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# The Challenges of Human Presence on the Surface of Mars

The human presence on the surface of Mars poses many challenges for the planned expeditions *(Figure 1),* the most important are: compensating for the unpleasant environmental parameters, providing conditions for life maintenance and various further needs, satisfying technical and engineering needs, and achieving scientific and other exploration objectives. In addition, the maintenance of optimal social relations and morale of the crew, in addition to maintaining communication with the Earth must also be realised. These aspects are considered below, and please note that some specific aspects might fit into several of the themes presented.

## Unpleasant Environmental Parameters

The conditions on the surface of Mars are unpleasant compared to those on Earth, but still significantly better than those characteristic in space. There is no single aspect of the Martian human presence that poses such a difficulty that cannot be overcome, but there is still a wide range of needs for improvement in various methods and technologies. In addition to durable and reliable operation, small devices that can be easily repaired are preferably done on Mars, and most critical devices need back-ups that can be activated during the mission in case of failure of one of them, or they are in parallel operation.

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Figure 1
*Artist's concept of a future manned Mars surface base*
*Source:* NASA 2019

## *Main difficulties*

- *Low* atmospheric *pressure:* the surface air pressure on Mars is about 1% of that on Earth, so the pressure conditions on the Martian surface are similar to those on Earth at an altitude of about 40 km above the ground. The pressure varies between 4 and 6 mbar in a day and also shows a seasonal variation of about a factor of two, as up to a third of the atmospheric carbon dioxide freezes out on the polar icecap in the winter hemisphere. The low atmospheric pressure is physiologically very uncomfortable, and correspondingly higher pressures must be maintained in the habitat and inside the spacesuit during the fieldwork. In the space suit it is possible to reduce the pressure modestly, but only gradually, to avoid astronauts getting "decompression sickness".
- The *temperature* is also very low at the surface, varying between about +10 and −120 °C, even on a daily cycle. The minimum around −120 °C would probably be very rare at the planned low-latitude landing sites.

The extreme coldness favours atmospheric carbon dioxide precipitation, and this frost can be technically damaging to some external equipment – but this is also something to be prepared for because such extremely low temperatures can rarely occur at low latitudes in the second half of cold nights, occasionally creating low-temperature carbon dioxide ice patches (Hargitai et al. 2021). Nevertheless, establishing and maintaining the right temperature is not a major challenge, even in the spacesuit of the astronauts.

- *The main component of the atmosphere is CO2,* which does not pose a major challenge, as astronauts breathe the oxygen produced or recirculated on site. Atmospheric gas does not cause a chemical problem either, as it does not react with the external surfaces of various equipment. However, it can be used as an important source of materials (see the ISRU section below).
- The Martian surface is generally *dry* (about 0.1% relative humidity during the day, but rarely <100% at night), which is also "pleasant" from a chemical point of view, as it rarely causes reactions on the surface of the outer units, and frost formation is rare on the planet. At the same time, atmospheric vapour could be an easy source of $H_2O$ for on-site acquisition, but its concentration is generally very low.
- The *regolith is chemically aggressive* due to the peroxides and hyperoxides it contains. This partly causes chemical corrosion of external surfaces, but is also harmful to health, like the metal content in regolith. All this would not be a problem if grains and dust of the regolith never enter the human body, but when manned work is carried out outside the spacecraft regularly, the outer surface of the spacesuits should not come into contact with the interior of the habitat. (A similar unpleasant situation was experienced by the astronauts during the Apollo space expedition, because the lunar dust was also chemically unpleasant, irritating the astronauts' noses and eyes after they entered the Lunar Module with the spacesuit.) The current idea for solving the Martian situation is to keep the spacesuits hanging outside the habitat, and there will be a smooth surface metal or plastic door

at the back, the surface of which could be cleaned easily. This technical solution is a bit complicated but easily excludes the dust from the habitat interior. However, if an astronaut breaks her/his leg outdoors, it is much more difficult to climb out of the spacesuit.

- *UV radiation* is intense at the surface due to the rare atmosphere and the lack of an ozone layer. This is dangerous to health but can be shielded by using a suitable UV filter, for example by covering the visor window of the helmet with it. The external surfaces of the various technical units can also be slightly damaged by UV radiation, which can be avoided by appropriate surface treatment or proper selection of materials. It is possible that UV radiation may have contributed to the deterioration of the wheels of Curiosity together with the rough surface (Arvidson et al. 2017).
- One of the most dangerous environmental effects on the surface of Mars is the *ionising charged particle radiation,* which mainly consists of protons and alpha particles from the solar wind (more common but lower energy component), and larger nuclei from galactic cosmic rays (less common but higher energy component). The Earth's surface is protected against these particles mainly by the global magnetosphere of our planet, with the atmosphere also contributing to a smaller amount. The dose of such charged particles at the surface of Mars varies significantly over time *(Figure 2),* partly as a function of the solar cycle (which sometimes releases fewer or more charged particles and also lets more or less galactic origin particles to the inner parts of the solar system). For protection against ionising radiation, a layer of rock (or a slightly thinner layer of solid metal) nearly a metre thick is adequate. For comparison, a 500-day stay outdoors on the surface of Mars is roughly equivalent to 100 years of exposure on the International Space Station. Accordingly, an almost metre thick radiation shielding above the habitation unit provides full protection. This shielding material is not worth transporting from Earth because of its great mass, but in practice, it could be created from local materials. This shield could be produced of excavated regolith material and consolidated grains, which are built up by robotic machines before

the astronauts are even arrived – but it is also possible to put the habitat in a cave, which is also suitable for radiation protection. The latter can provide additional weight reduction: in this case, a particularly strong and solid habitat unit is not needed, and an inflatable unit can be placed there, with the shape and size of the latter being much less constrained than for a solid unit. The consequences and management of ionising radiation are similar to those of an operating nuclear reactor on Earth, where the staff members have personal dosimeters and need to monitor their total radiation exposure continuously. Accordingly, there may be days (especially during the arrival of a coronal mass ejection cloud to Mars) when astronauts should not go out to the Martian surface from their safe habitat.

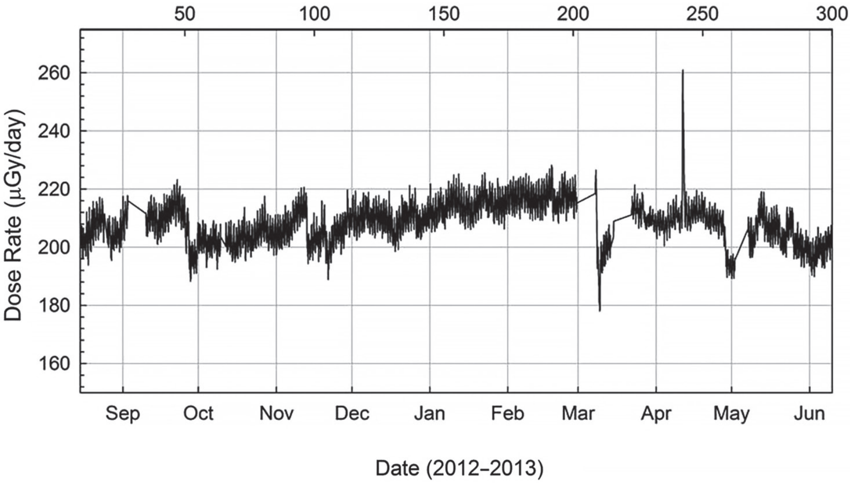


Figure 2
*Data from the RAD instrument onboard the Curiosity rover showing the variation of the galactic cosmic rays mainly, and to a lesser extent the solar wind*
*Note: The vertical axis shows the microgravity/sun dose and the prominent peak marks the arrival of a large particle mass ejected from the Sun*
*Source:* NASA/JPL-Caltech/SwRI 2013

Other hazards include dust storms, but these are likely to be able to pick up only very fine-grained dust. They can, however, corrode external surfaces and cause electrostatic charging. The main inconvenience here may be dust attached to the surfaces of external instruments.

## SUSTAINING CONDITIONS FOR LIFE ON MARS

The main needs for life support can be outlined below. A key priority is to use as many local resources as possible, e.g. to avoid transporting most of the water or oxygen from Earth to Mars, which would increase the cost of the expedition enormously. Another important factor is to recycle as much of the materials used on Mars as possible. The energy needed for the activities listed below can be found in the chapter of this book entitled *Bon Voyage: Sources of Energy for Space Exploration and Its Current Regulatory Insights* authored by Zsolt Hetesi and Zsófia Biró.

An ideal, stable and safe environment can be maintained in an enclosed volume of space, known as a *habitat unit,* or simply HAB. Optimal HAB design solutions should combine radiation protection, exclusion of external toxic regolith, stable temperature and energy saving aspects. The whole system should be as self-sustaining as possible, and the "smart solutions" that are proliferating on Earth today are expected to help in optimising this *(Figure 3).* Continuous monitoring of the indoor environment should also include microbial conditions – as a single unpleasant bacteria can cause serious problems in the internal air or in systems that maintain the recirculation of fluids, food production, etc. The development of the necessary solutions relies heavily on ground trials, which have included the construction of solid, inflatable, site-built living units using local materials.

The main sites of such Earth-based analogue tests on habitation units are the Mars Desert Research Station (MDRS, Utah, desert region, USA) (Westenberg–Nelson 2010; Boros-Olah et al. 2009), the Flashline Mars Arctic Research Station (FMARS, Devon Island, Northern Canada) (Binsted et al. 2010), ESA's Concordia Station in Antarctica, where effects of isolation and health maintenance are tested, but also the extreme surrounding environment could be analysed (Napoli et al. 2022), and the Mars 500 experiment, an indoor experiment in Russia, partly to test group behaviour (Groemer–Ozdemir 2020). Useful experiments and developments have been carried out on board the International Space Station (ISS) on radiation exposure and physiology, as well as on the usability of human end-products, water recirculation and exhaled carbon dioxide sequestration.

In-Situ Research Utilization (ISRU) is a key element of the human Mars expedition. The idea is to bring as small mass and volume of material and equipment from Earth as possible and to produce as much as possible on Mars (in the same way we do not take drinking water, stored electricity or air with us when we travel abroad – but of course, the situation is different on Earth). Under ISRU activities, one needs to produce oxygen mainly for inhalation and also as fuel, drinking water, methane or hydrogen as fuel, as well as energy and some building materials on site. This significantly reduces the mass to be launched from Earth to Mars and the difficulty and the cost of the whole mission.

ISRU activities require the transport of sophisticated equipment from Earth but also use on-site raw materials to make the targeted products. It is also worth taking advantage of the fact that this production does not necessarily require human presence – for example, the fuel or other materials needed to lift off the Martian surface can already be produced by automated systems that landed before the arrival of the manned mission. The technology to do all this is not yet mature, but in theory and simpler experimental form, it has already been tested with several success in Earth based laboratories. In addition to the use of on-site resources, recycling and recirculation are of high importance (in this respect, the manned Mars expedition will be particularly environmentally friendly). The purification of used water will save energy and increase the security of the supply of the system, and the solid human end product will be valuable and useful as a "manure" resource to support crop production. The expedition will produce little waste, which is also important for the protection of the Martian environment and to ensure the representativity of the measurements there (free from terrestrial contamination).

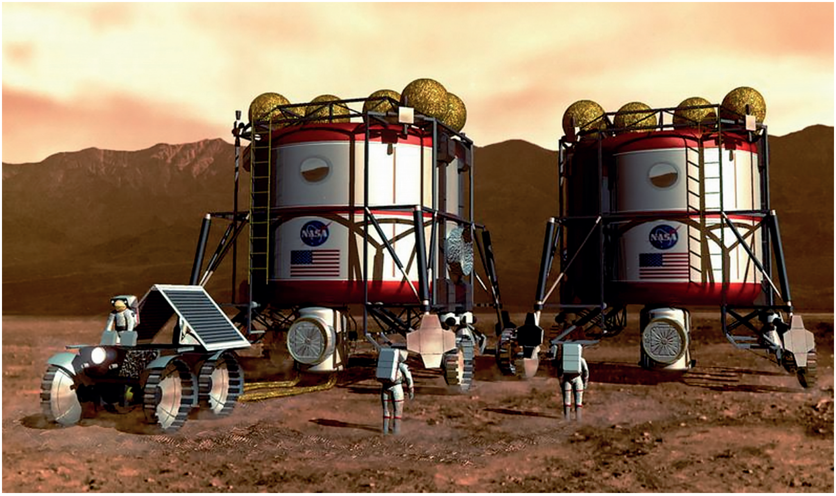

Figure 3
*Artist's concept of landed habitation units on the surface of Mars*
*Source:* Launius 2019

One of the important ISRU products is oxygen, which can be extracted from the atmospheric carbon dioxide or from water ice extracted on site. The most popular chemical method for producing oxygen from $CO_2$ is the Sabatier process (see below for methane production), but other electrolysis-based methods also exist. The instrument called MOXIE (Mars Oxygen In-Situ Resource Utilisation Experiment) has been successfully tested on the Perseverance rover on the Martian surface. The 17 kg, 30 cm long device produces oxygen by solid oxide electrolysis of atmospheric carbon dioxide at a rate of 5–6 g/hour, with an atmospheric gas inflow of 55 g/h. This amount produced in one hour is enough oxygen for a person for nearly 10 minutes, about the same level as the daily oxygen production of an average tree. Martian atmospheric gas is sucked in through a HEPA filter and compressed by a pump, heated to 800 °C and then sent through a solid oxide electrolysis (SOXE) unit, where $CO_2$ flows along nickel-based cathode and zirconium oxide ceramics to catalyse the separation of oxygen ions, which eventually got combined to form molecular oxygen. At the end of the process, $CO_2$, CO and inert atmospheric gases (N, Ar) are exhalated. MOXIE has been successfully operated under different conditions (day, night, lower and higher atmospheric pressure, different seasons). Its future larger version would start operating on the red planet before the human mission arrives to Mars and continue during the expedition. Among other oxygen production methods, biogenic ones are worth mentioning. For example, the bacterium Chroococcidiopsis cubana produces oxygen by reducing atmospheric $CO_2$ and is still cost-effective if the system is properly designed. Moreover, the microbe in question is highly resistant, requires little "protection" and can ideally produce oxygen equivalent to 40% of its body weight per day (Krings et al. 2023).

The production of water, which is needed for food processing, cooking and cleaning, in addition to drinking and maintaining the humidity of the air to breathe, is a priority. Martian river valleys have long been dried up (Hargitai et al. 2019; Steinmann et al. 2020), and atmospheric humidity is not significant on the planet. The term "water ore" is used in the literature to describe sites of interest for extraction, such as $H_2O$ on Mars that are worth exploiting, both for processing and transport. The main on-site sources of $H_2O$ are:

– Large amount of *ice or snow mass*: the most prominent of these are the permanent polar caps, but a manned base is expected to avoid the polar regions due to the very low temperatures there during winter nights, including the formation of a permanent $CO_2$ ice there. Below the polar caps, in a larger area especially in the south, the polar layered sediments contain a large mass of water ice and dust mixture – but even these are at very high latitudes. Outside the polar caps, important sites are the snow-ice masses buried at mid-latitudes. Beneath the thin dust and regolith cover, buried $H_2O$ is more easily accessible in the 50°–70° latitude range, while ice masses in valleys and craters are covered by a thicker dry debris cover of about 10 m thick. A separate issue is whether the excavated $H_2O$ should be transported for final usage. However, the cementation of the debris cover is not known, but the difficulty of accessing the underlying ice is primarily affected by the physical thickness of the dry cover.

- There are also *water-bearing minerals* on Mars, such as polyhydrated sulphates and phyllosilicates. Extracting water from them may generally require more effort than extracting buried ice masses, but these minerals may be more widespread, especially at lower latitudes, than buried $H_2O$ masses. These minerals generally hold low $H_2O$ contents, sometimes up to 8–10% (Milliken et al. 2007).
- There are several other ways to extract $H_2O$, including mining and processing of *permafrost* (frozen mixture of ice and rock debris), which may be present at shallow depths at high latitudes but can occur in deep regions at lower latitudes. However, permafrost is much harder than pure ice or hydrated minerals. Some $H_2O$ can also be extracted from the generally dry atmosphere (Pal 2019), but only at a very small rate of about 1 kg $H_2O$ from 200,000–300,000 $m^3$ of atmospheric gas, and accordingly, atmospheric origin is probably not an appropriate method for extracting $H_2O$. Despite some theoretical models and questionable observations by the MARSIS instrument onboard the Mars Express spacecraft, it is unlikely that there is currently any liquid groundwater on the planet.

Many technological aspects of extraction methods are under development. When comparing the occurrence of $H_2O$ with the demand and supply potential, the most likely sources are buried snow or ice masses at mid-latitudes. One option for their acquisition is surface mining (after removal of the dry overburden), but in this case, the exploitation of water ice deepens and widens horizontally with extraction, while surface sublimation may also be a problem. Drilling assisted extraction would be more efficient and simpler when the overburden does not need to be removed. In this case, maintaining the heating and pressure needed to produce liquid water would be a fast but energy-intensive method while pumping the molten water. A more energy-efficient solution is dry hot gas flow downward, which involves sublimation of ice at depth and cold trapping of the outflowing water vapour at the surface. During exploitation, especially in shallow (1–2 m deep) cover, the decreasing subsurface $H_2O$ mass will result surface subsidence over time, which must be taken into account. Any exploitation should also be used to obtain scientific data, as the ice is expected to contain paleoclimatic information.

In further processing, if $H_2O$ is extracted from minerals, pulverisation and heating to an even higher temperature than mentioned above are required. Based on field and laboratory studies, extraction rates of the order of 100 kg/hour are realistic for an expedition of 4–6 people, while for soil processing a few kg/h are more likely – theoretically, the latter production rate may be sufficient to supply the crew, even including fuel production (Sanders 2016). In case of fuel processing (production of liquid hydrogen and oxygen), electrolysis of water and separation of the produced components is expected to take place under high pressure and low temperature (cryogenic) conditions for storage in the liquid phase. The distance between the $H_2O$ mine, the processing plant and the final point of use of $H_2O$ is also a factor, as the extracted material has to be transported if not recovered on site.

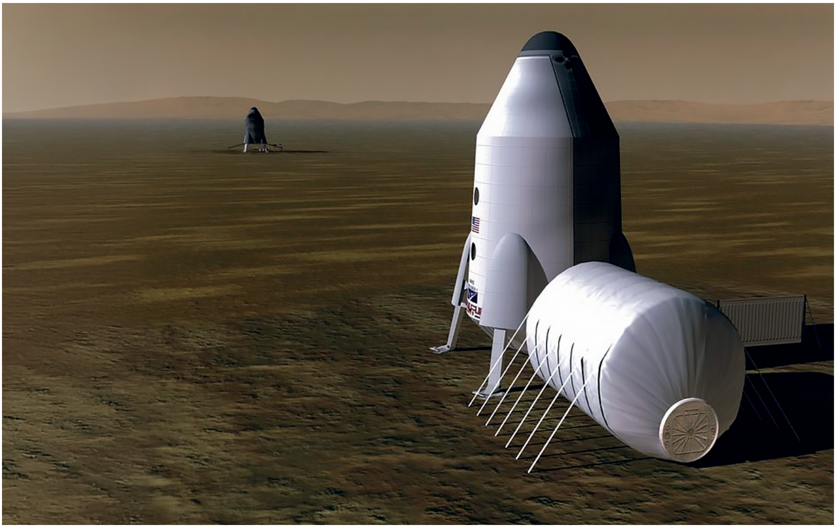

Figure 4
*Artist's concept used to return from the surface of Mars, with an inflatable unit next to it and a fuel-producing unit in the distance*
*Source:* NASA/JSC by John Frassanito and Associates 1997

Methane is mainly important as a fuel on Mars, both as a propellant for rockets *(Figure 4)* and for rovers or other surface and possibly airborne transport vehicles (although a mixture of liquid hydrogen and oxygen is more efficient as a rocket propellant, but methane is more easily used in rovers). Methane is currently present in the Martian atmosphere in very small and varying amount. There are no known local sources of methane that could be exploited in significant quantities – but the easiest way is to use atmospheric carbon dioxide. The most widely known and tested methane production method is the Sabatier process (Zlindra et al. 2021), where hydrogen is produced from atmospheric carbon dioxide using terrestrial hydrogen (or locally from $H_2O$ by electrolysis) at temperatures of 300–400 degrees Celsius and elevated pressures (3 MPa) by the following reaction: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2\ O$ can be recovered, but there is a low temperature electrolysis of $CO_2$–$H_2O$ around 255 K that can support the production of both methane and oxygen (Shahid et al. 2022). The Sabatier process for methane production on Mars was proposed early on by Robert Zubrin (Zubrin et al. 1996).

By using local carbon-dioxide, sunlight and $H_2O$, a special group of cyanobacteria can produce sugars from the Martian atmosphere (under proper conditions but in the Martian open air also). Another group of bacteria converts these sugars into propellant, such as butanediol. However, the process is much slower than a chemical one, but requires only a third as much energy and roughly 3 times the equipment compared to a chemical one (Kruyer et al. 2021). Storage must be cold and pressurised, temperatures that are easier to maintain on Mars than on Earth. In addition to methane, other hydrocarbons have been proposed, such as methanol propane, which require additional or different processing (e.g. Fischer-Tropsch synthesis). Among them methane seems to be the simplest solution and the most "green" propellant. It is worth noting that the use of these materials as rocket fuel requires about twice as much oxygen as methane.

## FOOD AND HEALTH ON MARS

Roughly about 1–2 kg of food per person per day is needed – it would be extremely expensive to transport all the food from Earth for a long expedition. The production of local solid nutrients can be done in greenhouses, but not necessarily in transparent foil tents exposed to sunlight, although growing plants with good radiation tolerance (good regeneration capacity) in inflatable, transparent but UV insulated tents would be promising. The selection of the vegetables produced should be based on high resistance (not only to possible unpleasant radiation conditions, but also to the nutrient and temperature–lighting conditions received) and high nutrient content. Among the "classical" crops, the cultivation of improved varieties is likely, as well as the cultivation and consumption of nutrients such as algae, which are not yet particularly popular, and of meat products of arthropods and molluscs. Although these are uncommon foods, being a good source of protein as rich as that of domesticated and familiar animal-based food.

A miniature ecosystem on Mars could also help to provide food, but also to convert carbon-dioxide into oxygen, process waste and purify water. The 43% of solar radiation that reaches the Mars compared to Earth is still abundant enough for photosynthesis. The creation of suitable soil is possible by cleaning and transforming the local regolith and supplementing it with special bacterial colonies of terrestrial origin – the resulting topsoil is not needed in large quantities inside the greenhouses. But some plants can also produce crops without conventional soil by their roots in a suitable nutrient solution (hydroponics) or by roots in humid air (aeroponics). Of course, such mini ecosystems could only be maintained with proper monitoring and regular intervention. Solutions to the difficulties encountered in the Biosphere 1 and 2 experiments on the Earth could be of great help (Nelson et al. 2008: 2199).

Figure 5
*A greenhouse designed for crop production on the surface of Mars*
*Note:* The natural light is supplemented by LED radiation, and the astronauts rarely visit the particle radiation-resistant genetically modified plant species, so the radiation total exposure is harmless to them
*Source:* Herridge 2016

An important aspect will be the reuse or repair of broken equipment – as little as possible should be thrown away. Protecting the Martin environment is also of high importance, so any waste should be stored hermetically or destroyed, including by bacterial decomposition, which can even provide a small amount of energy.

The most important health risks are the increased radiation exposure, lower gravity than on Earth, toxic substances in the regolith, and possible microbial infections in the confined internal volume of the habitat and spacesuits (Table 1).

Table 1.
*Main biological and medical challenges and possible solutions on Mars*

| Topic | Difficulty | Possible solution |
|---|---|---|
| Ionising radiation | May be too large outdoors | Time-limited outdoor work, continuous dosimetry |
| Microbial balance in the housing unit | Unpleasant microbes can multiply | Continuous monitoring, chemical–biological intervention if necessary |
| Need for surgery | No specialist | Robotic surgery supported by artificial intelligence |
| Unexpected illness | Unknown illness, problematic diagnosis, missing drugs | Remote diagnosis and interpretation by Earth-based medical team, local microbial laboratory, pre-mission genetic screening of inclination |
| Accidents | Non movable persons, lack of experts | Specific safety protocols, robotic support |

*Source:* Compiled by the author

Any diagnosis is supported by modern analytical instruments and methods, and by the detailed interpretation of chemical, biological and physiological test results sent to the Earth-based supporting team. There will be medicines to be carried by the astronauts, as well as surgical instruments that can be used in a modular way.

One of the problems of providing medical care on Mars missions is that it is not possible to return to Earth for specialised medical care, and the task has to be done with a small staff there. The currently planned crew of six is expected to have only one doctor or at most two. The Earth-based supporting team will therefore have a key role during the mission, including medical consultations – but active back-and-forth communication is subject to delays of around a quarter to a half hour due to the long distance. The most critical situations are likely to be the surgery actions that may be required, which, because of the time delays, cannot be easily performed by today's rapidly evolving remote robotic surgeons, but which could be supported in many ways by artificial intelligence and simulations, including microscale surgical procedures.

## FURTHER TECHNICAL NEEDS

The technological challenges for working and sustaining life on Mars are wide-ranging, some of them have possibly concrete suggestions or even tested solutions, but most are not yet developed and put into practice – although there are no technical challenges that seem theoretically impossible – so almost all of them can be solved with the right development, but this requires concerted and sustained work and related funding.

Fuel is important for local transport. Here, oxygen, methane and hydrogen can be used as fuels, with the methane-oxygen mixture being used to power rovers and robots (including excavators and heavy machines to dig and transport regolith), while lower-powered equipment will presumably use electricity generated on the Martian surface. Fuel will also be needed to return to Mars orbit (from where, under most plans, the team will return to Earth via a space station there, or in a few plans the spacecraft will continue the way from the surface of Mars directly to Earth). The latter would, according to the models, require oxygen and methane, or a mixture of oxygen and hydrogen. In an ideal case, these would be produced locally.

Figure 6
*Artist's concept of a field survey of a steep sedimentary sequence on the surface of Mars*
*Source:* NASA/Pat Rawlings 1989 (https://www.humanmars.net/search/label/Pat Rawlings)

An important part of the expedition is the field work out on the surface of Mars *(Figure 6),* the so-called Extra Vehicular Activity (EVA). This requires a suitable spacesuit, which is technically feasible. Although today those used for EVA on the International Space Station are optimised for space, walking on the surface of Mars with even a rare atmosphere would be possible with slightly different (somewhat simpler) spacesuits. The main hazard of surface work is ionising radiation. Permanent protection is provided only by the habitation unit in the long term. However, it is the total radiation exposure suffered by the human body that counts. Therefore, work on the surface of the planet is safe up to a low level of total exposure. Accordingly, cumulated doses during the period spent outdoors should be monitored. It is estimated that several hours a day of outdoor work is sustainable in the long term, but on days of intense radiation (which can be estimated from space weather forecasts) astronauts should remain in the habitat unit.

Fieldwork will require a wide range of equipment, among them simpler ones can be carried by the astronaut, but there will also be more complex and heavy equipment, for example drilling equipment, excavators and equipment for repairing external units (Weidinger et al. 2008). It is expected that there will be also robots to assist with the more difficult operations. Presumably, all vehicles will be partially remote-controlled or autonomous, with some operations being carried out supported by autonomous methods.

Surface mobility will be provided by rovers *(Figure 7).* Among them the short-range ones will be open air vehicles, which can be used by astronauts in spacesuit. These vehicles will be used to transport heavy equipment, cover distances of 10–20 km quickly and can be controlled remotely. The closed-air cabin supported vehicles will allow longer surface expeditions, with astronauts spending the night in the vehicle and returning to the central habitation unit after days or weeks. A wide range of Mars analogue sites on Earth are suitable for testing surface operations, the tools and methods to be used, where the logistics of realisation can be developed, and targets similar to Mars can be analysed (Józsa–Bérczi 2004).


Figure 7
*A ground copy of a manned vehicle developed for surface mobility on Mars as part of NASA's Desert Rats programme*
*Source:* www.wikidata.org/wiki/Q4049635

Planetary protection for Mars has a dual purpose: on the one hand, Mars needs to be protected from living organisms originated form the Earth, including their dead remains and other contaminants from the terrestrial environment. All this would support the field studies carried out there, in particular some organic substances such as amino acids or proteins from the Earth would be highly misleading in the search for the possibility of life. On the other hand, planetary protection involves protecting the Earth's environment from samples and materials brought from Mars. The latter is close to the topics familiar from science fiction movies, in which a Martian "virus" or "disease" would destroy life on Earth. However, this is considered not realistic by experts (just as meteorites from Mars falling to Earth are not dangerous). Still, it should be avoided that terrestrial contaminants and organisms get into the samples from Mars and falsify the findings relevant to the red planet. The spacecraft to be sent to the surface of Mars are usually sterilised, which requires a very expensive procedure, and in the case of a human expedition, it is presumably not possible to completely isolate the Martian environment from human activity.

## ADVANTAGES AND DISADVANTAGES

There is no doubt that human Mars travel requires huge resources and effort *(Figure 8)* – the question is what favours it and what is against its implementation. The main difficulty in getting there is the stable funding (Taylor 2010), which needs to be sustainable over a 10–20 years scale – longer than the typical average political lifetime of the leaders on research funding. The total cost could be in the order of USD 500–1,000 billion, and all this requires several large teams of scientists and engineers working jointly. It is interesting to compare the effort required to achieve a manned lunar landing. In the 1960s and 1970s there was a strong political will for manned lunar travel through the Cold War supporting the fast development and realisation. The Moon, on the other hand, is an order of magnitude closer – thus in contrast, all the units and equipment of a Mars mission must operate properly on yearly timescales, with no possibility of further supply from the Earth. However, there is no doubt that many of the planned tasks can be performed only with robots with much less money, less risk but with more time and less flexibility. However, the human conquest and "occupation" of extraterrestrial space by robots alone is not the same as the human expansion.

Figure 8
*A fantasy sketch of a complex manned Mars base from the distant future, with a habitation unit, greenhouses, a flying drone, a surface mobility rover and a rocket about to take off*
*Source:* NASA 2016

It is a big question what the long-term goals of mankind for the conquest and possible colonisation of Mars are. The creation of a permanent colony, as seen in science fiction films, would only be possible in the distant future. However, it is worth mentioning the topic of terraforming, which cover the process of making Mars 'Earth-like'. This idea also appears in science fiction, man would provide water by melting the ice cap, and by injecting carbon-dioxide trapped below the surface into the atmosphere, making the atmosphere denser and the greenhouse effect stronger and the surface temperature higher. However, the exact behaviour of a planet as an interacting system is not well known enough to adequately predict the impact of such a drastic action. It is not certain if a given intervention would produce the expected result, nor can it be predicted whether some unforeseen, possibly even more damaging consequence would emerge. Above all, operations considered under terraforming are in the category well beyond what humanity will be capable of in the next century.

It is also occasionally suggested in popular press that humanity might consider Mars as a "planet B" option, a place where humanity could move when Earth becomes uninhabitable or too unpleasant to live there. Even if we consider the expected cheaper space travel in the future, it is not realistic to put the population of even a single country to Mars, especially not all of humanity. It has to be accepted that Mars is a very valuable long-term option for humanity, but it cannot provide another habitable planet instead of Earth – it may only be transformed more habitable only as a result of the persistent work of a permanent Martian colony over many centuries or thousands of years, but even then, we cannot expect pleasant Earth-like conditions.

In conclusion, there does not seem to be any inevitable theoretical obstacle to the implementation of manned travel to Mars. However, it is also clear that a sustained and substantial investment is needed to carry out the first expedition, which will require, in addition to stable long-term funding, a permanent pool of experts to develop and test the system. This substantial investment will probably require not only the governmental sector but also other industrial and entrepreneurial partners, and sustained support from the general public – all in international cooperation.

## THE IMPORTANCE OF MAKING MANNED MARS EXPEDITIONS

The key scientific questions that human expeditions can answer in 2023 are: to better understand the possibility of past or present life on Mars, to better understand the early evolution of Earth-like planets, to reconstruct the evolutionary history of the planet from ancient wet environment toward the current dry surface, thus better understand why its evolution has diverged gradually from those of Earth over time. An important question is the reason for launching a manned Mars expedition rather than exploration with robots only. Whereas the question of robot or human was the dominant one earlier, a scenario involving the joint activity of robot and human has emerged recently – indeed, no human expedition is currently planned without robots.

One of the main arguments in favour of human expeditions against robots (despite the many difficulties) is that a robot cannot (or can only do much less) development and realisation of unprogrammed procedures, apply completely new solutions, or even new tools by modifying available parts. Although artificial intelligence is developing rapidly, we cannot still make a robot with the creativity, expertise and flexibility of a well-trained human with many years of practical experience, capable of solving a wide range of problems. Another important group of arguments in favour of human expeditions over robots is that the significance of human expeditions is more than 'just' the scientific aspect: it is a huge step or leap in human history, motivated by the exploration and conquest of the unknown, going beyond the achievements and capabilities of our predecessors. From this point of view, difficulty can also be seen as trigger and motivation, as challenges lead to new discoveries and technical innovations. The logical way forward for humanity's development is to expand beyond our planet, which would not only enrich human knowledge, culture and history beyond measure, but would also increase the chances of survival of our species and human society. Of course, a human voyage to Mars would only be a small, early stage of such a long journey.

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