MARTIAN BASE BASED ON ISS TECHNOLOGIES

AEROO Space Settlement Competition 2025

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Team name: Surge

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1. Abstract

The creation of a habitable environment for humans on Mars is a difficult undertaking, as the current surface conditions pose significant challenges. These include elevated radiation levels, the presence of toxic regolith, psychological challenges for humans, and unstable atmospheric conditions.

Project Objective

To develop a concept of a sustainable human base on Mars that ensures stable life-support systems, protection from radiation and reliable energy.

Hypothesis

If proven ISS technologies (oxygen production, water recovery, CO_2 removal) and habitat protection using Martian regolith are combined in a modular station, then humans can live and work on Mars.

Methods

Study of existing solutions, engineering analysis, 3D modeling, and evaluation of systems such as oxygen electrolysis, LiOH scrubbers, hydroponics, and hybrid power supply.

Stages

1. Research of Martian conditions
2. Finding suitable technologies
3. Habitat architecture sketch
4. 3D model development

Results of the Work

A complete concept for a Mars surface station, including protected habitat modules, autonomous life support systems, power sources, and hydroponic food production, was created, along with a 3D model demonstrating how these technologies could mitigate risks and enable long-term missions to Mars.

2. Problem and Goals

Missions to Mars require a high level of technological preparedness, specifically in the areas of life support, radiation protection, power supply, and human health care. It is obvious that operations on Mars involve high radiation exposure, and limited emergency delivery opportunities.

Figure 1 Highest resolution photo of Mars' surface. Source: National Space Grant Foundation

The surface of Mars is characterized by a prevalence of toxic dust, extreme temperature variations, dust storms, and an atmosphere so tenuous as to offer virtually no protection from cosmic radiation and micrometeorite impacts. It is evident that sustaining a prolonged presence on the surface is perilous and technically demanding.

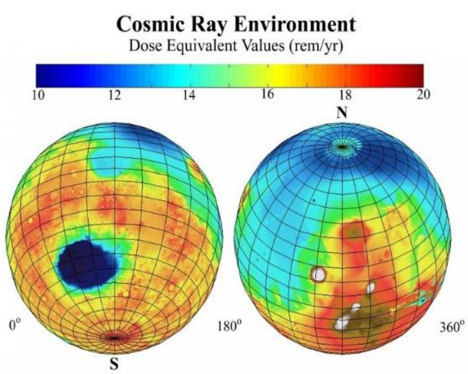

Figure 2 How bad is radiation on Mars? Source: phys.org

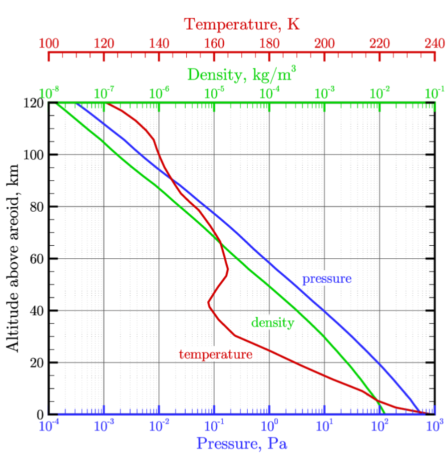

Figure 3 Mars atmosphere. Source: ResearchGate

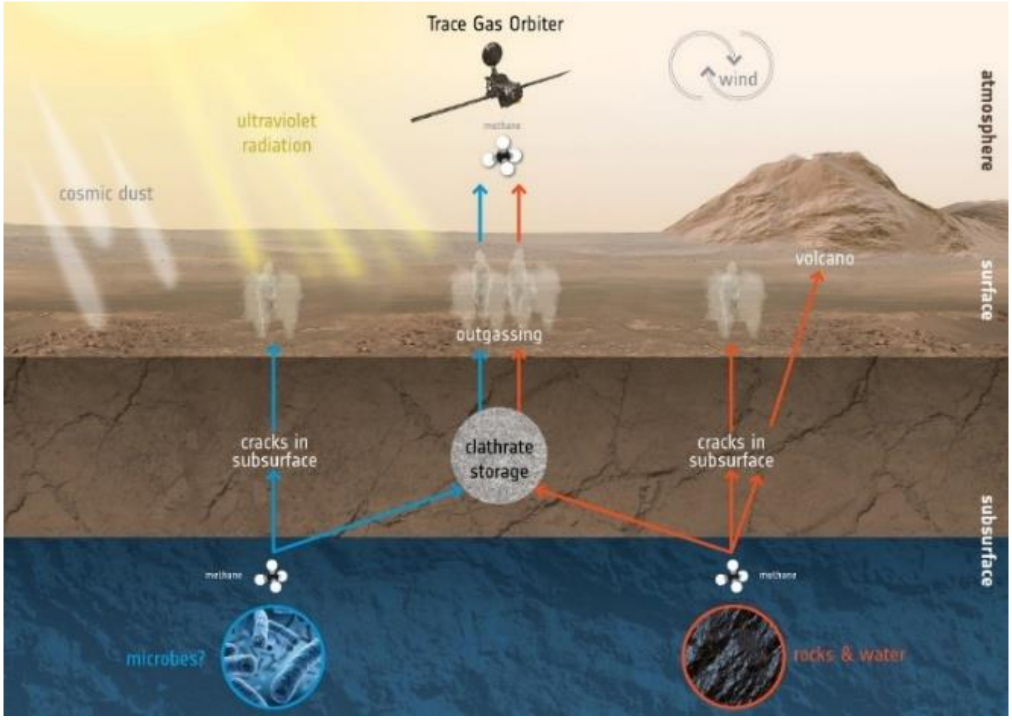

Figure 4 Creeating and Destroying mathane on Mars. Source: ESA

A fully functional Martian base is essential as an intermediate step between current space exploration and the colonization of Mars. It allows astronauts to remain in the Martian system for extended periods of time, conduct scientific research, test life support technologies in natural conditions, and prepare for future landing missions without direct exposure to hazardous surface factors.

Project goals:

1. Develop a 3D design for an orbital habitat
2. Integrate closed-loop life support systems. These provide a continuous supply of oxygen, MOXIE, CO_2 removal, and water recovery.
3. Provide a reliable power supply using nuclear powers.
4. Use of hydrogen-rich materials and waterproof shielding to provide protection from radiation.
5. Supporting the physical and mental well-being.

Additional challenges:

1. The availability of solar energy is limited by two factors: reduced solar radiation and frequent sandstorms. Therefore, it is essential to ensure the availability of reliable backup energy sources, like a compact reactor fueled by U-235 or Pu-239. In the future, this could include locally installed fast neutron breeder reactors utilizing U-238. Radioisotope thermoelectric generators (RTGs) powered by Pu-238 have been suggested as a means of providing continuous, low-power, long-term power to critical systems, as demonstrated in missions such as Curiosity and New Horizons.

2. Life support systems should provide a closed cycle including an oxygen supply from liquid oxygen (LOX) tanks, water electrolysis, carbon dioxide removal and water recycling. The transformation of organic waste into fertilizer or biogas is of paramount importance, while the recycling of inorganic materials through three-dimensional printing (3D printing) is a key driver in promoting sustainable resource utilization.
3. It is imperative that living quarters are equipped with protection from Martian regolith and active thermal control systems to maintain a stable internal environment, despite extreme external temperatures and cosmic radiation.

Figure 5 Radioisotope thermoelectric generator for Cassini: 10 years on plutonium batteries. Source: Habr

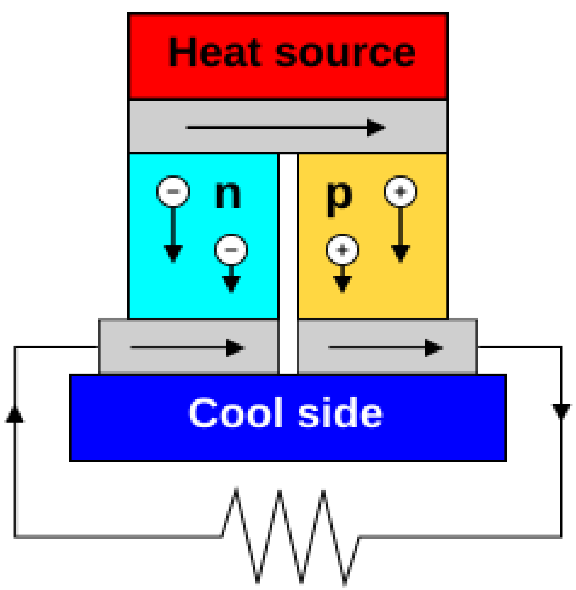

Figure 6 Thermoelectric Generator Diagram. Source: Wikipedia

3. Review of sources

Life support systems are cruical for humans to survive on Mars. We can utilize technology from the International Space Station to create systems.

Main components:

1. Oxygen generation system uses water to produce oxygen and hydrogen from the process can be discarded or used for other purposes.
2. Carbon dioxide scrubbers devices remove carbon dioxide from the air, making it safe to breathe. LiOH is used in this process, which reacts with CO2 to form Li2CO3. $CO_2 + 2\ LiOH \rightarrow Li_2CO_3 + H_2O$
3. MOXIE produces oxygen directly from carbon dioxide on Mars, operating at high temperatures to help if other systems fail.

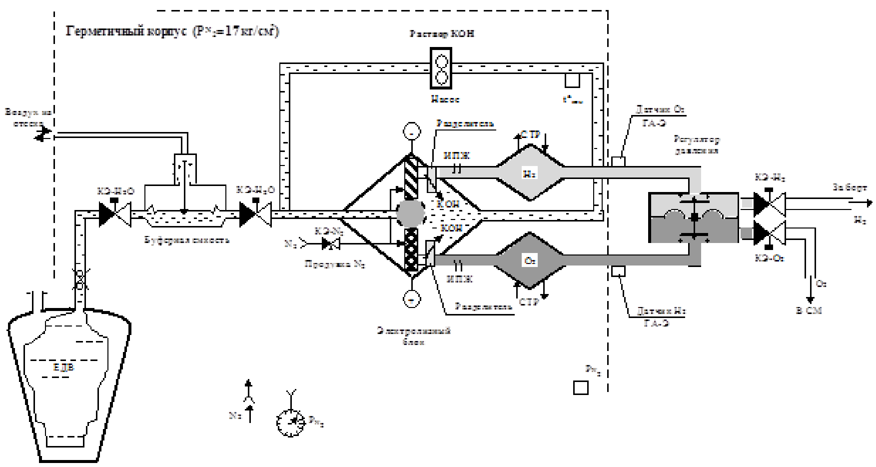

Figure 7 Electron-VM oxygen supply system. Source: studwood

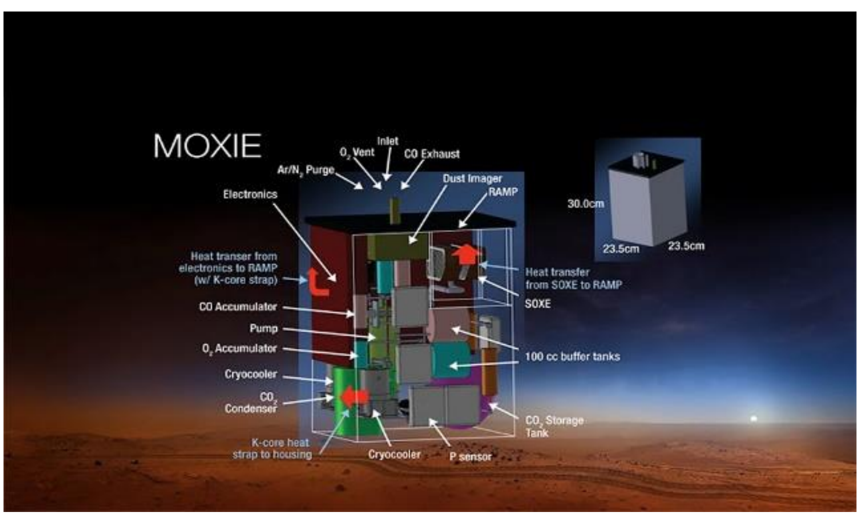

Figure 8 Mars Oxygen ISRU Experiment Instrument for Mars 2020 Rover is MOXIE. Source: NASA Science

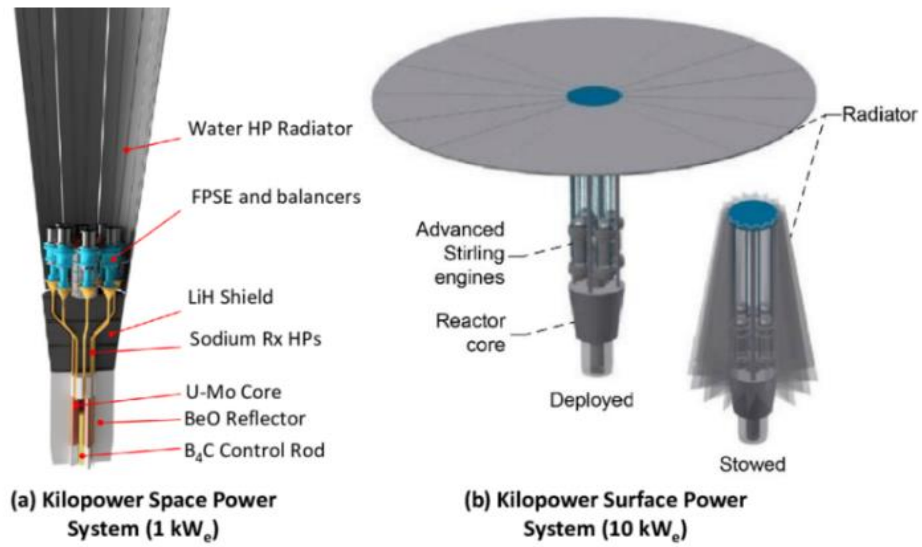

Figure 9 Conceptual design of Kilopower. Source: Research Gate

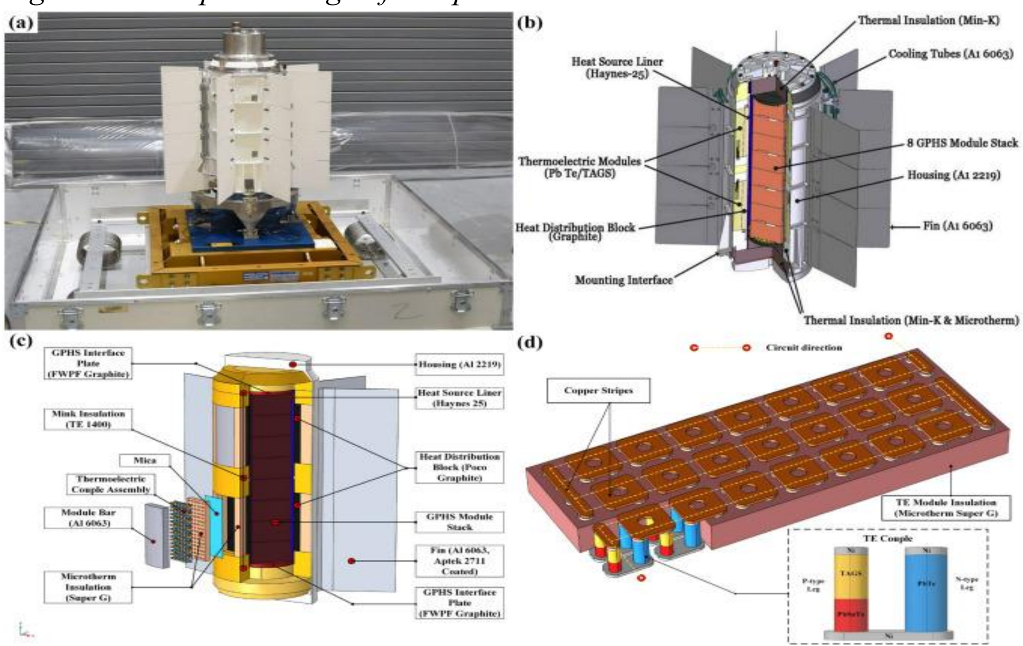

Figure 10 MMRTG. Source: ScienceDirect.com

1. Oxygen storage: Liquid oxygen is stored at -183°C for emergencies. When astronauts are outside the spacecraft, it becomes a gas and mixes with other gases to create breathable air.
2. Water systems: Systems in place to purify water, extract ice from the ground, and return water. These systems have been tested on Earth and have proven to be effective for use on Mars.
3. Power systems: Solar panels generate most of the energy, but we also need other methods due to the dust covering the panels and limited light. We utilize nuclear reactors for power generation. These reactors are known as Kilopower and employ U-235 and Pu-239 to produce 40 kilowatts of energy even during nighttime or when there is a high amount of dust. Additionally, we utilize radioisotope thermoelectric generators (MMRTGs) that utilize Pu-238 for a modest amount of long-term power.

Radiation protection and heat management are essential for missions, as the surface of Mars is exposed to high levels of radiation from cosmic rays and solar flares, as well as extreme temperatures (-125°C to +20°C) and dust storms that can last for weeks, blocking sunlight from reaching solar panels. So, bury modules into the Martian soil to shield them from radiation exposure and build our buildings with a round shape and a radius of 20-25 meters to withstand the weight of the soil above. The walls and insulation of the houses help maintain a warm interior, utilizing heat sources such as solar energy, Kilopower fission reactor, and metabolic heat from food consumption. There are gardens with potatoes, lettuce, radishes, tomatoes, onions, and garlic. Food is grown in water, and waste is not thrown away. Instead, it is turned into fertilizer or used as gas for energy or made into new things. This approach helps to use fewer supplies from Earth and makes the habitat completely independent.

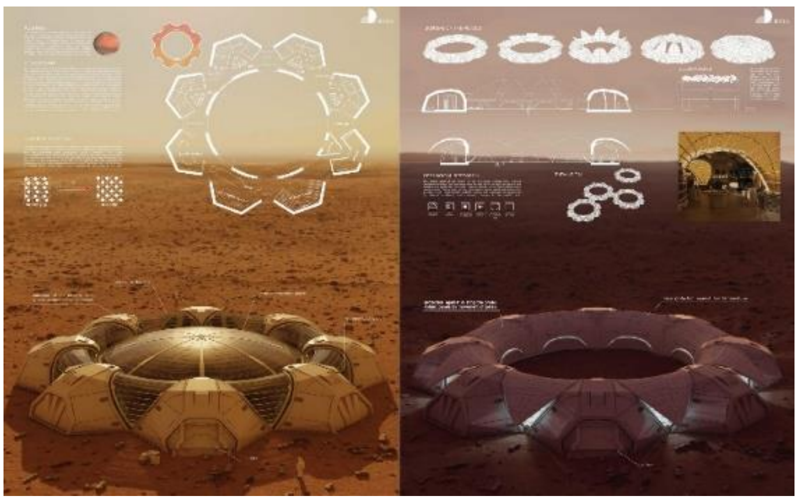

Figure 11 Dome Martian base. Source: Innspace

Figure 12 SLS LOX tank foam. Source: NASASpaceFlight.com

4. Architecture / Method

The architecture of the base was developed using the latest engineering principles, advanced computer modeling and knowledge. The goal is to create a safe, durable and sustainable environment capable of supporting human life on Mars for a long period.

Structure:

1. **Habitable domed modules:** Some modules have a domed structure with a diameter of 20 to 25 meters. ISS-derived cylindrical modules for laboratories, power systems and logistics, connected to regolith-protected domed habitats designed specifically for human accommodation and food production. Domes covered by 2–3 m regolith shielding, reducing radiation dose (≤0.5 Sv/year).
2. **Placement within natural features:** Modules will be strategically placed in natural recesses. craters on the surface of Mars to provide protection from radiation, micrometeoroids and dust storms. The outer shell of the habitat is made of lightweight materials and provides effective protection from radiation due to its unique composition. Some parts also use phase-change materials that help to store and distribute thermal energy. To ensure oxygen supply, carbon dioxide removal, and water recycling, these systems have been carefully planned and distributed throughout the habitat.
3. **Heat control**: The heat from the equipment and people is taken away through the walls and floor. With the help of the sun and the earth, the inside is kept warm. This makes it cozy for the people. Specialized protective systems and reinforced materials are used to protect the crew from harmful radiation.

In addition, the interior walls include layers of water tanks and ice panels that act as additional radiation barriers and enhance protection from cosmic rays. The regolith coating also provides protection from radiation.

Pre-production of modules:

The modules are prefabricated on Earth and then shipped to Mars for final assembly to minimize the impact of dangerous conditions on astronauts during the assembly process, ensuring their safety. In-Situ Resource Management (ISRU) involves the use of regolith and local ice on Mars for various purposes such as structural reinforcement, thermal insulation, and radiation protection. This reduces the need for materials delivered from the Earth and increases the overall efficiency of construction.

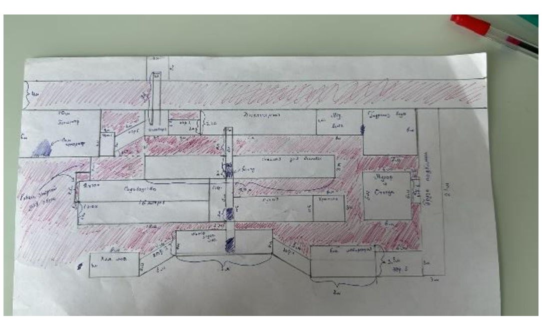

Figure 13 Habitat sketch

5. Verification Plan and Metrics

Verification objectives:

1. **Constructive integrity:**
   1. Dome-shaped modules are designed to withstand the load of regolith, simulated meteorite impacts, and dust storms.
   2. Thermal insulation and heat protection are maintained throughout the Martian temperature cycle (-125°C to 20°C).
   3. Radiation protection has been tested through simulations of cosmic rays and solar flares. Layers of regolith and ice reduce radiation exposure to below 0.5 Sv/year.

2. **Life support systems:**
   1. Oxygen production systems, including water electrolysis and MOXY installations, ensure stable oxygen production. The oxygen content in the habitat is maintained at 19-23%.
   2. Co_2 removal using LiOH scrubbers ensures a safe oxygen level in the atmosphere (<1000 ppm).
   3. Water extraction and recirculation systems, including condensation, ensure efficiency of more than 90% when operating in a closed cycle.

3. **Energy systems:**
   1. Solar panels provide reliable energy generation in different light conditions and dust conditions.
   2. 40 kW nuclear reactors provide continuous power generation at night and during dust storms.
   3. MMRTGS provide a long-term supply of additional energy.
   4. Energy storage and distribution systems ensure uptime of >99% for 30 days.

4. **Food production and waste disposal:**
   1. Hydroponic gardens produce more than 0.5 kg/m2 in salt, providing potatoes, lettuce, radishes, tomatoes, onions and garlic.
   2. Waste recycling converts organic material into fertilizers, energy gas or reuse resources, ensuring complete autonomy of the habitat.

5. **Autonomy and robotic support:**
   1. Robotic systems efficiently assemble and maintain modules, completing construction in less than 120 hours per module.
   2. Automated environmental monitoring and life support systems ensure more than 95% accuracy.

Verification methods:

1. Simulation modeling: Structural, thermal and radiation modeling confirms the stability of the structure in Martian conditions.

2. Ground testing: Scaled prototypes and analog tests in cold desert conditions test the systems before deployment.
3. 3D Model Verification: The digital 3D model of the base accurately reproduces the location of modules, internal systems, and the integration of life support systems and hydroponic gardens.
4. Phased implementation: Mission-critical systems have been consistently tested in isolation and then integrated to verify full functionality.

6. Risks and limitations

1. The gravity on Mars is about 38% of Earth' and it affects human health: weakening of muscles and bones, as well as changes in blood circulation, are possible. Regular exercise and medical monitoring are essential to minimize these effects.
2. The main source of energy on Mars is solar panels. but dust storms can reduce their effectiveness. Nuclear energy is mostly generated using RTGs (Radioisotope Thermoelectric Generators), well-shielded systems that produce heat from the decay of plutonium-238. These systems undergo rigorous safety checks to minimize the risks of radiation exposure.
3. Extreme temperature fluctuations are observed on Mars: from -125°C at night to +20°C during the day. Heating and thermal insulation systems are installed in residential modules to maintain a comfortable temperature.
4. The atmosphere of Mars contains about 95% carbon dioxide and 0.2% oxygen. Oxygen generation and carbon dioxide removal systems such as MOXIE and LiOH scrubbers are installed in residential modules to provide respiration.
5. Food production and waste recycling are used to ensure food security; hydroponic systems are used to grow plants without soil. Waste is recycled using closed-loop processes, minimizing the need for supplies from the Earth.
6. Psychological and physical aspects affect us and can cause psychological and physiological problems such as depression, stress, and a weakened immune system. To prevent them, regular psychological counseling, communication support with the Earth and the creation of a comfortable living environment are necessary for human beings

Metric	Measurement Method	Result
Oxygen Levels	ppm in habitat	19.5–23.5% O_2
CO_2 Levels	ppm in habitat	<1000 ppm
Water Recycling Efficiency	% water reused	>90%
Energy Reliability	% uptime	>99% over 30 sols
Radiation Shielding	Sieverts/year	<0.2 Sv/year
Hydroponic Yield	kg/m² per sol	>0.5 kg/m²
Structural Stability	Max stress	Within safety factor 1.5
Autonomous System Accuracy	% correct operations	>95%
Module Assembly Time	hours/module	<120 h via robots

Table 1 Key indicators for Mars habitat. 1. Sources: NASA, resenv.media

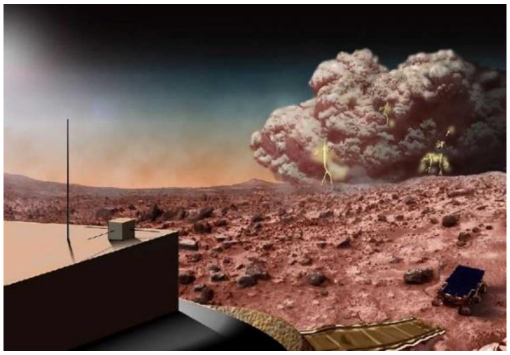

Figure 14 Martian dust storm. Source: NASA

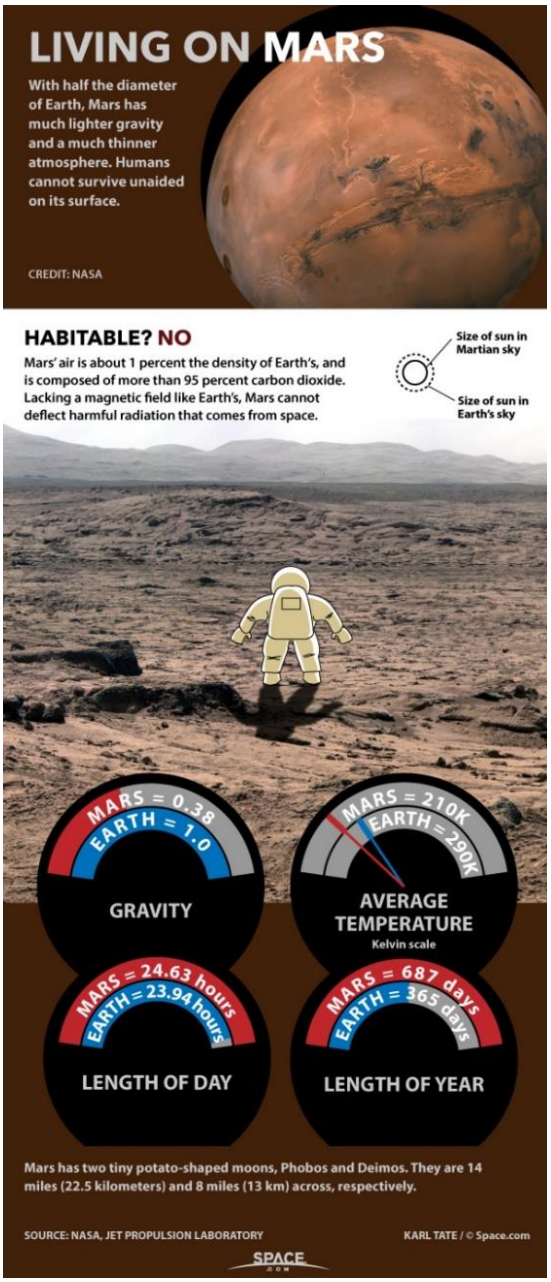

Figure 15 How Living on Mars Could Challenge Colonists. Source: space.com

7. Conclusion

The proposed habitat on the surface of Mars is a strategically designed solution aimed at ensuring a long-term human presence and scientific development on Mars. By combining the proven technologies of the International Space Station with advanced surface construction and in-situ Resource management (ISRU) techniques, the base minimizes dependence on ground supply and enhances operational sustainability. Dome-shaped structures protected by regolith provide protection from radiation and maintain structural integrity in the face of sudden fluctuations in temperature and atmospheric conditions. A closed-loop life support system, including water recovery, oxygen and carbon dioxide processing, as well as hydroponic farming, ensures a sustainable lifestyle while processing resources by more than 90%. Hybrid power systems combining solar panels, high-power nuclear reactors, and energy storage ensure near-continuous operation of critical systems, even during global dust storms. Automated robotic assembly and monitoring reduce risks for the crew and increase operational efficiency. Despite the remaining challenges, especially reducing a gravity, psychological adaptation, and long equipment life, the proposed technical solutions demonstrate that these obstacles can be overcome through continuous monitoring, training protocols, habitat design, and backup of critical infrastructure.

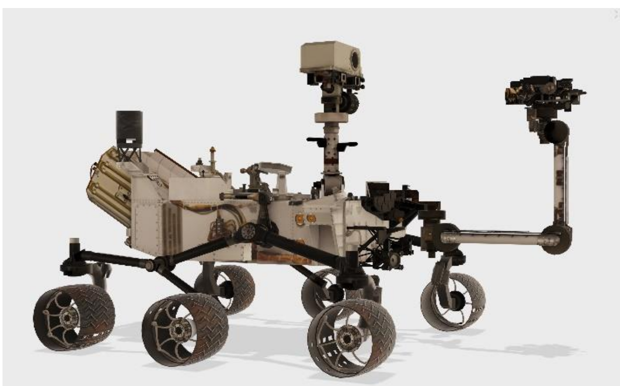

Figure 16 Curiosity. Source: NASA Science

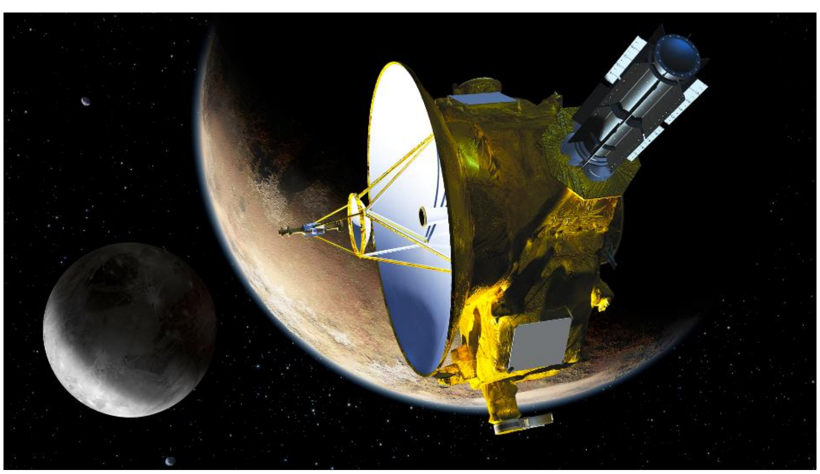

Figure 17 New Horizons. Source: NASA Science

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