicon, which can be extracted in huge quantities from both Moon and NEOs. More exactly, we will use silanes, which are analogous to hydrocarbons. As the basic building block of hydrocarbons is the methane (CH_4), that for silanes is silane (SiH_4). The main structure of the compounds will be SiH_3-(SiH_2)$_n$-SiH_3.

Silicons can be prepared in more than one way. The most commonly used method is reacting

$$C + H_2O \xrightarrow{t^o} CO + H_2$$
$$CO + H_2 \longrightarrow hydrocarbons + H_2O$$

The resulted hydrocarbon composite contains $CH_4, C_2H_6, C_3H_8, etc.$

C_2H_6 is the most suitable hydrocarbon for generating rubber and plastic. Therefore we must disassociate it from the rest of the mixture.

$$CH_4, C_2H_6, C_3H_8 ... \xrightarrow{t^o/-H_2} C_2H_4, C_3H_6, ... \xrightarrow{t^o} -(CH_2 - CH_2)_n - ... + copolymers$$

chlorsilane with water. After condensing, the obtained hydroxyl intermediate will form a polymer –type

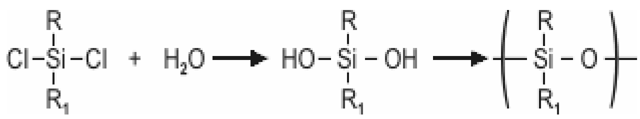
$$\text{Hydrocarbon mixture} \xrightarrow{separation} C_2H_6 \xrightarrow{t^o/-H_2} C_2H_4 \xrightarrow{polimerization} -(CH_2 - CH_2)_n -$$

structure.

Alkoxysilanes, chlorosilanes and other silicone precursors can also be used for obtaining polymer type structures. The chemical process involves the reaction of elemental silicone with an alkyl halide: Si + RX ? R_nSiX_{4-n}.

Raw silicon rubbers will be cured using different peroxides. For improving the poor tensile strength of silicones we will use reinforce fillers, such as silica in the form of silica fume or even carbon black. It is known that silicones have better fire resistant properties than other types of rubbers. Still we can improve this quality by adding flame retardants such as aluminium trihydrate or zinc compounds. Heat stability can be achieved by adding ferric oxides. As we must also consider esthetics, different organometallic compounds can be used as pigments.

The main advantages of this type of rubbers are the good thermal conductivity, the ability to repel



water, the constancy of properties on a large temperature scale, the excellent resistance to oxygen, ozone and sunlight, the good electrical insulation, the low toxicity and low chemical reactivity, the good flexibility and the anti-adhesive properties. The good thermal stability does not allow properties such as volume, resistivity, power factor and dielectric strength to be affected by the different changes in temperature. Silicons are flexible at low temperatures and tend to stiffen at higher temperatures.

Silicons will have multiple uses onboard the Settlement, including applications in mechanical engineering, electrical engineering and medicine.

CHAPTER VI

Life support

VI..1. The radiation factor

a. Measuring radiation levels

Ionizing radiation in space comes in three main types. The first is Galactic Cosmic Rays. Astronomers believe that these rays originate mainly in supernovae, although they also appear to come from quasars and solar flares from stars outside the Solar System. Every star reaches a point in its lifetime when the hydrogen in its core has all been converted to helium. This starts a series of reactions which forces the core to collapse in on itself. When a star with a mass 10 times that of the Sun collapses, a vast amount of energy is released in an explosion. A shock wave travels from the core and blows apart the star. Positively charged nuclei of atoms are spewed into space. These highly energetic nuclei travel through space almost as quickly as light.

The second type of radiation that astronauts and space colonists must be concerned with is solar protons. The protons originate in the sun. For reasons not fully understood by scientists, the sun sometimes ejects magnetic energy in the form of solar flares. Solar flare activity is linked with sunspots and the Sun's eleven year cycle. During a flare, temperatures range from 10 to 20 million degrees Kelvin. The high temperatures accelerate particles in the solar atmosphere. One of the most astounding things about solar flares is the amount of energy released in a single eruption. A flare usually releases 10^{27} ergs/sec. During the course of the entire flare, the released energy would be the same as that given off by the simultaneous explosion of several million, 100-megaton hydrogen bombs! This energy takes the shape of many things, including solar protons. The protons travel through space in the solar wind which has a velocity of approximately 400 km/sec.

The third type of radiation is high energy electrons and protons trapped by the Earth's magnetic field. The areas of trapped radiation are called Van Allen belts. Protons surrounded by an inner and outer belt of electrons form a belt which circles the Earth like a doughnut. NASA discovered these belts in 1958 during the Explorer I mission. They are referred to as the inner and outer Van Allen radiation belts, after James Van Allen who designed Explorer I. The inner region is centered at about 3000 km above Earth and has a thickness of about 5000 km. The outer region is centered at about 15,000 — 20,000 km above the surface of the Earth and has a thickness of 6,000 — 10,000 km. Typically, manned space flight (such as the Shuttle) stays well below the altitude of the van Allen radiation belts. Safe flight can occur below altitudes of 400 km or so. The particles in Van Allen belts come from solar flares, magnetic storms, and collisions of cosmic rays with particles in the Earth's atmosphere.

All three forms of radiation can be extremely dangerous to astronauts, especially when they are performing extravehicular and extra-colonial activities (EVAs). The risk of radiation sickness will also increase on longer voyages to places like Mars.

Ionizing radiations in space				
Name	**Energy type (MeV)**	**Charge**	**RBE**	**Location**
X-rays	N/A	0	1	Solar radiation, radiation belts and in the secondaries made by stopping electrons and nuclear reactions
Gamma rays	N/A	0	1	
Electrons	1.0	1	1	Radiation belts
	0.1	1	1.08	
Protons	100	1	1-2	Inner radiation belts, cosmic rays, solar cosmic rays
	1.5	1	8.5	
	0.1	1	10	
Neutrons	0.05 eV (thermal)	0	2.8	Produced by nuclear interactions; found near the planets and the Sun and other matter
	.0001	0	2.2	
	.005	0	2.4	
	.02	0	5	
	.5	0	10.2	
	1.0	0	10.5	
	10.0	0	6.4	
Alpha particles	5.0	2	15	Cosmic rays
	1.0	2	20	
Heavy primaries	N/A	≥ 3		Cosmic rays

The detection and measurement of radiation is one of the most important functions the colonists will perform in determining if radiation and/or radioactive contamination is present inside or outside the settlement. Since humans can not sense ionizing radiation with their natural senses, they will rely on instruments for detecting and measuring radiation. They must be familiarized with the proper operation and use of the instruments they have and intend to use even before reaching the orbital colony. That is why both traditional and new radiation measurement methods will be used on the Space colony.

Portable instruments, often called “survey meters”, will play a major role in radiological protection inside the Settlement. They are primarily used to detect contamination and to determine radiation field intensities. Many radiation safety decisions, such as the need for decontamination, shielding, personnel monitoring, change in work procedures, etc., - will be based on radiological survey result using survey meters. The majority of portable instruments are ionization chambers or Geiger-Mueller counters.

Ion chambers are the simplest of all gas filled detectors. Their normal operation is based on the collection of all the charges created by ionization of radiation within the gas through the application of an electric field. In the presence of an electric field, the drift of the positive and negative charges represented by the ions and electrons constitutes an electric current. Assuming that recombination is negligible, and all charges are efficiently collected, the steady-state current which is produced is an accurate measure of the radiation.

One of the important applications of ion chambers is in the measurement of gamma ray exposure and exposure rate.

Portable ion chambers of many designs will commonly be used as survey instruments for radiation monitoring purposes. The typically consist of an air volume of several hundred cm3 from which the saturated ion current is measured using a battery powered electrometer circuit. Walls are typically air-equivalent, and are usually made of plastic or aluminum. These instruments will give relatively accurate measurements of the exposure from gamma ray energies inside the colony.

Another device efficient in measuring radiation levels is the Geiger-Mueller (G-M) counter, which is probably the best known radiation detector. It is popular because it is simple in principle, inexpensive to construct and purchase, easy to operate, sensitive and reliable as a detector of ionizing radiation. It will be particularly useful for radiation protection surveys.

Simply constructed, a G-M counter consists of a type of gas (usually helium, neon or argon). A positive high voltage source is then connected between the shell and the wire. Any incident particle that ionizes at least one molecule of the gas will initiate a succession of ionizations and discharges in the counter.

These GM survey meters will be used for detecting alpha, beta, and gamma radiation. With the detector window facing the radiation source and held very close to it, all three radiations can be detected. With a solid metal part of the detector (probe) facing the source of radiation, only gamma radiation will be detected. The detection of either alpha and/or beta radiation suggests the presence of radioactive contamination.

X-ray imaging is also an important technique which will be used in variety of applications such as nondestructive evaluation, radiology in medicine, astronomical observations, X-ray diffraction for materials studies, and others. The ability of X-rays to penetrate deep in to matter allows investigation of interior components with possibility of real-time dynamic studies. However, while significant advances have been made in X-ray sources as well as image processing steps, the X-ray detectors will remain a limiting step in many of applications. Important requirements for the X-ray detectors used in such applications include large area (~ 20 cm x 20 cm), high resolution (100-200 um), wide dynamic range (10~), high sensitivity, compact design, and low cost. Ability to provide real-time images is an additional requirement in some applications. To address this situation, we have proposed to develop a solid state, large area, high resolution imaging detector by combining the semiconductor film (lead iodide, PbI2) technology being developed at RMID with the large format amorphous silicon (a-Si:H) readout technology. The detectors would be capable of performing static as well as dynamic imaging.

The Space Settlement will also serve as a huge laboratory for conducting a variety of experiments concerning radiation and radiation measurements technology. Some of these experiments will continue those of the ISS scientists.A good way to measure exterior radiation levels and their effects on astronauts is using a replica of human torso, similar to Fred, but with improved characteristics. Fred is NASA's Phantom Torso traveling in the International Space Station. This replica of a human torso is composed of 35 one-inch layers, each carrying passive dosimeters to measure the total radiation that travels through the torso. Real-time radiation levels will also be measured in the Phantom's brain, stomach, heart, colon, and thyroid. Fred's "skin" is made of Nomex, a non-flammable material used in the suits worn by NASCAR drivers. Two more passive dosimeters in the "skin" measure external radiation doses. The data from the internal detectors can then be compared with data from the external detectors. This experiment can provide information on how to better protect the astronauts and can also be used in measuring radiation levels in the immediate proximity of the space colony.

Two other solutions for measuring radiation, which are used onboard the International Space Station (ISS), could serve very efficiently the space settlement's needs. One of them is the German Space Agency's Dosimetric Mapping System. An improved version of the system will be designed to measure the different types of radiation that are penetrating the outside of the Settlement. Dosimeters specific to various types of radiation will be placed in the areas of major interest, such as residential and industrial areas. These dosimeters will record radiation levels for long periods of time. High energy particles entering the Space Colony will be measured by the tracks they leave behind in the Nuclear Tracking Detector Packages. Two Dosimetry Telescopes will be placed in the industrial area, where they will measure ions streaming into the Settlement, while 12 thermoluminescence dosimeters will measure the neutron dose.

The third measuring solution, the Bonner Ball Neutron Detector, comes from the Japanese Space Agency, NASDA. Its primary function is to measure neutron radiation. Because neutrons pass through an astronaut's skin and may damage the bone marrow, we will dedicate experiments to recording data on neutrons. The Bonner Ball consists of 6 spheres filled with Helium 3 and connected to the control unit by a wire. Each sphere is covered with polyethylene, the material used to protect sailors in nuclear submarines. Neutrons enter each sphere where they react with the Helium to form electrons. These electrons travel in a current down the wire into the control unit where this current's strength is recorded. Scientists will collect information which will allow them to assess the risk astronauts experience while traveling through the exterior layers of the Space colony.

b. Effects oF long term exposure to radiation

The radiation environments encountered in space are different from the natural background radiation on Earth and are complex in nature. Both bacteria and eukaryotes have evolved a series of mechanisms to respond to similar damages on Earth.

As we have already shown, the space radiation environment is largely comprised of positively charged particles such as protons and helium ions and negatively charged electrons. The Earth's magnetic field serves as a shield against charged particle radiations. The primary sources of radiation in space are traditionally classified into trapped particle radiation, galactic cosmic radiation, and solar particle radiation.

The galactic cosmic radiation (GCR) is the major radiation in interplanetary space and is comprised primarily of charged particle radiation. Of the different charged particles that make up the GCR, 87% are protons, 12% are helium ions, and 1% are heavier ions that are of high energies. Iron is the most important of these heavier ions due to its abundance and the amount of energy each iron ion can deposit as it interacts with matter.

The sun contributes in a dynamic way to the space radiation environment. Solar particle events (SPE) are large intermittent emissions of protons, helium, and sometimes heavier ions from the sun. The frequency of SPE varies within the solar cycle.

The different charged particle radiations in space have biological consequences that are dependent upon the spatial distribution of the energy they impart to the cell or tissue. As charged particles pass through matter, they slow down. The energy deposited is a function of the energy of a given particle, and the greatest amount of energy deposited by a particle comes at the very end of its track. Protons are generally sparsely ionizing radiations until they reach the very end of their tracks, while the heavier ions are densely ionizing at the beginning of their path and become more so as they slow down.

For short excursions outside the Space settlement, such as have previously occurred, the small dose increments might be expected to have little or no effect on astronauts. However, longer-duration space travel, such as to the moon or different celestial bodies, may be another story. Radiation doses may be sufficient to cause measurable increases in cancer or mutation risk. However, radiation-induced cancer and mutations are rare effects at any dose, and large populations are required to measure effects with statistical reliability. It may be possible, though not terribly likely, that some radiation doses in space may be sufficient to cause acute radiation sickness. This is a deterministic effect of radiation, with a threshold dose for symptoms of about 250 mSv at a high dose rate. For protracted exposure at a lower dose rate in space, the threshold dose is substantially greater, perhaps up to 1 Sv. The NCRP estimated that if a major solar particle event occurred during a visit to the moon, it could give the astronauts doses to their skin of 6 Sv (600 rem) with bone marrow doses of close to 0.9 Sv (90 rem). Cells, tissues, and whole organisms have evolved a myriad of responses to the types of damage that can be caused by charged particle radiations. The early responses to charged particle exposures include recruitment of DNA repair machinery, changes in gene expression, the initiation of programmed cellular responses such as apoptosis, and alterations in the tissue microenvironment(*).

Included among the initial types of damage that result in DNA following exposure to charged particle radiations are base damage, single-strand breaks, and double-strand breaks. Bacteria and eukaryotes have highly complex systems for the repair of these alterations, which can also result from naturally occurring errors in replication, changes that result from ongoing oxidative metabolism, and exposure to chemicals of various kinds. Following exposure to sparsely ionizing radiations, base damage and strand breaks are widely scattered throughout the cell nucleus. For densely ionizing radiations such as iron ions, the alterations are often clustered. Most of the initial damage to DNA is efficiently removed prior to the next cell division cycle by processes including nucleotide excision repair and double-strand break repair. It has been suggested that the clustered damages associated with densely ionizing radiation exposures may recruit multiple repair pathways to the site of damage. The resulting “traffic jam” may lead to an alteration of the efficiency of repair.

The programmed cell death pathway may be important in maintaining tissue integrity in the space radiation environment by removing damaged cells before they can divide. Virtually all cells in multicellular organisms have evolved a system of altruistic suicide that is often referred to as programmed cell death or apoptosis. This process is critical to normal development and tissue homeostasis. Apoptosis is regulated by a series of proteins that function as either effectors or suppressors of the process. Through a complex series of heterodimeric and homodimeric interactions, these proteins act as a “rheostat” to promote or suppress apoptosis. The amounts of the various components of the “rheostat” are altered in response to exposure to both sparsely and densely ionizing radiations. One of the key players in the regulation of the apoptotic process is the p53 gene, which has been referred to as the “guardian of the genome”. P53 is expressed in response to ionizing radiation exposures and serves to downregulate one of the natural suppressors of apoptosis, bcl-2. Cells which have lost the ability to initiate the normal apoptotic pathway appear to accumulate mutations more readily following exposure to sparsely and densely ionizing radiation.

In the context of organized tissues, there are additional factors that mediate responses to charged particle radiations. The extracellular matrix (ECM) and the cytokine environment provide signals that help maintain tissue integrity and normal development of the organism. The ECM influences cell morphology, mediates proliferative capacity, and regulates gene and protein expression. The ECM can promote cancer progression and incidence. Tissues respond to charged particle radiations by rapidly remodelling the ECM. The time course and characteristics of the remodelling are different in different tissue compartments. The long-term effects of this remodelling are fertile areas of investigation.

In conclusion, biological systems have evolved a series of mechanisms at the cell and tissue level to respond to the types of damages that occur as a consequence of exposure to the various components of the space radiation environment. In large part, these responses evolved to protect the integrity of the organism.

Still radiation can cause immeasurable damage by penetrating the skin and destroying cells. Many possible problems can ensue, depending upon the severity of the damage. Temporary sterility in men and women, bone-marrow damage, radiation burns, cancer, chromosome breakage, and damage to the central nervous system are all possibilities. Although these run the gamut from mild to serious for those of us on Earth, they all spell trouble in space. If an colonist on the Space Settlement becomes ill, he may not be able to complete all necessary tasks and may have impaired judgment. That is why prevention and protection procedures must be efficiently conceived and fully operable.

*Information compiled from the NASA Astrobiology Department

c. Radiation prevention and protection

As said, a significant difficulty for manned missions outside of the Earth's magnetosphere, including colonization related activities, asteroid exploration, and space-based mining and manufacturing, is the hazard of crew exposure to particulate radiation. Crew radiation shielding must become an active problem for investigation.

Two types of radiation are particularly significant and must be reduced as possible: solar flare protons, and high-energy galactic cosmic rays (GCR). Solar flare protons come in bursts, lasting a day or so, following an energetic solar event. The proton flux is omnidirectional; although the source of the radiation is solar, the actual radiation comes from all directions, and hence the orbital colony must be shielded in all directions, and not just in the direction of the sun. In the absence of shielding, a single large solar flare would likely be fatal to the crew, either immediately or as a result of cancers induced by the radiation dose. Cosmic rays are a continuous background consisting of extremely high energy heavy nuclei, and are also omnidirectional. While the GCR background is not immediately fatal, the integrated GCR dose over long missions will approach or exceed the recommended maximum allowable whole-body radiation dose.

The dangerous components in both solar flare and GCR radiation consists of positively charged particles. Neutral radiation (gammas, neutrons) are a negligible component of the radiation ambient; negative particles (electrons), while present, can be easily shielded. The positive particles, however, are extremely penetrating, and require massive shields. In the case of GCR, a small amount of mass shielding has no benefit, or even negative benefit over no shielding at all, since the impact of GCR nuclei on a light shield will produce secondary radiation considerably more intense than the original GCR.

Since the particles involved are charged, an alternative solution to the problem of shielding is the use of active electromagnetic shields. The simplest such device would be the magnetic dipole shield. The magnetic field of the Earth is a good example of a magnetic shield, and is responsible for the relatively benign radiation environment on Earth. A magnetic shield makes use of the fact that a charged particle's trajectory in a magnetic field is curved. As a particle enters the region of high magnetic field, its trajectory will curve away from the region to be protected. The advantages of a magnetic shield to crew safety and health are obvious.

An additional advantage of the magnetic shield is that no secondary radiation is produced by interaction of the shielded area with the incident radiation.

The limit to the mass needed to produce a magnetic field is determined by the tensile strength of materials required to withstand the magnetic self-force on the conductors. For the minimum structure, all the structural elements are tensioned, and from the virial theorem, the mass required for withstand magnetic force can be estimated as:

$$M = \frac{\rho}{S} \cdot \frac{B^2 V}{2\mu}$$

where ρ is the density of the structural material, S is the tensile strength, B the magnetic field, V the characteristic volume of the field, and μ the permeability of vacuum.

An alternative to the magnetic shielding is to use an electrostatic shield. Since both solar flare protons and heavy nuclei in GCR radiation are positively charged, shielding would simply require adding a positive charge to the object to be shielded sufficient to repel the particles. To shield against solar flare protons would require an electrostatic potential of on the order of 1 E8 volts; shielding against cosmic ray nuclei as well would require as much as 1 E10 volts.

Unfortunately, the situation is complicated by the interplanetary plasma. Attempting to simply charge the colony in Earth orbit would result in electrons being attracted by it. This would discharge the settlement very quickly. In this case, to maintain a charge of 2.E8 volts would require a power of 1 E7 kilowatts.

Con-centric spheres of opposing charge to repel both positive and negative particles, would reduce the discharging, but maintaining the required voltage difference over a small distance is beyond the range of current technology.

Another solution would be using a hybrid of the magnetic shield and the electrostatic shield, the "plasma shield." An electrostatic charge is applied to the vehicle (or habitat) shell to repel the positively charged radiation; a magnetic field then prevents the plasma electrons from discharging the vehicle. At large distances the shield is charge neutral, since the magnetically confined electrons exactly neutralize the charge on the shell. Since electrons are lighter than protons by a factor of 1860, the magnetic field required for the plasma shield is reduced over that for a simple magnetic shield by the same ratio, and hence the weight associated with the field generation and structure. This ratio is even more favorable for shielding from cosmic rays.

The required electron confinement time tau to maintain the charge, assuming a maximum allowable energy expenditure of 10 kW (for the 5m. radius torus assumed), is 100 minutes. With the assumed plasma density n of 2.E9 e-/cm3, the confinement product n tau is 1 E13/cm3-sec. Magnetic containment systems for fusion applications have demonstrated n tau products in excess of E14 /cm3-sec at considerably higher temperature, so maintaining the charge is not unreasonable.

The plasma shield will be made even more effective if it is used in combination with a passive mass shield, since the mass shield is most effective for low energy particles.

Still the most efficient and simple way of protecting against radiations and solar flares is using an electromagnetic shield. This topic is detailed in the next chapter ("Electromagnetic shielding").

The choice of material and thicknesses for best radiation blocking are dictated primarily by structural and thermal considerations. Metals (which meet all these considerations) are generally opaque to UV, X-ray and gamma-ray radiation.

Recent advances in high-temperature superconductors mean that it is reasonable to consider superconductors operating at 77K or higher on the orbital colony. This is a range which will allow use of passive cooling, where the temperature is achieved by directly radiating excess heat to space, a considerable advantage over use of superconductors requiring liquid He temperatures.

Extremely high strength to weight composite materials could be the best solution. Since the limit to magnetic field strength is produced by the tensile strength of materials required, composite materials with strength to weight ratios five times (Kevlar 49) to 7 times (PBO) higher than that of steel allow considerable weight reduction in the tension members.

The most important enabling technology, which must be available on the orbital colony, will be the ability to form high-temperature superconductors into wires, process which will take place deep inside the industrial core of the settlement. While magnetic shielding can be done using conventional (low temperature) superconductors, the pay-off in simplicity and weight of higher temperatures is so great as to be mission-enabling. Clearly, advances in the critical current and the transition temperature will also allow significant gains to be made as well. A second required technology which must be demonstrated is the cooling of wires to the superconducting transition temperature using passive cooling, essentially shielding the wire from the sun and allowing it to radiate to deep space.

However, the skin of the forward fuselage of the orbital or mining modules will be made of 'conventional 2024 aluminum alloy', while the crew compartment will be constructed of 2219 aluminum alloy plate. The windows will be comprised of either 2 or 3 panes of glass, depending on the window location, with the panes between 0.25 and 1.3 inches and made of either aluminosilicate or fused silica, similar to those found on today's shuttles.

Spacesuit and spacecraft windows will be specifically designed to block most of the UV radiations that pass through.

An important requirement is that little or no magnetic field should penetrate into the inhabited region, due to concern about the hazardous effects of long-term exposure to magnetic fields. However, considerably simpler engineering designs can be made if some magnetic field is allowed to penetrate into the shielded region.

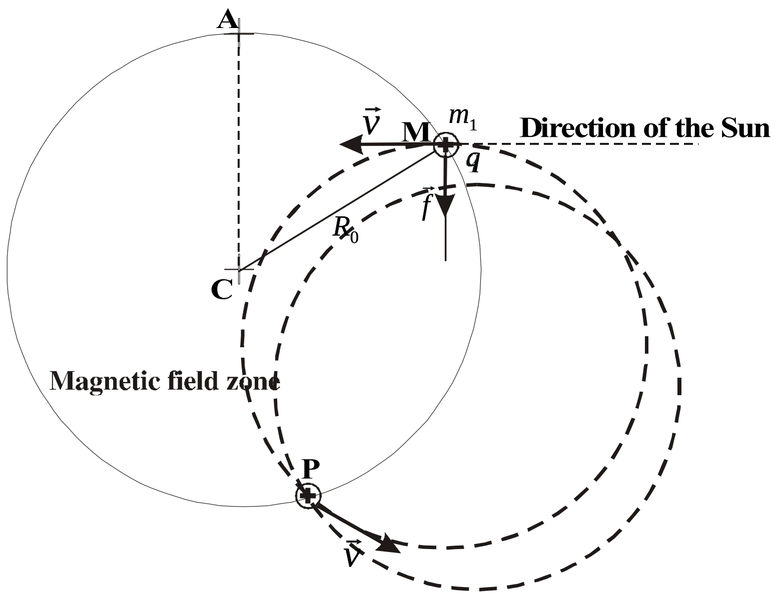
In cases of emergency, well-shielded areas that can sustain life for a few days until the particles die down can work as shelter from unusual powerful solar flares. A good place for such special radiation-isolated areas would be in the center of the ship, surrounded by the water tanks.

The moon may also represent a source of radiation which must be taken into account during the mining operations. The majority of radiation on the moon is in the form of charged particles (protons and helium nuclei) from the sun. Most of the rest is ultraviolet radiation (UV). UV, of course, will not penetrate even a small thickness of lead, and neither will charged particles. On the other hand, these radiations will not penetrate other materials, such as rock, plastic, and so forth. It's not necessary to use lead for shielding on the moon because it's too heavy. The use plastic will be more efficient. As for the thickness, it depends on the energy of the incoming protons—a few cm may suffice, or maybe as much as a few tens of cm.

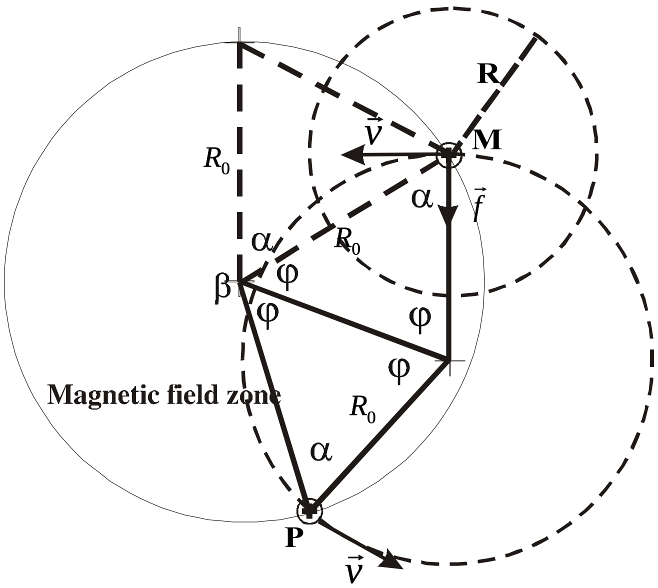
d. Electromagnetic shielding

As we said before, electromagnetic shielding is the most convenient way of protecting against ionizing radiations in space. The principle is in fact simple: the magnetic shield is based on the fact that a charged particle's trajectory in a magnetic field is curved. When the particle enters the region of high magnetic field, its trajectory will be curved away from the region we want to protect from radiation.

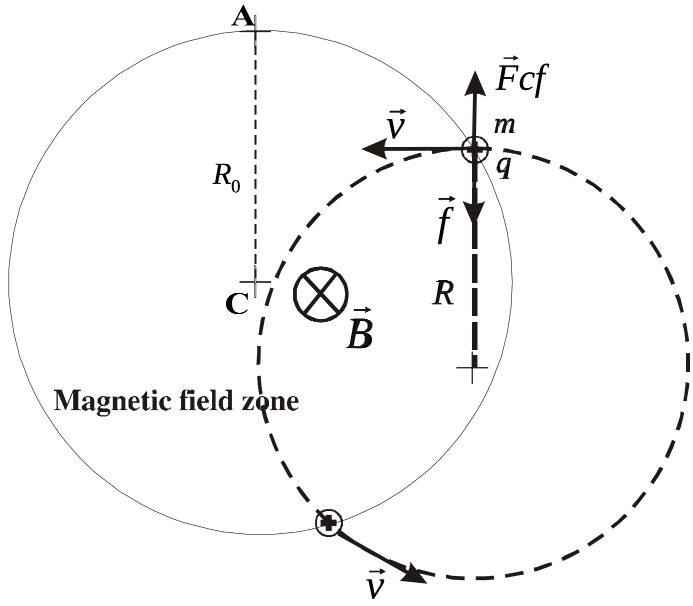
For example, let's consider the Alpha particles ($_{2}^{4}\alpha$) as radiating factor. They represent 8% of the maximum amount of ionizing particles found in space. Their mass (m_1) is 4 μ, their speed (v) is of approximately 1000 Km/s and their electric charge (q) is 2e. The figure below shows the particle's change of trajectory when entering a magnetic field zone.



We notice that in all cases the trajectory of the particle is tangent to the magnetic field zone in point P. This can also be shown using a geometrical demonstration, based on the drawing below:



Knowing the electromagnetic induction of the field ($\vec{B}$), the mass (m), the speed ($\vec{v}$) and the charge (q) of the Alpha particle, we can determine the Lawrence force ($\vec{f}$) and the radius of the particle's circular trajectory (R).



$$\vec{f} = q\vec{v} \times \vec{B}$$

$$f = qvB\sin\frac{\Pi}{2} = qvb$$

$$Fcf = \frac{mv^2}{R}$$

$$f = Fcf$$

$$qvB = \frac{mv^2}{R} \Rightarrow R = \frac{mv}{qB}$$

Let's assume that $R=R_0$ (the radius of the magnetic field). For generating and maintaining a certain magnetic field around the torus we will use a series of close wound bobbins placed on the exterior margins of the torus, powered by photovoltaic panels. The distance between coils can be calculated by taking into account the electromagnetic induction we wish to generate.

We can determine the inductance of a singe-layer coil according to the Wheeler formula, which states:

$$L = \frac{d^2 n^2}{1 + 0.45d}$$

We can also find the amperage needed to maximize the efficiency of the electromagnetic field.

$E_0 = 1380 \frac{W}{m^2}$; E_0 - the Solar power per square meter

$R_0 = \frac{mv}{qB}$; R_0 - the radius of the electromagnetic field

$$B = \frac{\mu_0 \mu_r nI}{l}$$

$$\mu_0 = 4\Pi \cdot 10^{-7} \frac{H}{m}$$

$$\mu_{\sup ermalloy} = 10^6 \frac{H}{m}$$

$$B_m = \mu \frac{nI}{2R}$$

Taking into account that the coils will be entirely exposed to the ionizing radiations, we have chosen the radius of a coil (R_0) to be half of its length (l).

$$R_0 = \frac{l}{2}$$

$S = l^2 = 0.25 m^2$; S- the surface of the coil face to the Sun

$P = ES\eta = 1380 \cdot 0.25 \cdot 0.15 \approx 52$; P – the power generated on a coil; η - the efficiency of the photovoltaic panel

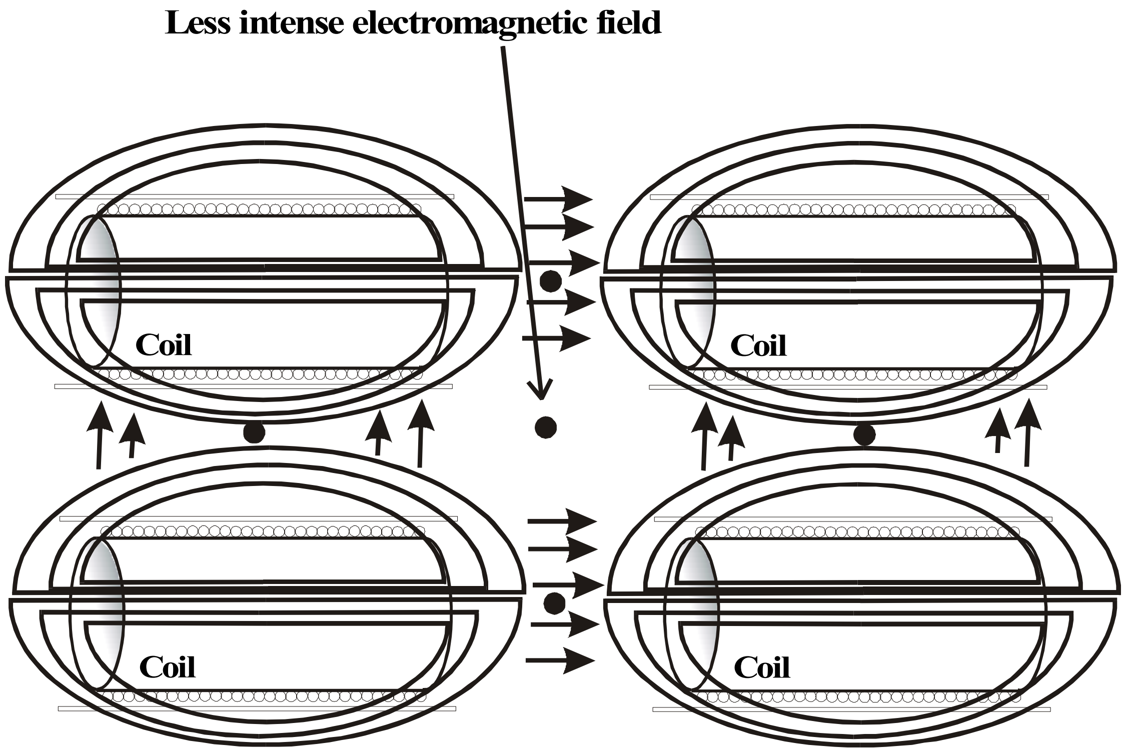
$B = \frac{mv}{qR_0} = \frac{\mu_0 \mu_r nI}{l}$; n – the number of turns ($n=10^4$)

$$I = \frac{mvl}{qR_0 \mu_0 \mu_r n} = \frac{4 \cdot 1.67 \cdot 10^{-27} \cdot 10^6 \cdot 0.5}{2 \cdot 1.6 \cdot 10^{-19} \cdot 0.5 \cdot 4\Pi \cdot 10^{-7} \cdot 10^6 \cdot 10^4} \approx 10^{-5} A$$

The determined amperage is very low and thus it is very easy to generate. The electromagnetic field created by the sysem of coils will be functioning at satisfactory efficiency and will protect the torus from ionizing radiations.

For obtaining a more intense electromagnetic induction using the same amperage and without having to increase the length of the coil systems we could use multi-layered coils, which consist in a number of concentric common coils. We will be able to generate a more intense electromagnetic field with almost the same use of energy.

Still there will be points found in less intense electromagnetic field somewhere between the coils, but they will not raise any problem because of their simetric repartition.



VI.2. Artificial gravity

a. Means of creating pseudogravity

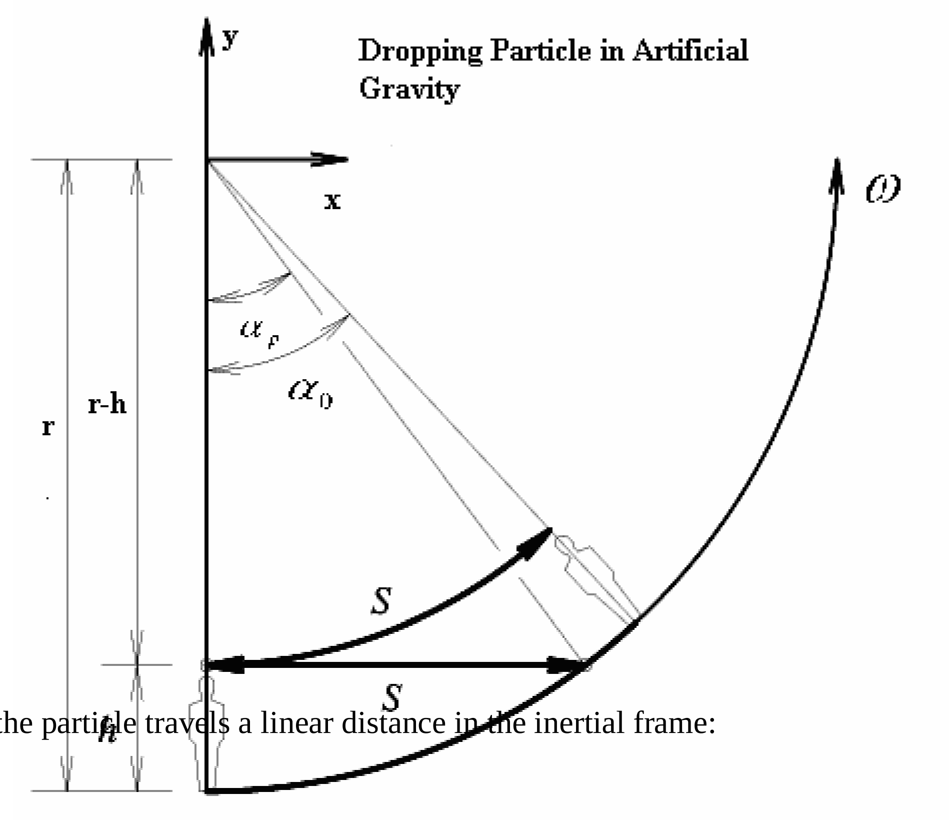
After studying the effects of the 0 gravity habitats, we reached the conclusion that artificial gravity is extremely necessary for the health and the normal life course of the colonists.

While the Space Settlement is spinning, the floor of the space station would apply a centripetal force on the person to keep them traveling in a circular path, thus an object in circular motion with angular velocity ω around a circle of radius *R* experiences a *centripetal acceleration* $A_{cent} = R \cdot \omega^2$ which will be the pseudo constant g similar on Earth.

Abnormalities in free-fall motion reveal abnormalities in the gravity itself. To facilitate a side-by-side comparison of various gravity environments, it's useful to specify a few standard tests:

- Drop a body from an initial height *h*.
- Hop vertically from the floor with an initial relative velocity *v*.

Drop



Before striking the floor, the particle travels a linear distance in the inertial frame:

$$S = \sqrt{r_f^{\,2} - r_h^{\,2}}$$

, and subtends an angle of:

$$\alpha_p = \arctan\left(\frac{S}{r-h}\right)$$

The figure shows the motions of an observer and of a particle which drops from a height *h*.

In the inertial frame:

$$x = 0$$
$$y = -(r-h)$$

If the observer had not dropped the particle it would have traveled the same distance on a circular path subtending an angle of:

$$\alpha_0 = \frac{S}{r}$$

This is the angle that the observer subtends while the particle is falling.

In the observer's rotating frame of reference, the particle will strike the floor at an arc distance from the observer:

$$d = r(\alpha_p - \alpha_0) = r\left(\arctan\left(\frac{S}{r-h}\right) - \frac{S}{r-h}\right)$$

, where positive is east (prograde) and negative is west (retrograde). The particle always deflects to the west, because:

$(\forall)n > 0, \arctan(n) < n$

The angles α_p and α_0 depend only on the initial height *h* and the floor radius *r*. If the expressions are rewritten in terms of the ratio $\frac{h}{r}$, they become:

$$a = \frac{h}{r}$$
$$\alpha_0 = \frac{\sqrt{2a - a^2}}{1-a}$$
$$\alpha_p = \arctan\left(\frac{\sqrt{2a - a^2}}{1-a}\right)$$

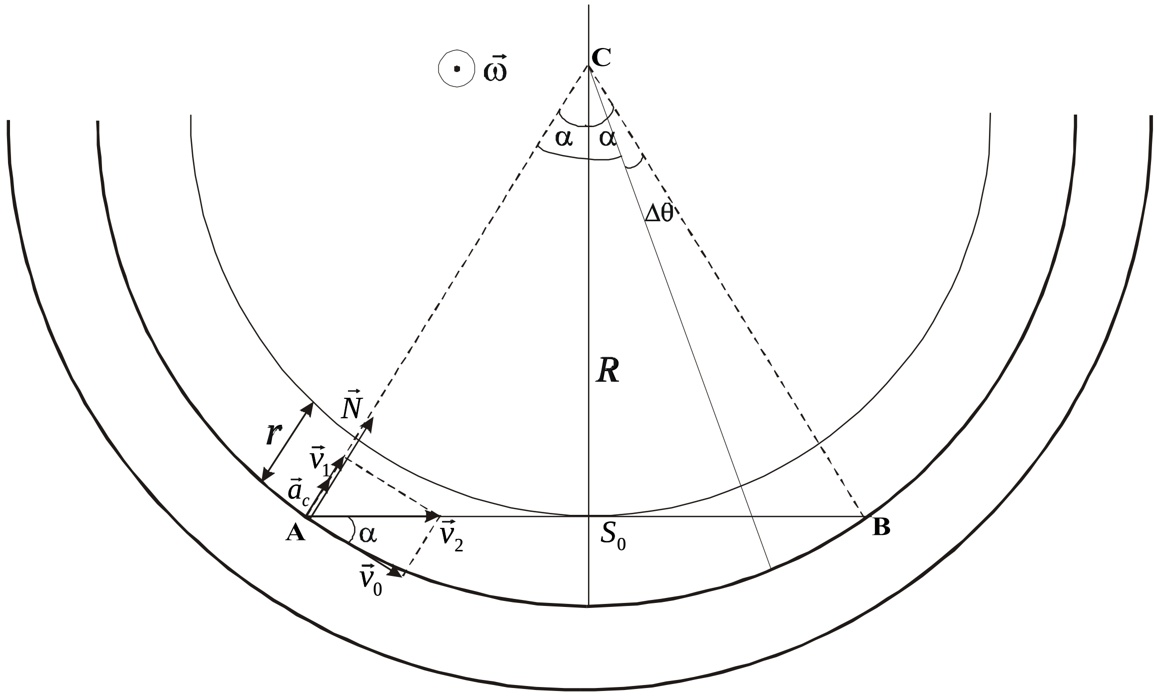
Smaller ratios of *h* to *r* result in smaller angles, smaller angle differences, and a more vertical path as seen from the rotating frame.

The angular velocity ω and centripetal acceleration A_{cent} influence the speed at which the particle falls, but not the path it follows. The elapsed time will be: $t = \frac{S}{\omega \cdot r}$

Hop

The figure below shows the motion of a particle that hops vertically from the floor with an initial relative velocity *v*.

When the body detaches from the floor of the torus, it will cease its curvilinear motion as it will enter the state of impoderability. It will follow an uniform motion along a linear trajectory until the floor of the moving torus will reach the body again. This phenomena is somehow simmilar with the natural terrestrial hop..



First we write the tangential velocity dependency of the radius

$$v_0 = \omega R$$
$$\omega = \frac{2\Pi}{T}$$

The resultant force is 0 thus,

$$0 = ma \Rightarrow a = o$$

$$N = m \cdot a_c$$

For our particular case:

$$\cos\alpha = \frac{R - r}{R} = 0.875$$
$$\alpha \cong 29^o$$
$$\tan\alpha = \frac{v_1}{v_0}$$

From here we calculate the normal velocity:

$$v_1 = v_0 \cdot \tan\alpha = R \cdot \frac{2\Pi}{T} \cdot \tan\alpha = 109.9\frac{m}{s}$$

Now we can calculate the composed velocity from:

$$\cos\alpha = \frac{v_0}{v_2}$$
$$v_2 = \frac{v_0}{\cos\alpha} = \frac{2\Pi R}{T\cos\alpha} = 247.8\frac{m}{s}$$

Here we calculate the distance between the detachment and the landing points:

$$S_0 = AB = 2R\sin\alpha = 3889.14m$$

The time between the detachment and the landing moment:

$$t_{AB} = \frac{S_0}{v_2} = \frac{3889}{247.8} = 15.69s$$

$$\theta = \omega \cdot t_{AB} = \frac{2\Pi}{T} \cdot t_{AB} = \frac{6.28 \cdot 15.69}{127} \approx 0.78rad = 44^o$$

and

$$\frac{\Delta\theta}{2\alpha} < 1$$

We can calculate the angular difference caused by the rotation of the torus:

$$\Delta\theta = 2\alpha - \theta = 58^o - 44^o = 14^o$$

b. The effects of artificial gravity and zero-gravity on human metabolism

Zero gravity has diverse effects on the human body, some of which lead to significant health concerns. We can easily conclude that it would be much healthier for crews to provide artificial gravity for long duration space habitation. This means rotating the habitat to produce artificial gravity by use of the centrifugal force.

For very small habitats, rotating them produces artificial gravity which results in some very noticeable differences with real gravity due to the Coriolis Effect. When you drop an object, it does not fall straight now, but falls by a curve (according to the perspective of the person inside the rotating habitat).

While standing up, your upper body will find itself significantly leaned over if you are in a small habitat rotating fast. For larger habitats, these effects are diluted to where they are humanly unnoticeable. If we want artificial gravity in spacecraft or small habitats and strive for a most economical design, then we need to understand the significance of rotation on humans. The analogy to the comfort of sailors on ships at sea is appropriate. Large ships are more comfortable than small ones. Based on experiments on people in centrifuges and slow rotation rooms, it appears that the maximum rotation rate appears to be around 4 revolutions per minute.

The main reason for lowering radius would be simply economics in an early space habitat in that lower radius means less material needed, including designs for stress. However, in a scenario using asteroidal or lunar material whereby the costs of material in orbit is much lower; we will opt for larger habitats and Earth-normal gravity.

Space stations in low Earth orbit have not used artificial gravity for several reasons: so that they could be smaller and cheaper; many of the experiments to be conducted by the station were in microgravity.

For connecting the spent fuel tanks to produce a space station situated in orbit, we can just put a long cable between them and rotate the structure.

Studies indicate that familiarity with gravity is learned in infancy. An infant at 4 months begins to realize that a rolling ball cannot pass through an obstacle, but are not yet aware that an unsupported ball will fall. When they have 5 months, they discriminate between upward and downward motion. At 7 months, they show sensitivity to gravity and the “appropriate” acceleration of a ball rolling upward or downward. By adulthood, falling objects are judged to move naturally only if they accelerate downward on a parabolic path. These judgments are based not on mathematical reasoning, but on visual experience.

These common-sense ideas, rooted in the experience of terrestrial gravity, permeate architectural theory. A habitat design for a gravitational environment distinctly different from Earth’s requires a fundamental reexamination of terrestrial design principles. The goal is not to mimic Earth, but rather, to help the inhabitants adapt to the realities of their rotating habitat. In artificial gravity, the effects of Coriolis acceleration and cross-coupled rotation arise only during relative motion within the rotating habitat.

One phenomena which is taken for granted on Earth but cannot be in space, is vestibular perception. It might be possible, through experience in a properly designed habitat, to acquire a transformation tendency to vestibular perception from visual, acoustic, haptic, or other perceptions. The goal is not to induce motion sickness by the mere sight of some visual cue. Rather, it is to provide visual or other reminders that motion relative to these cues will result in certain inescapable side effects, inherent in the artificial gravity. These perceptual cues would act as signals, triggering adaptive coordination in the inhabitants. From the designer’s point of view, a consistent vocabulary of such signals would have to arise from convention. From the inhabitants’ point of view, these conventions might to some extent be taught, but the unconscious transformation to a vestibular image would rely on association based on direct experience.

It is ironic that, having gone to great expense to escape Earth gravity, it may be necessary to incur the additional expense of simulating gravity in orbit because the consequences of long-term exposure to weightlessness.
(*)

Effect	**Description**
fluid redistribution	Bodily fluids shift from the lower extremities toward the head
fluid loss	The brain interprets the increase of fluid in the cephalic area as an increase in total fluid volume. In response, it activates excretory mechanisms. This compounds calcium loss and bone demineralization. Blood volume may decrease by 10 percent, which contributes to cardiovascular deconditioning. Space crew members must beware of dehydration
electrolyte imbalances	Changes in fluid distribution lead to imbalances in potassium and sodium and disturb the autonomic regulatory system
cardiovascular changes	An increase of fluid in the thoracic area leads initially to increases in left ventricular volume and cardiac output. As the body seeks a new equilibrium, fluid is excreted, the left ventricle shrinks and cardiac output decreases. Upon return to gravity, fluid is pulled back into the lower extremities and cardiac output falls to subnormal levels. It may take several weeks for fluid volume, peripheral resistance, cardiac size and cardiac output to return to normal
red blood cell loss	Blood samples taken before and after American and Soviet flights have indicated a loss of as much as 0.5 liters of red blood cells. Scientists are investigating the possibility that weightlessness causes a change in splenic function that results in premature destruction of red blood cells. In animal studies there is some evidence of loss through microhemorrhages in muscle tissue as well

muscle damage	Muscles atrophy from lack of use. Contractile proteins are lost and tissue shrinks. Muscle loss may be accompanied by a change in muscle type: rats exposed to weightlessness show an increase in the amount of "fast-twitch" white fiber relative to the bulkier "slow-twitch" red fiber. In 1987, rats exposed to 12.5 days of weightlessness showed a loss of 40 percent of their muscle mass and "serious damage" in 4 to 7 percent of their muscle fibers. The affected fibers were swollen and had been invaded by white blood cells. Blood vessels had broken and red blood cells had entered the muscle. Half the muscles had damaged nerve endings. which is independent of weightlessness.
bone damage	Bone tissue is deposited where needed and resorbed where not needed. This process is regulated by the piezoelectric behavior of bone tissue under stress. Because the mechanical demands on bones are greatly reduced in micro gravity, they essentially dissolve. While cortical bone may regenerate, loss of trabecular bone may be irreversible. Diet and exercise have been only partially effective in reducing the damage. Short periods of high-load strength training may be more effective than long endurance exercise on the treadmills and bicycles commonly used in orbit. Evidence suggests that the loss occurs primarily in the weight-bearing bones of the legs and spine. Non-weight-bearing bones, such as the skull and fingers, do not seem to be affected
hypercalcemia	Fluid loss and bone demineralization conspire to increase the concentration of calcium in the blood, with a consequent increase in the risk of developing urinary stones
immune system changes	There is an increase in neutrophil concentration, decreases in eosinophils, monocytes and B-cells, a rise in steroid hormones and damage to T-cells. In 1983 aboard Spacelab I, when human lymphocyte cultures were exposed in vitro to concanavalin A, the T-cells were activated at only 3 percent of the rate of similarly treated cultures on Earth. Loss of T-cell function may hamper the body's resistance to cancer -- a danger exacerbated by the high-radiation environment of space
interference with medical procedures	Fluid redistribution affects the way drugs are taken up by the body, with important consequences for space pharmacology. Bacterial cell membranes become thicker and less permeable, reducing the effectiveness of antibiotics. Space surgery will also be greatly affected: organs will drift, blood will not pool, and transfusions will require mechanical assistance
vertigo and spatial disorientation	Without a stable gravitational reference, crew members experience arbitrary and unexpected changes in their sense of verticality. Rooms that are thoroughly familiar when viewed in one orientation may become unfamiliar when viewed from a different up-down reference. There is evidence that, in adapting to weightlessness, the brain comes to rely more on visual cues and less on other senses of motion or position.
space adaptation syndrome	About half of all astronauts and cosmonauts are afflicted. Symptoms include nausea, vomiting, anorexia, headache, malaise, drowsiness, lethargy, pallor and sweating. Susceptibility to Earth-bound motion sickness does not correlate with susceptibility to space sickness. The sickness usually subsides in 1 to 3 days
loss of exercise capacity	This may be due to decreased motivation as well as physiological changes. Weightlessness also makes it clumsy: equipment such as treadmills, bicycles and rowing machines must be festooned with restraints. Perspiration doesn't drip but simply accumulates.
degraded sense of smell and taste	The increase of fluids in the head causes stuffiness similar to a head cold. Foods take on an aura of sameness and there is a craving for spices and strong flavorings such as horseradish, mustard and taco sauce
weight loss	: Fluid loss, lack of exercise and diminished appetite result in weight loss. Space travelers tend not to eat enough. Meals and exercise must be planned to prevent excessive loss

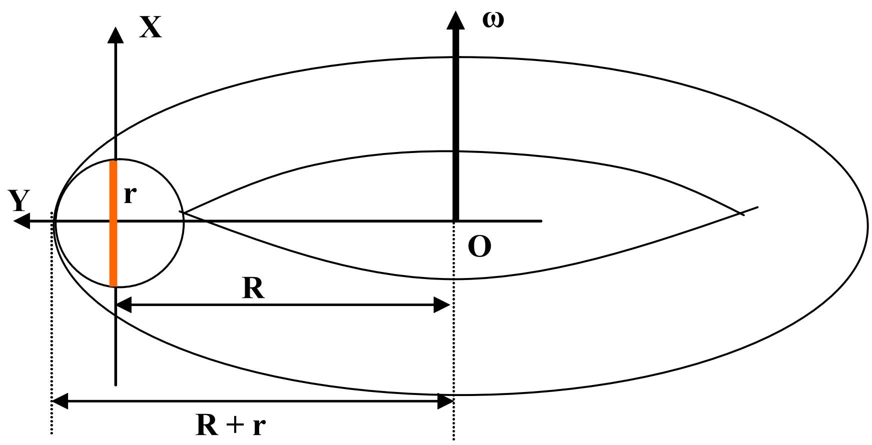
flatulence	Digestive gas cannot "rise" toward the mouth and is more likely to pass through the other end of the digestive tract
facial distortion	The face becomes puffy and expressions become difficult to read, especially when viewed sideways or upside down. Voice pitch and tone are affected and speech becomes more nasal
changes in posture and stature	The neutral body posture approaches the fetal position. The spine tends to lengthen. Each of the Skylab astronauts gained an inch or more of height, which adversely affected the fit of their space suits
changes in coordination	Earth-normal coordination unconsciously compensates for self-weight. In weightlessness, the muscular effort required to reach for and grab an object is reduced. Hence, there is a tendency to reach too "high"

A conclusion after all these is that artificial gravity can approach Earth-normalcy within any non-zero tolerance, provided that the radius and tangential velocity are large and the angular velocity is small.

*Compiled from http://www.permanent.com/

VI.3. Athmosphere

a. Effects of the artificial gravity on the atmosphere



The spinning motion of the Settlement around its symmetry axis causes different atmospheric pressure values in different points of the colony, depending on their distance to the center of the torus. The atmospheric pressure will decrease from the exterior circumference of the torus to its center, following the law deduced in this chapter.

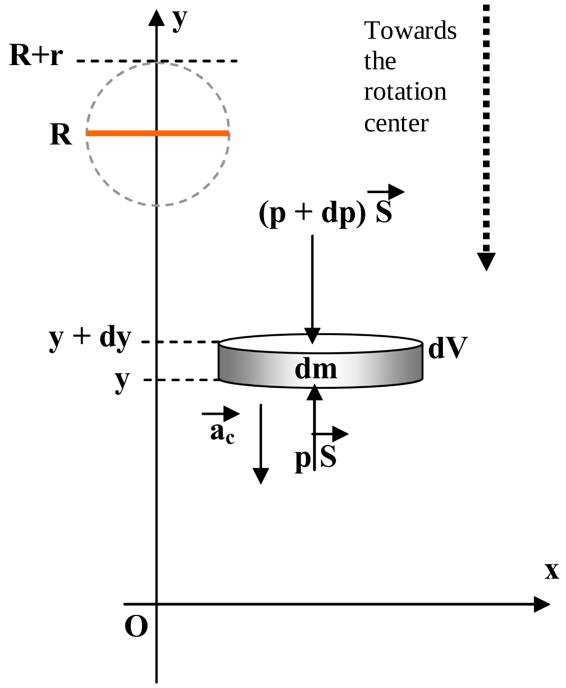
Towards the OY axis we consider a very thin disc of air of mass **dm**, found in mechanical equilibrium under the action of the forces of pressure which simulate the effects of gravity on the atmosphere. The “disc” is shown in following figure.

We can apply the fundamental principle of dynamics for the state of equilibrium:

$$pS - (p + dp)S = (dm)\omega^2 y \qquad [1]$$

We can also express the **dm** mass as:

$$dm = \rho dV = \rho S dy \qquad [2]$$



The equation of state for the gaseous disc is:

$$pV = \frac{m}{\mu} R_g T \quad [3]$$

resulting in

$$p = \frac{m}{V} \cdot \frac{R_g T}{\mu} = \frac{\rho R_g T}{\mu} \quad [4].$$

According to relations [2], [3] and [4], relation [1] becomes a differential equation:

$$\frac{dp}{p} = \frac{\mu\omega^2}{R_g T} ydy \qquad [5]$$

In the mathematical relation above, *p* is the air pressure at distance *y* towards the center of the Settlement, *dp* – the pressure rise according to the *dy* dsitance, *ì* – the molar mass of the air, *ù* – the angular speed of the torus around its axis, *T* – the average termodinamic temperature inside the colony, which is assumed to be constant and equal to 293 K (corresponding to 20^{o}C), R_g - the universal gas constant (8310 J Kmol^{-1} K^{-1}). The equation can be solved by performing an integral calculus:

$$\int \frac{dp}{p} = \int \frac{\mu\omega^2}{R_g T} ydy, \qquad \ln p = \frac{\mu\omega^2}{R_g T} \cdot \frac{y^2}{2} + C \quad [6],$$

C is an integration constant. Its value can be determined by requiering the pressure at ground level (*y=R;, R – the major radius of the torus; R=4011m)* to be similar to that on Earth ($p = p_0 = 10^5$ *Pa*).

$$\ln p_0 = \frac{\mu\omega^2}{R_g T} \cdot \frac{R^2}{2} + C \qquad \text{resulting in} \qquad C = \ln p_0 - \frac{\mu\omega^2}{R_g T} \cdot \frac{R^2}{2} \quad [7]$$

By interpolating relation [7] in relation [8] we obtain:

$$\ln\frac{p}{p_0} = \frac{\mu\omega^2}{R_g T}\cdot\frac{(y^2 - R^2)}{2} \qquad [8]$$

We can transorm the logarithmic function into a exponential dependency. Therefore, relation [8] becomes:

$$p = p_0 e^{\frac{\mu\omega^2}{2R_g T}(y^2 - R^2)} \quad [9],$$

Relation [9] puts forward in an adequate form the variation of the air pressure inside the Settlement according with the distance from the residential surface, measured towards the center of the torus, along a transport column leading to the center of the orbital station.

We notice that the pressure inside the 0 gravity body is not null.

$$p = p_0 e^{\frac{\mu\omega^2}{2R_g T}(-R^2)} = p_0 e^{-\frac{\mu R^2}{2R_g T}(\frac{2\pi}{T_{rot}})^2} = p_0 e^{\frac{-28,9\cdot(4011)^2\cdot 4\cdot 3,14^2}{2\cdot 8310\cdot 293\cdot 127^2}} = 0.791\cdot p_0 \qquad [10]$$

T_{rot} is the rotation period of the settlement around its simmetry axis (T_{rot}=127s).

It appears that the pressure inside the central body of the colony is eligible for sustaining life in case part of the population is evacuated and sheltered there, as it exceeds the air pressure on top of the highest mountains on Earth.

b. Athmospheric composition and generation

Creating an atmosphere that can sustain life is extremely important, but at the same time extremely difficult, because there are many problems to consider.
Pressure and its influence on blood absorption of gasses is one of the major problems, because of its' physiological implications.
High pressures create embolia, the gass absorption being stopped and we do not need that. This is the reason why we calculated a normal air pressure in the settlement of ½ atmospheres, in order to make the blood gas absorption easier. This also creates a smaller amoung of gass that has to be generated or imported to the station.

Atmosphere Composition

In order to preserve acceptable living conditions we have to recreate Earth's atmospheric pressure, keeping the molar fractions of the gasses constant.

Earth's atmosphere consists of: 20% O_2 , 78 %N_2, and 2% other gasses (volumes).
Oxygen's molar fraction is: 20/100=0.2 (volume percents equal mole percents because a mole of any gas in the same environment conditions occupies the same volume; for example: in normal conditions at 0^o Celsius (273K) and 1 atm a mole of any gas occupies a volume of 22.4 L or dm^3 according to Avogadro's law). Nitrogen's molar fraction is 0.78, and other gasses' molar fraction is 0.02.

The total volume of the space station is 19754175000 m^3 (the volume of the torus) + 815125000 m^3 (the central body's volume), for a total of 20569300000 m^3.

ν - number of moles

ν_2 - number of moles of air needed in the settlement's conditions

$$\nu_2 = \frac{p_2 V}{RT} = \frac{1atm \cdot 20569300000m^3}{0.082 \cdot 10^{-3} \frac{m^3 atm}{molesK} \cdot 298K} \approx 841762154198 Kmoles \text{ of air}$$

Oxygen's molar fraction is: x_{O2}=0.2

Number of kmoles of oxygen is : $x\,O_2 \cdot \nu_2 = 0.2 \cdot 841762154198 = 168352430839.7$ kmoles of oxygen

Nitrogen's molar fraction is : x_{N2}=0.78

Number of kmoles of nitrogen needed :
$x\,N_2 \cdot \nu_2 = 0.78 \cdot 841762154198 = 656574480274.44$ kmoles of nitrogen

Number of kmoles of other gasses:
$x\,\text{other gasses} \cdot \nu_2 = 0.02 \cdot 841762154198 = 16835243084$ kmoles of other gasses

Chemical generation of Oxygen

In order to preserve the gaseous pressure in the station, we will have to constantly monitor the oxygen, nitrogen balance and volume.

Some of the Station's oxygen will be generated different ways, from two different types of substances: from lunar and asteroidal ores that contain metal oxides, using the separation methods presented in chapter 3, and from heated lunar ice water, by its electrolysis:

2* |cathode (-) $2H_2O$(liquid) +2e$^-$=> H_2 (gas)+2OH^-(aqueous) [reduction]

anode (+) $2H_2O$(liquid) -4e$^-$ => O_2(gas)+4H^+ (aqueous) [oxidation]

Total process:

$2H_2O$ => $2H_2$ + O_2

This reaction needs 285,5 kJ per mole of water. $dH_{reaction}$= 571 kJ

This is also a source of hydrogen.

Oxygen is also used for the fabrication of ozone (ozein= to smell), it's triatomic allotropic state O_3.It can be obtained with UV lamps or by the cryogenic liquefaction of air. This can have a plentitude of uses: medical uses and water disinfectant (see waste management). It's a very powerful oxidizing agent, and it must be produced close to its source of application.

Hydrogen generation

Hydrogen generation is made from thermal extraction and electrolysis (see separation methods). Another method would be from large ammonia transports, by decomposing it into elements: 2 NH_3=>N_2 +3 H_2, altering the equilibrium created with the reverse reaction (by Le Chatelier's principle). Asteroids contain also hydrogen volatiles from which we can obtain the hydrogen.

Nitrogen generation

This gas is extremely important (a little rare), being one on the gasses we have to transport in large amounts from Earth, under the form of ammonia, so that we will be able to use the entire cargo. Lunar ice water which was newly discovered to have amounts of nitrogen dissolved in it. This is another source of N_2. The reason for this surprising fact could be the meteor and asteroidal impacts in the past; another space nitrogen source is asteroid volatiles containing nitrogen gas along other gasses.

The lack of some volatiles can determine major problems. Nitrogen is one of the most important because nitrogen sources are few and the necessary quantities are great. Once created the biogeoecosystem the import of ammonia will stop, because the circuit will be closed, and matter will not be lost any more.

c.CO_2 concentration control and removal

Carbon Dioxide Elimination

Biological elimination is made by plants, which take the carbon dioxide form the atmosphere and they use it as their own food.

We are aware of the importance of photosynthesis in the carbon dioxide elimination process, but we have to take safety measures, and find a backup system of elimination of CO_2.Accidents may happen with the plant population. We can use the dioxide to form water and methane with hydrogen, and the compounds formed can be used to form water and in this manner to reform the cycle.

Carbon Dioxide Reduction System (CRS)

In this cycle, CO_2 reacts with hydrogen and forms methane and water:

$$CO_2 + 4H_2 \Rightarrow CH_4 + 2H_2O + Q$$

This reaction can happen in a reactor, in catalytical conditions. The water vapour formed in this manner is condensed on a cold surface, so that the gas stream is composed only by methane. Water obtained this way can be collected and the methane separated in a combustible gas chamber or pipe.
The water can support the process of electrolysis, and it is decomposed in Oxygen and hydrogen. Oxygen is released at the anode and is collected and seprated, and hydrogen molecules are formed at the cathode. This last gas is used at the restart of the cycle.

METAL OXIDES

Silver oxide reacts with CO_2 and forms a silver carbonate. Also Magnesium and lithioum oxides are viable to take part in this process, but the highest chemisorbtion of CO is made by Ag.

$$Ag_2O + CO_2 \Rightarrow Ag_2CO_3 \text{ (in an aqueous environment)}$$

SOLID AMINE WATER DESORBED

This is an elimination method that uses an ion exchange resin that has the proprety of being able to chemically bond CO_2 molecules to its structure. The total elimination of the gas can be made in vacuum or even space, when tha dioxide molecules are dispersed.

ION EXCHANGE ELECTRODIALYSIS

This method has the same principle as the ne mentioned above, but it is at the same time different. The compounds formed at the surface contact between the ion-exchange resin and the dioxide are carbonates, that can be easily eliminated in an electrical field, and at the same time the resin is regenerated.

THE 4 BED MOLECULAR SIEVE (4BMS)

This device has a water side and a chemically active side. In the active side, on of the beds has the function of actively adsorbing water molecules, and at the same time the air is passed to the bed and the CO_2 is adsorbed. The other beds have the purpose of desorbing the water, which is eventually returned to the first phase of the cycle.

THE SABATIER PROCESS

This process is based on the burning of CO_2 in H to produce Oxygen and methane gas. The process is exothermic (323K/mole CO_2) because of the destruction of the two double C=O bonds.

$$CO_2 + H_2 \Rightarrow CH_4 + O_2 + Q$$

THE BOSCH PROCESS

This is another process of transforming CO_2 in other products. In this case the products are solid black C and gaseous O_2. This reaction generates 431K per mole of CO_2.

$$CO_2 \Rightarrow C + O_2 + Q$$

d. Measuring toxicity levels and contamination prevention

Preventing contamination involves eliminating the risk factors which could lead to the incapability of the organisms to function within their normal adaptation limits.

Measuring toxicity levels inside a fully operative ecosystem will surely not be an easy thing to achieve. For estimating the distribution and level of toxicity we must first study the response of the different communities of humans, animals and plants based on a specific biochemical, physiological or behavioral endpoint.

For determining if exposure to a certain toxicant substance will result in adverse responses for the Settlement's biotope we must first calculate the dose, the time and the frequency of exposure.

Therefore all habitats onboard the Space Settlement must be permanently monitored and carefully studied. To achieve this, periodical tests must be conducted upon both aquatic and terrestrial organism, including plants, invertebrates and vertebrates. This complex monitoring system will be based on highly sensitive chemo-sensors which will constantly examine the chemical composition of air and water vapors and send the precise results to the central data logger (trace contaminant control) for further analysis.

Still the best way of preventing contamination and thus endangering the artificial ecosystem will be creating a strict set of rules concerning the use, waste and recycling of the different materials onboard the Settlement. Therefore, the distribution, exploiting and dumping of materials will have to respect a certain cycle; meanwhile, several norms concerning the industrial activities and the industrial waste management will help in preventing chemical contamination.

The different substances onboard the Settlement will have to follow the cycle presented below:

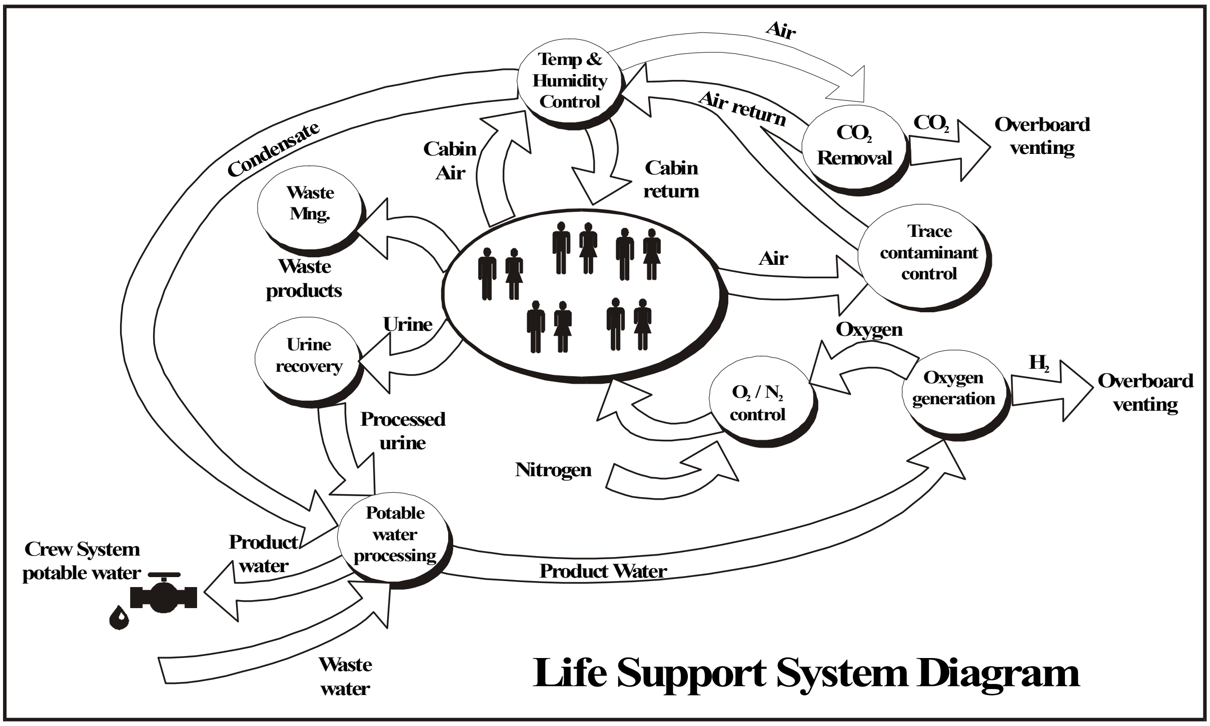


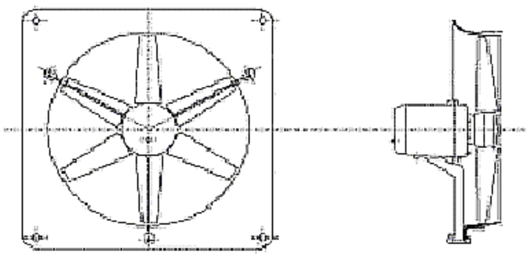
Diagram inspired from http://science.nasa.gov/

e. Ventilation and ventilation devices

Because we have a perfect isolated habitat we need a very good ventilation to replenish oxygen, dilute the concentration of carbon dioxide and water vapor, preventing the infiltration of dust and atmospheric pollutants, and minimize unpleasant odors. Thereby we will stop the effects of a poor air quality which can lead to headaches, respiratory difficulties, sinus congestion, fatigue, throat and eye irritation and poor concentration. For the houses' interior we can use the Indian Teepee principle.

The exhausted air will be replaced with fresh air found at the temperature of the torus, which is drawn into the building via low level louvers and doorways, thus providing vertical air movement, which is the most natural and efficient way to ventilate buildings.

Vertical air movement occurs due to lower density, warm air rising as it expands becoming more buoyant. As cool air, which is dense and therefore heavier, enters the building at low level it pushes the warm air upwards thus developing convection currents. For the artificial "wind", in the residential zone and also in the agricultural one, we can use common fans with aluminium palettes for high efficiency.



General scheme of a common ventilation fan

f. Temperature and humidity control

We must have automatic temperature control systems all over the torus and the central body for maintaining a constant normal temperature. A sensor will monitor the temperature inside the habitable area and the agricultural area. If a temperature variation appears it communicates with the controller, which will be linked to a microchip which is able to increase or decrease the required temperature with a margin of safety of maximum +/- 0.5°C.

A Dehumidifier is an appliance that removes moisture from the air. Most of the dehumidifiers work like refrigerators and air-conditioners. They have cooling coils. Water vapor is condensed and removed from the air going through the dehumidifier. This requires a lot of energy to condense water vapor and the higher the background humidity level, the more energy it takes.
Other types of dehumidifiers are made with the help of a silica gel impregnated on a desiccant wheel with a fast heating coat made out of paper or fiber-glass. This wheel is like a deep porous material that forces the air to get to the desiccant substance. This chemical compound attracts the water molecules in its pores, taking all the moisture from the air and incorporating it.

Low humidity also can be harmful since excessive evaporation can irritate the mucous membranes of the nose and bronchi, thus we need a device for creating humidity. Studies show that for a person wearing light clothes, the ideal conditions of well-being occur when the environmental temperature is between 23...25°C, and the relative humidity is between 40...60%. Also, in some industrial processes the humidity favors we can avoid various inconveniences consisting in the formation of electrical charges.

Besides the natural humidification which has lot sources, we must use artificial ones too. A type of artificial humidifier would be the one which nebulizes the water producing a fine mist that is blown into the torus by a small fan incorporated in the machine. The mist then evaporates immediately, humidifying the air. The mist outlets can be orientated in every horizontal direction.

All these features will make an efficient and versatile atmosphere control, suitable for creating an agreeable way of life.

VI.4. Flora

a. Plant growing and maintaining process

Plants will be needed to produce O_2 and food from simple substances like CO_2 and H2O and they are essential for life support on the station. But plants also need themselves conditions to live. The most important factors that influence plant growth are nutrients (minerals, C, H, N, O, P, S), the soil and climateric conditions (temperature, light, humidity, atmosphere composition). Plant processes (like photosyntesis, circulation and respiration) are of major interest for plant growing as well as for humans (photosyntesys produces oxygen and organic compound such as glucose, intense respiration consumes oxygen etc. *see nutrition in plants). If one of these functions is altered, the result will be abnormal growing or even death.

The soil is very important to plants, because it offers both support and almost all nutrients. Because natural soil takes millions of years of development making manufacturing almost impossible and its transportation from Earth would be very expensive, artificial soil will be used with similar properties as the natural one. The soil is in fact a solution; which contains both organic and inorganic molecules.

Since nutrients are by nature inorganic, the organic component is not strictly necessary (in nature is a continuous source of inorganic compounds, but the station will be a closed system, so the organic detritus will be recycled and transformed in simple, inorganic substances, which will be returned back to the soil).

The artificial soil will have two components: a biotic one (plant roots and other organisms, needed to maintain the soil balance) and an abiotic component. The abiotic component will comprise a polymer (which will have a structure and consistency resembling with a sponge - like the natural soil- providing support and space for water and other dissolved compounds -like nutrients), sand (silica)-small quantities, calcar ($CaCO_3$)-small quantities, nutrients and organic detritus (in small quantities). An average depth of 5-7 meters will be sufficient for all type of plants grown on the station. The soil will stay on a bed of rubber (10 cm deep), which is impenetrable for all substances solved in earth. Water will be held in small spaces by capillarity (all spaces with a diameter smaller than 0.5 mm). Nutrients will be held by solving in water and by their attraction to the negative charged membrane of the root absorbing cells.

The nutrients are divided into two major groups: macronutrients (which are required in large amounts - approx. 1 mg per gram of dry mass: C, H, O, N, P, S, K, Ca) and micronutrients (100 microg per gram of dry mass: Cl,Fe,Mn,B,Zn,Cu,Ni,Molybdeum). These nutrients can be obtained initially from the Moon and the Earth and then integrated into natural cycles to be reused by the plants.

1. Sources of nutrients

2. Carbon source: => plants use CO_2 as source of carbon. CO_2 will be obtained from respiration of humans, animals and plants.

3. Oxygen source: => for glucose (monozaharide) and polyzaharides or derivates (fructose) obtained from it the main source of oxygen is CO_2. In respiration, oxygen is taken from O_2 - produced by plants themselves. Even if O_2 is consumed during plant respiration and pho-

torespiration (a special type of respiration that occurs when photosynthesis is blocked), the quantity of oxygen produced during water hydrolysis (first part of photosynthesis) is much higher than the quantity used for respiration, thus resulting a surplus that may be used by humans and animals.

4. Hydrogen source: => the main source of hydrogen is water or the free H^+ ions from the soil.

5. Phosphorus source: => acids :(H_2PO_4)- , $(HPO_4)_2^-$; salts: K_3PO_4, Na_2PO_4.

6. Potassium source: => K^+ from potassium salts: KCl, K_2SO_4 , KI solved in water (Ionized form; e.g. for potassium and clorure, free ions of K^+ and Cl^-).

7. Calcium source: => Ca_2^+ from salts ($CaSO_4$, $CaCl_2$) or fine divided Ca.

8. Nitrogen source : => nitrogen will be taken from (NO_3)-, (NH_4)+, NH_3 and from the artificial atmosphere through nitrogen fixation.

9. Iron, Zinc, Copper, Nickel, Manganese, Magnesium : => from fine divided metal or their salts ($FeCl_2$, $FeCl_3$, $CuSO_4$, $ZnSO_4$ etc.).

10. Boron source: => $(BO_3)_3^-$, $B4O_7$.

11. Molybdenum source: => fine divided molybdenum.

12. Chlorine source: => chlorine will be obtained from salts in their ionized forms (K^+, Cl^-, Na^+- Cl^-).

13. Sulfur source : => $(SO_4)_2$-, from salts or acids, solved in water.

Nutrients are absorbed by plants in their ionized form (K+, Cl-, Mn_2+, Mg_2+, Fe_2+, Fe_3+, Cu_2+, Ca_2+, (NO_3)-, $(SO_4)_2$- or as gases (CO_2,O_2) or liquids (H_2O) through osmosis. Generally, nutrients are available for plants in their most oxidized form (carbon as CO_2, hydrogen as water, phosphorous as phosphate, nitrogen as nitrate, and sulfur as sulfate). In addition to CO_2 and O_2, plants are able to take up other compounds through their leaves such as some sulfur oxides from the atmosphere. Plants can also be fertilized by spraying their leaves with a nutrient solution (copper, manganese and iron are more efficiently absorbed from such foliar spraying than from the soil), but the pH of the solution and the concentration of nutrient ions within must be carefully adjusted (in very large quantities, iron is toxic for plants and a very low pH prevents ion absorption), and the plants must be sprayed at the right “time of day”. Plants can adapt to nutrient - deficient soils by directing their roots to patches of soil where the nutrients they lack can be found.

Plant roots manifest a certain degree of selectivity. However, the mineral composition of plants often reflects the composition of the soil and water in which they grow, meaning that some minerals that are not necessary for plants can accumulate in their body. Plants growing on mine tailings, for instance, may contain gold or silver, and the nutritional value of fruits and vegetables may vary depending on the composition of the soil. But that means also that some elements that humans and animals need (like selenium or natrium) can be absorbed by the plants from the soil and then used in alimentation; they can provide a plentiful source of elements (provided that the soil contains these elements).

Needed quantities and deficiency symptoms of major plant nutrients		
ELEMENT	**FRACTION (percent)%**	**MAJOR USES DEFICIENCY SIMPTOMS**
Carbon	45 - 50	In all organic molecules retarded or abnormal growth
Hydrogen	5 - 7	In all organic molecules retarded or abnormal growth
Oxygen	27 - 33	In most organic molecules; respiration retarded or abnormal growth
Nitrogen	8 - 10	In proteins, nucleic acids, coenzymes, Chlorosis of leaves, beginning with lower leaves
Phosphorus	2 - 3	In nucleic acids and phospholipids; coenzymes of energy metabolism; protein red, purple or brown pigments along veins
Sulfur	0.5	In proteins, coenzymes Chlorosis of whole plant, retarded growth
Potassium	4 - 5	Major divalet cation in cytosol; in chlorophyll; Dieback of growing points; blue-green or dark enzyme activator green color, leaf margins necrotic
Calcium	2 - 3	Cell wall component; maintains membrane Dieback of growing points; regulates cytoskeleton; second (undeveloped terminal buds); stunted root growth; messenger in signal-transduction pathway leaves curl
Magnesium	1	Major divalent cation in cytosol; in clorophill; Marginal chlorosis and red, purple, or brown Enzyme activator pigments in mature leaves first, with green venation

Micronutrients' concentration and role		
Micronutrients	**Parts per million**	**Role**
Chlorine	500 ppm	Photosyntesis; ionic balance in cytosol Young leaves blue-green color and shiny, then become chlorotic, necrotic, bronzed
Iron	500 ppm	Enzyme activator; electron carrier of ETS Chlorosis of young leaves, but larger veins remaining green; short, slender stems
Manganese	250 ppm	Enzyme activator;especially Krebs cycle and Stunted, interveinal chlorosis in leaves; pale amino acid biosynthesis enzymes overall coloring; leaves malformed, with necrotic
Boron	100 ppm	Cofactor in chlorophill synthesis; stems rough and cracked;carbohydrate transport; not well understood growing tips damaged; flowering inhibited; heart rot of root crops;
Zinc	100 ppm	Enzyme activator; auxin synthesis" Little leaf", rosette formation; leaves necrotic, twisted,misshapen; late summer mottling leaves
Copper	30 ppm	Enzyme activator, especially redox reactions Dieback of growing points; leaves chlorotic or and lignin biosynthesis; leaf margins curl or roll
Molybdeum	0.5 ppm	Enzyme activator, especially in nitrogen Interveinal chlorosis; pale, distorted, yellow fixation and nitrate reduction leaves, with margins that curl or roll; stunting
Nickel		Enzyme activator, nitrogen metabolism

As it results from the table, nutrients deficiencies may cause severe disturbances in plant metabolism. Any deficiency should be treated immediately after observed, otherwise the plant will die.

Light is essential for plants and they cannot live without it. It influences circulation and its absence prevents photosynthesis.Light is one type of electromagnetic radiation, a form of energy that behaves like both a particle and an oscillating wave, straining the human ability to represent natural phenomena realistically.

As a particle, each unit of EM radiation is called a photon. It travels at a velocity (c), which is 3x(10)8 meters/sec in vacuum; the radiation also vibrates with a frequency of a vibration per second and has a wavelength of lambda. The photon may be considered a packet or quantum of energy. But not all the light is used by plants. Only red ad blue light is absorbed and the rest is reflected (that's why the color of the plant is green - the only visible color which is not absorbed). The optimum intensity for plants is around 20,000 - 25,000 Lx, higher or smaller values lowering photosynthesis. To the plants from the station only red and blue light will be given, by filtering normal light through red or blue glass.

b. Fluorescent plants

There are two types of light that may be used: artificial and natural light, each one with is advantages and disadvantages. Artificial light can be obtained from illuminating systems such as ordinary lightballs and has a high intensity, but consumes a lot of energy. Natural light can be obtained from some bacteria, mushrooms, fishes and coelenterates (only the bacteria are of interest) or from the plants themselves if they are genetically modified. The light produced by bacteria (from genus Photobacterium: Photobacterium phosphorous and Photobacterium leiognath) is withe-green and cold (it doesn't contain infrared and ultraviolet rays) and of small intensity, so a huge quantity of such bacteria would be needed and is an oxygen consumer. The mechanism which will produce light is the following: a substance (called generically luciferin) is oxidized with molecular oxygen to luciferase, from this process resulting light. Substances from the luciferin group are: luciferil-sulphate, 2-benzil luciferin etc.

$$\text{Luciferil-sulphate} + O_2 \xrightarrow[\text{+ATP (cofactor)}]{\text{luciferil-sulfokinase}} LH_2 \text{ luciferin}$$

So, the bacterium grown on a nutritive medium (glucose and nutrients) in presence of oxygen can be used to produce inexpensive, small intensity light.

The light producing plants are genetically manipulated plants to which the luciferase enzyme (responsible for glowing) gene has been added. The nature of the light is similar to the light produced by the bacterium from the Photobacterium genus. The technique used is cloning the gene into a plasmid which permits their expression in plants treated with it. Plants obtained from the genetically modified plant will have the same properties as their parents (they will glow too).

VI.5. Food factor and Agriculture

In order to be able to conceive a permanent existence of a rather dense population on our proposed Space Settlement we began by imagining the model of a microclimate similar to that found on Earth. We then tried to artificially compensate for the lack of all those elements which are not to be naturally found on our station.

a. Food composition and preparation

Correct nourishment is a basic condition for a healthy population. Health does not mean only "not being ill", but also a physical, mental and social state of well-being.

Nourishment is the first among the eight principles which define a healthy way of living. That's why achieving a project of such magnitude implies special care and studies in order to find solutions to all human necessities.

Agriculture is the field which provides the essential raw materials to the food industry, therefore only by creating the conditions for getting quality produce can we ensure the necessary base of the food processing.

In this respect, we could also get rid of everything that has been harmful to people on Earth (tobacco, alcohol etc.) and direct our attention to healthy produce.

The nutritive substances are divided after their function in:

- nutrients with energetic role: glucids and proteins, which provide the vital energy
- nutrients with plastic role: proteins, used to repair cellular structures
- nutrients with catalytic role: vitamins, minerals, that influence metabolic reactions.

The optimal proportion between proteins, lipids and glucids (or carbohydrates) is 1:2.5-3.5:0.8. The quantity needed by a person varies after the "due body weight ". Due body weight, in kilograms, is equal to person's height in centimeters minus 100 (+-10%) - for men and minus 110 for women. Thus, for a person 160 cm tall, a due body weight is 60 kg +- 6kg. A correct amount of protein to be consumed in a day is approx. 1g per kg of due body weight. Thus, a person with 60kg needs to consume about 60+-6 g of protein to satisfy body's daily needs. Any excess of protein is converted to fat, provided energy requirements are met by other components. Using the ratio 1:2.5-3.5:0.8, the required quantity of lipids and carbohydrates can be calculated: 150-210 g of fat and 30 to 50 g of carbohydrate.
The needed energy is expressed in calories (1 cal = the quantity of heat required to raise the temperature of 1g of water with 1 grade). All body activities require energy, and daily needs vary with people due body weight and activities. For example, an adult with less activity needs about 2500 kcal, while a worker needs 5000 kcal and a performance sportive 8000 kcal. Energetic requirements are also higher for children: 4000-4500 kcal.

How much a healthy human requires protein per day? Opinions are divided: while the WHO protein figure translate into 56g of protein a day for a (75 kg) man and 48g for a(64 kg) woman, the recommendations of the UK Department of Health and Social Security (DHSS) are slightly higher:

68g a day for a sedentary or moderately active men, and 54g a day for women, but the quality is important. The quality of protein is measured by comparing the proportions of essential amino acids in a food with the proportions required for good nutrition. The closer the 2 numbers are, the higher the protein quality. Egg and milk proteins are high - quality proteins that are efficiently used by the body and are used as reference standards against which other proteins can be compared. Meat protein is of high protein quality, whereas several proteins from plants used as major food sources are relatively deficient in certain essential amino acids, e.g., tryptophan and lysine in maize (corn), lysine in wheat, and methionine in some beans. In a mixed diet, a deficiency of an amino acid in one protein is made up by its abundance in another; such proteins are described as complementary; e.g., the protein of wheat and beans combined provides a satisfactory amino acid intake. Under such circumstances, a greater total amount of protein must he consumed to satisfy requirements.

Regardless of their source, aminoacids that are not immediately incorporated into new protein are rapidly degraded and they are not stored.

All dietary proteins (proteins that can be used by humans) are digested and absorbed in the bloodstream as individual aminoacids. The body requires 20 different aminoacids, and only 8 can be synthesized. The daily needs of protein are calculated based on body weight, extra growth on infants require larger quantities. Pregnancy, lactation, tissue repair after injury, recovery from ilness, increased physical activity is other conditions requiring more dietary protein. Generally, a diet where 12% of the energy is supplied as protein is adequate.

Fats-or lipids-are a class of organic substances that are not soluble in water. In simple terms, fatty acids are chains of carbon atoms with hydrogen atoms filling the available bonds. Most fat in our bodies and in the food we eat is in the form of triglycerides, that is, three fatty-acid chains attached to a glycerol molecule.

Fat’s value as a “fuel” for our body increases with the increase in the amount of hydrogen per gram of carbon in its molecule, with the increase in the energy-contributing constituents. Chemically, the best are long-chain fully saturated fatty acids, that is to say, solid fats of animal origin. Only fats with the length of the chain above 10 carbon atoms are suitable to be utilized by our cells and tissues without conversion. These fats are directed straight to the blood stream via the lymphatic system, and they do not have to be converted and made suitable by the liver, as is the case with inferior fats (with shorter chains), or all other constituents of consumed and digested foods. Long chain fatty acids are the best medication for those suffering from liver diseases. Chemically and factually long chain fatty acids are the best “fuel” for our bodies.
By eating animal fats we not only receive concentrated energy, but we also receive all the fat-accompanying elements needed to obtain this energy, in the necessary quantity and proportion. The human body metabolizes animal fats easily and such metabolism is energetically economical. The digestive system is designed to slowly deliver the building blocks and energy containing matter

Carbohydrates are widely distributed in plants and animals, where they fulfill both structural and metabolically functions. In plants, glucose $C_6H_{12}O_6$ is synthesized during photosynthesis, while animals obtain it from plants or other animals. Animals can synthesize some carbohydrates from fat and protein but these quantities are much under their needs.
Most carbohydrates in the food form glucose, galactose and fructose. These are transported to the liver via the portal vein, where galactose and fructose are converted into glucose. Glucose is specifically required by many tissues, but does not have to be provided directly from food since other compounds like starch, fructose, galactose are transformed in glucose either during digestion (starch)

or in liver (fructose, galactose). A minimum daily intake of carbohydrates is about 50g to prevent ketosis and loss of muscle protein.

Vitamins are substances that act as catalytic substances. In their absence, some products cannot be synthesized, producing severe diseases to humans (loss of nocturnal sight, heart diseases, anemia, etc.)

The necessary vitamins are: A, B1, B2, B6, B12, C, D, E, K, and PP. Some can be solved in water (B1,B2,B6,B12,PP,C) and others in fats (A,D,E,K). Vitamin A can be found in fresh vegetables (especially carrots), milk, liver, butter, cheese and eggs; 12mg are required daily. Vitamin B1 is found in meat, cereals, vegetables, milk, liver; 1-2mg/day. Vitamin B2 can be found in almost all foods; 1-2mg/day. Vitamin B6 can be found in cereals, vegetables, and meat. Vitamin B12 is found in pork and beef meat, eggs and fish; 2mg/day. Vitamin C can be found in fresh fruits and vegetables (tomatoes); 70mg/day. Vitamin D is found in cheese, yogurt, milk, cream, liver, eggs, fish, fish oil; 1-2 mg/day. Vitamin E can be found in margarine, seeds, fresh vegetables, wheat, vegetal oils; 20mg/day. Vitamin K is found in fresh vegetables, liver, produced by intestinal bacteria; 4mg/day. Vitamin PP can be found in dried vegetables, cereals, eggs, milk, and liver. Vitamins are generally present in plants and they are less abundant in animals.

Although water isn't a nutrient, it has a very high importance because it represents the medium were all reactions take place and in which most substances are solved. The daily need of water is around 1.5-2 l/person, but this value can be much higher if transpiration is high (for example, when temperature is high). Water can be taken directly or from other products (the value required comprises the total water ingested).
Minerals have catalytic proprieties or they take part as components in some compounds (like iron in hemoglobin). Minerals are: P, Ca, Fe, Zn, Cu, Cl, Na, K, S, Se, Ni, Mn, and Mg.

As no single food contains all these elements, we have to use a variety of foodstuffs. In the case of living on a space station, there are two possibilities of ensuring the nourishment of the population.

One could be the classical way similar to that which we are familiar with on Earth. This presents, however, a variety of problems, connected to the diversity of the required technical means, complex methods and storage facilities. Another way would be a balanced vegetarian diet, without cholesterol and fats for the benefit of the human body. Furthermore, as the evolution of civilization aims at the creation of a new type of man, with higher aspirations but less time, we suggest a re-thinking and re-designing of the food industry, so that it would serve the interests of the individual, offering him the necessary state of health and comfort.

In this respect, we recommend the use of Soya as the basic raw material to obtain various foodstuffs ranging from diary produce to those having the taste of meat. Millet paste could successfully replace eggs.

A vegetarian diet can offer man the benefit of protein of superior quality such as glucose and lipids which are not harmful, nut-oil, seeds, olives, fiber, vitamins and total mineral salts.

This is the ideal we should pursue to avoid many of the causes of illness nowadays. Setting as our objective a healthy diet, the designing and construction of the technical facilities helps to achieve the above purpose.

On as pace station, crops an be grown on the seven levels used for agriculture, provided with red spectrum lights, adequate ventilation, system of keeping constant temperature and air humidity, as well as the polymer texture used as crop supports.

Crops must be treated with natural and synthetic fertilizers to get quality produce. Once the plants have grown, they are harvested and stored in appropriate spaces, until they are processed.

But, people's mentality being what it is, perhaps some may experience frustration in the absence of those useful domestic animals with whom they were used on Earth (poultry, livestock). Fish breeding facilities are also possible and from a psychological point of view.

In conclusion, the diet onboard L.E.D.A. will comprise a mixture of aliments from the following classes:

- Fruits and vegetables
- Cereals
- Milk and milk products
- Meat and eggs

Product	Values are taken from 100g/100ml of product, and they are expressed in g
sunflower seeds	P: 24.4 L: 43.7 C: 24.6; 566kcal
walnut	P:16 L:60.3 C:18.0;651 kcal
apples	P: 0.4 L:0.4 C: 12.1; 47 kcal
avocados	P:2 L:15.3 C:7.4; 161 kcal
pears	P:0.6 L:0.2 C:14.4; 55 kcal
soya beans	P: 34.3 L: 19.6 C: 32.7; 385 kcal
kidney-beans	P: 21.4 L: 1.6 C:61.6; 290 kcal
carrots	P:1 L:0.4 C:8.7; 27 kcal
potatoes	P:1.9 L:0.1 C:20.5; 86 kcal
tomatoes	P:0.9 L:0.2 C:3.6; 15kcal
mushroom	P:2.7 L:0.4 C:2.6; 17 kcal
bread (white)	P: 8.1 L:1.5 C:51.6; 240 kcal
flour	P:9.4 L:1.6 C: 74.1; 346 kcal
rice	P: 6.7 L:0.7 C:78.9; 347 kcal
butter	P:0.7 L:82.5 C:0.7;742kcal
full cream milk	P:3.2 L:3.7 C:4.7; 66 kcal
eggs	P:12.5 L:10.7 C:1; 151 kcal
beef	P:20.9 L:3.6 C:0; 116 kcal
chicken	P:16 L:2.2 C:0; 122kcal
pork	P:21 L:10 C:0; 175 kcal

Since cultivation will be reduced on the station, only the foods with the best quality will be grown.

b. Food depositing and quality control

In the area designed for industrial activities, the technical equipment for processing the agricultural and animal produce will be of major importance. They will ensure the mechanical and thermal treatment used in the process of getting both raw materials and the final produce.

We must design this equipment having in view the special conditions required when working in a space station environment, the necessity of recycling the residues, eliminating the effect of vibrations, noise, and odor pollution. The final products must be properly stored in special locations from which they will be delivered according to the demand.

The quality of the products is reflected in the quality of the population's state of health, therefore monitoring quality is essential during the entire production cycle.

VI.6. Water management

Most forms of life require water for their survival. On the Space Settlement, we will need to find ways of producing and effectively recycling the water for plants and humans.

REGENERATIVE LIFE SUPPORT - INPUTS AND OUTPUTS

INPUTS - kg/person/day	
Oxygen	0.83
Dry Food	0.62
Water in Food	1.15
Food Preparation Water	0.79
Drinking Water	1.61
Oral Hygiene Water	0.36
Hand and Face Wash	1.81
Shower Water	5.44
Clothes Wash Water	12.47
Dish Wash Water	5.44
Urinal/Comode Flush Water	0.49
Total:	31.0 kg

OUTPUTS - kg/person/day	
Carbon Dioxide	1.00
Water from Respiration and Perspiration	2.28
Urine	1.50
Urine Solids	0.06
Hygiene Water	7.18
Latent (Evaporated) Hygiene Water	0.44
Clothes Wash Water	11.87
Latent (Evaporated) Clothes Wash Water	0.60
Latent (Evaporated) Food Preparation Water	0.04
Dish Wash Water	5.41
Latent (Evaporated) Dish Wash Water	0.03
Feces Solids	0.03
Feces Water	0.09
Sweat Solids	0.02
Urinal and Commode Flush Water	0.49
Total	31.0 kg

From: Wydeven, T., and Golub, M.A., Generation Rates and Chemical Compositions of Waste Streams in a Typical Crewed Space Habitat, NASA Ames Research Center, Moffett Field, CA (1990) and Webb, P., Ed., Bioastronautics Data Book, NASA SP-3006, National Aeronautics and Space Administration, Washington, D.C. (1964).

a. Water Production

Initially, water will have to be extracted from the Moon, in the form of ice, the ice melted using solar energy and then purified. Also, the first spaceships arriving at the station will need to carry water supplies. On the settlement, water will be constantly recycled, since there are no viable water sources in space, apart for The Moon and The Earth, and the cost of supplying the station with all the necessary water from these places is too great.

Plants and animals eliminate water through breathing and excretion.

$$C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O$$

Excess humidity in the air will need to be condensed and the water recycled.

b. Water Storage

Water will be stored in a cluster of interconnected tanks located at the center of the space station. The connections of the tanks will be fitted with valves and pumps. When water from the tanks is used, the remaining water must be distributed evenly in order to avoid oscillations due to inertia. The storage area will need to be large enough to hold a few days' supply of water in the case of an emergency (about 54250 tons for a week, which means that the whole storage area should have a volume of 54250 cubic meters).

Since "gravity" increases as we advance towards the outer regions of the station (the inhabited area), water will flow naturally (or with little energy consumption) to where it is needed. However, sewage water will have to be pumped to the purification plant and then into the storage tanks using electric pumps.

c. Water Quality Control

A water processing facility will be placed next to the storage tanks. It should be able to handle a flow of 7750 cubic meters a day. Water purification methods include physical, chemical and biological purification and each method will be used at different stages of the process.

1. Physical purification involves the removal of solids from liquids using filters. Water is forced through a membrane under pressure, leaving impurities behind. Cross flow membrane filtration methods will be used to separate salts and organic matter from the water. The finest membranes will be able to filter particles as small as 0.001 microns (reversed osmosis). That includes most salts, bacteria, viruses, and metal ions.

2. Chemical purification consists of adding chemicals to the water. The chemicals act as biocides or prevent the formation of certain reaction products. Oxidizing agents can be added for disinfection or to neutralize reducing agents and reducing agents should be added to reduce oxidizing agents.

The most common chemical used for disinfection is chlorine. However, it is not a suitable solution for the space station because of its tendency to form toxic chlorine gas or to react to chloramines and chlorinated hydrocarbons. To prevent this, we could add chlorine dioxide (ClO2) to the water, as it is an effective biocide in very low concentrations. It reacts to amino-acids in the cytoplasm and kills the microorganism. The by-product of this reaction is chlorite.

Ultra-violet radiation can be used for disinfection, as well as ozone, iodine or silver. UV radiation treatment should be applied to water being stored in the tanks, since it prevents the division of cells and therefore the multiplication of microorganisms.

3. Biological purification involves the use of microorganisms, mainly bacteria to decompose remaining organic materials dissolved in the water.

4. A very useful method for preventing the water contamination by removing organic constituents and residual disinfectants is the activated carbon filter. This is a favored technique because of its multifunctional nature and the fact that it adds nothing detrimental to the treated water. Another advantage is that this method not only improves taste and minimizes health hazards; it also protects other water treatment units such as reverse osmosis membranes and ion exchange resins from possible damage due to oxidation and organic fouling. There are two principles by which activated carbon removes contaminants from water: absorption and residual disinfectants removed by catalytic reduction.

Water quality will be monitored to ensure against disease. The supply will conform to regulations concerning chemical, inorganic and organic matter concentration. The EPA current drinking water standards (units are milligrams per liter (mg/L) unless otherwise specified):

Microorganisms		
Contaminant	**MCLG (mg/L)**	**MCL or TT (mg/L)**
Cryptosporidium	zero	TT
Giardia lamblia	zero	TT
Heterotrophic plate count	n/a	TT
Legionella	zero	TT
Total coliforms	zero	5.0%
Viruses (enteric)	zero	TT

Disinfection Byproducts		
Contaminant	**MCLG (mg/L)**	**MCL or TT (mg/L)**
Bromate	zero	0.010
Chlorite	0.8	1.0
Haloacetic acids (HAA5)	n/a	0.060
Total trihalometanes (TTHMs)	none ---------- n/a	0.10 ---------- 0.080

Anorganic Chemicals		
Contaminant	**MCLG (mg/L)**	**MCL or TT (mg/L)**
Antimony	0.006	0.006
Arsenic	0	0.010
Asbestos (fiber>10 micrometers)	7 million fibers per liter	7 MFL
Barium	2	2
Beryllium	0.004	0.004
Cadmium	0.005	0.005
Chromium (total)	0.1	0.1
Copper	1.3	TT Action Level=1.3
Cyanide (as free cyanide)	0.2	0.2
Fluoride	4.0	4.0
Lead	zero	TT Action Level=0.015
Mercury (inorganic)	0.002	0.002
Nitrate (measured as Nitrogen)	10	10
Nitrite (measured as Nitrogen)	1	1
Selenium	0.05	0.05
Thallium	0.0005	0.002

Organic Chemicals		
Contaminant	**MCLG (mg/L)**	**MCL or TT (mg/L)**
Acrylamide	zero	TT
Alachlor	zero	0.002
Atrazine	0.003	0.003
Benzene	zero	0.005
Benzo(a)pyrene (PAHs)	zero	0.0002
Carbofuran	0.04	0.04
Carbon tetrachloride	zero	0.005
Chlordane	zero	0.002
Chlorobenzene	0.1	0.1
2,4-D	0.07	0.07
Dalapon	0.2	0.2
1,2-Dibromo-3-chloropropane (DBCP)	zero	0.0002
o-Dichlorobenzene	0.6	0.6
p-Dichlorobenzene	0.075	0.075
1,2-Dichloroethane	zero	0.005
1,1-Dichloroethylene	0.007	0.007
cis-1,2-Dichloroethylene	0.07	0.07
trans-1,2-Dichloroethylene	0.1	0.1
Dichloromethane	zero	0.005
1,2-Dichloropropane	zero	0.005
Di(2-ethylhexyl) adipate	0.4	0.4
Di(2-ethylhexyl) phthalate	zero	0.006
Dinoseb	0.007	0.007
Dioxin (2,3,7,8-TCDD)	zero	0.00000003
Diquat	0.02	0.02
Endothall	0.1	0.1
Endrin	0.002	0.002
Epichlorohydrin	zero	TT9
Ethylbenzene	0.7	0.7
Ethylene dibromide	zero	0.00005
Glyphosate	0.7	0.7
Heptachlor	zero	0.0004
Heptachlor epoxide	zero	0.0002
Hexachlorobenzene	zero	0.001
Hexachlorocyclopentadiene	0.05	0.05
Lindane	0.0002	0.0002
Methoxychlor	0.04	0.04
Oxamyl (Vydate)	0.2	0.2
Polychlorinated biphenyls (PCBs)	zero	0.0005
Pentachlorophenol	zero	0.001
Picloram	0.5	0.5
Simazine	0.004	0.004
Styrene	0.1	0.1
Tetrachloroethylene	zero	0.005
Toluene	1	1
Toxaphene	zero	0.003
2,4,5-TP (Silvex)	0.05	0.05
1,2,4-Trichlorobenzene	0.07	0.07
1,1,1-Trichloroethane	0.20	0.2
1,1,2-Trichloroethane	0.003	0.005
Trichloroethylene	zero	0.005
Vinyl chloride	zero	0.002
Xylenes (total)	10	10

Disinfectants		
Contaminant	MRDLG (mg/L)	MRDL (mg/L)
Chloramines (as Cl2)	4	4.0
Chlorine (as Cl2)	4	4.0
Chlorine dioxide (as ClO2)	0.8	0.8

Radionuclides		
Contaminant	MCLG (mg/L)	MCL or TT (mg/L)
Alpha particles	none ---------- zero	15 picocuries per Liter (pCi/L)
Beta particles and photon emitters	none ---------- zero	4 millirems per year
Radium 226 and Radium 228 (combined)	None ---------- zero	5 pCi/L
Uranium	zero	30 ug/L as of 12/08/03

MCLG = Maximum Contaminant Level Goal (the level of a contaminant below which there is no known or expected risk to health)
MCL = Maximum Contaminant Level (the highest level of a contaminant allowed in drinking water)
MRDLG = Maximum Residual Disinfectant Level (the level of a disinfectant below which there is no known or expected risk to health)
MRDL = Maximum Residual Disinfectant Level (the highest level of a disinfectant allowed in drinking water)
TT = Treatment Technique (the process intended to reduce the level of a contaminant in the water)

Other properties	
Total dissolved solids	500 mg/L
pH	6.5-8.5
Suspended solids	zero

VI.7. Waste management

The Space Settlement will need to contain a self-sufficient and almost completely isolated environment. Few resources will be brought from Earth or the Moon after building is complete. Therefore, the existing resources will have to be used efficiently and losses minimized. Much of the waste resulted from human activity on the station will have to be recycled.

a. Waste collection

Mainly, organic waste will result from agricultural and food processing activities, household activities and excretion. Agricultural waste, consisting mainly of inedible plant parts like roots or foliage will be collected directly from the food processing facilities.
Feces and urine will be collected through toilets similar to those on Earth and will be part of the sewage water, which will be purified.
Household waste will consist of both organic and inorganic matter (food scraps, glass, metal, pa-

per, plastic), and space station inhabitants will be advised to store different types of waste in designated containers, until it is collected and transported to recycling plants.

b. Waste processing and recycling

All types of waste will need to be recycled using specific processes.

A common way of recycling organic waste is composting, the method of breaking down organic materials. The decomposition is done by certain bacteria or fungi, and can turn organic waste into humus, which can be used as fertilizer for plants. The disadvantage of this method is that it is a slow process, taking place in weeks or even months. The process can be speeded up in a controlled environment.

Plant remains contain cellulose and may be used to make paper.

Plastics are also organic materials, but unlike other materials of this type, plastics are not biodegradable. Plastics are polymers, made of a series of repeating units called monomers. The structure and degree of polymerization of a certain polymer determine its physical and chemical properties. Linear and branched polymers are thermoplastic (they soften when heated) while cross-linked polymers are thermosetting (they harden when heated). Thermoplastics are commonly used polymers and include high density polyethylene (HDPE)-used in pipes, bottles and toys, low density polyethylene (LDPE)-used in plastic bags and flexible containers, polyethylene terephthalate (PET)-used in bottles and food packaging, polypropylene (PP)-used in food containers, polystyrene and polyvinyl chloride (PVC)-used in bottles, cable insulation and medical products. Thermosetting polymers are hardened by heating and are difficult to recycle since they cannot be re-melted. Commonly recycled plastics are: both types of polyethylene, polypropylene, polystyrene and polyvinyl chloride. Plastics are often composite materials, making recovery and recycling difficult. Reclaimed plastics will be melted and homogenized and then used to manufacture new products.

Glass will be crushed into small pieces by a mechanical processing system, metals and other impurities will be filtered out using magnets and vacuum systems and the remaining glass will be melted in a furnace operating at about 1400-1600°C (2552-2912°F). Only at these high temperatures can glass be molded into the desired shape.

Recycling paper involves shredding it and mixing it with water and chemical preservatives until it becomes a viscous liquid, which is then passed under a heavy roller (best done in normal gravity conditions) or between two rollers (in low-gravity conditions) that press the fibers together and dry the paper (water is squeezed out by the pressure).

Metals will also need to be melted and re-manufactured. Metals in alloys can be separated by using their different melting points. Powerful magnets can be used for the separation of ferrous from non-ferrous metals.

Melting points of various metals	
Metal	**Melting Point (°Fahrenheit)**
Aluminum	1220
Antimony	1167
Barium	1562
Bismuth	520
Brass	1650
Bronze	1841
Cobalt	2696
Copper	1981
Gold (24K)	1945
Iron	2082
Lead	621
Magnesium	1202
Manganese	2273
Mercury	-38
Nickel	2651
Platinum	3224
Potassium	144
Silicon	2605
Silver	1761
Steel	2500
Tin	450
Titanium	3272
Zinc	787

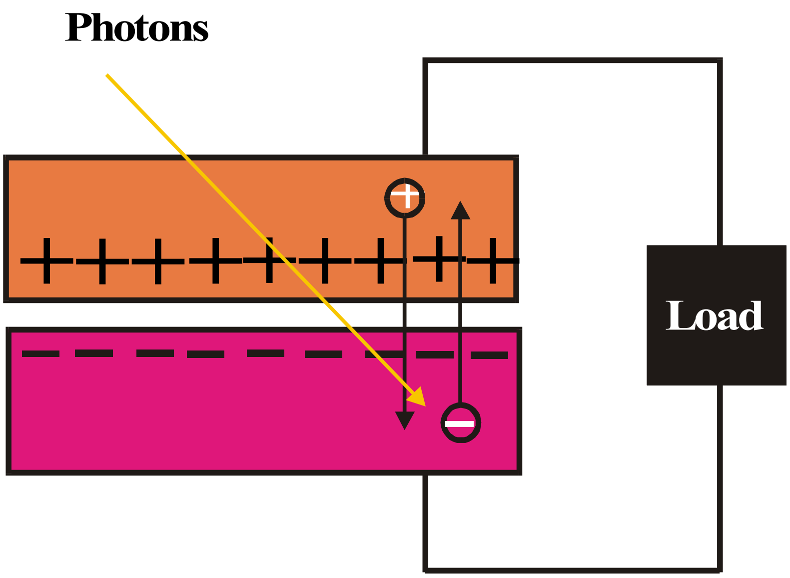
c. Removal of unrecyclable waste

If recycling on the space station is efficient, only small amounts of waste would remain unprocessed (mainly waste that cannot be processed). This material will be exposed to high temperatures in an oxygen-deprived environment (incineration is not a good solution since it consumes large amounts of oxygen). The water evaporated could be collected, condensed and recycled and the ash residue would be released into space.

VI.8. Power

a. Power sources

Electricity will be generated from photovoltaic (PV) systems which produce zero emissions, are modular, and can produce energy anywhere the sun shines. Such systems will be the main source of electric energy on LEDA. Photovoltaic, as the word implies (photo = light, voltaic = electricity), convert sunlight directly into electricity.



The effect of the electric field in a PV cell

Photovoltaic (**PV**) cells are made of special materials called **semiconductors** such as silicon, which is currently the most commonly used. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely. PV cells also all have one or more electric fields that act to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off to use externally. This current, together with the cell's voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce.

Silicon has some special chemical properties, especially in its crystalline form. An atom of silicon has 14 electrons, arranged in three different shells. The first two shells, those closest to the center, are completely full. The outer shell, is having only four electrons. A silicon atom will always look for ways to fill up its last shell. Pure silicon is a poor conductor of electricity because none of its electrons are free to move about, as electrons are in good conductors such as copper. Instead, the electrons are all locked in the crystalline structure. The silicon in a solar cell is modified slightly so that it will work as a solar cell.

We will use silicon with impurities. These impurities are actually put there on purpose.

When energy is added to pure silicon, for example in the form of heat, it can cause a few electrons to break free of their bonds and leave their atoms. An empty space is left behind in each case. These electrons then wander randomly around the crystalline lattice looking for another space to fall into. These electrons are the electrical current. The process of adding impurities on purpose is called doping, and when doped with phosphorous, the resulting silicon is called N-type ("n" for negative) because of the prevalence of free electrons. N-type doped silicon is a much better conductor than pure silicon is.

Actually, only part of our cell is N-type. The other part is doped with boron, which has only three electrons in its outer shell instead of four, to become P-type silicon. Instead of having free electrons, P-type silicon ("p" for positive) has free holes. Holes really are just the absence of electrons, so they carry the opposite (positive) charge. They move around just like electrons do.

Before now, our silicon was all electrically neutral. Our extra electrons were balanced out by the extra protons in the phosphorous. Our missing electrons (holes) were balanced out by the missing protons in the boron. When the holes and electrons mix at the junction between N-type and P-type silicon, that neutrality is disrupted. Right at the junction, they do mix and form a barrier, making it harder and harder for electrons on the N side to cross to the P side. Eventually, equilibrium is reached, and we have an electric field separating the two sides.

This electric field acts as a diode, allowing (and even pushing) electrons to flow from the P side to the N side, but not the other way around. It's like a hill — electrons can easily go down the hill (to the N side), but can't climb it (to the P side).

So we've got an electric field acting as a diode in which electrons can only move in one direction. When photons hit the solar cell, its energy frees electron-hole pairs. Each photon with enough energy will normally free exactly one electron, and result in a free hole as well. If this happens close enough to the electric field, or if free electron and free hole happen to wander into its range of influence, the field will send the electron to the N side and the hole to the P side. This causes further disruption of electrical neutrality, and if we provide an external current path, electrons will flow through the path to their original side (the P side) to unite with holes that the electric field sent there, doing work for us along the way. The electron flow provides the **current**, and the cell's electric field causes a **voltage**. With both current and voltage, we have **power**, which is the product of the two.

There are many types of semiconductors which can be used for Photovoltaic Cells.

Gallium arsenide (GaAs) is a compound semiconductor: a mixture of two elements, gallium (Ga) and arsenic (As).Gallium arsenide's use in solar cells has been developing synergistically with its use in light-emitting diodes, lasers, and other optoelectronic devices. GaAs is especially suitable for use in multijunction and high-efficiency solar cells for several reasons:

1. The GaAs band gap is 1.43 eV, nearly ideal for single-junction solar cells.
2. GaAs has an absorptivity so high it requires a cell only a few microns thick to absorb sunlight. (Crystalline silicon requires a layer 100 microns or more in thickness.)
3. Unlike silicon cells, GaAs cells are relatively insensitive to heat. (Cell temperatures can often be quite high, especially in concentrator applications.)
4. Alloys made from GaAs using aluminum, phosphorus, antimony, or indium have characteristics complementary to those of gallium arsenide, allowing great flexibility in cell design.
5. GaAs is very resistant to radiation damage. This, along with its high efficiency, makes GaAs very desirable for space applications.

One of the greatest advantages of gallium arsenide and its alloys as PV cell materials is the wide range of design options possible. A cell with a GaAs base can have several layers of slightly different compositions that allow a cell designer to precisely control the generation and collection of electrons and holes. (To accomplish the same thing, silicon cells have been limited to variations in the level of doping.) This degree of control allows cell designers to push efficiencies closer and closer to theoretical levels. For example, one of the most common GaAs cell structures uses a very thin window layer of aluminium gallium arsenide. This thin layer allows electrons and holes to be created close to the electric field at the junction.

The greatest barrier to the success of GaAs cells has been the high cost of a single-crystal GaAs substrate. For this reason, GaAs cells are used primarily in concentrator systems, where the typical concentrator cell is about 0.25 cm^2 in area and can produce ample power under high concentrations. In this configuration, the cost is low enough to make GaAs cells competitive, assuming that module efficiencies can reach between 25% and 30%. Researchers are also exploring approaches to lowering the cost of GaAs devices, such as fabricating GaAs cells on cheaper substrates; growing GaAs cells on a removable, reusable GaAs substrate; and even making GaAs thin films similar to those of copper indium diselenide and cadmium telluride. High-efficiency solar cells based on gallium arsenide (GaAs) and related “III-V” materials have historically been used in space applications. Devices are also being investigated using low-cost substrates (such as glass). The long-term objective for researchers is to establish III-V materials as a competitive terrestrial PV technology by developing the materials science, advancing related science and engineering, coordinating relationships with industry and university partners, and facilitating commercialization.

Gallium arsenide	
Name	Gallium arsenide
Chemical Formula	GaAs
Melting point at SP	1513 K
Electron mobility at 300 K	0.92 $m^2/V\cdot s$
Hole mobility at 300 K	0.04 $m^2/V\cdot s$
Efficiency	25% - 30%

Another type of Photovoltaic Cells can be made of materials like Copper Indium Diselenide ($CuInSe_2$ or CIS).

The current world record thin-film solar cell efficiency of 17.7% is held by a device based on copper indium diselenide.

Materials like Cadmium Telluride (CdTe) can be also used as a basic material for Photovoltaics Cells.

An alternative can be sending microwaves from a satellite equipped with Photovoltaic Cells to the Space Settlement which will transform them back intro electric power. Another possibility of generating energy can be the ^3He Fusion knowing that from 1 kg of ^3He we can get 10 MW of electrical energy. Also, like a future alternative we can convert plasma energy intro electrical energy at high efficiency.

Another source of electric energy and stability for LEDA would be having many electromagnetic coils with big mass(for big inertia force) on the exterior part of the torus. Many magnetic cores, also located on the exterior of the Space Settlement, will oscillate inside the electromagnetic coils. Therefore the torus vibration will produce electric power. Still this process is very difficult to achieve because the permanent magnets must be changed after a period of time.

Studying all the alternatives, we find out that the most adequate source of electric energy will be the Photo Voltaic Cells made of Gallium Arsenide because they have the highest efficiency and the highest melting point.

b. Power generation

$$E_o \approx 1380 \frac{W}{m^2}$$

S_{rlipse} - the elliptical surface of the light flux

R_{mirror} - the radius of the mirror

$S_{elipse} = \Pi \cdot a \cdot b$ [1]

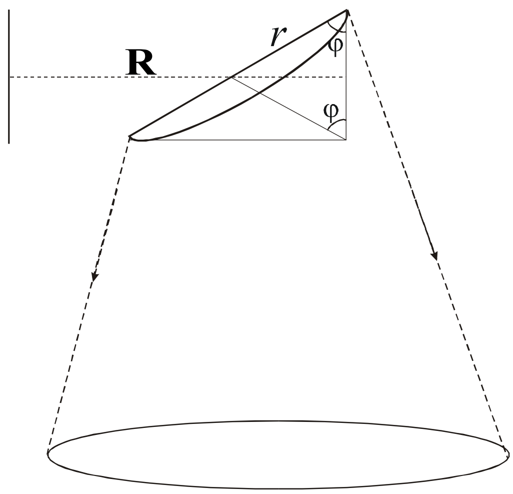
$b = R_{mirror} \cdot \sin\varphi$ [2]

From [1] and [2] $\Rightarrow S_{elipse} = \Pi \cdot R_{mirror}{}^{2} \cdot \sin\varphi$

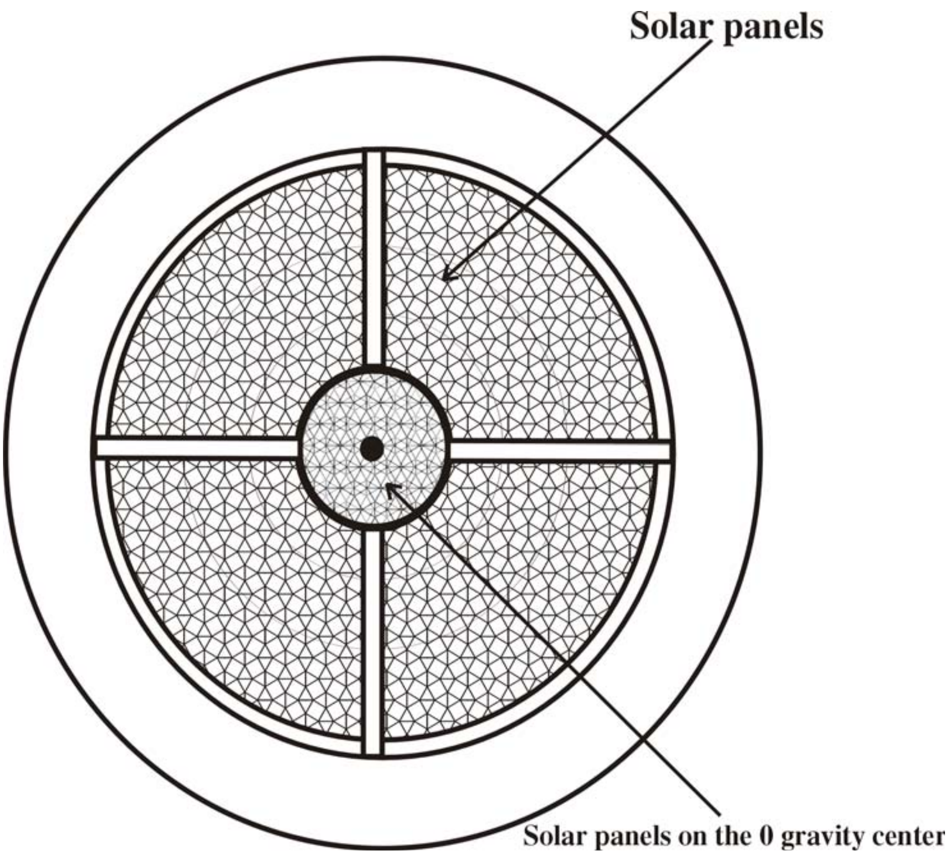
$$E = \frac{\phi}{S_{elipse}} \Rightarrow \phi = E_0 \cdot \Pi \cdot R_{mirror}{}^{2} \cdot \sin\varphi$$

$$\phi = E_s \cdot \Pi \cdot R^2$$

$$E_s = \frac{E_0 \cdot R_{mirror}{}^{2} \cdot \sin\varphi}{R} \approx \frac{E_0}{8} \approx 172 \frac{W}{m^2}$$



The total are of solar panels will be approximately 77 000 000 m^2 which means an amount of 2664 MW of electric energy. This energy is enough for the colonist's needs and the Space Settlement's industry. A very important economic fact is that we can also send energy with microwave technology to Earth or another Space Settlement with defect solar panels.



Distribution of the solar panels

c. Power distribution

The power will be distributed for each user via copper cables , inside the Space Settlement and for bigger distances the cables will be on the outside, and will be superconductors..

Superconductors are substances that permit electrons to flow freely, with no resistance. Because energy is not wasted through electron flow, these substances would be useful tools in industry.

Conventional superconductors are generally pure compounds, while those that operate in higher temperature ranges are generally made up of a series of complex layers.

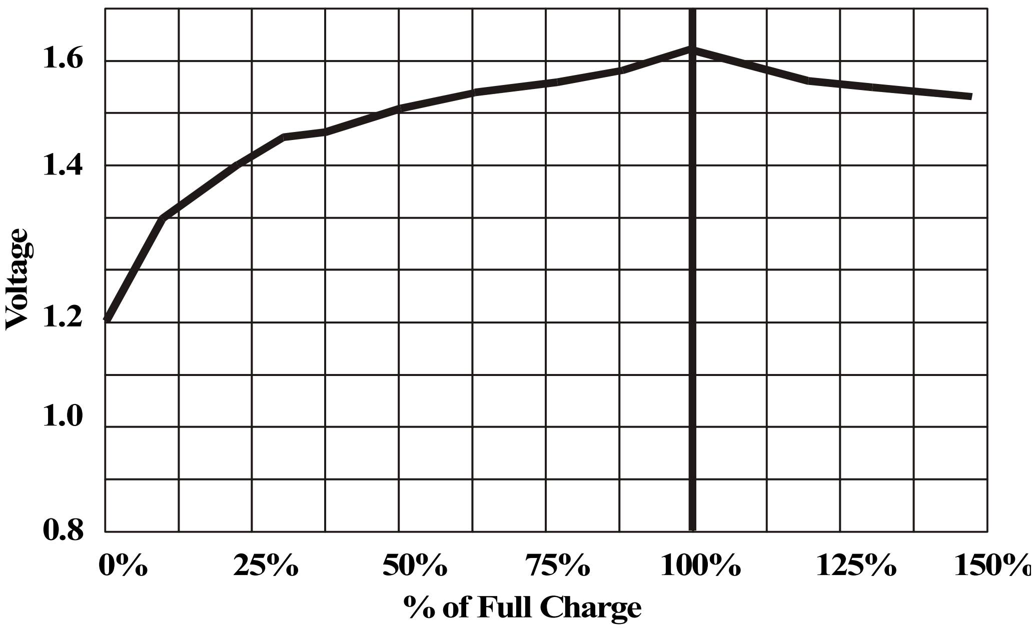
We must make a structure made up of strontium, calcium, copper, bismuth, and oxygen. The system is composed of two layers of bismuth oxide and one layer of strontium oxide, followed by two layers of copper oxide. The copper oxide layers have calcium molecules in between them.

Copper oxide layers provide the bulk of superconductivity. Scientists theorize that copper electron pairs, which cause the materials to superconduct, are far apart from each other in conventional superconductors are often separated by thousands of atoms. In high-temperature superconductors, scientists believe that the copper pairs are adjacent making the flow of electrons from one atom to another much more significant.

d. Power storage and electrical line maintenance

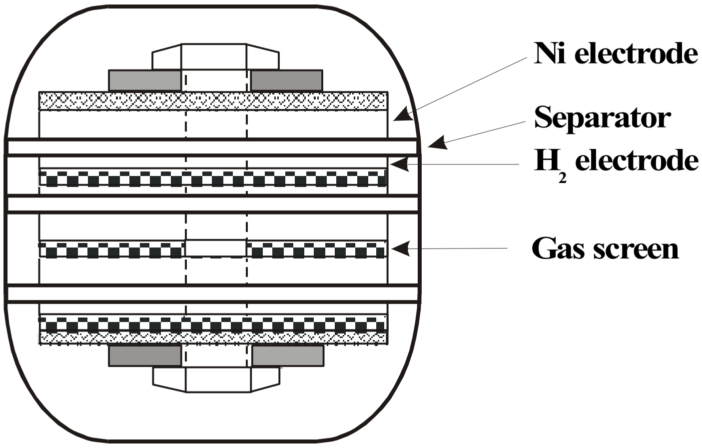
It is difficult to use the power generated by solar power sources directly, so the electricity is usually stored in special batteries for use when it is needed.

The nickel-cadmium battery has been the common energy storage companion for solar cells on satellites. Specific energy densities (energy per unit mass) of 10 Whr/kg are common at the 10- to 20-percent depths of discharge used to provide cycle life. As a rule, the energy storage subsystem is the heaviest and largest part of a solar power system. This need poses additional system constraints as power system voltage increases to the 100-kilowatt level and beyond.



NiCd batteries are sensitive to overcharge; hence each cell must be carefully controlled

Individual pressure vessel (IPV) nickel-hydrogen battery systems are being developed to provide increased energy densities .



There will be two high-capacity energy storage systems under consideration for the space station. These are the hydrogen-oxygen regenerative fuel cell (RFC) and the bipolar nickel-hydrogen battery.

Thus, when energy densities of 1000 Whr/kg are combined with lightweight solar arrays and high voltage power management systems, the overall system promises specific powers near 500 W/kg. It should be noted, however, that the mass of a 1000Whr/kg storage system to provide 100 kW of power during lunar night would be roughly 33 600 kg.

The bipolar NiH_2 technology marries battery and fuel cell technologies to the benefit of both. Chief advantages are substantially increased cycle life over IPV NiH_2, easy high-voltage battery design by adding more plates, and extremely high discharge capability (20 times charging rate). Bipolar NiH_2 systems appear equivalent in mass to state-of-the-art regenerative fuel cells at 100-kW capacities

Another important aspect concerning the power supplying of LEDA is the maintenace of the electrical lines. First of all, cables will not be visible. They will be situated under the false "ground" of the residential area so that the electrocutation risk will be avoided. The earthing element will be the titanium body of LEDA. Every home or enterprise consumer will be provided with electronic plug fuses to avoid short circuited lines. A team of engineers and workers will permanently supervise the good randament of the electrical line.

VI.9. Risk factors

a. Fire prevention, detection and suppression

Uncontrolled fire will be especially dangerous on the Space Settlement, because it consumes oxygen rapidly, and in the enclosed areas of the settlement, inhabitants face the threats of suffocation and burning. First of all, the possibility of a fire should be reduced to a minimum. Uninflammable materials should be used for construction and interior arrangement. Flammable substances will be avoided in household objects and textiles should be treated in order to become fire resistant. Flammable or explosive substances will be stored in isolated storage areas.

In the event of a fire, early detection and suppression is crucial. Efficient fire detection involves the presence of fire detectors and alarms, which will be placed throughout the space station. Different types of fire detectors include heat detectors, smoke detectors, gas-sensing fire detectors and flame detectors.

Heat detectors are inexpensive and have a low false-alarm rate. However, they have a slow response and should be used in conjunction with other types of fire detectors. Fixed temperature heat detectors operate on a simple principle, using metals that will expand or melt when the temperature rises. In a bimetallic detector, two metals with different expansion rates are joined together to form a strip. When the temperature rises, one of the metals expands more rapidly, causing the strip to bend and close a circuit, activating the alarm. The triggering temperature is determined by the types of metals used, so fixed temperature heat detectors are available in a variety of temperature ranges and can be installed in different parts of the station. Rate of rise detectors are based on the fact that air is heated more rapidly in a fire and are triggered when the rate at which the temperature increases exceeds a predetermined value. They consist of a small air-filled chamber, a diaphragm and a small vent. If the temperature rises at a high rate, the air expands too quickly to escape out the vent, causing and increase in pressure that will trigger the alarm.

Smoke detectors are designed to respond faster than heat detectors, but have a higher false-alarm rate. Their use is unadvisable in areas where there is normally a high concentration of particles in the air. Ionization smoke detectors contain a small amount of americium, a radioactive material capable of ionizing the air around it and an ionization chamber, two metal plates with a small distance between them. The alarm is triggered when smoke particles disrupt the current between the two plates. Photoelectric smoke detectors use a T-shaped chamber, with a light-emitting diode (LED) and a photocell. The LED emits light across the horizontal bar of the chamber, while the photocell sits at the bottom. Smoke particles that enter the chamber reflect some of the light to the photocell, which in turn generates the electric current that powers the alarm. Photoelectric detectors are faster than ionization detectors, but should only be placed in areas where there is little ambient pollution like dust or steam or where there is increased danger of a smoldering fire.
Gas-sensing detectors fall into two categories: semiconductor gas detectors, which use semiconductors whose conductivities are affected by oxidizing and reducing gasses, and catalytic element detectors, which use catalysts to increase the oxidation rate of combustible gasses, causing the temperature to rise and the detector then functions like a heat detector. These detectors sense gasses produced by fires.

Flame detectors are sensitive to light energy emitted by fires and have a very fast response. They can detect visible, ultraviolet and infrared light and precautions must be taken not to obstruct their view.

Depending on the type of fuel, fires are also divided into categories. Class A fires are fires in ordinary combustible materials such as wood, paper and canvas. Class B are fires in substances like gasoline, fuel oil, diesel oil and lubricating paints. Class C fires involve electrical equipment and class D fires are fires in metals like zinc, powdered aluminum, magnesium, zirconium, potassium, sodium or titanium.

The substances best suited for extinguishing fires on the Space Settlement are water and carbon dioxide (CO_2), since they both have the advantage of leaving no contaminants and they can be retrieved after being used.

CO_2 is effective against all types of fire (except class A fires) and extinguishes a fire by suffocating it. It can be stored in liquid state at normal temperatures and under high pressure (800-1200 psi) and passes to gas state after it is released because of the difference in pressure. This process is endothermic, that is, it cools the environment. The gas is non-toxic, but is dangerous in high concentrations as it can cause suffocation. Therefore, it will only be used in large quantities after the area has been evacuated. CO_2 can be stored in large pressurized containers between walls in the industry and research areas and released when needed.

Water sprinklers should be placed in the inhabitable area, but only at some distance away from electrical appliances, since water is a good electrical conductor. CO_2 from regular fire extinguishers will be used to put out fires caused by electrical equipment in homes, while water will only be used for class A fires.

Both CO_2 and water extinguishers will be placed in all parts of the space station.

b. External and internal damage prevention and repairing

The only possible cause of external damage to the space station is collision with a foreign body with enough kinetic energy to penetrate the outer hull. Meteoroids pose little damage to us on Earth because most of them burn completely due to friction with the atmosphere. But in space, there is no friction and nothing to slow down and approaching body. The probability of collision of a large meteoroid with the space station is very small, but even a 1 gram meteoroid colliding with the hull would produce a pressure wave dangerous to anyone in the vicinity. Another notable fact is that meteors usually occur in clusters, so when one collision is probable, so are others. One way to avoid collisions would be to equip the station with a powerful radar and rocket engines. The radar would use radio waves to detect any approaching bodies and measure their speed (radio waves have the advantage of traveling fast (at the speed of light) and over long distances; a radar sends out o short burst of high-frequency radio waves and, if the waves are reflected off an object, it measures the time it took for the echo to arrive to determine the distance to the object and the Doppler shift to determine the object's speed relative to the space station), and alert of any possible collisions. Computers will be used to calculate the path and the engines will need to be powerful enough to move the station out of the way (to achieve this, we could place a cluster of engines instead of one). The propulsion engines (or groups of engines) will need to be built into the station at regular intervals to prevent oscillations in motion. Also, because the radar operates with radio waves, the antenna will need to be located in such manner as to avoid interferences caused by the magnetic field. Fuel consumption will be very little, as showers of meteoroids only occur on a time scale of a few hundred years. After the danger has passed, a new path will be calculated to place the station into orbit.

All the equipment inside the settlement will have to conform to safety standards. It will also be subjected to regular maintenance so that potential problems can be discovered and remedied in the early stages.

All repairs on the outside of the station will be done using remote-controlled robotic devices and inside repairs can also be done manually.

c. Dealing with informatical and technical problems

For safety reasons, computers and mainframes controlling the life-support systems on the space station will function in pairs, so if one of the control systems fails, the other one will take over until the necessary repairs are carried out.

In the event of a malfunction in the air ventilation systems, the rest of the ventilators must be able to support the increased load. Water and air supplies must be large enough to support life on the station in times of need.

d. Dealing with health problems and diseases

The space station is an enclosed environment and because of this, an epidemic would rapidly spread and cause considerable damage.

All potential inhabitants of the station will be subjected to thorough medical examinations. Introducing dangerous viruses, like AIDS on the station should be avoided. However, if we create an entirely sterile environment, even a less serious disease would wreak havoc among the colonists. The inhabitants of the station will also be subjected to periodical medical exams, so that any potential disease is discovered in the early stages, when it is easier to cure.

There will be separate clinics for patients with contagious diseases. In case an epidemic breaks out, all the infected crewmembers will be put in quarantine and the areas which have not been infected will be sterilized as a measure of precaution. If the disease is unknown, much of the research on the station will be directed towards identifying and finding a cure for that disease.

CHAPTER VII

Accomodation

VII.1. Basic concerns

a. Climate

An important condition for having an efficient and productive colony is having an adequate climate. Biologist studies have demonstrated that the optimum temperature for good life development is 295 K (~22° C).Higher or lower temperatures would cause colonists poor performance ratings and tiredness. The adequate relative humidity will be between 50 – 70%.

For creating an environment similar with that on Earth, we should also create artificial rain. The apparatus for generating artificial rain must consist in 2 structural parts. The first part is the spraying tube located on the “ceiling” of LEDA. The second structural part is the water tank which will supply water under pressure as the water collects on the pointed teeth; it eventually falls off in droplet form when the volume and weight of the water overcomes its surface tension. A control system will regulate water pressure in the apparatus during use conditions. When the apparatus is deactivated, water is recycled in the tank while maintaining a balanced head pressure in the apparatus so that activation and deactivation takes only a few seconds.

Another important aspect is creating wind and controlling its speed. This can be done using both natural and artificial methods. Building parks with ornamental trees will scatter the soft breezes, while artificially centralizing the thermostats onboard the settlement at the same temperature and locking the temperature differences at constant values will generate air currents.

b. Illumination

NASA standards advise that “bright and uniform” wide-spectrum light should be employed in work areas. At night we must use warm white light; this would also serve in helping the average human’s association of “warm” light with pleasant activities. Natural lighting via the windows could serve the purpose of wide spectrum light. The house windows are important for orienting the colonists to their external environments. We must also take special care not creating large light contrasts which will affect the colonist’s sight. We must also program the automatic mirrors for 14-hour days and 10-hour nights.

For increasing the photosynthesis rate and efficiently using electric power, fluorescent tubes situated under the habitable area will generate artificial red light, most of it being used in the raising of crops. We can also use light-emitting devices (LEDs) which can be obtained with the use of polymerization. This type of structured polymer can produce light patterns with sizes as small 0.8 ìm. A film of a precursor to p-phenilen vinylene(PPV) is micromolded (in a solvent), in order to make variations in the thickness of the created film, and as such, to copy the relief on the mold. The thermal shaping of this precursor created a PPv with the same surface topography. The light emitting devices created in this process emit light preponderantly in the thin parts of the film. These types of devices can also be used in near field optics (being able to lead to new subwave length light sources).

The duration of days and nights in the agricultural areas will accord to the different plant metabolisms, so that growth and production will reach optimum efficiency; the plants will experience longer periods of light to intensify growth and maintaining their health.

c. Interior layout

The equilibrated psychology of the colonists is very important thus we must satisfy their vital psychological needs. We must take into account the minimum comfortable space needed for living, the diversity and the variability of an ideal environment suitable for human activities. We need to keep a symmetrical arrangement of the houses in the torus, thus people can not personalize their houses. An interesting solution would be painting the house's facades with 3D stereograms which can create the illusion of any form of architecture.

d. Vibration

Vibration can be a very disturbing and unhealthy factor for those living onboard LEDA. It can affect both the psychological and physical integrity of colonists. Therefore we must minimize the amount of vibrations by isolating their sources. Locating the industrial zone in the central body of the torus will partially resolve the vibration problem. Anyway building parks within the residential ring will reduce the amount of vibrations reaching the inhabited areas.

e. Noise

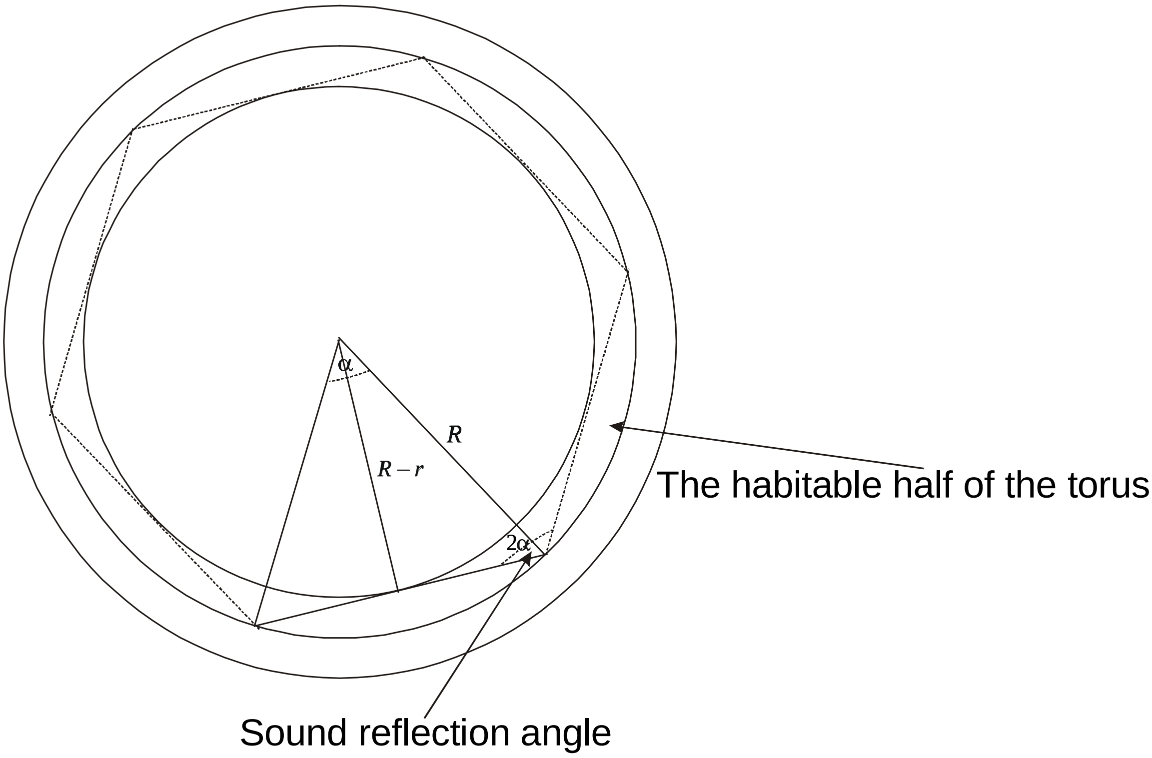
In any acoustical environment, such as the LEDA, the impact of outside noise and vibration sources (traffic, subways, industry etc.) and of in-house noise and vibration sources has to be carefully analyzed and then minimized for comfort and privacy reasons. Therefore, creating noises higher than 70db will be prohibited to those living onboard the colony. Still there are multiple other sources of noise which must not disturb colonists. Environmental noise will not only consist of building vibrations, but also of different sounds. Sources of sound may be the industrial areas, the transportation system, the livestock growing facilities, the crowded places onboard the settlement, the docking facilities, just to name a few. Taking into account the toroidal shape of the Settlement, we can determine how sounds will reflect inside the residential half of the torus by calculating the reflection angulations.

$$\cos\frac{\alpha}{2} = \frac{R-r}{R} = \frac{3511}{4011} = 0.875$$

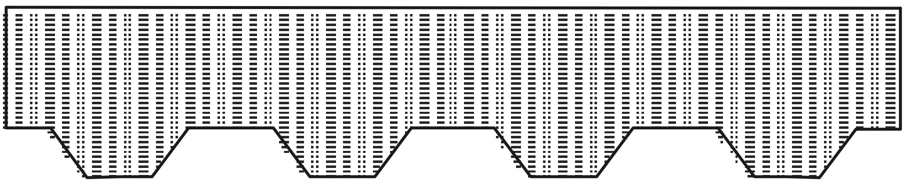
$$\frac{\alpha}{2} = \arccos(0.875) \cong 29^o$$

$\alpha = 58^o \approx 60^o$

$2\alpha \approx 120^o$ - the sound reflection angle inside the torus



Melamine and Polyurethane Acoustic foams will help to absorb sound in nearly every setting inside residential or industrial areas, including education institutions, offices, industrial environments, apartments and more. Their characteristic shape allows an efficient noise isolation which could be improved by placing them in the right places and respecting several sound isolation norms. The picture below shows the shape of the Acoustic foam walls:



The shape of the noise reducing foam panels

Metal coatings could also be used in the same purpose; in addition they will act as an electrical shield, protecting the sensitive electronic circuits inside the torus from electronic noise.

Another efficient way of reducing sounds is using vacuum based isolation systems inside the walls of the different noise-generating buildings.

Low intensity noises will be absorbed by the ornamental trees located in parks especially created for this purpose.

f. Odor

Unpleasant odors will be absorbed by special air filters which will liquefy and send them through the same process water does for recycling. Another method of purifying the air and removing odors, as well as killing viruses, is using ozone generators and Ion Generators which simply negatively charge the air's ions so that floating dust particles will cling to outer surfaces. The artificial rain has also a very important role removing unpleasant odors.

g. Hygiene

The colonists must maintain their body hygiene without using a large amount of water. They will have showers and toilets very similar to those on Earth.

Different types of detergent will also be produced in the chemical compound on board of settlement.

Detergents are substances that are added to water to clean different solid materials.

The act in three different ways:

1. Through the reduction of the surface tension of the aqueous solution, so that it can spread uniformely, instead of forming drops.
2. By facilitating the dissolution of fat molecules in water
3. By maintaining the filth molecules from the objects to be washed , in suspension, in water

The detergent molecule is a large molecules formed by a hydrocarbonated chain with a functional group at one of the molecule's ends (this is a polar end). The non-polar chain is hydrophobic (rejected by water), and the polar end id hydrophil (attracted by water). In water, these molecules group together to form a mycelium.

The mycelium is a spherical group of detergent molecules in water. Oils and fats are dissolved in the hydrophobic center of the mycelium. Myceliums keep the fat formation in suspension in water.

Soap is one type of detergent, which consist of the sodium salt of a long-chained carboxylic acid (such as octadecanoic acid $C_{18}H_{18}O_2$). This will be obtained from the reaction of animal fat, or vegetable oil (esters) with strong alkali hydroxides (NaOH , KOH).The soap made with KOH is softer than that made with NaOH. The process of fabrication of soap is called saponification. Soap molecules form myceliums in water. Soap makes foam in water with an abnormal durity.

Measured quantities of fats or vegetable oils will be introduced along with sodium hydroxide or potassium hydroxide in a columnar structure with high temperature and pressure. Soap is formed and glycerin (1, 2, 3-trihidroxy propane). The formed mixture shall dissolve in salt water. The final part of the saponification process is called adjustment. Any long hydro carbonated chain that didn't react at first is neutralized with alkaline solutions and the salt concentration is then adjusted. The mix is then centrifuged to separate the soap from the remaining solution.

$$\begin{array}{llll} C_{17}H_{35}COOCH_2 & & & CH_2\text{-}OH \\ \quad\quad | & & & \;| \\ C_{17}H_{35}COOCH & + 3\,NaOH \underset{\text{saponification}}{======>} & 3C_{17}H_{35}COONa^{+} \;+ & CH\text{- }OH \\ \quad\quad | & & & \;| \\ C_{17}H_{35}COOCH_2 & & & CH_2\text{-}OH \\ \text{Ester} & & \text{Soap (sodium stearate)} & \end{array}$$

All soap molecules are potassium or sodium salts with long chains of carboxylic acids acid. In this example the soap is a salt of the octadecanoic acid (stearic acid).

h. Food

At least 3000 kilocalories per person should be available in different food types. Food will be grown in a controlled environment.

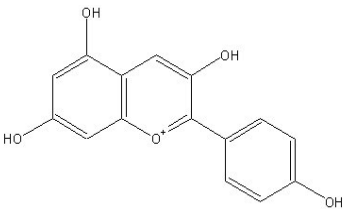
Meat, wheat, rice, potato, soybean, lettuce, sweet potato, tomato must not lack from the colonist's meals.

i. Decors, surfaces and colors

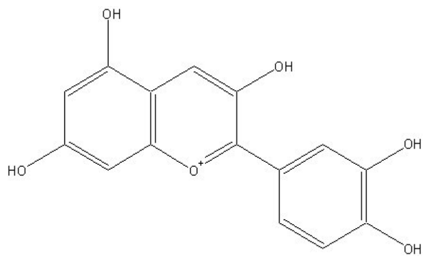
Psychologists say that decors and room colors are very important thus we must create perfect psychological conditions on the Space Settlement. We must color the “sky glass “with a pale blue to imitate the effect of blue sky. We must also color the interior titanium walls of the torus in blue to create the illusion of horizon. Houses must be painted in light colors. The different colorants used in the painting or coloring processes onboard LEDA must not be toxic and need to be durable. Some of them are largely discussed below:

Antocyans and Antocyanides

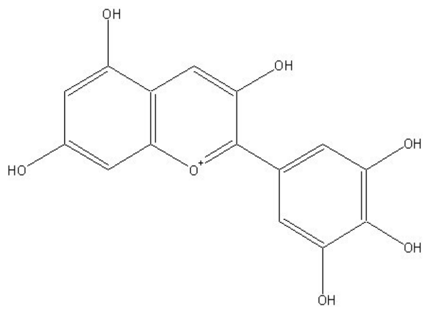
Pelargonidine



Cyanidine



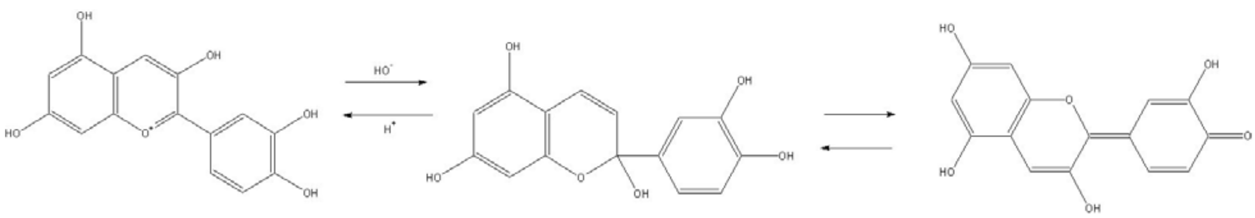
Dolphynidine



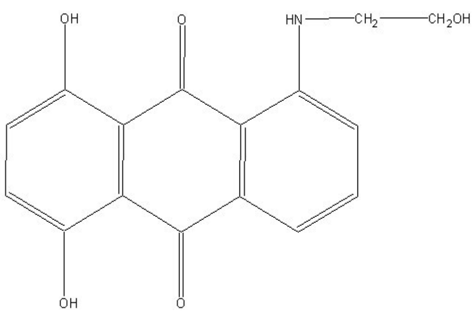
Their salts are red.

- in neutral solution (pH~7) → purple
- pH>7 → colorless formation
- strongly basic solution → blue

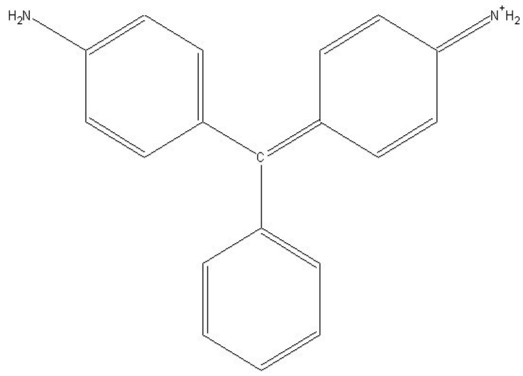
Kinomethanic Colorants



Celeton B (blue-green)



Fucsimonium- orange and not intense



Colorless compounds will be obtained from the reduction of their salts.

The color of the colored cathions (and colorants) appears thanks to the extended conjugated system determined by the participation of auxocromic groups (free base – electron donor; cathion – electron acceptor), which amplifies the intensity of the conjugation (delocalization of the p and ð electrons), and which stabilizes the system.

j. Pests

Pests commonly are the carriers of deadly disease and cause great discomfort, being also associated with low standards of living. Common pests of home, people, and pets found on earth include ants, bed bugs, bees and wasps, recluse spiders, carpenter bees, carpet beetles, cliff swallows, clothes moths, cockroaches, fleas, house flies, house mice, mosquitoes, pantry pests.

All colonists and eventually immigrants will be screened for pests, and active control will be undertaken. In spite of this, the possibility of pests and pest eggs reaching the LEDA still exists. The most common form of pest control, pesticides, would be hazardous to be used onboard, but in a limit situation we can move all the colonists in the 0 gravity center for a short amount of time for completely pest removing.

VII.2. Long time aspects

a. Space Settlement Political System and interior order

One of the major concerns about long-term living inside the orbital colony is setting up a political system able to support all kind of needs and demands from the human community inhabiting the space settlement. The development of the orbital society strictly depends on the stability and efficiency of the political system coordinating all other aspects of life in the settlement. That is why we must choose a political system which has proven to be most appropriate for human demands here on Earth. In this case, democracy would be the only suitable solution for our long time colony, as its doctrine combines the notion of free will with that of law and citizenship obligations.

The state form that we have chosen is a democracy, led by an elected council, with five representatives from each of the seven sectors of the station. The council will be elected by the inhabitants of the station and the president will be elected by the members of the council. Each member of the council will have to take part in maintaining the internal order and safety. To do so, the council will have to be divided into small groups of two or three and each group will be assigned with a matter of the “state”. The committees formed in this way will be: Power, Industry, External Affairs, Internal Affairs, Security, Life Support, Health Department, Agriculture, Research, Transports, Education and Economic Department.

The success of democracy is largely measured by the public’s participation in the process and responsiveness of the system to popular demands. Democracy is a government of the people; therefore it must be established by the people. That is why we must very carefully take into account the concept of citizenship. Citizenship is a status bestowed on all those who are full members of a community. All who will possess the status of citizen of the space settlement will be equal with respect to the rights and duties with which the status is endowed. That is why citizenship will require a direct sense of community membership based on loyalty to a civilization which is a common possession.

The protection of the political and personal rights of the citizens onboard the orbital colony, including those in the minority, will surely depend upon the constitutionalism and civil society. All the political system will be institutionalized under the rule of law. This will lead to an autonomous civil society, whose individuals will join together voluntarily into groups with self-designed purposes to collaborate with each other through mechanism of political parties and establish through freely contested elections a system of representative government.

LEDA will have a set of rules with the purpose of maintaining internal order, preserving human rights and preventing crime. The law will be enforced by specially trained personnel.

As a well-developed civil society is an exact indicator of democratic government, we must ensure the four aspects which make the orbital civil society functional. They are listed in the table below:

Political/legal dimension	**Social dimension**
Political citizenship refers to political rights and duties vis a vis the political system.	**Social citizenship** refers to the relations between individuals in a society, and demands loyalty and solidarity.
Cultural dimension	**Economic dimension**
Cultural citizenship refers to consciousness of a common cultural heritage.	**Economic citizenship** refers to the relation of an individual towards the labor- and consumer market and implies right to work and to a minimum subsistence level.

The cultural dimension of citizenship will be achieved through information technology, mass media, different intercultural experiences, combating racism and discrimination, the preservation of the environment and the predominance of certain norms and values. The social dimension will be assured by combating social isolation and social exclusion, by safeguarding human rights, bringing together different groups of society, working for equality of the sexes, for personal and general security. As for the economic dimension, it must be sustained by the different aspects of market economy, by assuring a certain rate of employment, by integrating groups into the economic process, by emphasizing the principles of labor legislation and consumer rights.

A series of social studies must be conducted on the orbital settlement, for permanently monitoring the different demands of colonists and assuring certain commodities in various aspects of life.

1. Socialization and education	gives insight in socialization processes, the role of the mass media
2. Environment, living and social relations	primary groups, gender relations, ways of living together, environmental problems
3. Work and leisure	social and economic issues
4. Technology and society	technological and scientific developments as a factor in society
5. Political structures and processes	the political system, political decision-making, political ideologies, the juridical system, criminality
6. International relations	global political, social and economic interdependencies

Themes for Social Studies have to be chosen out of six fields:
Migration aspects are of outmost importance. We are considering the fact that part of the young population will desire to leave the station due to more than one reason. Immigration of workforce will have to be strictly controlled, by subjecting the contestants to tests and examinations. The two aspects above will have to be balanced and controlled so that the population on the space station doesn't exceed the maximum capacity.

A suitable infrastructure must complement the social aspect of living inside the space settlement, promoting the citizenship education and increasing the quality of democracy. That is why publishers will have to produce adequate teaching materials and specialized magazines for students, committees will have to evaluate and assess the educational process and institutions for civic education will produce activities, services and will offer advice on citizen participation.

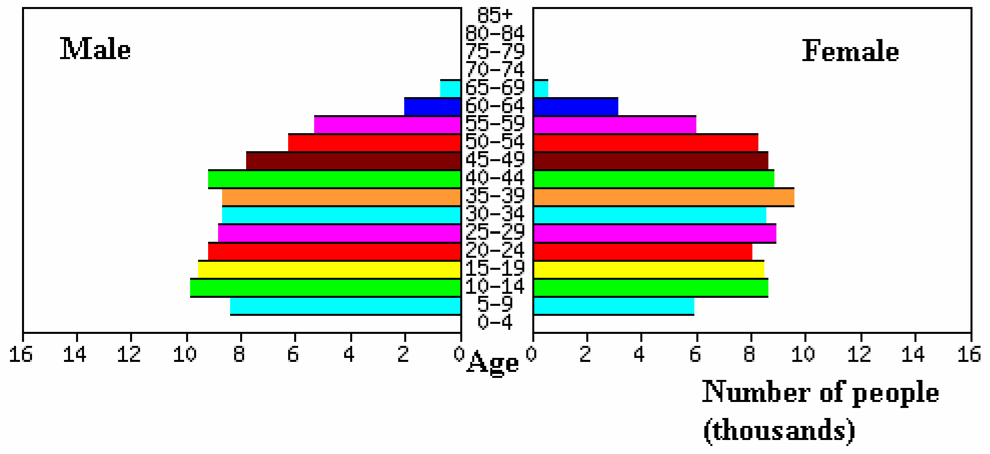
Sometimes it would be appropriate to give attention to historical and global aspects, so that pupils onboard the colony will learn how to study and analyze other social and political problems.

b. Monetary system

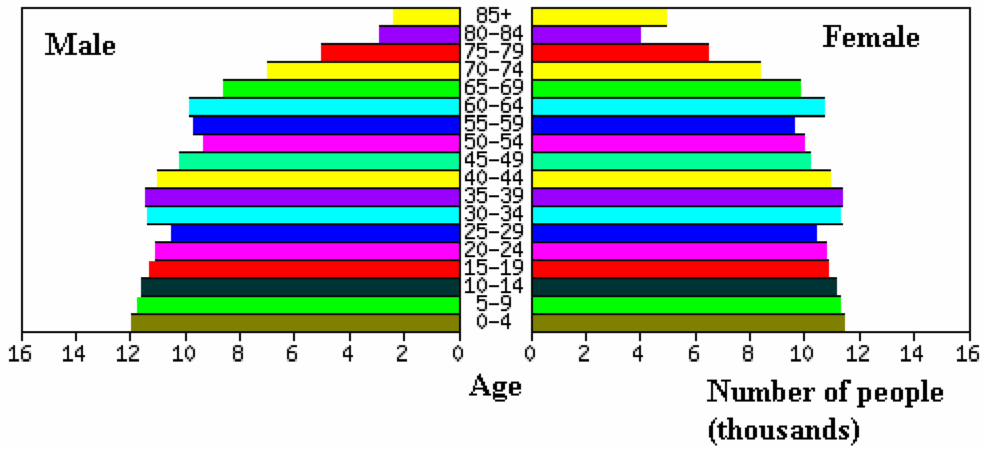
The main sources of income for the space settlement will be space tourism and ore smelting and refining. The income from these activities will be used to finance research and to pay salaries. Processing ore in 0 gravity conditions is cheaper and the resulting metal has a high purity and can be exported to Earth.
There will be a special currency for the space station (space dollar). All employed crew members will have an account in a database and will receive payments on credit cards. The money on these credit cards would be exchangeable in any currency on Earth, in case a colonist decides to leave the space station.

c. Crew composition and employment

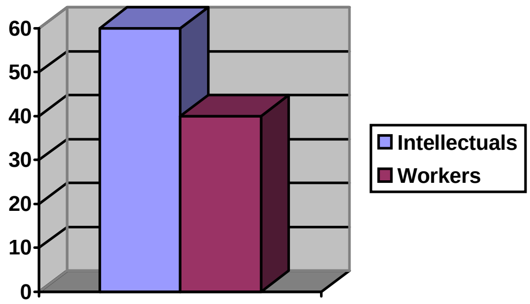
A very important aspect of LEDA is its crew composition. We can not afford the risk of transporting colonists under 5 years old or up to 70 because of the risk of not supporting the launching



The graphic above shows the initial population transported from Earth



In a period of approximately 20 years we estimate a spectacular population growth



Considering the high level of civilization and the main interest in research, we must select a proportional work force

Occupation	Percentage	Qualifications
Agronomists	2%	Medium/High
Auxiliary Medical Personnel	1%	Medium
Auxiliary Scientific Personnel	6%	Medium
Biologists	2%	High
Chemists	2%	High
Communications	2%	Medium/High
Computer Operators	4%	High
Diplomats	0.5%	High
Electricians	1.5%	Medium/High
Food Production	1%	Medium/High
Law Enforcement Personnel	1%	Medium/High
Metallurgists	1.5%	Medium/High

Physicians	1%	High
Physicists	2%	High
Plumbers	1%	Low/Medium
Psychologists	0.5%	High
Teachers	10%	High
Technicians	10%	High
Waste Disposal Personnel	3%	Low

With these characteristics of the population the space settlement will have a spectacular intellectual, industrial and financial evolution.

The rest of 48% of population is considered non-working population, formed by children and elders.

d. Health care

Health care is a very important aspect on the space station, as in any community. Therefore, some of the income will be directed toward health insurance for the colonists and funding hospitals. There will be one large hospital on the station, with departments covering all aspects of health care, and several clinics in each of the sectors. The amount of medical personnel on the station will be approximately 1% (one doctor for every 100 people).

The doctors onboard LEDA must examine the effectiveness of a great variety of health care interventions. The health care must be concentrated on the preventive area and on the research one. Health exams, tests and immunizations are vital to preventive care. We must make information about health and disease accessible and also the doctors must offer advice about health or healthcare and cannot substitute for a healthcare practitioner.

e. Education

The importance of education onboard LEDA is quite clear, as education represents the knowledge of putting one's potentials to maximum use. It makes man a right thinker and teaches him how to take the right decisions. Only through the attainment of education, man is enabled to receive information from the external world and to acquaint himself with past history, receiving in the same time all necessary information regarding the present. The school system will have a crucial role to play in both raising expectations of pupils qualified to enter institutions of higher education and, in particular, in increasing the number of young people able and willing to pursue courses in engineering and science.

For achieving this, the first efforts must be directed towards producing a highly qualified, balanced, thoughtful, well-motivated and caring teaching force, secured through decent pay and conditions, general esteem and a feeling of pride and satisfaction in its work. Although teachers themselves will always hold the responsibilities for making their profession more successful, the government onboard the Space Settlement must create the right environment for professional success. This implies providing a framework of support for the highest standards of professional development, appropriate working conditions, to safeguard teachers' academic independence and to promote constructive relationships between teachers, parents, students and the different communities. Meanwhile, professional behavior will be maintained in all schools and colleges, to develop further methods by which excellence and efficiency can be achieved.

As education, training and learning constitute important means of developing human resources, they must be properly applied at all levels. It is known that the efficiency of learning depends of its diversity. Therefore a pre-school, a school, an out-of-school and a professional education institution must exist and develop teaching activities onboard the Settlement.

The educational system will be very similar to that applied in the developed countries on Earth: primary, basic, secondary levels (including a lyceum, a gymnasium, and a boarding school), a school for the low mentality and handicapped children, a house of creativity for children and youth and a sports school will be included within the Orbital Education System.

f. Transports

Since the torus will be approximately 25.13 kilometers long, with a radius of 4 kilometers, an effective means of transportation must be found, both for traveling within the torus and from the torus to the center of the station (the 0-gravity point), where the majority of industrial and research facilities will be located. The main means of transport inside the torus will be a kind of train, similar to subway. It will run through a tube located “under” the habitable area, on electrified tracks. There will be at least three sets of tracks, two for traveling in both directions and at least one for maneuvers. The tracks need to be made of high conductibility materials, so that a minimum amount of power is lost due to electrical resistance.

Elevators will be used for traveling to the center of the station. The elevator shafts will be located in the four tubes connecting the torus to the center. Colonists will be strapped in inside the elevators, since the centrifugal force decreases with the distance to the center and they would soon find themselves in 0 gravity conditions.

g. Transit facilities

Once the space station is in orbit, spaceships heading beyond Earth can stop and restock here. Docking facilities will also be needed if space tourism is to become an economical activity on the station. Part of the structure at the center of the station will be used as a spaceport. There will be docking sites and small storage facilities. Spaceships arriving at the spaceport will use their guiding systems, aided by computers on the station to position themselves for docking. At this point, a terminal will be attached to the spaceship, also helping to hold it into place. Air will be pumped inside the terminal before the doors are opened.

h. Communications

The Space Settlement will house a large computer network for communication purposes. The computers in the living quarters will be interconnected using fiber optic cable, because using of wireless in a closed metallic habitat is not adequate. The advantage of fiber optic cable is that it is very fast. Fiber optic links consist of multiple transparent glass or plastic cables that guide any type of information (sound, video and data) to its destination by means of light waves. The message is converted into a series of binary digits, which are used to switch a light source on and off. This creates a sequence of light pulses, which are decoded by the receiver at the destination and the original data is reconstructed. The most widely used light sources are lasers. Lasers are described by their wavelength and output power and the three wavelengths currently in use for fiber optic networks are 850nm, 1310nm and 1550nm. All these wavelengths are infrared light, which is invisible to the human eye. The longer the wavelength, the greater the distance the laser can transmit.
A kind of telephone can also be used for communication, using the same kind of transmission

media as the computer network.

i. Entertainment

On the Space Settlement, we will try to create living conditions similar to those on Earth. This includes forms of recreation and entertainment.

Since the first radio transmissions in 1907 and the first television transmissions in the 1930s, radio waves transmitted from Earth have been traveling toward outer space. These transmissions could be received on the space station by means of an antenna receiver. This receiver should be placed outside the station's magnetic field, to avoid interferences. The radio and TV signals, once picked up by the receiver, can be distributed to the rest of the station. This way, colonists will be able to receive television and radio programs and even Internet transmissions from Earth. However, there will be an inconvenience. The channels will shift every few hours due to the difference between the revolution periods of the Earth and the station (the Earth completes a rotation around its axis in one day, while the station moves around the Earth in one month), but this problem can be solved by placing a network of communication satellites around the Earth.

We must also build theaters, concert rooms and cinemas. We can build a transparent wall in the connector tubes special designed for walking and admiring the space. Organizing excursions in outer space has never been so little energy consumer thus cheaper, being a very attractive way of relaxation.

Other motivating entertainment activities will be those placed in the 0 gravity zone. We will build a special entertainment facility in this zone, where colonists can play different sports, swim in the 0 gravity pool, sleep restful nights in a 0 gravity hotel and going in 0 gravity discos.

j. Privacy

Privacy is an important aspect for attracting colonists to LEDA. The concept of privacy differs from individual to individual and can refer to a number of meanings. We will have to ensure that every inhabitant of the station is provided a large enough living area (approximately 45 square meters) and that population density isn't too high. Also, living quarters will have to be phonically insulated, so any private conversation remains private. Security cameras will be installed throughout the station (especially in high-risk areas). However, they will be completely absent from the living quarters and the use of monitoring equipment without the subject's consent will be forbidden, excepting only extreme cases.

Control over possessions or private information will be guaranteed, as will freedom of speech and freedom of activity. There will be forms, for evidence of population, but colonist will not be required to give out confidential or personal information. Children will choose the kind of education they receive according to the career they want to pursue.

k. Judicial system

Social and economic well-being also involves providing financial security and social safety net for all citizens. Therefore the judicial system onboard the Settlement will need to define a shared morale sense, to create public rules, to encourage democratic laws and to protect the rights of the citizens. This can be achieved by creating a judicial structure similar to that of the democratic countries on Earth. To accomplish its goal and guarantee the rule of law, the judicial structure must include both sufficient personnel (judges, courts, staff) and supportive elements in the work of the

judiciary (as police departments).
Judges onboard the Settlement will be independent in performing their duties and will have full judicial competence with respect to their functions and according to the Constitution. The judicial structure will consist of a supreme court, two appeal courts and two courts of first instance. The law will specify the jurisdiction, divisions and other matters related to Judiciary.

The profession of advocacy should also be established onboard the Settlement to express the values of justice, the correctness and legality, to minimize injustice, to seek conciliation between adversaries and to facilitate legal aid for citizens in accordance with the law.

An effective access to justice for all groups in a society is imperative as it implies the success and validity of the judiciary act.

l. Psychological needs

Still, satisfying the physical and social needs of the individual is not enough. Life onboard the Settlement cannot develop properly without a solid psychological support. Each human being has three primary needs which are more important than the other six. Without a suitable psychological background, colonists will act according to momentary instincts, will become irrational or even irascible, will lose their analytical judgment and will often suffer depressions. A certain psychological equilibrium will be essential onboard the Space Settlement as the success and efficiency of the different human activities strictly depend on the behavior, morale and mood of the population.

Each psychological need has its positive and negative aspects. It is also known that people sharing the same psychological needs are somehow bond to each other. Those working together will experience hard times if not connected through similar priorities. Therefore, employment and personnel distribution onboard the Settlement must take into account the similarities and differences between people; this can only be achieved by conducting psychological studies among the employed population.

One of the basic human needs is safety. It manifests in the people's desire to know ahead of time what is going to happen, to be informed. The feeling of security can be enhanced by knowing the personal family, historic and ethnic background, by living in a safe community, near friends and family, by having deep faith regardless of the future, by being financially assured. This will finally help colonists to feel balanced, connected, safe, optimistic and secure. From the human activity point of view, people needing security will be more displeased by sudden changes and events happening without warning.

The need of freedom is also essential for the psychological well-being of the population. It consists in the need to have choices, to be independent and always in control of things. The need of freedom is often combined with the need of safety and adventure. Allowing people to have personal options and to take decisions, to freely move around the Settlement, to choose their work assignments, to be themselves will lead to a feeling of independence, self-esteem and self-confidence among the Colony's inhabitants.

Letting people occupy positions of responsibility will assure their feeling of accomplishment and leadership, improving the organizational feature of the crew. Therefore, the need for power is directly bounded to professional success.

Satisfying the need of exchange entails allowing a certain trade o knowledge and information. Communication, friendship, justice and public services will therefore be essential aspects of life onboard the Settlement. Always staying in touch, participating in different discussions, working with similar people, trusting the judiciary system and the principle of equality, sharing information and human relations will effectively enhance one's need of exchange, assuring a well-balanced, informed and ethical population.

We must also take into account one's need for expansion. Building new environmental elements, such as roads and buildings, extending physical and spiritual knowledge, surpassing the boundaries of science, psychology, medicine or art can provide a suitable support for the need of expansion. This will help colonists to better understand the way things work, the other members of the community and even themselves.

Authorities onboard the Settlement must respect the citizen's need for expression. A good way of improving the freedom of expression is allowing periodical public speaking about topics of general interest. This way the creativity and the ability of the man to function efficiently and productively will be encouraged.

Being accepted by others is also one of the major needs we must consider, without which social life onboard the Settlement will surely be impossible. Colonists must be tolerant with others and must feel acceptance by neighbors and coworkers. People with the sense of acceptance will be valuable additions to any community or group.

Another important demand of the human being is that of belonging to a certain community, to have people around. It strictly refers to the man's need for family life and citizenship. Satisfying this need will lead to a highly sociable and responsible population.

Therefore psychologists onboard the Settlement must carefully monitor the behavior and psychological needs of the population, to ensure a rapid and efficient development of the colonial society.

VII.3. Industry

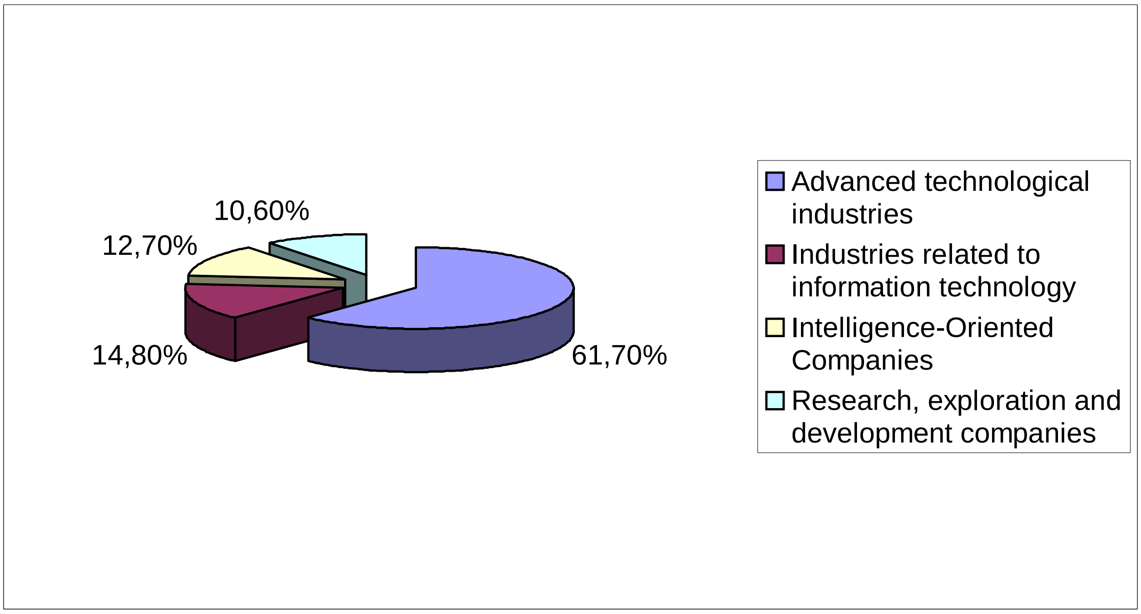
a. Organizing the industry

Inhabiting the Settlement for long periods of time will surely be impossible without the support of an efficient, productive and durable local industry to assure the colony's self-sustaining feature. As the main purpose of building an orbital space colony is creating an Earth-like environment able to maintain life by proper means, the existence of a diverse and fully operative industry onboard the Settlement is imperative. Therefore, the different branches of manufacture will need to satisfy both individual and community demands by covering as many necessity fields as possible.

The table below shows the industry categories needed to be found onboard the Space Settlement and the basic industrial facilities required for best self-sustaining results.

Types of industry	Specific industrial facilities
Advanced technological industries	Medical supply and agrochemical medium manufacturers
	Engineering plastic manufacturers
	Semi-permeable chemical fiber membrane manufacturers
	Special electric ceramic ware manufacturers
	New carbon and graphite product manufacturers
	Compound and reinforced inorganic fiber manufacturers
	Semiconductor substrate material manufacturers
	Nonferrous metal special alloy manufacturers
	Nonferrous metal precision casting manufacturers
	Shape memory alloy manufacturers
	Advanced metal machine tool, metal finishing machine, and related parts and accessories manufacturers
	Advanced equipment and tool manufacturers
	Valve manufacturers
	Precision bearing manufacturers
	Precision metal mold, and related parts and accessories manufacturers
	Industrial robot manufacturers
	Servomotor and miniature motor manufacturers
	Advanced switching device, distribution panel and power control unit manufacturers
	Wire communication equipment manufacturers
	Radio communication equipment manufacturers
	Electronic parts and device manufacturers
	Electric measuring instrument manufacturers
	Solar battery, and solar battery accessories and device manufacturers
	Automotive parts and accessories manufacturers
	Test equipment manufacturers
	Medical engineering equipment manufacturers
	Advanced optical equipment manufacturers
	Industrial design industry
Industries related to information technology	Semiconductor manufacturing device manufacturers
	Radio and television manufacturers
	Optical fiber cable manufacturers
	Chemical machine and device manufacturers
	Battery manufacturers
	Information recorder manufacturers
	Recreational goods and toy manufacturers
Intelligence-Oriented Companies	Software industry
	Information provision service industry
	Information processing service industry
	Industrial facility cleaning industry
	Machine repair industry
	Management consulting industry
Research, exploration and development companies	Physics research institute
	Chemistry research institute
	Biology research institute
	Technology research institute
	Human sciences research institute

The following graphic represents the ratio between the different industry categories onboard the



Space Settlement:

Taking into account the limitation of space inside the Settlement, the competition between industries onboard the colony will be almost inexistent, as there will be only one industrial facility for each field of demand. Still on-orbit industries could compete or cooperate with industries situated on Earth. The eventual transactions and goods exchange will be available through commercial shuttles and orbital commercial “warehouses”.

b. Mining, processing and manufacturing

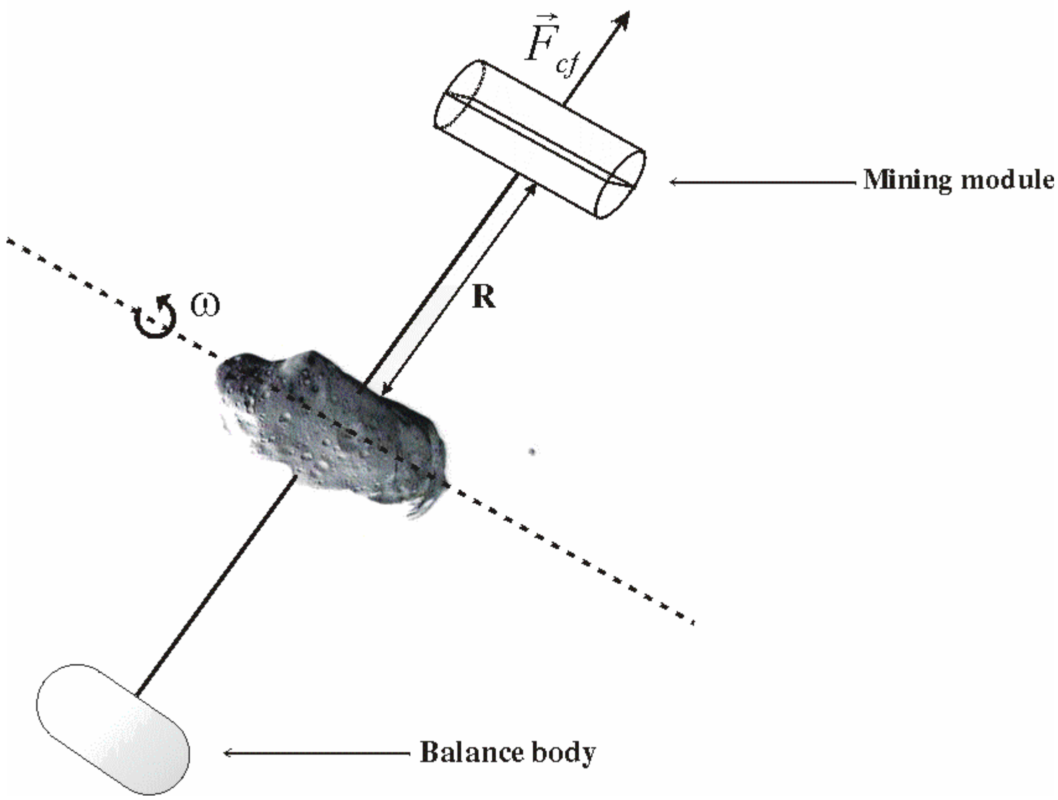
It is known that both asteroids and comets contain considerable natural resources. Long term human activity in space would not be possible without the support of a local extracting industry to provide LEDA with raw materials. The success of the mining activity will be determined by several factors, such as geological development, finances and available technology.

Mineral extraction can only be economically feasible if the ore found on the asteroid reaches reasonable expectations concerning its form and quantity. The mineral deposits must be well evaluated so that mining revenues will surpass the total costs of the extraction process. Costs basically depend on the current technological development in the mining and processing area, while revenues can be estimated by testing the market.

Mining and processing asteroid ores can only be accomplished by using technologies based on the characteristics of space environment. Therefore, the most efficient way of mining the surface of asteroids will be taking advantage of the least-controllable environmental conditions. For example, a viable solution will be using the centrifugal force for reducing or stopping the spinning motion of the asteroids while creating artificial gravity onboard the mining modules. The principle is discussed in this chapter.

Assuming that an asteroid will be determined to contain sufficient valuable material to be economically eligible for mining, a series of mining methods must be debated. The mining technology will strictly depend of the type of minerals needed to be extracted. Mining multiple resources in the same time will certainly call for sophisticated mining and processing techniques. Further more, microgravity will surely entail complications. For example, the stones loosen from the asteroid will not fall to the ground. Everything will have to be well anchored to the NEO's surface, otherwise the mining equipment and even miners couls be "thrown" off into space. A dense netting system covering the surface of the asteroid will solve the problem by providing a suitable support.

First of all, miners will have to reduce or even halt the high rates of spin of the asteroids for being able to set the mining equipment on their surface. Therefore, an efficient way of achieving this would be using the centrifugal force to diminish the angular speed of the asteroid. The mining module will anchor itself to the surface of the asteroid using a solid cable; symmetrically towards the center of mass of the asteroid, another body (a counterweight with the same mass as the mining module) will be anchored using a similar cable. By doing this, the radius of the entire body system will increase; as the asteroid tends to keep its kinetic momentum and therefore the centripetal acceleration of its extreme points, the angular speed of the system will decrease. The following drawing describes the principle:

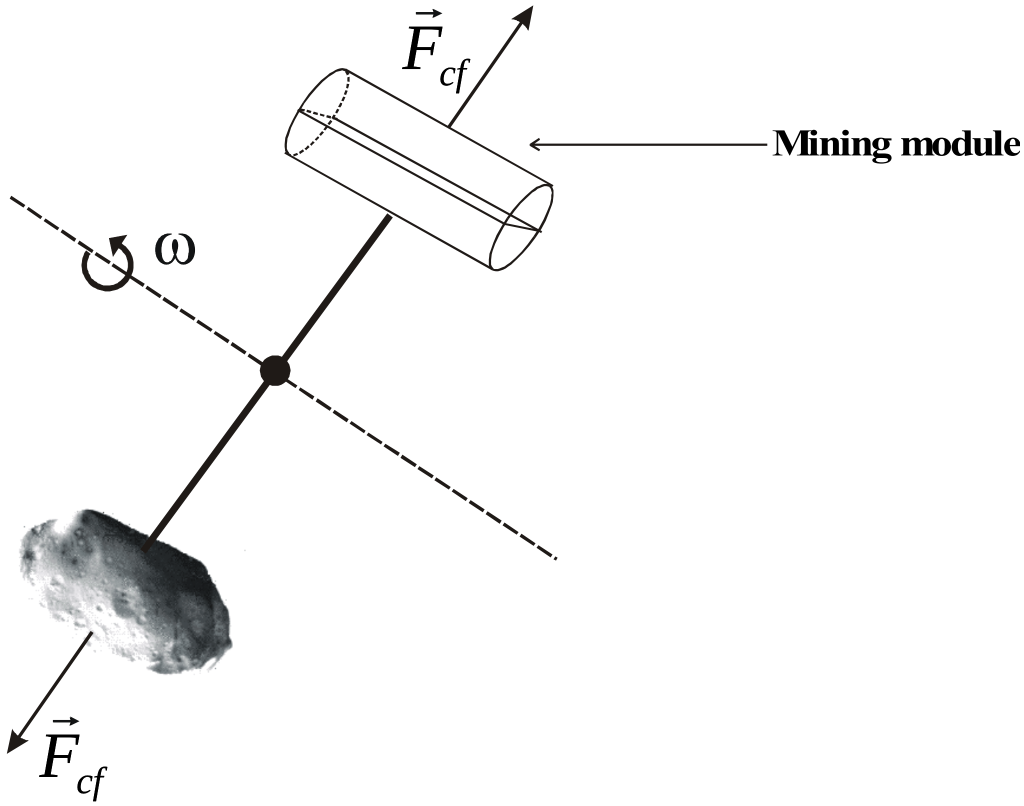


$$a = \omega_1^2 R_1$$
$$a = \omega_2^2 R_2$$
$$\frac{\omega_1}{\omega_2} = \sqrt{\frac{R_2}{R_1}}$$

If $R_2 > R_1$, than $\frac{\omega_1}{\omega_2} > 1$, which means that $\omega_2 < \omega_1$.

Where:
a – the centripetal acceleration
R_1 – the initial radius of the system
R_2 – the final radius of the system
ω_1 - the initial angular speed of the sytem
ω_2 - the final angular speed of the system (after attaching the two bodies to the asteroid's surface)

Still there is another way of generating artificial gravity both on the asteroid and the mining module. It entails connecting the mining module to the asteroid surface using a rigid bar or cable and moving the rotation center of the system in the center of mass of the rigid bar. This way, the centrifugal force will provide both bodies with artificial gravity. The major impediment is that for achieving this, the mass of the mining module must be approximately equal to that of the asteroid. Otherwise the center of rotation will change and the rotation equilibrium will become unstable. The principle is shown in the figure below:
As we said, a network of cables and metallic structures in the form of rigid cages is necessary for binding



the asteroid together. Otherwise, the mining actions and the movement control can affect the asteroid's integrity, leading to its splitting. The next phase will require mining platforms to be set on the metallic structures, as they need a solid support to improve the efficiency and safety of the equipment. Operating platforms for mining machinery and transport modules must also be provided for best performance.

The mining process itself will involve the fragmentation of the asteroid ore, the excavation and the transport of the crushed rocks to the processing plants onboard the Settlement.

There are multiple types of asteroids depending on their mineral composition, but only some of them are worth considering for mining activities. The mineral composition of asteroids can be easily determined using the reflectance of spectra, from the visible spectrum (4000-7000A) to the infrared (7000A+). For example, "the LL (low-low iron) chrondites contain about 4% (+ or - 1%) total metal, with

Ni comprising about 25%(+ or - 5%) concentration, and Co comprising about 1.2%(+ or - 0.2%) concentration. The LL chrondites may be further subdivided into varying concentrations of PT-group (Platinum) metals and non-metals. Some Non-metals that form composites within the LL group include Ga, Ge, and As. Ga ranges from 1 to 15 ppm, Ge, 200(+ or - 30ppm), and As, 1.2(+ or - 0.2ppm). Among the PT-group, PT contains 21 (+ or - 5ppm), Ru contains 12(+ or - 0.2ppm), Os contains 10(+ or - 2ppm), Ir contains 10(+ or - 2ppm), and Re contains 1.0 (+ or - 0.2ppm)."

(Space Resources - Breaking the Bonds of Earth by John S. Lewis and Ruth A. Lewis, Columbia University Press, Copyright 1987, page 257)

The LL chondrites will be suitable for mining, as they contain Ga and As, elements needed in the production process of high efficiency solar panels. Other types of asteroids worth considering are those belonging to the C1 and C2 NEO categories.

Ice covered comets can be a viable source of water. The ice will be melted and pumped into a storage tank where it will refreeze. While returning to the Settlement, some of the ice can be used in propelling the transportation module; the process involves heating the ice using solar energy, boiling it and harnessing the resulted steam to "push" the module forward.

Still the most important source of materials will be the Moon. Therefore, building a lunar mining facility capable of sustaining life and exploiting the lunar ilmenite will be vital for the Settlement. Small vehicles powered by both solar energy and chemical batteries will analyze the surface of the Moon by taking different samples of lunar soil and bringing them to the lunar outpost for further research. Mining machinery will extract the needed ores (especially ilmenite) from the lunar rocks. Onboard the orbital station, ilmenite will be then refined into oxygen, hydrogen, nickel, iron, manganese, silicon, chromium and other metals found in smaller ratios within the lunar soil.

c. Exploration and research

Excepting the artificial gravity created inside the ring of LEDA and the natural gravity of the Moon, the central body of the Colony and the space environment offer 0 gravity conditions. This will enlarge the field of options for both exploration and research. Various sciences related to physics, including the study of materials, fluids, processing systems, combustion phenomena, can be operated within 0 gravity conditions. The effects of microgravity on living organisms, including cellular and tissue development, metabolism, biological functions and growth can also be studied only in the low gravity conditions provided by the central body of the Colony.

Final considerations

Final Considerations

The building of LEDA will initially involve the setting up of a lunar mining facility which will then provide the assembling site with current and sufficient amounts of materials.

LEDA will be built using both materials mined from the Moon and materials brought from Earth (such as some volatiles) and will be assembled in the Lagrangian point L5.

The basic shape of LEDA will be that of a torus. Some secondary structural elements, such as the central body, the four main elevators and the two symmetrical large mirrors will enhance the settlement's functionality.

LEDA will measure 9022 m in diameter. The height of the residential segment will be of 500m, while the diameter of the central body will measure approximately 1020m. Two main mirrors will reflect the solar light both onto the solar panels and the small adjustable mirrors lightening the artificial sky of the Settlement.

The industrial area of LEDA will function within the 0 gravity center and will be permanently supplied with the raw materials obtained from mining the lunar surface and the different Near Earth Objects.

Materials will be exploited and processed using different extraction and separation methods. Their characteristics will be improved in order to obtain more reliable building materials.

Radiation levels onboard LEDA will be measured using both common measuring devices and the latest technological developments in this field. Radiation will be minimized using different shielding methods. The one we foremost propose is the Electromagnetic shielding.

Gravity onboard LEDA will be artificially recreated by rotating the torus around its symmetry axis. The gravitational constant within the residential area will be identical to that on Earth.

By studying the effects of artificial gravity on atmosphere we propose an optimum air pressure inside the torus and a suitable chemical compostion of the atmosphere.

Alimentation onboard LEDA will consist in both vegetal and animal food and will efficiently satisfy all the needs of the human organism by providing a complete utrient composition.

Water will be obtained from simple elements (H_2 and O_2) or from lunar ice. It will then be chemically treated, used and recycled. Its chemical composition will be permanently monitored to avoid contamination.

Waste onboard LEDA will be recycled, processed and reused in the different industrial activities.
The different risks will be minimized by permanent monitoring of the human activities and by creating a strict set of norms and rules.

The basic power supplying system of LEDA will use solar energy.

Conclusively, LEDA will initially be home for 250 000 colonists aged 5 to 70. The employment grid will firstly take into account the basic needs of the Settlement, focusing on the building and life maintaining activities.

By artificially recreating the life conditions found on Earth (light, gravity, atmosphere, water, climate), by providing sufficient amounts of energy, by setting up a productive and economically feasible self-sustaining industry, by minimizing all unpleasant and unhealthy factors (vibration, odor, noise, toxicity), by assuring a proper alimentation and an effective social system the minimum needs of the orbital population will be satisfied.

A democratic government, an efficient and varied system of social facilities and an eligible infrastructure will provide a solid support for the development of a healthy and civilized society.

Although, our generation is familiar with the last discoveries that man’s greater and greater wish for knowledge has generated, the issues which the proposed subject of this project deals with have such complexity that a lot more space would be needed for them to be fully debated.

We were born after that unforgettable step of Neil Armstrong on the Moon, so small for a man but such a giant leap for mankind.

To think that man could live in other places of the Universe, places that could be adapted to his needs can really become a challenge for our generation.

But the issues raised by fulfilling such a challenge, imply large spectrum of knowledge, dedication and imagination.

It is difficult to predict a deadline for the achievement of such an ambitious dream, but when it will come true, just think of how many of our problems today will find their solutions!

We can’t end our presentation without thanking you for the opportunity you have offered us to concentrate our creative imagination on such daring, exciting, though overwhelmingly vast subject.

There is no doubt that the subject is still open to more through study and research, but one thing is certain: working on the project has definitely made us reassess our options regarding our future professional choice!

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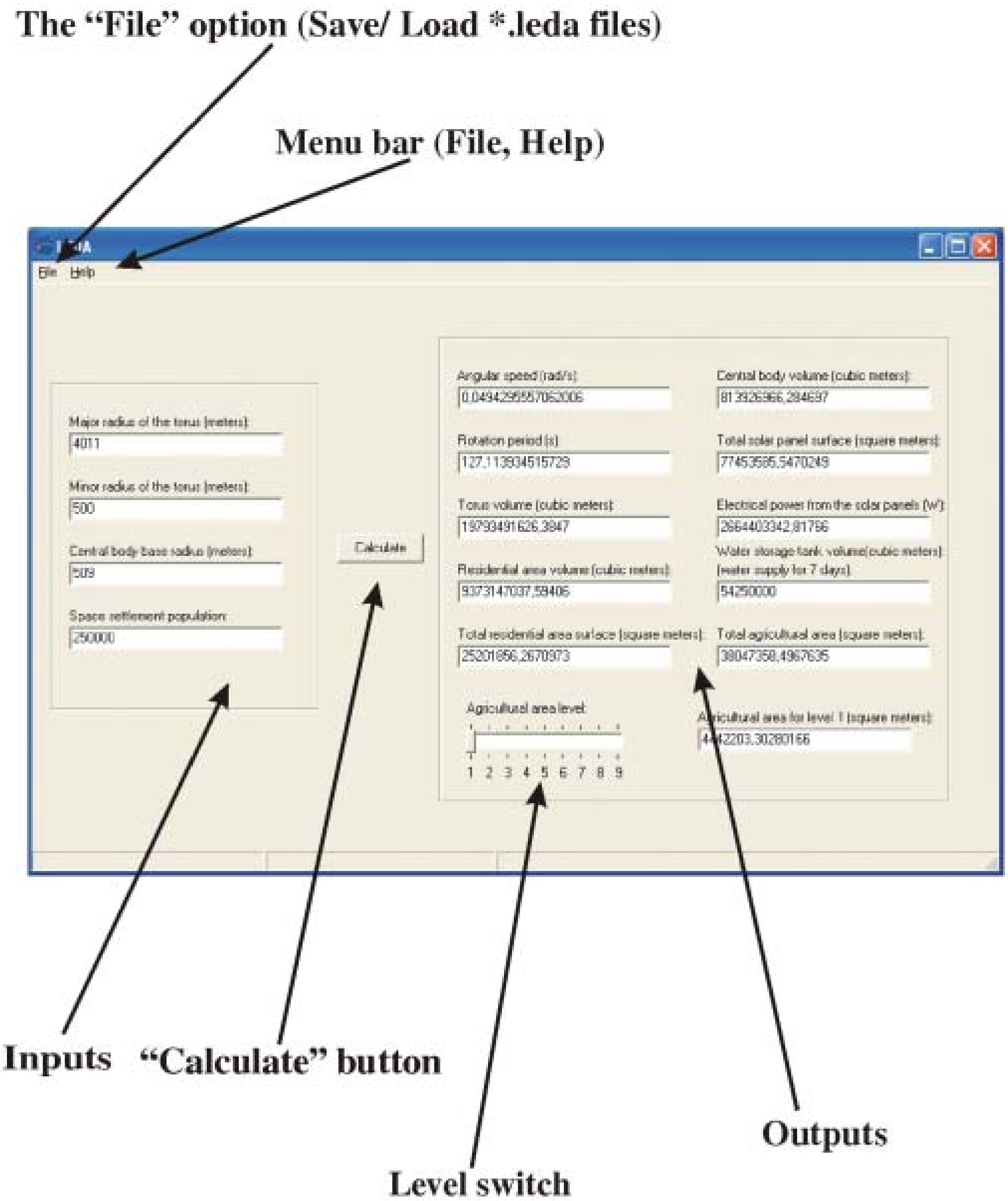
* All graphics (including the cover) were made by us in Corel Draw 8.0, 3D Studio Max and the executable program was compiled in Visual Delphi. The text was edited in Microsoft Office XP and Adobe Pagemaker 6.5.

Annex

LEDA.exe - Software description



This program was designed to calculate relevant data for a space stettlement.

Insert real values above 0 (natural numbers for population).

It is possible to save data or load data from file (the "File" menu).

This software was written for the 2004 edition of the NASA Ames Annual Space Settlement Contest