I. Introduction

The project is to design the life-support systems for a Mars space station.

II. Preliminary Information on Mars

Before beginning the space station design, it was important to investigate the environment in which it would be built. Therefore, preliminary research on Mars was conducted.

Previous Missions to Mars

Although no country has successfully built a space station on Mars, several missions have been completed to obtain basic information about the planet.

Mariner Missions

The Mariner Missions represent the first attempts by the U.S. government to study Mars. Mariner 4 was the first spacecraft to complete a mission to Mars successfully (Williams, 2005). It was launched in 1964 and reached Mars in 1965 after 7.5 months. On a fly-by mission, the Mariner 4 took close-range images of the Martian surface. Mariner 4 was also tasked to take measurements of Mars's magnetic field. The images that the Mariner took were over about 1% of Mars's total surface. The Mariner 4 consisted of an octagonal magnesium frame with four solar panels attached, which provided power to the spacecraft (Grayzeck, 2010).

Mariner 9 was the first spacecraft ever to orbit Mars. It was launched in May 1971, and arrived at Mars in November 1971. Its mission was to take in-depth pictures of up to 70% of Mars' surface, look for signs of volcanic activity, and examine Mars's moons, Phobos and Deimos. Mariner 9 successfully took pictures of approximately 80% of the Martian surface and gave the first indication of possible traces of water with flow features. The design of Mariner 9 was similar to other Mariner missions, but it was larger, and required more thrust to maintain orbit.

Viking Program

Although the Soviets lay claim to the first objects landed on Mars, both of these landings immediately were lost after contact with the surface. It was the United States' Viking program that boasts the first successful mission on the Martian surface.

The Viking program consisted of two orbiters and two landers, Vikings 1 and 2. According to NASA, their mission was to "obtain high resolution images of the Martian surface, characterize the structure and composition of the atmosphere and surface, and search for evidence of life." (Williams, Viking Project) Viking 1 was launched in Aug. 1975, and landed in July 1976. Viking 2 launched in Sept. 1975 and touched down in Sept. 1976. The Viking landers lasted a combined 10 years on the surface of Mars. They took multiple pictures of the surface, and observed temperatures at their landing sites that ranged from 150 to 250 K.

Other Programs

Other programs of note that studied Mars include the Mars Global Surveyor, achieving orbit in 1997. This orbiter lasted 10 years before failing in 2006. The Mars Pathfinder mission, which carried a lander named Sojourner, landed on Mars in 1997. Recently in 2008, the Phoenix Mars lander touched down in the north polar region of Mars. Its primary mission was to obtain surface samples. The Phoenix found evidence of water, in the form of ice.

<u>Meteor Strikes on Mars</u>

A significant obstacle to a space station on Mars is prevalent meteor strikes. These impacts have been mapped by the Mars Global Surveyor Mars Orbiter Camera. In mid-latitude gullies, twenty new craters of diameters over 20 m wide have been formed between 1999 and 2006. Typically, 12 impacts above 4 m in diameter occur per year and may be as large as 148 m in diameter. It is assumed that surfaces devoid of craters are younger than surrounding areas.

Soil Composition

Previous missions have performed basic soil analyses on Mars. The Viking mission, launched in 1975, served to image the surface of Mars in detail. The Pathfinder Mission, commenced in 1996, served to analyze the atmosphere, climate, and soil composition on the planet. The Pathfinder rover contained an alpha-proton, x-ray spectrometer (APXS), which analyzed everything except H and He. Figure 1 shows the relative amounts of various elements in the Martian soil.

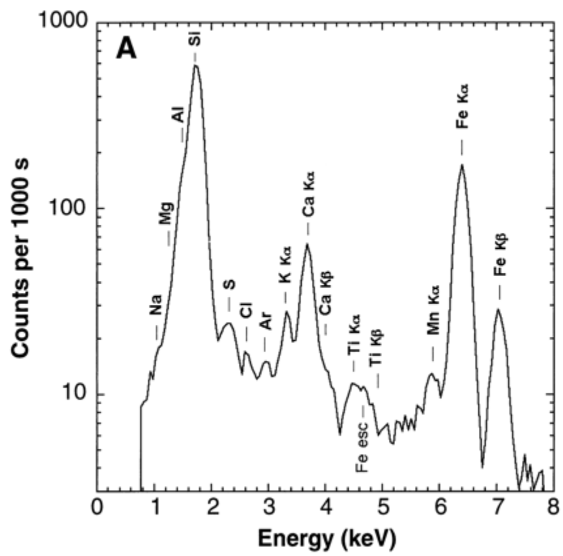

Figure 1: APXS – alpha mode, proton mode, x-ray mode (Rieder, 1997)

This soil composition is very similar to that on the surface of Antarctica. As pointed out by Chang (2008), “The sort of soil you have [on Mars] is the type of soil you’d probably have in your backyard.” The soil has a slight alkaline composition with a pH of 8-9, while still being full of mineral nutrients. Some plants that grow well in alkaline soil are sweet peas, asparagus, and okra (Lewis, 2010). An oven experiment confirmed the presence of water in the soil, although the soil itself does not contain any carbon or hydrogen compounds.

Ice Caps

While it has not been undeniably proven, it is generally accepted by NASA that there is water on mars (Found It, 2002; Water, 2008). However, it is unknown as to the quantity, purity, and exact location of the water. The current belief is that the vast majority of the ice exists as a 50/50 water-dirt mixture (Found It, 2002). The location of this slush mixture has been determined by the neutron spectrometer onboard NASA’s 2001 Mars Odyssey spacecraft, which detects gamma and neutron radiation excited from the Martian soil by cosmic radiation. Hydrogen’s radiation signature has been detected in the colder regions of the planet, namely the poles, where water would most likely be present. Images created by NASA using the neutron spectrometer can be seen in Figure 2.

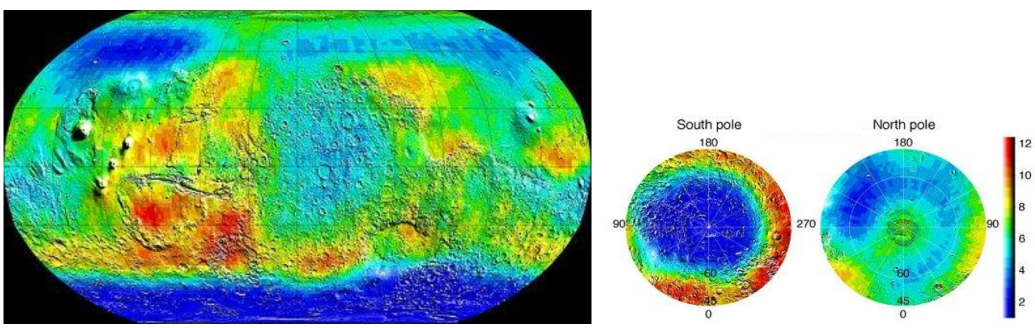

Figure 2: Hydrogen, indicated by the dark blue color, may indicate water in the form of ice on the red planet (Found It, 2002)

In summary, it is estimated that there exists at least 2,360 cubic miles (9,840 cubic km) of dirty water (water/dirt mix at least 50% water) on Mars to a depth of approximately two feet (Found It, 2002).

Atmospheric Conditions

The atmosphere on Mars is very thin, consisting of mostly carbon dioxide (Darling, 2005). The pressure on the red planet is only about 0.7% that of the pressure found at sea level on Earth. The pressure changes slightly in the winter months when the temperatures drops to the point that the carbon dioxide in the atmosphere can freeze and create "snow" on the polar ice caps (Darling, 2005). The Martian surface is also plagued by dust storms and very high winds. The composition of the atmosphere on Mars can be seen in Table 1.

Table 1: Mars Atmospheric Composition (Darling, 2005)

Viking Atmospheric Measurements[1]		
Composition	95.32%	Carbon Dioxide
	2.70%	Nitrogen
	1.60%	Argon
	0.13%	Oxygen
	0.07%	Carbon Monoxide
	0.03%	Water Vapor
	Trace	Neon, Krypton, Xenon, Ozone, Methane
Surface Pressure	1-9 millibars, depending on altitude; average 7mb	

For most of the year, the temperature on the surface of Mars is well below the freezing point of water (Darling, 2005).

<u>Rotation, Orbit, and Gravity</u>

The axis of rotation on Mars is slightly greater than that of Earth. However, Mars rotates around its axis in the same direction as the Earth, east to west. The rotational speed of Mars is approximately 4 minutes per degree, Mars moves around the sun about half a degree during each rotation. Figure 3 shows the Martian axis of rotation in comparison Earth's.

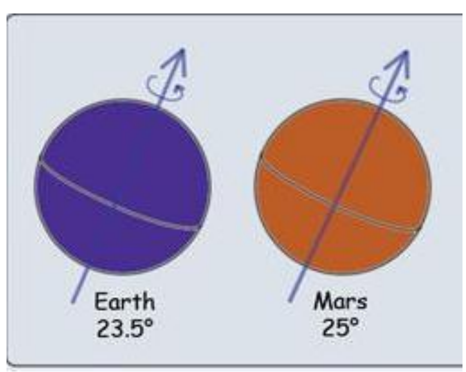

Figure 3: Axis of Rotation (Seligman)

The orbital period and length of a day are slightly different for Mars in comparison to Earth. A year on Mars is nearly twice as long as a year on Earth; however, a day is nearly the same length of time. Table 2 shows values for rotation times.

Table 2: Mars's vs. Earth's Rotation (Seligman)

Object	Orbital Period	Rotation Period (sidereal period)	Rotations/yr	Days/yr	Day Length (synodic period)
Earth	365.3 days	23 hr 56 min 4.1 sec	366.3	365.3	24 hr 0 min 0 sec
Mars	687.0 days	24 hr 37 min 22.66 sec	669.6	687.0	24 hr 39 min 35.24 sec

The gravity on Mars is also significantly less than on Earth. It has been found that the gravity on Mars is approximately 38% the gravity found on Earth. In other words, 100 kg on Earth would only weigh 38 kg on Mars. This could pose a problem to the astronauts, because their muscles will begin to atrophy after prolonged exposure to the lowered amount of gravity.

Seasons

The seasons on Mars are similar to those on Earth in that both planets have a total of four; however, Martian seasons are much longer and generally colder. During a common summer on Mars, the temperatures can be as high as 20°C, and during a typical winter, the temperature can go down to as low as -140°C (Weather and Seasons On Mars, 1999). The numbers of days per season are displayed in Table 3.

Table 3: Days per Season (Weather and Seasons On Mars,1999)

Seasons	**Earth**	**Mars**
(Northern Hemisphere)	(in days)	(in Earth days)
Spring	93	171
Summer	94	199
Fall	89	171
Winter	89	146

Sunlight, Wind, and Temperature

Sunlight exposure on Mars is approximately one-third that of Earth's. Figure 4 compares the intensity of sunlight on earth to the intensity on mars.

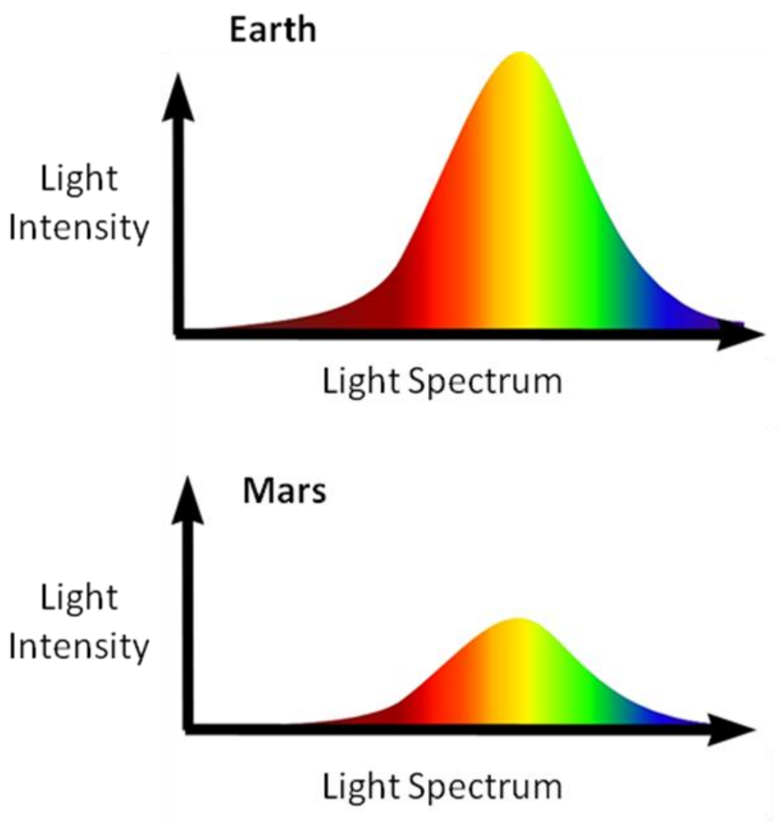

Figure 4: Comparison of light intensity of Mars and Earth ("Tomatoesphere", 2011)

The further distance from the sun is the primary reason for the difference in intensity. The incident energy on Mars ranges from 50-180 W/m^2 (Landis et.al., 2004). This energy range is based on a half-day, half-night Martian day, or a Sol. One Sol is equivalent to 24.66 hours on Earth. Mars has an equator like Earth, which is where the half-night and half-day time periods occur. The tilt of Mars's axis causes seasons and extended periods of light and dark in the polar regions. This is similar to the extended exposure times seen in Alaska.

Mars lacks a magnetic field. This causes solar winds to affect the atmospheric conditions on Mars. The solar winds create a less-dense atmosphere. Equatorial wind speeds have reached 60 km/hr (Europlanet Media Centre, 2008). The polar regions have recorded speeds up to 20 km/hr, much less than that of the equatorial winds.

The lack of atmosphere also affects the temperature on Mars, which is much colder than that on Earth. The highest surface temperature recorded was 25°C ("Universe Today", 2008). The air temperature taken less than 1 m off the ground rarely reaches 0°C. The poles on Mars can reach temperatures as low as -140°C. The highest air temperatures are found in the Gusev Crater. Figure 5 shows the temperature readings over one Sol from the Viking landing, which measured temperatures near Mars's equator.

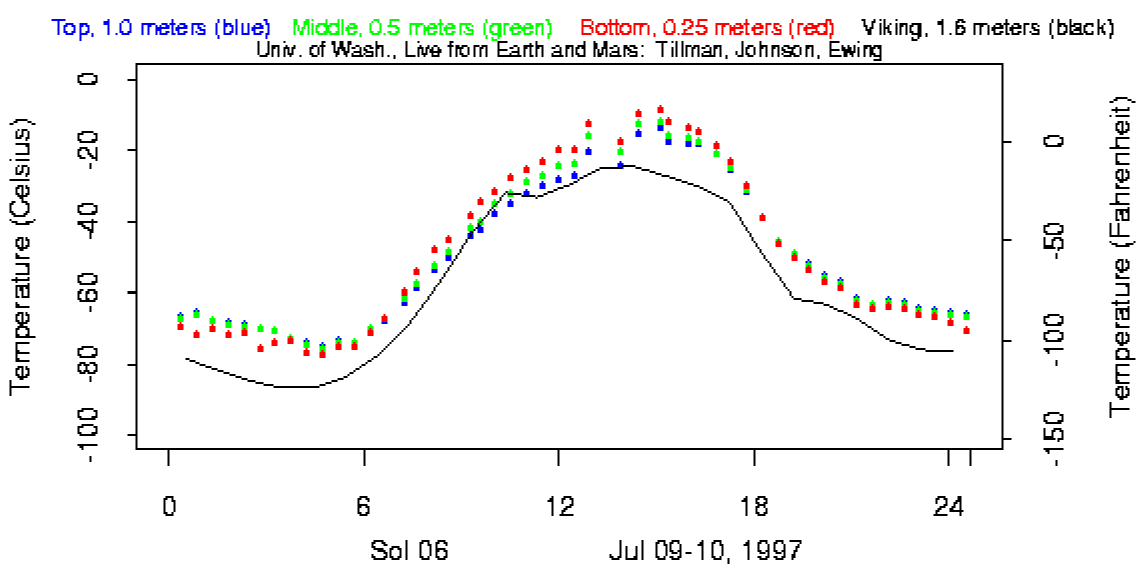

Figure 5: Temperature readings for a Sol (Tillman, 2011)

III. Current Issues Associated with Traveling to Mars

Although a human mission to Mars is a definite goal for NASA, there are several problems that must be overcome before it will be possible. The first of these difficulties is cosmic collisions. Meteoroids travel through space at speeds as high as 20,000 mph. At these high speeds, the particles can easily penetrate through the metals that would make up a spacecraft's walls. Simulations carried out by a gun built by NASA showed that particles as small as a grain of sand could pierce through several pieces of metal, creating increasingly large holes that reached a diameter of over a foot. Currently, tests are being done on foam shields that would be placed between the layers of metal to absorb the fragment's energy.

Another issue associated with traveling to Mars is the effect of cosmic rays. There are subatomic particles traveling close to the speed of light through space. These particles have very high energy and, as previously mentioned, there is no atmosphere on Mars to stop them. The particles break apart DNA and expose cells to cancer. So far, there are no solutions to this problem. There are also other health problems associated with traveling to Mars, one of which is bone and strength loss because of the zero gravity conditions. NASA testing showed that exercise did not stop these problems. Therefore, artificial gravity must be implemented. This could be done by building a room that spins based on centripetal force.

A problem NASA has been battling since the beginning of space travel is air pressure. With no air pressure, such as the conditions in space, the astronauts would continuously expand and their blood would boil. To avoid such extreme consequences, NASA developed space suits with 1/3 atm pressure. However, this causes the space suits to be very stiff, which leads to limited mobility. Due to the long mission time, if astronauts were to travel to Mars, they would need new suits. NASA is currently developing "shrink wrap" suits. These suits are made of a tight, spandex material laced with copper mesh and they compress the astronauts' bodies. Currently, they have only obtained a pressure of 2/9 atm with the design, so more experiments will have to be carried out before the suits are finalized.

Another existing issue is food supply. NASA has always had to develop unique food sources for space travel, but this difficulty is greatly amplified when traveling to Mars is considered. Current food sources do not have an adequate shelf life. However, thermally stabilized foods that will have a shelf life of at least five years are being researched.

Lastly, there is the difficulty of the time required to travel to Mars. Currently, a round trip to Mars takes at least a year. This makes it difficult to carry enough supplies to last between resupply missions. NASA is currently researching a new engine design that heats Argon gas to 1,000,000°C. They have encountered material of construction problems because of the heat given off by the plasma. However, utilizing magnets to create a heat shield around the plasma might be a solution. This engine could lead to speeds of 126,000 mph and could reduce the round trip to Mars to five months ("Can We Make It to Mars?", 2010).

IV. Assumptions

Because of all of the previously discussed issues associated with traveling to Mars, several assumptions had to be made before any designs could be determined. Firstly, it was assumed that at the time of the design execution, solutions to the problems of cosmic collisions and cosmic rays would have been developed. Also, it was assumed that the gravity present on Mars would be sufficient to have ordinary activity such as water flow in showers, normal plant growth, and normal mobility conditions. Because this is the design of the Mars base, and suits are not necessary to survive inside the base, the issue of the space suits was not considered.

To carry out design calculations, it was assumed that a resupply mission would return every 18 months. This would allow time for optimum planet alignment, as well as time to travel to Mars (“Can We Make It to Mars?”, 2010). Also, because this design focused on steady-state processes, initial equipment was not considered in the optimization. Instead, optimization was done based on resupply mission requirements. The objective function for optimization was weight. A value of $1 million/lb was used for shipping costs to Mars (“Can We Make It to Mars?”, 2010). Because this is such an extreme cost, all purchase and installed costs of equipment were assumed to be negligible.

V. Results and Discussions

The first steps taken in designing the space station were determining the necessary subsystems to support human life. After preliminary research, it was found that a food and biomass subsystem, a water subsystem, a solid waste subsystem, an air subsystem, and a thermal-management subsystem would be required. For the current design, it was assumed that a power-generation system to meet the needs of the base was available, but this system was not included in the design.

To fulfill the needs of the five subsystems, a base case was established in which all necessary supplies were brought up to Mars on 18-month resupply missions. The requirements for this case can be seen in Table 4.

Table 4: Base-case resupply mission requirements

Item	Weight (kg)	Cost ($ Millions)
Water	239,000	526,995
O_2 Tanks	5079	11,199
CDRA	359	792
MREs	8,940	19,713
TOTAL	**253,378**	**558,698**

As shown in Table 4, the base case would cost $560 billion every 18 months. Because this cost is so significant, it was necessary to optimize the system. This optimization included growing plants as a food source and recycling water, which will be discussed in more detail the subsystem sections. The resupply mission requirements for the proposed case are displayed in Table 5.

Table 5: Proposed-case resupply mission requirements

Item	**Weight (kg)**	**Cost ($ Millions)**
Water	214	471
Metal halide bulbs	3,446	7,598
Genesis units	318	702
Initial nutrients (ions)	875	1,930
Replenishment nutrients (ions)	1,136	2,505
Tofu	1,802	3,974
Whey	408	900
Additives	-	-
TOTAL	**8,200**	**18,080**
Emergency Supply		
O_2 Tanks	408	900
CDRA	359	792
MREs	81	179
TOTAL	**848**	**1,870**
Overall		
TOTAL	**9,048**	**19,950**

It can be seen from Table 5 that the proposed case eliminates the need to bring up air on resupply missions and drastically reduces the required amounts of the other supplies. This reduces the resupply mission cost to $18 billion, which is a 97% reduction in price. Even including the one-time emergency supply requirement, the cost is only $20 billion. Figure 6 shows the integration of the five subsystems in a process flow diagram.

It can be seen from Figure 6 that the Mars space station runs on a continuous loop, other than the water provided by the resupply tank, V-304, and the unrecoverable waste stored in the waste tank, V-306.

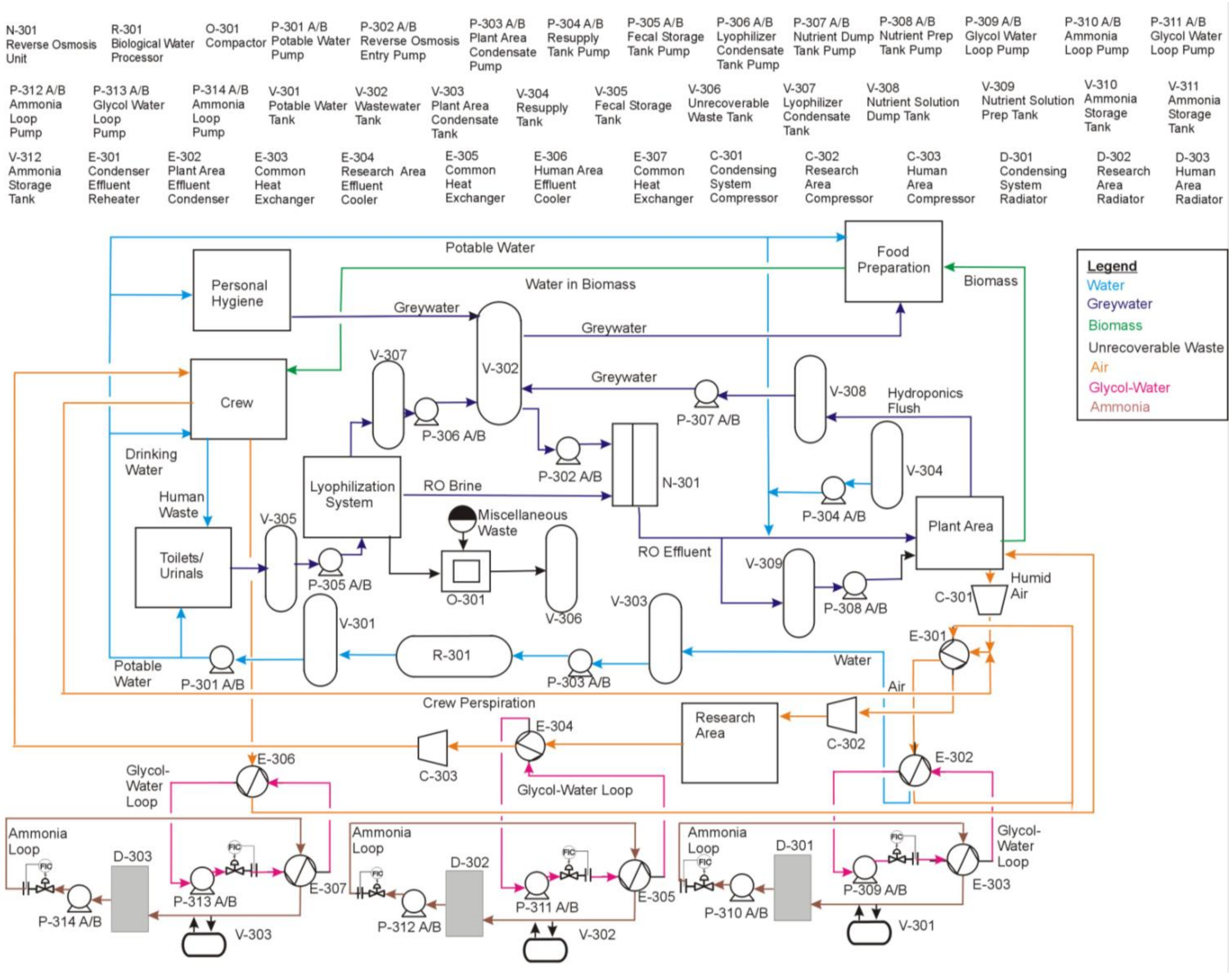

Figure 6: Process flow diagram for proposed Mars space station

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