**A review of Surface power systems for Martian colonisation**

**1. Introduction**

Establishing surface power systems will be an integral part of any manned Martian colonisation mission. The surface power system will provide all of the power that is required to recharge and repair equipment, grow and prepare food, synthesize oxygen for the crew, and ensure a stable climate within the colony over the two-year re-supply period. These systems must contain a safe and stable power source for the colony, and a means of storing excess energy for later use.

This review will focus on two major surface power system options, nuclear power reactors, and photo-voltaic (PV) solar cells, as well possible storage solutions for the power they generate. This will take into consideration their power output, safety, and transport feasibility. These comparisons will help draw conclusions on the use cases of these systems in future Mars missions, highlighting further areas of study needed to ensure their success.

**2. Background**

It is estimated in the NASA Design Reference Architecture [1] that a surface power system utilising nuclear power will need to handle a continuous 32-kWe load per day/night cycle. The power demands of nominal outpost operation, including habitat maintenance, logistics systems, rovers, and ascent stage keep-alive power will account for 12-kWe of this load. The remaining 25-kWe load will be used to operate In-Situ Resource Utilisation (ISRU) plants, which will convert the Mars atmosphere into 02 for use as propellants and life support [1][2].

When using a surface power system that utilises PV solar cells, the system will only be able to produce power during the day cycle, being unproductive overnight. This leads to the system needing a much higher average power output of 98-kWe per day [1] [3]. This is to compensate for the effects that fluctuations in weather, seasons, temperature, and position will have on the output of the PV surface power system [4]. The system must also be accompanied by a power storage solution, either batteries, or regenerative fuel cells [4]. This will allow for the continual powering of the outpost, and the ISRU.

**3. Nuclear Surface Power Systems**

There are two major concepts for nuclear surface power systems, the Pellet Bed Reactor system (PeBR), and the Potassium Rankine System (KRS) [6]. Both systems rely on the production of alpha radiation, radiated from alpha generating radioisotopes. This radiation is then absorbed, producing the temperature potential difference used to generate electricity. Isotopes 238Pu and 241Am are recommended due to their long lifespan of 87.5 and 458 years respectively [3] [6].

**3.1. Nuclear Power Safety Considerations**

Nuclear surface power systems must contain an external shield to protect the crew form radiation emitted by the reactor. In the Design Reference Marketecture 5.0 (DRM 5.0) supplied by NASA [1], a radiation dosage of 5 rem/yr from the reactor is adopted. To achieve this, it is suggested that a shaped shield is employed. This will limit radiation in the direction of the colony to the required 5 rem/yr (at 1 km), and 50 rem/ye in all other directions. This will limit the required total mass of the reactor but will also reduce the total habitable area of the colony. It is also advised that the reactor be buried beneath Mars’ surface or encased in water. These options will help greatly diminish the radiation output of the reactor [6].

**3.2. Nuclear Power System Transportation Considerations**

The ability to transport the nuclear power system to Mars’ surface is a major consideration for its feasibility. Both power systems concepts will require large amounts of shielding to protect the crew during their initial transport to Mars [5]. Both systems will also require the same level of external shielding to accompany them, used for protecting the crew upon instillation on Mars [6].

Fuel will also need to be included and transported with these systems. The PeBR system has an overall specific mass of 3.29 Kg/kW, the KRS system an overall specific mass between 4-10 Kg/kW [6]. Due to their continuous operation, a nuclear-powered system is not required to produce the equivalent of a full day/night cycle’s power solely within the day cycle. From this they can have a lower energy density when compared to a solar array, while still outputting the same total power. This also means that the Nuclear system will require very little external storage in terms of batteries [3].

**4. Solar Surface Power Systems**

The solar surface power system is comprised of a network of individual PV panels. This power system is a highly reliable and low-cost power generation method. Its lack of moving parts, simplicity in setup, and its relative safety make it a viable option for Mars colonisation [1] [7]. However solar surface power systems also suffer from a wide range of issues. The power output of said system can vary greatly depending on a wide range of external factors. These include but are not limited to dust build-up on panels, dust concentration within air, geographical location, solar irradiance, and storage of power for use when the system is inactive [1] [3] [5] [8].

**4.1. Solar Power System Electrical Storage Considerations**

Due to the non-continuous nature of the power generation of a solar surface power system, external power storage must be employed [7]. This storage will enable ensure the continued powering of the colony, and ISRU systems, during night hours where the solar array is inactive [3]. Since external factors such as weather events will influence the output of the power system system, the storage system must also have the capacity to support the colony for extended time periods. There are two main options available for electrical storage, conventional Li-ion batteries, or regenerative fuel cells. Li-ion Batteries feature a mass-specific energy density of 150 Wh/kg and a volume specific density of 270kWh/m3, while regenerative fuel cells feature a mass-specific energy density of 250 Wh/kg and a volume specific density of 200kWh/m3 [5].

**4.2. Solar Power System Transportation Considerations**

A solar surface power system will require substantial space to transport and occur a substantial fuel cost in terms of transportation of mass. This is due to requiring a much larger PV array than would generally be demanded. This must be done to account for all possible external events [8]. The DRM 5.0 states that in conditions such as a dust storm, a total mass of 8,000 kg of panels will be required, totalling for a 4,300 m2 panel area [3]. The provided array of panels will also require that a large power storage system accompany it, due to its inconsistent and non-continuous power output.

**5. Discussion**

This review has looked at and considered the current viability of nuclear and solar surface power systems in the context of Martian colonisation. Both systems have clear advantages within the contexts of the Martian landscape, and any successful colonisation attempt will attempt to combine these two systems for a more versatile power system.

Due to the continuous power output of a nuclear surface power system, they will be far more reliable for powering vital systems such as the colony buildings and their life support [1]. Due to the lower power density requirements of the nuclear power systems [5], they will also be the more economically feasible option, as they require a smaller overall storage area, and lower mass requirements [1] [3]. Nuclear power systems however do require substantial research into their safety. Research into the lifespan of such a system in the Martian environment is imperative for the safety and success of any colonisation attempt. Further research into optimising the efficiency of such systems would also be recommended, utilising all aspects of the thermo-nuclear process. Possible combination of the nuclear surface power system with the ISRU system could lead to increases in efficiency, excess radiation produced by the reactor could be utilised to split water into hydrogen, and oxygen for use in fuel cells.

Solar surface power systems benefit from their simplicity, and their safety, Being easy to set up immediately upon landing, they will most likely be the first source of power for any Mars colonisation mission [3]. PV arrays however lack the ability to continuously provide power, and because of this require a might higher energy density when compared to nuclear [4]. Further research into increasing the efficiency of PV panels will be required, as well as research into Mars specific PV panels. Mars specific PV panels will be optimised to receive light from the spectrums that are most readily available.

Further research into power storage possibilities will also greatly improve the chance of success of future Mars missions. Current information suggests that the power storage option providing the highest energy density per volume will be the Li-ion batteries. However, regenerative fuel cells have a higher energy per mass [5]. Because of this it will be important to optimise for which option will provide the greatest power storage overall. This will require research into the possible costs of transporting these options.

**Reflection**

Overall this assignment has been very useful. It has given me a much more in-depth knowledge of the researching process that is required before you can begin to work on a solution. However, a few of the lectures were very dull, and very simple. If the lectures were made to be a little more engaging and give more examples of good writing style rather than bad, I feel more could be gained from the course. Also the in lecture ‘Quizzes’ seem to be very trivial overall, maybe instead of in lecture quizzes, have the labs include some marked work.

# **References**

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