Powering a Colony on Mars

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Introduction

Fig. 1: Images of Mars before and during a global dust storm. [6] (Courtesy of NASA)

With the recent advances in commercial spaceflight comes a renewed public interest in colonizing Mars. However, there are significant challenges in establishing a self-sufficient outpost on the Martian surface. A principal requirement is a reliable source of energy - to keep electronics and human occupants warm in the frigid Martian weather, to enable scientific research, to produce propellant from in situ resources for return flights, and so on. To date, the two energy sources utilized for Mars missions have been sunlight and radioactive decay. A manned mission or permanent settlement would likely also have to choose between these two.

Solar

Though a number of robotic probes sent to the explore the Martian surface have successfully utilized solar arrays for their power needs, such an approach would have trouble scaling to support human habitation. The principal concern with using solar power to support a mission is intermittency: solar panels only provide power when there is sunlight. This is a familiar problem on Earth, and a major obstacle to wider integration of renewables into the grid. The intermittency problem on Mars is more pernicious: enormous global dust storms (Fig. 1) envelop the planet typically once a year from 35 to 70 or more Martian days (sols). [1] These dust storms tend to have an opacity, or optical depth, of at least 1 - meaning that the solar flux at the top of the atmosphere is attenuated to less than $e^{-1} = 0.37$ (37%) of its original value when it reaches the surface. In addition, because Mars is farther from the Sun than Earth is, it already only receives roughly half the average solar irradiance. This intermittency introduced by multi-month dust storms, combined with the usual diurnal oscillation in solar flux, would necessitate a considerable amount of energy storage.

Nuclear

Nuclear power is an attractive alternative to solar for several reasons. Its power output is constant in time, meaning less risk of prolonged power shortages that could prove hazardous to a human crew. It also weighs less per nameplate capacity than does solar when considering a Mars operating environment - a 2016 NASA study found that about 18,000 kg of solar power generation equipment would be needed to match the output of a 9000 kg fission system. [2] This was considering a relatively small system meant to provide 21 kW peak electric power for a handful of astronauts, which translates to roughly 1.2 watts per kilogram for the solar power system and 2.3 watts per kilogram for the nuclear system.

The nighttime temperature on Mars as measured by the Opportunity rover reach as low as -98°C with diurnal temperature variations of up to 100°C, so even a temporary power loss in such an environment could quickly become life-threatening as the heating systems fail. [3] This presents another advantage of nuclear power: even in the event of an electrical fault, the passive heat from the reactor or radioisotopes could be used to warm the habitat.

A nuclear power system on Mars would look quite different from a fission nuclear plant on Earth. It would be small, modular, and self-contained, and rather than using a large steam turbine it would likely use a thermoelectric generator to convert heat from non-fissile radioisotopes, most commonly Pu-238, directly into electricity. Radioisotope thermoelectric generators (RTGs) have already been proven effective in multiple space missions, including the Pioneer and Voyager spacecraft as well as the more recent Mars Science Laboratory (Curiosity) rover. [4] However, NASA is also currently evaluating the performance of its prototype "Kilopower" system, which would use a fissile uranium core instead of plutonium, and a Stirling engine instead of an RTG, to provide 1-10 kW of power per reactor. Though still unproven, this design would be more scalable because of the greater availability of uranium fuel, and would enable higher-powered systems than previously available with RTGs. [5] However, because fissile radioisotopes have the inherent danger of a meltdown, the RTG design may yet win out due to safety considerations.

Conclusion

Though solar is increasingly popular on Earth, its intermittency, especially in the face of extreme weather events like long-lasting dust storms, makes it is less attractive on Mars. Considerable storage would be necessary to provide adequate backup power, which would result in a very heavy system. In contrast, nuclear power could provide both steady electricity and a constant source of direct heat. Thus, from a reliability perspective, nuclear power appears better suited to powering a small Mars colony. However, this is not to say that nuclear power is necessarily the best technology for extraterrestrial planetary outposts - it does introduce a set of safety and environmental concerns that may necessitate further testing and research to address.

References

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