1.0 Mission Plan

The schedule for the mission includes the timeline, launch operations, Earth to Mars trajectory, landing protocol, and integration with the Mars Direct Plan. These mission parameters define how the mission will be accomplished from launch to deployment.

1.1 Timeline

CERES will be launched two years prior to crew departure and will arrive about 180 days later. By sending the module ahead of the crew, a test harvest cycle can be performed and evaluated from earth to determine if adjustments or modifications need to be sent with the crew. The 180 days for the transit are based on a higher energy departure than that required for a Hohmann transfer[2]. A possible option would be to send the module in conjunction with the crew. If this option had been selected, the level of automation would be reduced. However, by sending the module prior to crew arrival, all systems can be checked and a test harvest cycle evaluated. Thus, possible failures can occur and be investigated prior to crew launch and corrective measures may be applied.

Upon arriving at Mars, aerobraking maneuvers will commence to enter orbit with the assistance of Reaction Control System (RCS) thrusters. From orbit, the landing site will be evaluated to determine if it is safe to land. Dust storms can obscure the landing site and prevent a safe landing. Ground control will determine if conditions are safe and send the command to start the entry and landing sequence. A possible option would be to directly enter Mars' atmosphere upon arrival. This option would be very dangerous since the approach trajectory may not be as accurate as it needs to be for this maneuver. In addition, the surface may be under cover by dust storm activity, which could hamper the landing. Either of these conditions could potentially destroy CERES. The safer option is to enter Mars orbit upon arrival and begin the landing sequence after conditions are certified safe.

Systems checks will be performed after landing to evaluate the integrity of all the subsystems. Prior to deployment, a full landing site evaluation will be performed with video from ground control. The site must be clear of obstructions before the growing bays are deployed.
Upon ground control approval of safe landing, the command will be sent to deploy the first of six growing bays for testing purposes. When the bay is deployed successfully, the command will be given to start the test growing cycle. If the test cycle is successful, and the rest of the landing site has been certified safe, the rest of the growing bays will be deployed. This cycle will be timed so that the crew can harvest the crop after arrival. A description and diagram of the deployable bays can be found in the appendix.

Control of the module operations will be transferred from ground control to local astronaut control with assistance from Earth after the crew arrives. Autonomous monitoring and control of environment conditions, pH, and nutrient content will also be used.

1.2 Launch Operations

An ARES heavy lift vehicle will be used to lift off from Earth to LEO and an upper stage will be used for the interplanetary trajectory. The ARES is a proposed vehicle derived from space shuttle components. Two solid rocket boosters, an external tank, and a pod with three SSMEs comprise the vehicle. This vehicle will be capable of lifting 119.09 tons to LEO with a 250,000 lb thrust upper stage and 132.87 tons to LEO with a 500,000 lb thrust SSME upper stage[2]. The ARES will be capable of delivering 28.15 tons to the surface of Mars. The module will be inside the payload shroud which has an inside diameter of about 10 meters. After being placed in LEO, the upper stage will place it in a transfer trajectory to Mars. Another option would be to use a Magnum heavy lift launch vehicle[1]. The Magnum is also derived from shuttle technology. However, the lift capacity is only about 80 metric tons to LEO. By using the ARES with a SSME for the upper stage, the lift capability is greater.

1.3 Earth to Mars Trajectory

The transit to Mars will take place over a period of approximately 180 days[2]. Either a conjunction or an opposition trajectory can be used to send CERES to Mars since both will take about 180 days. The Earth's orbital velocity is 30 km/s and that of Mars is 24 km/s. The approach velocity with respect to Mars is about 3 km/s. This relatively slow velocity allows the module to use aerobraking for orbit capture at Mars. This trajectory exposes the module to less than 52 rem[2]. There are a range of Earth departure velocities, which can be used to send the module to Mars. These velocities affect the transit time to Mars as well as the aeroentry possibilities.

Departure Velocity	Transit to Mars	Aeroentry
3.34 km/s	250 days	Easy
5.08 km/s	180 days	Acceptable
6.93 km/s	140 days	Dangerous
7.93 km/s	130 days	Impossible

Table 1. Departure Velocities and Atmospheric Entry Risk[19].

The above table does not show a reliance on RCS thrusters. By allowing the use of RCS thrusters to decelerate at Mars, the higher velocity trajectories become possible. However, since the cost would increase due to the increased fuel load required to depart Earth and to slow down at Mars, the selected transit is the one with 5.08 km/s departure velocity and 180 days transit.

1.4 Landing Protocol

The landing sequence begins when the ground control team sends the command to de-orbit upon verification of safe landing site. RCS thrusters will be used to initiate the de-orbit burn. CERES will be protected by a heat shield (aeroshell) for atmospheric entry. After the atmosphere has slowed down CERES enough, a drogue chute will be deployed. A parachute will be used later to slow down further. The aeroshell will be ejected in order to initiate the final sequence of the landing. Hypergolic fuel will be used to ignite the engines for a soft landing. CERES will soft land within +/- 15° of the equator. Ground contact sensors in the landing legs will be used to detect the landing when the weight of the module is distributed among the legs. The sensors will then activate the engine shut down sequence. For safety, the sensors will not initiate the shut down sequence until four or more detect the landing. After engine shut down and landing position confirmation, the relevant data will be sent to Earth.

1.5 Integration with Mars Direct Plan

In concert with the Mars direct mission plan, the module will also rely on in-situ resource utilization. The main component of the internal environment is CO_2, which will be obtained from the Martian atmosphere. Experiments to be conducted include utilizing the Martian regolith to grow crops. In order to link to the main habitat section, two connection ports are provided. One connection will be used to link with the habitat for a shirtsleeve environment. The other port will be used to connect other greenhouses when the techniques become well established to successfully operate a greenhouse to provide the required nutrition for the crew. The ultimate goal of the Mars Direct plan is human colonization of the planet. CERES is designed to accommodate these requirements by being expandable with multiple greenhouses to eventually provide 100% of the food requirements of future crews.

2.0 Mission Operations

Mission operations include autonomous operations, crew operations, and also communications and data transmissions.

2.1 Autonomous Operation

Since CERES will arrive two years before crew arrival, it is imperative for it to startup, run through systems tests, and transmit collected data autonomously.

2.1.1 Startup

Upon successful landing on Mars, CERES will begin startup. First a series of tests will be conducted in order to insure subsystems are up and running and ready for bay deployment (see appendix). Once the landing site is determined to be safe, one of the six bays will be deployed and inflated, which is considered the test bay. The test bay will begin its test growing cycle. If the test cycle is successful, and the landing site considered safe, the rest of the bays will be deployed. This cycle will be timed so that the crops can be harvested upon crew arrival.

2.1.2 Life Support Test

Following the startup and test cycle, life support systems for the habitat will be tested. These support systems cannot be tested until there are full-grown plants within the bays (since the plants will provide oxygen through photosynthesis, and water filtration from plant roots). Systems include: CO_2 reduction, oxygen production, and water filtration.

2.1.3 Data Collection and Transmission

After successful landing, data from systems tests will be collected, position evaluated, and data transmitted to Earth ground control. Progress of startup and test growth cycles will be monitored by ground control until crew arrival. There are two options for data transmission: one is by using relay satellites, and the other option is direct link to Earth.

2.2 Crew Operations

Upon crew arrival, CERES operational controls will be transferred to the crew with ground control assistance. The crew will perform daily tasks for the greenhouse including germination of seeds, harvesting, post processing, and storage. Other tasks will include research, communications, and data transmission.

2.2.1 Research

The secondary mission objective is to investigate if plants can be grown in Martian soil. Soil will be brought inside the greenhouse in order to provide a controlled environment. The Martian soil will then be chemically modified in order to remove iron oxides, and other substances that prohibit plant growth. Variations of nutrients will be added and tested with different crops. The crew will monitor progress.

2.2.2 Harvest cycles, storage

Harvest cycles vary by crop, anywhere from 20 to 100 days. The crew will harvest as necessary, and begin post processing tasks and storage. After harvesting, the crew will begin another growth cycle. Options for storage include: drying, freeze drying (for long shelf life), and refrigeration.

2.2.3 Communications and Data Transmission

In order to isolate operational failures, a network of subsystems will be responsible for maintaining the functional parameters of CERES. A main central computer will be "fed" data from subsystems including: thermal control, atmospheric control, water and nutrient delivery, and lighting control. The central computer is linked to the habitat module for crew assessment, as well as mission control (Earth) via satellite or direct link. Until there is a manned crew to maintain the network, it is essential that the network of subsystems be highly autonomous.

3.0 Module Structure

The module has a plan view shape of an octagon, with six of the sides swinging down to become the growing areas. The central core of the greenhouse is a circular pressure vessel containing a laboratory, emergency life support and mechanical systems. The overall size is 9.5 meters across with each side measuring 3.935 meters. Each 'petal' of the growing bays is 3.2 meters wide and 4.72 meters long. The inside core is divided into two stories, each approximately 2.3 meters high. The lower deck has access to the outside, access to the growing bays, pre/post processing, germination, product storage, and room for research. The upper deck houses a majority of the mechanical components needed for the subsystems, emergency life-support (a backup "lifeboat" for the crew), communications, and research computers. Under the first deck is a subdeck .5 meters high. The subdeck houses the landing thrusters, thruster fuel and oxidizer, and the hydrogen and liquid oxygen tanks. The upper and lower decks are opposite in space distribution, the lower deck has a central core for mechanical components and the upper deck has the central core for crew access and the outer ring houses the mechanical components.

CERES has two airlocks at opposing ends of the module; the second airlock is for emergency use and to incorporate the flexibility to become modular. The airlocks measure one meter deep by 3.2 meters wide by 2.3 meters high. However, due to the fact that the environment suits are to be stored in this area, the available space is limited to one crew entering at a time. The space above the airlock houses the pumps, tanks, and filters needed for operation.

To preserve space and maintain hull integrity, the internal doors are all sliding – recessing into the hull. There are a total of eight of these doors, two to the airlocks and six to the growing bays. The space just to the inside of the sliding doors is the first floor access corridor, measuring about .7 meters wide. Along the walls between the doors are equipment racks for experiments and sensors. This space can also be leased out to the private sector, allowing private research to accompany the mission. Central to the first floor is the research/processing area. We envisioned a circular worksite 4.9 meters in diameter, with one third dedicated as storage and seed germination. In the other two thirds, the worksite takes the form of a circular bench, one meter wide. It is in this area that research is conducted, as well as providing a space for technical repairs, preprocessing of the plants, and post processing of the crops. In the very center of the first floor is where the water tanks for the module lie, as well as nutrient storage and distribution.

Below the first floor is the subfloor. The subfloor houses the descent thrusters as well as their fuel, the landing struts, and any 'dangerous' fuels such as liquid oxygen and liquid hydrogen. The idea behind having a subdeck is for two reasons. First, raising the structure above the surface creates a convective barrier – taking advantage of the low density of the Martian air. Second, CERES is designed to be crew accessible. So placing combustible or toxic elements outside the pressure vessel reduces the chance of violations to the controlled environment and reduces the risk if a major breech were to happen. Depending on the space available, part of the subfloor can be used as storage, accessed from the corridor of the first floor.

The second floor, accessible via two vertical ladders in the side of the first floor workbench, is the module 'control center' as well as providing an emergency habitat. From a diameter of 4.94 meters in is habitable space, while the area beyond 4.94 meters to the hull holds most of the modules mechanics. This includes the computer systems, storage tanks for the various constituents of the controlled atmosphere, scrubbers, filters, and the power systems. The habitable space is intended for communication/control, personal computer usage, and an emergency habitat as well as a micro galley and a restroom so the crew does not have to go all the way back to the habitat.

4.0 Plant Selection

4.1 Dietary Needs

The crew's daily dietary requirements are one of the key factors concerning long-term human space missions, such as missions to Mars. The average energy intake requirement for men is 4396.4 kcal/day, and for women, it is 3340.5 kcal/day[3]. This assumes a mass of 68.2 kg for men and 65.77 kg for women, as well as, an additional 1000 kcal/day for high activity levels.

The total calories consumed will come from proteins, carbohydrates and fats. Protein should be between 12 to 15 percent of the crew's daily caloric intake[3]. The greenhouse will provide 3.9 percent of the crew's daily protein requirement. Carbohydrates should be 50 to 55 percent of the daily calories[3]. The greenhouse will provide 20.5 of the crew's daily carbohydrate requirement. Fat should be 30 to 35 percent of daily calories[3]. The greenhouse will provide only 0.54 percent of this requirement. If CERES operates at optimal levels then 24.94 percent of the crew's daily nutritional requirements are provided.

4.2 Plant Selection

The following considerations were used in selecting plants/crops[4,5]. The crops will have high yields, be fast growing, and they will have a high harvest index (ratio of edible to inedible). The crops will have minimal processing requirements and should be low growing. Table 2 shows a variety of possible candidate crops. The plants in a bay will have similar environmental requirements, such as, temperature, lighting, photoperiod, etc.

Wheat	Sweet Potato	Broccoli	Soybeans	Strawberries
Rice	White Potato	Kale	Peanuts	Tomatoes
Oats	Beets	Snow peas	Pinto beans	Melons
Carrot	Cabbage	Green peas	Lettuce	Radish
Onion	Spinach	Mushrooms		

Table 2. Possible Crops for CERES[4,5,6,7]

Wheat	White potato	Soybeans
Lettuce	Tomatoes	Spinach
Carrots	Mushrooms	

Table 3. Selected Crops for CERES

Table 3 lists the crops selected for the MDG. These crops most closely match the above selection criteria than the others listed. Lettuce, spinach, carrots and tomatoes were selected solely for palatability and for roughage. They contribute little to the overall protein and carbohydrates intake of the crew, but enhance the daily meals by offering fresh salad components. Wheat will be the major source of both protein and carbohydrates. It will be processed into wheat flour for breads and pasta. White potatoes will offer a substantial biomass loaded with carbohydrates to give volume to the daily meals. Soybeans will be processed into soymilk, tofu and meat substitute.

Crop	Temperature Range (°C)	pH Levels Preferred	Photoperiod Preferred (hrs)	Harvest Cycle (days)
Wheat	21 – 23	5.0 – 6.0	18 –24	25
Potatoes	15 – 20	5.0 – 6.0	10 –14	100
Soybeans	20 – 25	6.2 – 7.5	10 – 14	66
Lettuce	20 – 25	6.2 – 7.5	14 – 18	21
Tomatoes	20 – 25	5.8 – 6.5	14 – 18	40
Spinach	20 – 25	6.2 – 7.5	14 – 18	21
Carrots	15 – 20	5.8 – 6.5	14 – 18	45

Table 4. Crop Environmental Requirements and Harvest Cycles[6,8]

Crop	Yield (g/m^2)	Area required (m^2)	Total grams (100 d period)	kcals of Carbs	kcals of Protein	kcals of Fat
Wheat	2650	18	47700	469511.1	88397.6	11858.2
Potatoes	4281	9	38529	5471.118	628.023	33.0848
Soybeans	344.8	11	3792.8	1232.66	1446.005	757.801
Lettuce	3810	3	11430	109.728	68.58	9.9761
Tomatoes	3384	2	6768	131.299	24.771	9.5388
Spinach	1412	2	2824	82.4608	74.5536	8.2799
Carrots	3866	3	11598	1020.624	101.2969	15.5645

Table 5. Crop Yields and Nutritional Content[9,10]

The selected crops will require a total growing area of 48 m^2 in order to provide the 25 percent projected daily caloric intake (Table 5). Each bay will provide 8 m^2 of growing area; therefore, all six bays will be fully utilized. The yields listed are based on the 100-day harvest period for the potatoes. During this time, wheat will have produced 4 harvests. Lettuce and spinach will have produced 5 times, while carrots and tomatoes will have been harvested twice. Table 4 shows the various temperature ranges, pH levels, and harvest cycles of the crops.

5.0 Environment

5.1 External Environment

The harsh environment of Mars is greatly considered in order to select a landing site and also structural materials for the survivability of the greenhouse.

5.1.1 Atmosphere

In comparison to earth, the atmosphere of Mars is exceptionally thin. Atmospheric pressure on Mars is less than 0.1% of Earth. Surface pressure ranges from 6.9 mbar to 9mbar as recorded by the Viking Lander. The composition of the Martian atmosphere is as follows[11]:

Major:	Carbon Dioxide (CO_2)	95.32 %
	Nitrogen (N_2)	2.7%
	Argon (Ar)	1.6%
	Oxygen (O_2)	0.13%
	Carbon Monoxide (CO)	0.08%
Minor (ppm):	Water (H_2O)	210
	Nitrogen Oxide (NO)	100
	Neon (Ne)	2.5
	Hydrogen-Deuterium-Oxygen	0.85
	Krypton (Kr)	0.3
	Xenon (Xe)	0.08

5.1.2 Landing Site

A proposed landing site for the greenhouse module is of great importance to the mission. The rock-hewn Martian landscape is riddled with craters, sand dunes, and many large boulders. The large Valles Marineris system has thousands of offshoot outflow channels. The innumerable quantities of artifacts on the surface are targets of great interest for scientists. However, there are also areas of great concern due to the possible hazards and damage to the greenhouse. As part of the Mars Direct Plan, CERES will be stationed adjacent to the Mars Cryogenic and Consumable Station (MCCS). The decision to chose a landing site is based on certain drivers that affect the location chosen. The scientific drivers insist on landing in a location with abundant sources for investigation into the possibilities of previous existence of water, and also an evidence of extinct life. However, to insure the safety of the module, the landing site must be clear of any large and dangerous obstacles, including boulders, landslides, and canyons. One guideline set forth by the NASA MarsPort committee is to limit the landing site to 15° above or below the equator.

POSSIBLE LANDING SITES	LOCATION	CHARACTERISTICS
Medusae Fossae	2S 159W	Area rich in dark sediments, origins unknown. Lava flows and water channels.
Southwest Tharsis Bulge	12S 150W	Lava flow channels filled with water flow sediments.
Apollinaris Patera	7.5S 182W	Deposits intersected by channels.

Table 6. Possible Landing Sites[12]

Several possible landing sites have been chosen (Table 6), based on several driving factors including those mentioned above. The area of Medusae Fossae in the southern hemisphere is a cratered plateau, rich with relatively recent lava flows and flood plains. The area is a sunken basin, where the accumulation of sediments from heavy water flow is evident from satellite photos and other data. The dark sediments located here of unknown origin and an expedition here would answer many questions as the nature of this global covering dust. Another possible location for the greenhouse is an area southwest of the Tharsis Plateau and Olympus Mons. This area is rich in geological artifacts and areas eroded by past water flow. It is also a location with large areas of level uncluttered fields in which to land. Another landing site is in the vicinity of Elysium Mons, in the area known as Apollinaris Patera. Similar to the previously mentioned site, the Apollinaris Patera is a shield volcano region situated in an area of great diversity, both geologically and scientifically. It consists of field deposits crossed by channels. All three of these sites have relatively level fields for which to safely land the greenhouse module.

5.1.3 Temperature

Surface temperatures range from a minimum of 150 K to a maximum of 310 K; averaging approximately 210 K[11]. Due to the thin Martian atmosphere there is basically no atmospheric greenhouse effect as there is on Earth. Because of Mars' distance from the Sun and lack of atmosphere, radiant cooling is extreme during the night, and insulation during the day does not compensate for the night cooling. Radiant cooling occurs during the day and night, although incoming sunlight more than balances the cooling during the day. The net loss of heat will be made up and controlled by heaters (thermal control system) inside the greenhouse[7].

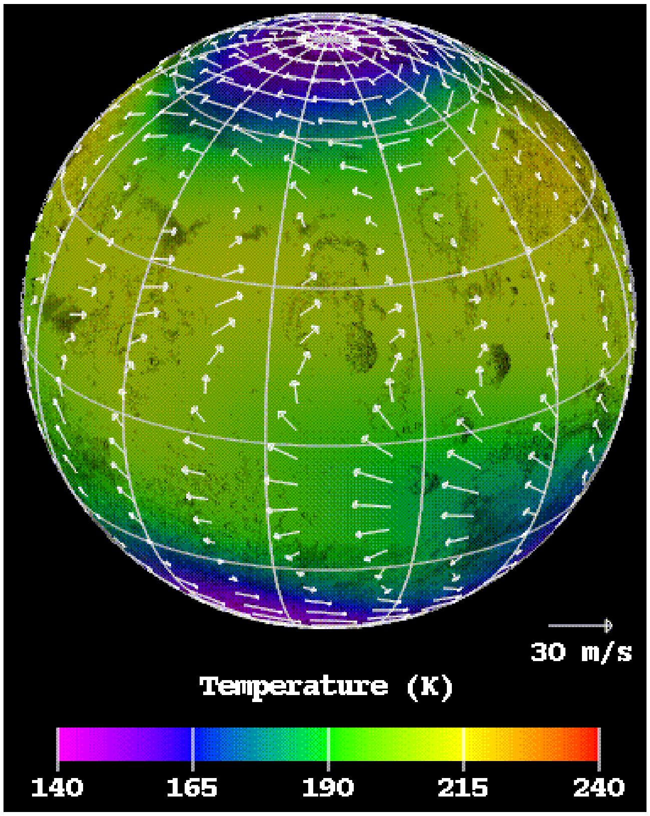

Figure 1. Mars Temperature Distribution and Wind Direction[3]

5.1.4 Wind Speed/Direction

Wind speeds and direction must be considered when designing a greenhouse, especially the occurrence of local or even global dust storms. Wind speeds vary by seasons. During the summer winds range from 2-7 m/s, and in the fall 5-10 m/s.[11] Dust storms can cause winds anywhere from 17-30 m/s and last weeks, or even months.[13]

Hundreds of dust storms occur every year, and occasionally a dust storm will expand to encompass nearly one or both hemispheres. Great dust storms tend to occur in the southern hemisphere, during its summer when Mars is nearest to the sun and there is maximum solar heating. The storms usually work their way north from south. The occurrence of dust storms, especially great, intense ones greatly affect the performance of the greenhouse.

5.1.5 Radiation and Solar Intensity

High-energy solar storms are much stronger on Mars than at the Earth's surface, because of Mars' distance from the sun and little to no protection from the Martian atmosphere. Therefore, ultra-violet radiation from the sun is able to penetrate to the Martian surface. Plants are susceptible to high-energy photons from cosmic rays to the ultra-violet part of the spectrum; therefore photons from solar storms may be the crops' greatest threat.

The irradiance at the Martian surface varies from 37% to 52% of the irradiance above the Earth's atmosphere. Besides the occasional dust storm, the Martian sky is mostly cloudless, whereas most agriculture places on Earth are often cloudy. Therefore, there should be sufficient light for efficient photosynthesis. The Martian day is 24.7 hours. Hours of sunlight vary with latitude and season (similar to Earth) because the equator is tipped 25° to the plane of its orbit. Plants that are sensitive to day length will respond to seasons in a Martian greenhouse just as much as they would on Earth. However seasons are longer on Mars than on Earth, with a Martian year being 686.99 Earth days long[7].

5.2 Internal Environment

5.2.1 Environmental Variables

Each bay of the greenhouse is isolated and capable of maintaining a controlled environment to optimize the performance of the plants. Five parameters of the environment are controlled for each of the six bays; temperature, pressure/partial pressures, length-of-day, light composition, and humidity. In this section, these parameters are described and evaluated for their effect on plant growth to maximize production. The specific environments for each of the bays are described in the next section (4.2.2).

Crops on Earth are categorized into two main season groups, cool season crops and warm season crops. The optimal temperature range for cool season plants is 25-30 degrees C with a lower threshold at 5 degrees C. Warm season crops are threatened by frost and perform best in a temperature range of 30-40 degrees C, depending upon the specific plant variety[14]. However, the MarsPort constraint is to stay within a temperature range of 10-30 degrees C. This indicates that the crop selection may have to grow in an environment just slightly cooler than encountered in nature. By reducing the natural temperature of the plants, it is hoped to eventually breed a 'Mars suited' variety of the selected plants. With this in mind, the cool season crops have a temperature margin of 15-20 degrees C and 20-25 degrees C for the warm season crops.

The specific partial pressures that are of interest to maintain are of oxygen, carbon dioxide, and buffer gasses (nitrogen and argon). It would be greatly advantageous to have a reduced interior pressure so that the internal/external pressure difference is minimized, thereby reducing the structural demand. For the design an overall pressure of .7 atm will be maintained, which is a generally accepted limit for extended human performance. The design constraints are to keep the partial pressure of carbon dioxide between .1 and 3.0 kPa and the partial pressure of oxygen above 5.0 kPa. On Earth the partial pressure of oxygen is 21.21 kPa and the partial pressure of carbon dioxide is .0318 kPa. However humans can tolerate oxygen levels from 19 kPa to around 28 kPa without any serious side effects for extended periods of time. Likewise, humans can tolerate partial pressures of carbon dioxide up to .40 kPa for long periods of time. Plants in general perform well in carbon dioxide partial pressures of up to .2 kPa, while the partial pressure of oxygen may vary depending upon the species. However, the germination partial pressure of oxygen is lower than tolerable levels for humans, which is why it was decided to provide isolated germination chambers where the atmosphere can be tailored without harm[15]. All of these described partial pressures are taken at one atmosphere, so the final design parameters reflect the reduction in overall pressure to .7 atm. With this in mind, the atmosphere will consist of 14 kPa (20 kPa at 1 atm) of oxygen, .14 kPa (.2 kPa at 1 atm) carbon dioxide, and around 56.56 kPa of buffer gas (which includes the vapor pressure of water due to humidity). Depending upon the different plants, each bay can be tailored to have a different partial pressure of oxygen ranging between 13 kPa and around 16 kPa.

Crops across the world experience dark periods of varying length, depending open geography. However, tests have indicated that changing the length of day has not significantly enhanced the growth, with a few exceptions (such as wheat, which can grow for practically 24 hours). As long as normal crops receive light for about 10-14 hours a day and experience a daily dark period, they will achieve optimal performance[16]. One Martian day is about 24.5 Earth hours, therefore the normal length of the Martian day around the equator will bring a “normal’ light and dark period. So the length of day will be passive with the Martian length of day as much as possible.

Plants utilize two types of a molecule called chlorophyll to transfer solar energy into chemical energy. These two types are simply called chlorophyll a and chlorophyll b. Chlorophyll a absorbs light most at wavelengths 430 nm and 662 nm (blue light is around 400-450 nm while red light is around 620-660 nm) and chlorophyll b absorbs most at 453 nm and 642 nm. This specific range of wavelengths needed for plants presents a great opportunity to control the light composition for greater efficiency. Currently at the Kennedy Space Center Biomass Production Chamber, experiments are being done to determine just how much of the two ranges of light should be used for optimal performance[17]. Initial tests have shown that most crops have the best response using a combination of red light at a wavelength of 650 nm plus 10% blue light[17]. Our design will use 85-90% red light in a wavelength range of 640-660 nm and 10-15% blue light in a range of 430-450 nm.

Our last environmental variable is the relative humidity within each bay. Humidity is part of an overall concept called vapor pressure deficit (vpd), which is a measure of the propensity of a certain atmosphere to absorb evaporated moisture[15]. Vapor pressure deficit is a common variable in botany and green house research, it is inversely proportional to the relative humidity and directly proportional to the temperature. Low vpd (high relative humidity) tend to result in reduced leaf area due to a lack of calcium, increased stomatal transfer of gas, reduced final yield and crop size, and a higher chance for disease. Conversely, high vpd (low relative humidity) can result in dehydration, closure of the stomates, and blossom-end rot. In general, it is commonly recommended to keep the vpd on the high end of the scale, with an upper limit of around 1 kPa. This drastically reduces the chances of disease and ensures a healthier crop size[18]. Only one of the selected plants respond better to a lower vpd, which is the tomato. Our target vpd is .5-.55 kPa for the tomatoes and .8-.85 for all of the other plants.

5.2.2 Internal Environment of Each Bay

5.2.2.1 Bay 1 and 2

Both bays one and two will grow only dwarf wheat, with a growing area of 8 m^2 in each bay (two meters wide by four meters long). The effect of reducing the growing temperature on these bioengineered species of wheat is not precisely known, so the internal temperature of bays one and two is 21-24 degrees C. The initial partial pressures will be as follows: oxygen 14 kPa, carbon dioxide .14 kPa, buffer gas 53.69 kPa, water vapor .85 kPa. As further research is conducted, the partial pressure of oxygen can be varied to optimize growth. The light composition for the wheat bays are 85% red LEDs in a range of 640-660 nm and 15% blue LEDs in a range of 430-450 nm. With a vpd level of .85 kPa and an internal temperature of 21-24 degrees C, the resulting humidity is 65%-73%.

5.2.2.2 Bay 3

Bay three houses two square meters of dwarf wheat, two square meters of tomatoes, and four square-meters of soybeans. The internal temperature is 21-24 degrees C, and the partial pressures are: oxygen 14 kPa, carbon dioxide .14 kPa, buffer gas 53.89 kPa, water vapor .65 kPa. The light composition is 87% red LEDs at 640-660 nm and 13% blue LEDs at 430-450 nm (arranged so that the 2 m^2 of wheat receive 15% blue and 85% red, while the rest receive 10% blue and 90% red). The vpd level is to be a compromise between the needs of the tomatoes and that of the wheat and soy. The target vpd of the tomatoes is .5-.55 and the target vpd for the wheat and soy is .8-.85. So the bay target vpd level is .65. With an internal temperature of 21-24 degrees C, the relative humidity of the bay is 73-78%.

5.2.2.3 Bay 4

Bay four holds seven square-meters of soybeans and one square-meter of micro potatoes. The internal temperature is 15-19 degrees C and the partial pressures are the same as for bays one and two: oxygen 14 kPa, carbon dioxide .14 kPa, buffer gas 53.69 kPa, water vapor .85 kPa. The light composition is 90% red at 640-660 nm and 10% blue at 430-450 nm. The target vpd level is .85, which results in a relative humidity of 50-60%.

5.2.2.4 Bay 5

Bay five will grow only micro potatoes. The internal temperature is 15-19 degrees C and the partial pressures are: oxygen 14 kPa, carbon dioxide .14 kPa, buffer gas 53.69 kPa, water vapor .85 kPa. Artificial light is 90% red at 640-660 nm and 10% blue at 430-450 nm. The target vpd is .85, at a relative humidity of 50-60%.

5.2.2.5 Bay 6

Bay six houses three square-meters of carrots, two square meters of spinach, and three square-meters of lettuce. The initial internal conditions match that of bay five, with the option of modifying the environment for optimization.

5.2.3 Trade options

Due to the diversity of the plant selection, the major trades in this section stem from whether the environment should be specifically tailored to each bay or maintained constant throughout. If the specific variables were maintained constant, there would be a general reduction in production but also a reduction in the complexity of the system. Inversely, controlling each variable to the specific needs of each bay will result in a greater yield but also a greater complexity of the system. The specific tradable variables are as follows:

Temperature: Plants are divided into cold season crops and warm season crops with a target temperature difference of about 5-10 degrees C. The temperature could be maintained at a single constant value or specific to each plant's optimum growing conditions.

Air Composition: As described in section 1.7.1, the main constituents of the greenhouse air are oxygen, carbon dioxide, and buffer gas. There are three main trades in this area. The first is that the atmosphere in the growing bays could be optimal for plant growth, and therefore be less hospitable to the crew (oxygen masks would be needed for long duration exposure). Secondly, one could take advantage of the overlapping optimal requirements for both humans and plants. This would result in a common atmosphere that is not detrimental to either plant or human, but not optimal to either. And third, the entire module could be kept at a composition most suited for humans, making the greenhouse safer but less efficient. Of course there is also the option of varying each bay versus keeping them all the same.

Length of Day: The major trade in this area is to allow each bay to vary its length of day independently. As stated above, this would complicate the system, but allow for optimal conditions in each bay.

Light Composition: Each plant has a slightly different demand for the two main wavelength ranges described in section 1.7.1. Therefore, the amount of blue and red LEDs in each bay could be varied to meet this demand. The alternative is to fix the ratio of blue to red LEDs for all the plants. Again, the varying system optimizes performance but adds a greater complexity to the system.

Humidity: As with the other variables, each plant has a slightly different vpd level. The main trade in this area is to keep the entire greenhouse at a constant vpd that would be a compromise between all of the plants. Just as with the other areas, this will reduce the complexity of the system and reduce the productivity.

6.0 Greenhouse Subsystems

6.1 Hydroponics Growth System

The hydroponics system incorporated into this design will be the Nutrient Film Technique (N.F.T.). This system is considered to be an active recovery type hydroponics system[19]. Two different types of designs incorporate the ideals of the N.F.T. For plants with a root system like wheat and soybeans a net pot or grow-basket will be used to suspend the crops above covered trays. The roots will then grow through the hydrocorn resting in the nutrient supply solution. This allows for maximum root growth with optimal opportunity to absorb air and nutrients[19]. Plants such as potatoes that do not have the traditional plant and root system will simply be placed in open bins with the nutrient supply flowing under them. These grow-baskets and trays will be completely opaque to ward off algae growth. Also, the bins will be placed at an angle so that the new nutrient solution is always supplied to the plants.

An alternative to using the NFT is the Porous Tube System. The pros of this technique are found in the conservation of space and minimization of water. The cons of this system are found in its effects to plant growth success. The tubes can become clogged with a build up of nutrients[20]. Also, the roots have less area to grow. This lack of area generates a problem with the supply of air to the root system.

Other, more commonly used hydroponics techniques are an Ebb and Flow System or a Continuous Drip System. These systems commonly use a growth medium, which adds to the mass of the design. Also, both of these techniques create a large water supply demand[21]. Taking into consideration the location of the hydroponics in the greenhouse these systems become complex to implement.

6.2 Nutrient Supply System

The nutrient supply system will be a re-circulating hydroponics system containing a refill solution and a circulating solution. The re-circulating system will minimize costs. The system will incorporate the "mass balance" principle used by the University of Utah to grow their super dwarf wheat. With the "mass balance" principle, the nutrients are located in two possible places, the plant or the solution. Therefore, the nutrient supply will depend on the desired amount for the plant to absorb from solution. Imbalances in the nutrients of the circulating solution are cumulative; therefore, it is important to produce a refill solution that can replenish the water as well as the nutrients[22].

The ratios of nutrients in solution are specific to each plant. The composition of nutrients in solution will be similar to the ratio of the nutrients found in the leaves of the plants. The life of a plant can be categorized into three stages. The first stage is the "early vegetative growth" of mostly leaf tissue. The second stage is the "late vegetative growth" period. The final stage of plant growth is the "reproductive growth" period. A different refill solution with different ratios will be produced for each stage of growth[22].

The concentration of nutrient ions in solution depends on how much water is absorbed by the plants compared to the amount of nutrients absorbed by the plants. In order to determine the concentrations of ions in the nutrient supply refill solution, the electrical conductivity must be monitored. For instance, if the conductivity increases the refill solution should be made more dilute while maintaining the same composition. A float valve will be installed to automate and maintain the nutrient concentrations[22]. Upon arrival of the crew, plant tissue will be analyzed to better refine the refill solutions at each stage of growth.

A slightly acidic solution increases the availability of nutrients to the plants; therefore, a prescribed range[20] for pH is 5.5-5.8. However, it is not easy to maintain pH in this small of a range. Studies at the University of Utah claim that plants grow equally well at pH levels ranging from 4 – 7. An automated pH control system will be used to monitor and control the pH of the nutrient supply system. This system will have three parts: a pH electrode, a pH controller, and an acid/base solenoid.

The containers and flexible hoses for the nutrient supply system will be sterile and corrosion resistant. Metals are to be avoided for the material of the containers in order to avoid contamination and oxidation of the nutrient solution. Both container and tubing must be completely opaque to prevent algae growth. A common tank will be placed in the center of the first floor to hold the nutrient solution. A slow flow rate of about 8 liter per minute will be used to provide a consistent water and nutrient supply to plants. An air pump will be placed in the nutrient supply container in order to aerate the solution.

6.3 Air Filtration/Composition Maintenance

The most important aspect of the Mars Deployable Greenhouse is the internal atmospheric composition. With the necessary elements, in proper conditions, both human and plant life can survive. The life support systems of the MDG must be maintained at a specific balance in order to insure crew safety and optimal crop growth. A suitable total ambient pressure in the module would be set at about 70kPa. This level has been chosen based on several factors to achieve the desired results in the growth compartments and to support human needs.

There are two primary drivers that must be taken into account to determine the optimal pressure. The major engineering and structural constraint is to keep the pressure as low as possible to minimize the pressure gradient relative to the external environment. If the pressure is too high, the need for heavier, costlier, reinforced structural components arises. However, certain biological constraints also influence the pressure selection. Human lungs need a specific alveolar O_2 pressure to sustain adequate performance, which would also minimize the risk of Decompression Sickness. Decompression Sickness is an ailment that arises from placing the body in an environment where the barometric pressure is so low that the inert gases that are usually dissolved in tissues and fluids in the body, such as nitrogen and argon, begin to force out in the form of miniscule bubbles. These bubbles rise to the surface and cause extreme pains and possible death.

This level of 70kPa barometric pressure must also have a balanced composition of elements. Normal atmosphere at sea level on Earth is comprised mostly of nitrogen at 78%, oxygen at 21%, carbon dioxide at about 0.033%, and a remainder of various other gases. Martian atmosphere, while relatively thin compared to Earth's atmosphere, does include a variety of elements. Of vast proportion, carbon dioxide is by far the greatest component of the atmosphere at 95.7% of the total atmosphere. Nitrogen and argon round off the major constituents at 2.7% and1.6%, respectively[23]. To obtain a sufficient level of atmosphere within the module, CERES can carry with it a supply of gases from Earth to provide the necessary constituents of an atmosphere. By already having the internal environment prepped for the mission, the controllers would be allowed to forgo any time consuming process of creating the atmosphere. Another possible option is to introduce the ambient external atmosphere into the module. With the addition of acceptable amounts of oxygen, a correct compositional balance could be achieved to efficiently produce the internal atmosphere instead of relying on pre-contained gases. By continuing with the theme of In-Situ Resource Utilization as part of the Mars Direct Plan, the costs associated with atmospheric control are dramatically reduced. The introduction of the native elements in the atmosphere, including argon, would allow the pressure to be lowered to, and maintained at, 70kPa. Table 8 illustrates the two possible choices for producing the internal atmosphere for CERES. Based on the very limiting factor of cost, it seems more likely to utilize the native Martian atmosphere as the basis of the internal MDG environment.

Atmosphere Development Options	Advantages	Disadvantages
Earth-based Pre-contained Gases	Significantly less mission prep time, no timely processes of atmosphere creation.	Extremely costly, increased weight including storage canisters.
In-Situ Atmospheric Production	Reduces costs and weight issues dramatically, virtually unlimited atmospheric resources for experimentation and to compensate for leakage.	No guarantee for successful production.

Table 8. Atmospheric Production Trade Options

As mentioned previously, a specific range of pressures for oxygen is necessary to prevent ailments, such as Decompression Sickness and hypoxia, a lack of oxygen in the body. Increased levels of oxygen would allow for lower pressures, and therefore less stress on the structure. However, it also introduces the catastrophic factor of increased flammability. A set level of oxygen would be used to provide adequate supply to the lungs. An addition of nitrogen and other inert gases is used to maintain the total pressure determined. In order to monitor the levels of oxygen, a sensor must be installed in each compartment. An infrared gas analyzer (IRGA) or a gas chromatograph could be used to monitor not only the oxygen concentration levels, but also the various other gases in the atmosphere.

With the introduction of humans and the crop stuffs, the effects of new biomass into the closed system must be accounted for. Microbial contamination is a major concern to be handled promptly and safely. The risk of diseases, to both humans and plants, increases dramatically with the increase in humidity, temperature, and bacteria. Each compartment will house a variety of crops, each with its own distinct characteristics. To avoid any possible cross contamination, each compartment is isolated from the main core section by means of a sealed door. Once through the door, the crewmember would then be flushed with an anti-microbial spray and compressed air to remove any harmful particles. A collapsible entranceway, similar to that used in bioresearch clean rooms, is then opened to access the main compartment. Air filtration scrubbers will be located throughout the central core area and also in each compartment. These filters will prevent the spread of harmful particles and bacteria around CERES. Gaseous filters that are controlled by the IRGAs to help maintain the proper balance in the internal atmosphere might also accompany these filters.

6.4 Thermal Control

A very significant and yet often overlooked aspect of a closed life-support system is the generation, distribution, and dissipation of heat. Within any enclosed system, housing a variety of electronic components, bio-systems, or any other such heat-producing elements, environmental controls to manage this thermal addition is absolutely necessary.

The environment of Mars plays a key role in the development of an efficient thermal control system. The extreme cold temperature variation on the Martian surface would be completely disastrous for plant life. It is necessary to provide ample heating in the greenhouse structure to maintain adequate temperature ranges. The gravity on Mars is roughly 3/8th that of Earth's. This discrepancy would not only affect the growth of the plants, but also the heat transfer and control systems. On Earth, the pull of gravity causes the heavier cold air to sink to lower levels, and the lighter warmer air to rise. This convection circulates the air in an enclosed system, provided an adequate ventilation system is in place. On Mars, however, "…heat does not rise or dissipate well… [24]" In CERES, a higher level of air circulation and ventilation pumps and systems must be instated within the enclosed compartments housing the hydroponics bays. Waste heat is produced by many factors in a closed system such as CERES. The computer systems and equipment generate electrical heat, as do the experiments themselves. One of the greatest contributors to excess heat is the lighting system. Although LEDs and fiber optics might be used, to lower heat radiation, there is still a significant degree of heat accumulation. Human metabolic heat radiation and the slight heat loss from the plants also contribute to the heating. Heat transfer between other compartments and the exterior environment is caused by module heat leakage.

In order to properly maintain adequate temperature levels in CERES, certain requirements must be met. To compensate for the relatively low efficiency of the air circulation, ventilation fans and pumps must be used to distribute the air throughout the compartments. Anti-microbial heat exchangers must also be used to dissipate the heat generated by the various factors. This collected heat could be either distributed to other areas or converted to a form of energy. A very innovative idea to compensate for the heat generated by the lighting systems and possibly the electronic components is the use of water-cooled tubing. Bladders of water are arranged around the lighting and the computer systems. Connected by a series of encompassing tubes, the water circulation absorbs the dissipated heat and re-circulates it to other areas, much in the same manner as an air heat exchanger works for distributing heat in the ambient air. To insure safety, the cooling loops will be sized to "…accommodate greater than nominal heat loads should one cooling loop fail.[25]" Any excess accumulation of unwanted heat is sent to a heat rejection system to evacuate it from the module.

6.5 Lighting

There exist several possibilities for CERES's lighting system. The source and location of each design has its pros and cons. The light source must utilize a portion of the outside photosynthetically active radiation (PAR) and supplement with artificial lighting to produce the required daily 50W/m^2. The location of the light source is a large determining factor on the system to be implemented in CERES. The efficiency of light projected from the source to the plant surfaces must be high. However, tolerances must be given to allow for growth of the plants as to not burn the plants with too intense lighting. Another constraint to be considered in the lighting system is the various photoperiods each plant requires for optimal growth.

For the PAR lighting two trades can be implemented. The first option is to use a transparent material in the growing bays of CERES. This can encompass the entire ceiling or just a windowed portion. Several obstacles are encountered with this system. The major concern is with the survivability of the material in the harsh pressure gradient between the Martian atmosphere and the internal atmosphere of CERES. Outgassing of the CERES will be increased at edges of this transparent material. To accommodate the pressures on both sides the internal pressure could be lowered. This however would reduce the crop yields and present a health problem to the astronauts. Another condition to be considered from this lighting system is the thermal disturbances created by the PAR directly penetrating the greenhouse. The obstacle of directing the incident PAR to the plants must also be overcome. The appealing portion to this lighting design is its automation simplicity, where there are minimal moving parts and minimal mass to the system.

The second option for utilizing the photosynthetically active radiation is through fiber optics. Incident light would have to be harnessed by solar collectors and piped into each bay via the fiber optics. This system does not have the pressure gradient and thermal obstacles that the transparent system encounters. However, the complexity of this system minimizes its appeal. To provide enough light for plant use, the fiber optic bundles must be large. This is an increase in size and mass to the lighting system. The other obstacle encountered in this design is the automation of feeding the fiber optics stored in the bays prior to Mars deployment to a location above the plants once CERES is expanded. Reflective material would be used to disperse the focused light from the fibers to a larger area.

The artificial lighting will be supplied by LEDs. The LED is smaller and lighter than conventionally used lamps. Its flat thin shape allows it to be placed in various locations. A reflective material will be used to disperse the light supplied to a large area. The LEDs will either be suspended from the ceiling or fixed to posts protruding from the hydroponics bins. By fixing the LEDs to posts, the problem similar to the fiber optics in feeding them into an expanded bay post deployment is eliminated. Lamps were not considered for this design due to their high thermal outputs and large power demands.

6.6 Data Distribution and Storage

With such a complex and pioneering system as CERES, scientists on Mars and also on Earth must preserve the experimental results and operational data for use. An effective system of computer processors, data collection and storage devices, and analyzing tools must be accommodated for in the greenhouse module.

An integrated system of computers and processor units will be installed into CERES. Each compartment will be governed by a general command computer system. These general "governors," as it were, are primarily used for two main utilities, data relay and cache storage. Each hydroponics bay will have a variety of sensors, as well as compartmental sensors. There will also be variety of data input units to monitor the nutrient intake of the crew. A possible system of barcode readers would be used to record what foods the crew has eaten[26]. The data obtained by these devices is then relayed to the "governor" computer housed in the compartment itself. This system would organize and store the data in the temporary safety cache storage units. These units would most likely be a solid-state recorder type of media. The same data is duplicated and relayed to the Central Processing and Relaying Unit (CPRU). This central computer is the core of the integrated computer system, whereby it will collect all data from the various general command systems. The CPRU functions as the switchboard for relaying the incoming data from a compartment to other compartments, to the main storage unit, or to the transmitting station system. The main data storage unit (DSU) is a collection of solid state and tape recorders. The DSU would be housed in its own protective architecture to insure the survivability of the data. A secondary DSU unit (SDCU) would also be housed separately from the DSU, with a more highly compressed data structure to be used as a back-up system. Another parallel system to be used in conjunction with the CPRU is the Data Transmission and Command Transponder (DTCT). This transponder would be the main data communications link between CERES and Earth-based receivers. Figure 2 illustrates a very basic schematic for the computer units.

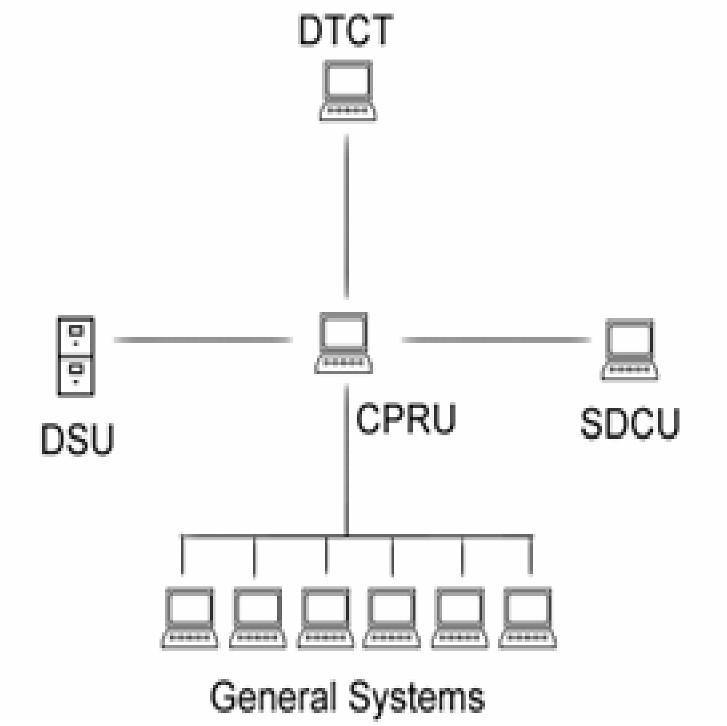

Figure 2. Viable Option for the Integrated Computer System

Another option to the concept of the computer systems is to have one main system combining the CPRU and DTCT as one unit, called the Central Processing Unit (CPU). This main unit would perform the majority of the tasks excluding the storage. The benefits of this option would be a reduction of costs by limiting the number of systems. Also the amount of weight and heat would be reduced. However, the first option of using a hierarchical system allows for a more improved data organization and distribution, a dramatic increase in safety as far as storage and handling is concerned, and the ability to modularize the system for updates, repair, and isolated uses. The following table illustrates these options.

DATA DISTRIBUTION AND STORAGE OPTIONS	ADVANTAGES	DISADVANTAGES
Hierarchical Network Approach	Redundancies, Data Safety and Storage, Modularization	Excess Heat and Weight
Concentrated Computer System	Less Complex, Inexpensive	Increased Risk of Data Loss, Any Damage to Component Collapses the System.

Table 9. Data Systems Options

Based on the complexity of CERES and the risks of possible failures, the hierarchical system is a very safe and effective technique to use on the mission. The level of organization and data safety is increased considerably. The excess heat must be accounted for in the thermal analysis and be accommodated for by the Thermal Control System. Since the majority of the systems will be small electronic components, the factor of weight can be adjusted for easily.

6.7 Power Systems

While the module is in transit, any power required is provided by hydrogen/oxygen fuel cells. In this scenario, the average power available over the duration of the outbound journey is directly dependant on the stored oxygen and hydrogen, and as such will be fairly low. However, this option will provide the water necessary as well as providing power on the way (plus the fuel cells can be refilled and used again). Once on the surface, the remaining power requirements are provided by Dynamic Isotope Power Systems (DIPS). Although DIPS are still in the design and test phase, the technology they use has been around for decades. DIPS are a variant to the RTG, or radioactive thermoelectric generator. The major downfall to most RTG designs is that they are a low power generator. DIPS solve this by taking out the thermocouple and adding a turbine with a working fluid. The radioactive decay heats the working fluid, which causes a convective flow – thereby turning the turbine. The benefit of this system is that it can generate kilowatts of power for very long periods. However, it is mechanical in nature so it will have to have a maintenance schedule. The power systems are located on the second deck in the mechanical ring, while the hydrogen and oxygen tanks for the fuel cells are located in the sub-deck.

7.0 Conclusion

The first crew to visit Mars will need a sustainable source of food crop to supplement their daily nutritional requirements. CERES will provide up to twenty-five percent of this requirement. In order to provide a viable greenhouse, specific criteria must be successfully developed and implemented.

The growth equipment on CERES will consist of hydroponics and support systems. Growth and harvest of crops will be mostly automated until crew arrival. NASA intervention during the initial deployment period will be limited to operational adjustments and commands. The crops selected include soybeans, tomatoes, lettuce, potatoes, wheat, mushrooms, spinach, and carrots. These crops contain high protein, carbohydrates, and caloric value per unit mass. Crop selection is of great importance since it dictates the structural and growth equipment architecture. The structure of CERES will consist of six inflatable growth bays, a food processing area, and a research lab. The outer shell will be sufficiently durable to withstand the differential pressure gradient as well as possible dust storm damage.

CERES will provide the necessary supplemental nutritional requirements and a suitable pressurized research station for the first human mission to Mars. This module is but one of the many components that will be part of the next era of space exploration.

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APPENDIX