International Journal of Research in Engineering, Science and Management
Volume-2, Issue-10, October-2019
www.ijresm.com | ISSN (Online): 2581-5792

Design and Optimization of Power Sources for Deep Space Missions

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***Abstract*: Space technology is going to be knocking down experience for all the people in the macrocosm. Deep space missions are designed for making interplanetary travel beyond the surface of earth. As the name suggests, space missions are utilized for making journey in the outer interstellar space with the help of rockets and spacecrafts. The space mission designs need the power sources for providing optimum power for path of spaceflight until to the return of starting point. In my research paper I am going to discuss about the power source which can be installed on spacecraft for giving maximum power to the technology and enhancing the vision of spaceflight.**

***Keywords*: Nuclear power, fusion and fission reactions, radioisotope piezoelectric generator, fuel cells, phosphoric acid fuel cells.**

1. Introduction

Deep space mission is the one which involves the exploration of space over the solar system. As the name insists the deep means the “distant” which utilizes the propulsion of advanced rockets and space manned flight vehicles. The deep space mission also focuses on interplanetary space travel form the earth surface. One of the deep space missions which has been send by NASA is voyager 1 which has reached the space travel in 2012 taking the couple of months to reach the inner planetary space travel. The deep space mission forms the basic concepts in atomic physics, beamed propulsion, and nuclear propulsion. These are some future advanced technologies by which space mission into deep space can be made possible. Although nuclear propulsion is risky and non-economic in nature in some cases, it can be utilised for discovering of exoplanets and effective study of properties over the solar systems. Deep space missions use the space physics and other available technology for making further exploration towards the space science. Interplanetary travel is the travel between the planets with the known sources of available space missions and design. In typical spaceflights they are confined to travel between the planets of solar system. Space probes are used in one side for making the deep space missions. Remotely guided space probes have been flown from Neptune to Pluto over the few decades and the properties of various planets has been studied with the help of voyagers. Currently some of the deep space probes are revolving around the planet Ceres over which some of the space probes has been left out in place. The cost of deep space mission is more when compared to the ordinary send of rockets and spacecraft’s over the space, as it involves producing exorbitant amount of thrust and huge packets of batteries and other electronic devices in the mission. This is the reason where most of the interplanetary space mission are not preformed frequently from every part of the developed country. The power sources are designed in such a way to tolerate the necessity of the spacecraft failure and the other design missions for the space mission design and analysis. While during deep space exploration, there must be enough amount of fuel for sustainability of the humans and the other electronic design instruments.

2. Interstellar travel

Interstellar travel is the travel of deep space mission which is usually denoted in astronomical units. The distance between the other planets will be generally lesser when measured in AU. On the other hand, the distance between the stars and galaxies will be measured in millions in terms of astronomical units. Thus because of vastness of the distances, interstellar travel would require more amount of speed of light, greater energy to reach the distance over space. The speeds required for interstellar travel exceeds than the spacecraft exploration.

3. Interstellar distance

The distance of the interstellar space is often measured in terms of astronomical units. The units od AU is 1.5×108 which is measured between the distance of the earth and sun. The closest planet in our solar system is Venus which entails the small astronomical units, and in same way the farthest planet is Neptune which weighs more in comparison. The distance between the space travel can be measured as follows with the help of the following table. Although all of the planets are not discussed here, some of the nearby and farthest planets is enumerated for reference. The distance measured between the stars in accompanied by the evaluation of microwave gravitations involved with the space and other patterns of waves occurring in space. Because of this, distance between stars are usually expressed in light years rather than the direct astronomical units.

4. Energy that involves with space travel

The significant factor which must be considered while making the interstellar travel is the amount of energy that must be supplied which must not interfere with any kinds of emissions and other medium. One way of doing is, calculating the amount of kinetic energy which is usually expressed as ½ mV2 where m is the mass in above equations. If the deceleration is not achieved within the following amount of energy than the spacecraft or stars hip will fail in the following manner. The velocity for manned round trip around the outer space objects is even much greater than the current spacecraft and the vehicles. Because of this, it cannot provide the required amount for making deep space missions and travel. The energy involves for this can be powered with the help of nuclear power sources available which can be provided with the help of helium and methane.

Fig. 1. Interstellar distance in terms of astronomical units for the nearby and farthest stars and planets.

Efficiency (%) = (useful energy out ÷ total energy in) x 100.

Gravitational Potential Energy = mass x gravity x height.
GPE = mgh.

Kinetic Energy = 0·5 x mass x velocity2. KE = $\frac{1}{2}mv^2$.

Work done = Force x Distance. W = F x d.

Work done = Energy transferred. W = E.

Power = Energy ÷ Time. P = E ÷ t.

The above equations are the basic energy equations which can be utilized for calculating the energy involved with the deep space missions and space travel as follows.

5. Space exploration

Space exploration is the vast term which involves the exploration of outer space with the help of advanced mission and sensors available with the technology. Space exploration is the branch of astronautics and astronomy which uses the propulsion of ion thrust engines, nuclear mannered propulsion, ion and electro static means of propulsion as follows. As the technology develops, we are in the need to get updated with advanced versions of modular of technologies. With the help of the space exploration systems and power sources it becomes possible to explore the future space and the world of mysteries involved outside space.

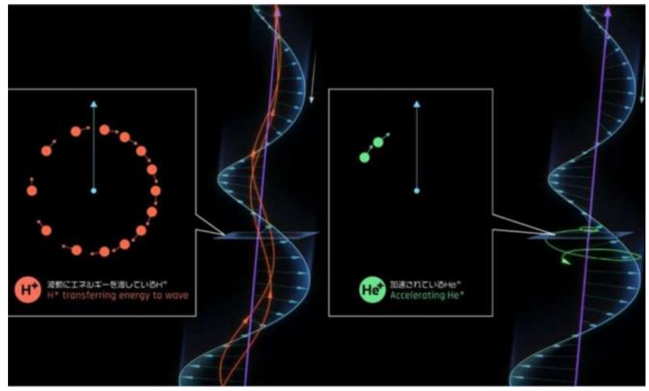


Fig. 2. Wave particle interactions allows collision free movements of particles inside the space

6. Nuclear power

Nuclear power is the nuclear reactions that uses the nuclear energy to generate heat which is the vast amount of the electricity than can be made via the sources of energy for future exploration of space. The nuclear reactions are produced by means of reaction with uranium and plutonium. These are the major two elements which are involved in the reaction of nuclear energy. The obtained power can be used for various kinds and applications and process. Thus, one must carefully examine the amount of energy required for generating the nuclear fusion and fission kinds of reactions. In 1932 physicist Ernest Rutherford discovered that when lithium atoms were "split" by protons from a proton accelerator, immense amounts of energy were released in accordance with the principle of mass–energy equivalence. However, he and other nuclear physics pioneers Niels Bohr and Albert Einstein believed harnessing the power of the atom for practical purposes anytime in the near future was unlikely. They are the first pioneers involved with the creation of nuclear energy for the generation of electricity.

Currently some of the advanced type of nuclear designs are available for the development and produces more energy than the usual amount of generation of electricity involved with the nuclear reactor. The advanced type of nuclear reactors can be used only in extreme rare occasions because of the much more available amount of energy involved with them. This kind of advanced type of nuclear reactors cannot be used with the space design mission because of the design and cost involved with them.

Nuclear reactions may be shown in a form similar to chemical equations, for which invariant mass, which is the mass not considering the mass defect, must balance for each side of the equation. The transformations of particles must follow certain conservation laws, such as conservation of charge and baryon number, which is the total atomic mass number. An example of this notation follows:

63Li + 21H→ 42He + ?36Li + 12H→ 24He +?

To balance the equation above for mass, charge, and mass number, the second nucleus on the right side must have atomic number 2 and mass number 4; it is therefore also helium-4. The complete equation therefore reads:

63Li + 21H→ 42He + 42He36Li + 12H→ 24He + 24He

Or, more simply:

63Li + 21H→2 42He

The above equation if balanced will generate the helium atoms involved with the lithium and hydrogen. Plutonium on the other hand cannot be involved with this because it will generate the unbalance among the equations.

Table 1
The model of the various decay type and emitted radiations from the Parent electron

Decay Type	Radiation Emitted	Generic Equation	Model
Alpha decay	${}^{4}_{2}\alpha$	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}X' + {}^{4}_{2}\alpha$	Parent → Daughter, Alpha Particle
Beta decay	${}^{0}_{-1}\beta$	${}^{A}_{Z}X \longrightarrow {}_{Z+1}^{A}X' + {}^{0}_{-1}\beta$	Parent → Daughter, Beta Particle
Positron emission	${}^{0}_{+1}\beta$	${}^{A}_{Z}X \longrightarrow {}_{Z-1}^{A}X' + {}^{0}_{+1}\beta$	Parent → Daughter, Positron
Electron capture	X rays	${}^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}_{Z-1}^{A}X' + \text{X ray}$	Parent, Electron → Daughter, X ray
Gamma emission	${}^{0}_{0}\gamma$	${}^{A}_{Z}X^{*} \xrightarrow{\text{Relaxation}} {}^{A}_{Z}X' + {}^{0}_{0}\gamma$	Parent (excited nuclear state) → Daughter, Gamma ray
Spontaneous fission	Neutrons	${}^{A+B+C}_{Z+Y}X \longrightarrow {}^{A}_{Z}X' + {}^{B}_{Y}X' + C{}^{1}_{0}n$	Parent (unstable) → Daughters, ENERGY, Neutrons

With the help of the above diagram the following different types of the alpha and beta decay and various kinds of emissions can be found out as follows. The positron emission is the one which emits greater amount of radiation among the decay present in the nuclear fusion reaction.

7. Nuclear fission

It is the process in which nuclear atom splits into two smaller nuclei atom or particles. This is the form of elemental transmutation. They are usually the bi-products usually in the form of gamma rays and other kinds of particles such as beta and alpha rays followed in the nuclear fission reaction. Fission of heavy elements is substantial reaction and can release useful number of products for further useful reaction of nuclear fission.

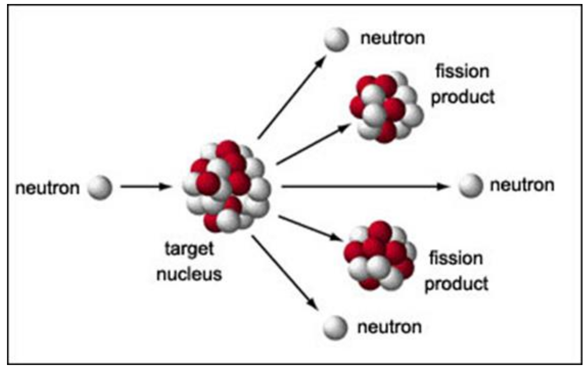


Fig. 3. Nuclear fission involved with neutron forming the target nucleus and various kinds of fission products.

8. Nuclear fusion

Nuclear fusion is the reaction in which the two or more atoms are combined to form the different atomic or nuclei atom for the fusion process. The difference is that the atomic weight of the atom changes during the nuclear fusion process. This arises due to the amount of binding energy which is associated with the atoms. The release of energy with the fusion of light elements is due to the interplay of two opposing forces: the nuclear force, which combines together protons and neutrons, and the Coulomb force, which causes protons to repel each other. Protons are positively charged and repel each other by the Coulomb force, but they can nonetheless stick together, demonstrating the existence of another, short-range, force referred to as nuclear attraction.

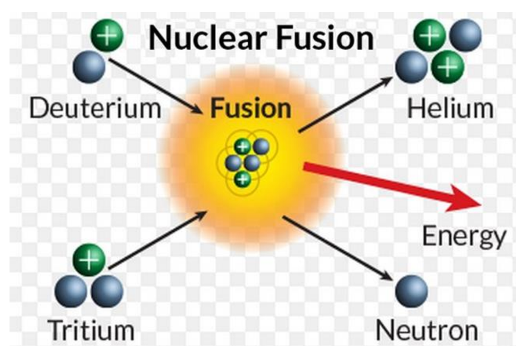


Fig. 4. Nuclear fusion entailed with the release of Deuterium and Helium.

Thus, the nuclear fusion and fission reactions can be combined in the nuclear power reactor to get more amount of the required power for the circuit and thus the nuclear reactor can assist in giving the required power. The amount of power produced by the nuclear reactor depends upon the combination of the fission and fusion reactions in the reactor as follows. The reactor makes the necessary action according to the various reactions which has been taken place in the nuclear reactor.

9. Radioisotope piezoelectric generator

Piezoelectric is the one which generates electricity when certain amount of mechanical stress induced on them. The term piezoelectric comes from the electrical means of application of materials. The piezoelectric works by placing the two metal plates and then applying the pressure in-between of them. In kinds of space station thus the metal plate is used or not depends upon the application to the power sources employed on them.

Nuclear powered generator can be employed for storing the energy for the future use of space reactions and the steps involved with them. Thus, the radioisotope nuclear generator consists of following parts

- Atomic battery
- Thermoelectric converter
- Nuclear voltage generator
- Optoelectrical nuclear battery

Each component is explained to get the following detailed explanation of the working of the nuclear generator.

10. Atomic battery

The atomic battery is the one which uses the decay of the radioactive isotope from the various reaction to generate electricity. This it is also known as the nuclear generator or the radioactive generator. Like nuclear reactors they generate electricity from the nuclear reaction, but only the difference is the one it does not use chain reactions. Compared to other batteries, they are very costly, but have an extremely long life and high energy density, and so they are mainly used as power sources for equipment that must operate unattended for long periods of time, such as spacecraft, pacemakers, underwater systems and automated scientific stations in remote parts of the world.

The pacemaker is the one which causes the formation of the nuclear fusion reactions in the reactor with the help of electrode and thermal insulation. The energy can be stored and can be converted further into voltage. There are also fuel capsule available which makes the storage of nuclear fuels inside the reactor. The following diagram shows the atomic battery involved pacemaker. Batteries using the energy of radioisotope decay to provide long-lived power (10–20 years) are being developed internationally.

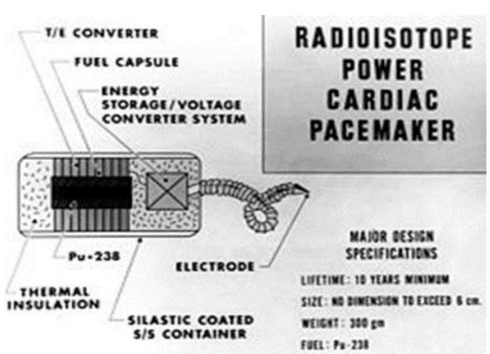


Fig. 5. Atomic battery with radioisotope power cardiac pacemaker

11. Thermoelectric converter

The thermoelectric converter is the one which converts heat into electricity. This kind be done in space with the help of the heat generated from the space shield which gives us the electricity involves with them. Thus, it converts the reversible chemical reaction. The most important part of thermoelectric converter is the equation is equilibrium which runs continuously on the shield of the reaction. The advantage of the thermoelectric converter is the battery is rechargeable and it can be used for many times as possible. Thus, it can be exploited best in engineering solution. With sufficient development, it can be able to compete with the available and developed technology of the generators and electrotechnical devices available.

$$V = S \times DT$$

Where:
V = the output voltage from the couple (generator) in volts
S = the average See beck coefficient in volts/°K
DT = the temperature difference across the couple in K where $DT = T_h - T_c$

When a load is connected to the thermoelectric couple the output voltage (V) drops as a result of internal generator resistance. The current through the load is:

$$I = \frac{S \times DT}{R_C + R_L}$$

Where:

I = the generator output current in amperes
R_c = the average internal resistance of the thermoelectric couple in ohms
R_L = the load resistance in ohms
The total heat input to the couple (Q_h) is:

$$Q_h = (S \times T_h \times I) - (0.5 \times I^2 \times R_c) + (K_c \times DT)$$

The above formula can be used for the finding of the generation of electricity in the thermoelectric converter.

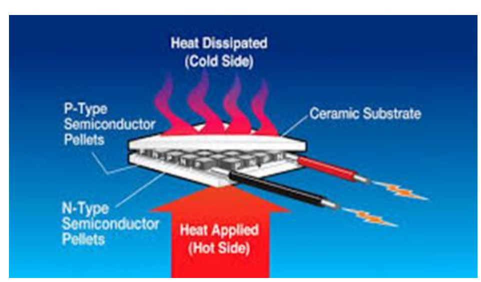
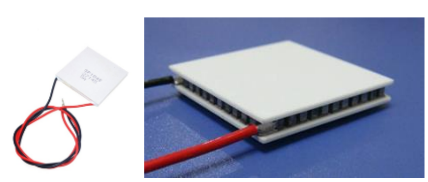


Fig. 6. Working of thermoelectric generator.



12. Nuclear voltage generator

Nuclear voltage generator is the one which generates nuclear energy with the help of the nuclear decay fission and fusion reactions which has occurred inside the reactor. The voltage generator is placed inside the reactor to generate the electricity. The nuclear voltage generator can be placed in the spacecraft or the rockets for providing the required amount of energy for generation of helium and plutonium inside the rector. The voltage generator as the name itself suggests is the one which generates voltage as the nuclear atom get split up into two. The voltage generator is placed such that generated voltage can be stabilized and stored inside the nuclear reactor.

13. Fuel cells

A fuel cell is an electrochemical cell that converts the chemical energy of a fuel into electricity through a pair of red ox reactions. Fuel cells are different from most batteries in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy usually comes from metals and their ions or oxides [3] that are commonly already present in the battery, except in flow batteries. Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied.

The first fuel cells were invented by Sir William Grove in 1838. The first commercial use of fuel cells came more than a century later following the invention of the hydrogen–oxygen fuel cell by Francis Thomas Bacon in 1932. The alkaline fuel cell, also known as the Bacon fuel cell after its inventor, has been used in NASA space programs since the mid-1960s to generate power for satellites and space capsules. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are also used to power fuel cell vehicles, including forklifts, automobiles, buses, boats, motorcycles and submarines.

There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows ions, often positively charged hydrogen ions (protons), to move between the two sides of the fuel cell. At the anode a catalyst causes the fuel to undergo oxidation reactions that generate ions (often positively charged hydrogen ions) and electrons. The ions move from the anode to the cathode through the electrolyte. At the same time, electrons flow from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, another catalyst causes ions, electrons, and oxygen to react, forming water and possibly other products. Fuel cells are classified by the type of electrolyte they use and by the difference in startup time ranging from 1 second for proton exchange membrane fuel cells (PEM fuel cells, or PEMFC) to 10 minutes for solid oxide fuel cells (SOFC). A related technology is flow batteries, in which the fuel can be regenerated by recharging. Individual fuel cells produce relatively small electrical potentials, about 0.7 volts, so cells are "stacked", or placed in series, to create sufficient voltage to meet an application's requirements.[4] In addition to electricity, fuel cells produce water, heat and, depending on the fuel source, very small amounts of nitrogen dioxide and other emissions. The energy efficiency of a fuel cell is generally between 40–60%; however, if waste heat is captured in a cogeneration scheme, efficiencies of up to 85% can be obtained.

The fuel cell market is growing, and in 2013 Pike Research estimated that the stationary fuel cell market will reach 50 GW by 2020.

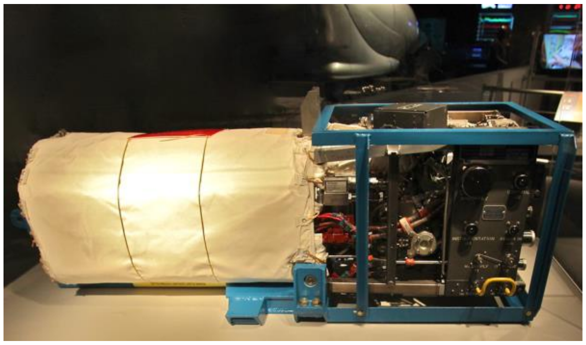


Fig. 7. Fuel cells used in space applications.

14. Phosphoric acid fuel cell

Phosphoric acid fuel cells (PAFC) were first designed and introduced in 1961 by G. V. Elmore and H. A. Tanner. In these cells phosphoric acid is used as a non-conductive electrolyte to pass positive hydrogen ions from the anode to the cathode. These cells commonly work in temperatures of 150 to 200 degrees Celsius. This high temperature will cause heat and energy loss if the heat is not removed and used properly. This heat can be used to produce steam for air conditioning systems or any other thermal energy consuming system. Using this heat in cogeneration can enhance the efficiency of phosphoric acid fuel cells from 40–50% to about 80%. Phosphoric acid, the electrolyte used in PAFCs, is a non-conductive liquid acid which forces electrons to travel from anode to cathode through an external electrical circuit. Since the hydrogen ion production rate on the anode is small, platinum is used as catalyst to increase this ionization rate. A key disadvantage of these cells is the use of an acidic electrolyte. This increases the corrosion or oxidation of components exposed to phosphoric acid.

15. Theoretical maximum efficiency

The energy efficiency of a system or device that converts energy is measured by the ratio of the amount of useful energy put out by the system ("output energy") to the total amount of energy that is put in ("input energy") or by useful output energy as a percentage of the total input energy. In the case of fuel cells, useful output energy is measured in produced by the system. Input energy is the energy stored in the fuel. According to the U.S. Department of Energy, fuel cells are generally between 40–60% energy efficient. This is higher than some other systems for energy generation. For example, the typical internal combustion engine of a car is about 25% energy efficient. In combined heat and power (CHP) systems, the heat produced by the fuel cell is captured and put to use, increasing the efficiency of the system to up to 85–90%.

The theoretical maximum efficiency of any type of power generation system is never reached in practice, and it does not consider other steps in power generation, such as production, transportation and storage of fuel and conversion of the electricity into mechanical power. However, this calculation allows the comparison of different types of power generation. The maximum theoretical energy efficiency of a fuel cell is 83%, operating at low power density and using pure hydrogen and oxygen as reactants (assuming no heat recapture) According to the World Energy Council, this compares with a maximum theoretical efficiency of 58% for internal combustion engines.

16. Opto electric nuclear battery

The opto electric nuclear battery is the one which converts the nuclear energy into light, which is later used for generation of electrical energy. The deuterium atom is used in the nuclear battery for the electricity and power generation. The diameter of the dust particle is so small such that dust particles cannot be accumulated inside the nuclear battery, so that it can be sustained for longer life and durability. The surrounding weakly ionized plasma consists of gases or gas mixtures (such as krypton, argon, and xenon) with excimer lines such that a considerable amount of the energy of the beta electrons is converted into this light. The surrounding walls contain photovoltaic layers with wide forbidden zones as e.g. diamond which convert the optical energy generated from the radiation into electrical energy.

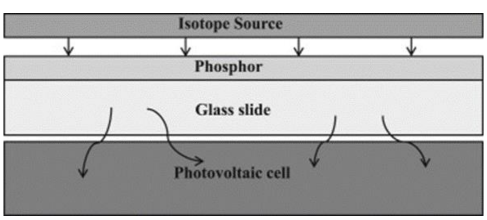
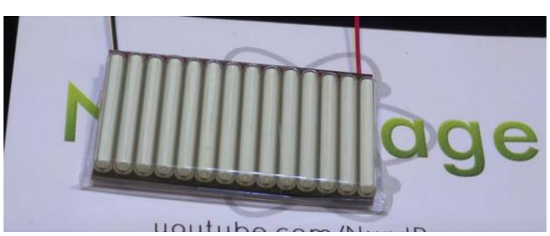


Fig .8. The light illumination and electricity generation using the Opto electric nuclear generator



The Nuclear generators are stacked in order for getting the maximum amount of energy to be generated in the manner so that more amount of energy can be stored and used for future use.

17. Results and discussion

Space journey is incredible and exciting for all the people in world. But, at the same time it involves taking much risk and involving with more economy. The above batteries and opto electrical devices discussed produced the absolute results for generation of nuclear power and conversion into electric power. Also, the stacks of nuclear battery powered the system and generated the fission and fusion reactions. The nuclear reactor is employed so that the reactions can multiply in the manner to get the required output and storage of energy can be obtained. The above discussed power sources provided the maximum output in sensing the environments and acting according to the sources present. Thus the power sources in implemented to provide the power for the spacecraft and space ship in case of hard and extreme weather conditions.

18. Conclusion

The space is an exciting journey for all the people in the world. When comes to the sources of operation, there occurs a problem in providing the operation and power cost for the mission. The above innovations will help in providing assistance to the spacecraft as well as the other devices to the spacecraft exploration systems.

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