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Alternative Power and Propulsion for Space Systems

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Abstract

What are the main sources of power and propulsion for space systems and what are their advantages, disadvantages, how do they work, and what are the politics behind them? The following topics will be analyzed solar panels, batteries, radioisotope thermoelectric generator (RTG), advanced stirling radioscopic generator (ASRG), reactors, nuclear thermal rockets (NTP), thermionic experiment with conversion (TOPAZ), electrothermal plasma thruster (VASIMR), ion propulsion, and finally nuclear pulse propulsion. The production of Pu-238 is extremely controversial but a vital source of fuel for many of these space systems. Soral and Batteries are the most common and the least controversial forms of power used in space systems today. However, is ineffective for deep space exploration as they only function for up to four years without needing to be recharged. This is where nuclear systems come into play. Nuclear systems such as an RTG will "live" up to 88 years. For example, Voyager 1 is powered by an RTG It has been traveling since 1977 and has left out solar system in 2012 and has yet to run out of power. However, this type of technology (nuclear) has many hurtles it needs to jump through before advancements in can go much further.

Introduction

In 1932 the atom was split, leading to many extraordinary discoveries and capabilities thought impossible before. In 1969 humans set foot on the moon, by 1977 Voyager One was launched, and in 2012 Voyager One successfully left our solar system; these great accomplishments came about because of nuclear power. Voyager and the Apollo missions and made use of radioisotope thermoelectric generators (RTGs), which are a plutonium-based fuel system. However, with Americas ever changing economic and political climate, deep space exploration came to a halt in 1968 when the Partial Nuclear Test Ban Treaty was signed, as a result of the Cold War. There is only so much one can achieve with our existing and most prevalent power and propulsion sources. Solar panels only work near the sun, batteries last for about four years, chemical propulsion needs tons of fuel to be effective. Reintroducing nuclear power can turn a 7-month trip to Mars into a 45-day trip. Given these challenges and potential benefits, how efficient and reliable are different types of space propulsion and power systems, how do they work, what are their fuel sources, and what are their political hurtles?

I. Power Generation

1. Solar Panels

Solar panels are the most common and widely utilized source of power for satellites. Even a space system such as the International Space Station is powered by solar panels. These panels absorb the sun's rays and convert them into electricity, keeping the crew of the ISS alive. There are two main types of solar panels: silicone panels and perovskite panels. Both have their advantages and their shortcomings. Because satellites are in orbit, they are almost always in direct sunlight. Even if the panels are turned 10 degrees away from the sun, they are still 98.5% effective. However, solar panels become less practical for rovers, landers, and deep space travel: the intensity of the sun decreases with distance, causing solar panels to become ineffective. In addition, landers work on the surface of planets and need to operate with no sunlight for half of the day. In this case solar panels can be used, but not as the main source of power. These are advantages and failings in silicone panels working at 18% quantum efficiency (measure of effectiveness converting photons to electrons) and up to 200 watts per square meter, whereas perovskite has 30% quantum efficiency and 350 watts per square meter. Therefore, perovskite has the potential for higher performance than silicon wafers. However, perovskite may decompose when exposed to moisture and oxygen due to its crystalline structure formed in fabrication, although research is being done to improve this material's stability.

Solar panels or photovoltaic cells are made by mixing sand and carbon heating it to 2000℃ to get 98% raw silicon. This silicon is then heated into its gaseous state where it is mixed with hydrogen for high purification SiHcl3 or polycrystalline is formed. The two structures that can be used for solar panels are monocrystalline and polycrystalline silicone. These are then cut into thin wafers to be the core of the solar cells. When light hits the silicon wafers the electrons gain a photon, making free electrons. However, these free electrons don't have a direction to make a cohesive tangible current. A driving force is needed; in this case a P-N junction is used. P-type doping is where one side of the silicone is injected with boron that was injected with 3 valance electrons. This gives every atom a hole that the free-flowing electrons from N-area automatically fill, creating a depletion region and making N-area positively charged and P-areas negatively charged. When enough light is absorbed, the depletion region acts as a wall to the free electrons and holes. Therefore, when a wire is strung from one side to the other, the electrons migrate over the wire to P area to fill the holes. One PV cell makes 0.5 volts. The voltage is amplified and strung together with other cells, making it a usable source. This form of power is popular because it is cost effective and has a positive view among the general population, but it is unable to help us on our path to deep space exploration. As solar is not always available an alternative to this is storing the energy in batteries.

2. Batteries

Another power option is batteries. Batteries accept, store, and release electricity on demand. Some batteries currently used in satellites are chemical, hydrogen, and lithium based.

Batteries have chemical potential: two electrical terminals (a cathode and an anode) separated by electrolytes are utilized to produce 50watts every hour. To accept and release energy the battery is coupled to an external circuit. Electrons move through the circuit to allow atoms and molecules with an electric charge to move through the electrolyte to produce usable electricity.

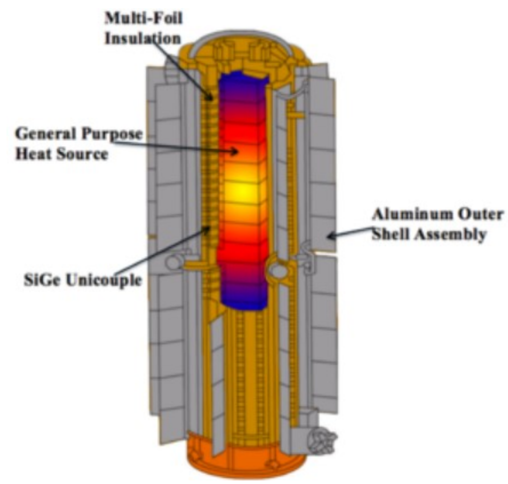
A common battery used in satellites is the BA01 High Energy Density Battery. When placed in a CubeSat satellite these batteries provide a minimum of 22.2Watt hours to a maximum of 50Watt hours. The life expectancy of these batteries is maximized by using space environment attenuation manifold (SEAM) is used. SEAM [1] is a packaging that blocks alpha, beta, and x-gamma radiation. It also blocks 67% of incoming heat and neutralizes electromagnetic pulse (EMP) and plasma discharge events. With this packaging it prolongs its life by 2 years for a total life of 4 years [2]. However, this is not a long enough battery life for deep space travel. Therefore, as an alternative to batteries nuclear power has been used for over 50 years.

3. Radioisotope Thermoelectric Generators (RTG)

Unlike solar panels or batteries, the RTG has a life span of 88 years. Using the laws of thermodynamics and taking advantage of radioactive decay, this power source can propel mankind into the future of deep space travel. The downside to RTGs, however, is that the most effective radioisotope for RTGs is no longer being produced.

How does an RTG work? The core of the RTG is surrounded by thermocouples (two equal and opposite forces) : these couples are exposed to the decay process that occurs in the core, which emits intense heat. The other side of the couples are exposed to the freezing temperatures of outer space. RTGs use thermoelectric semiconducting materials for the couples to generate an electric current using the two temperature extremes on opposite sides of the couples. Heat is transferred through a heat exchanger to a conversion system, which produce a magnetic field where a current or flow of electrons occurs resulting in a voltage power output. The greater the temperature difference across the couples, the stronger the magnetic field and the more electricity a couple produces. Most RTGs are equipped with radiator fins so that when the core produces an excess amount of heat, the fins will distribute the heat to keep temperatures regulated. The advantage to this system is it is a long-lived static operation that results in minimal complications.

In the core of the RTG the radioisotope used is plutonium-238 (Pu-238). One kilogram of Pu-238 generates 560 watts of thermal power and has a half-life of 88 years. This technology has other desirable qualities, such as being high heat, compact, and has low gamma and neutron radiation so it has no need for heavy shielding. Pu-238 was first produced in mass quantities at Oak Ridge National Laboratory. Development of Pu-238 is done by placing rods of urianium-235 (U-235) and rods of uranium-238 (U-238) separated by graphite (which slows down free neutrons) into a honeycomb structure in a reactor. When a neutron is released, it moves through the graphite[1] and if it hits a U-235 atom, the atom splits and releases a neutron. If this neutron hits U-238 instead of splitting and continuing the chain reaction, it absorbs the neutron and becomes neptunium-93 which decays into Pu-238 which will then continue



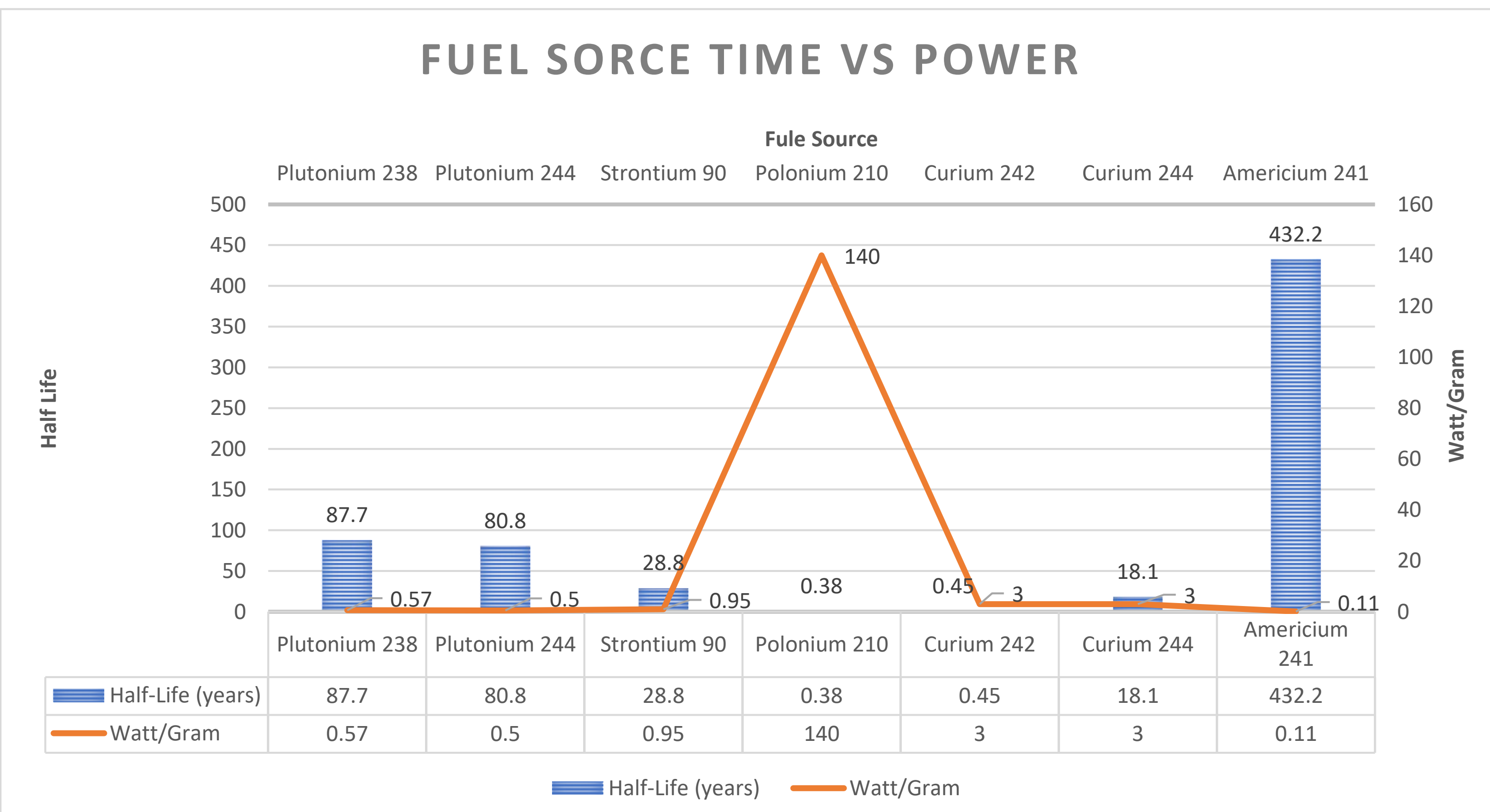
the chain reaction.

Figure 1: Radioisotope Thermal Generator [Wikimedia Commons. (March 15, 2015). SiGe RTG [Online]. Available: https://commons.wikimedia.org/wiki/File:SiGe_RTG.png]

Pu-238 is considered the best fuel source for an RTG. However, Pu-238 is a limited resource. After the Cold War ended in 1988, the United States terminated production of Pu-238 because of an agreement between themselves and Russia to not use nuclear power as a method of destruction. This is affects the production of Pu-238 Pu-235 is created simultaneously with Pu-238 and Pu-235 is weapons grade. During a period of relative peace between the United States and Russia in 2013, production of Pu-238 was reapproved at lab scale in small quantities. This is a huge political hurdle for RTGs to overcome to further their use in peaceful deep space travel. NASA needs an estimated two kilograms per year of Pu-238 just for robotic planetary missions.

What are possible alternatives to Pu-238 and what are the requirements they need to meet to replace Pu-

238? There are four primary requirements. First, they require good power density. Second, they require a good half-life. Third, they require little to no shielding. Lastly, they should have a high power to mass ratio (to minimize propulsion requirements). Some good candidates are strontium-90, polonium-210, curium-242, and curium-244. However, none of these meet all four requirements. Americium-241 is the best candidate to replace Pu-238 as it has a half-life of 150 years and is byproduct of regular power reactors (more abundant and easier to obtain), but the downsides to this radioisotope are that it is a quarter the density of Pu-238, is a greater radiation hazard, and is already being used in mass production for smoke detectors and moisture gauges making its cost and availability difficult. Another possible radio isotope is the rarer Am-242m (Americium-241 after it absorbs a neutron). However, this isotope needs more testing before it can be used. The graph below depicts the two main requirements for the chosen radio isotope, showing life span and power production.



	Plutonium 238	Plutonium 244	Strontium 90	Polonium 210	Curium 242	Curium 244	Americium 241
Half-Life (years)	87.7	80.8	28.8	0.38	0.45	18.1	432.2
Watt/Gram	0.57	0.5	0.95	140	3	3	0.11

Figure 2: Graph (Fuel sours VS Power)

4. Plutonium-238

Why is Pu-238 so desirable? How is it synthesized? Pu-238 is the best isotope that we know of to date that can handle long terms space missions, has a high-power density and is not harmful to people working with it because it needs little shielding to be effective. Pu-238 is a key force in deep space travel. The process of making Pu-238 starts in nuclear reactors. Savanah River National Laboratory (SRNL) used heavy water reactors, because they were ideal for making tritium because of its high-power density. Used before 1959 These heavy water reactors were contracted to produce tritium at SRNL. Making 95% of the United States tritium. Another point that made these reactors so efficient was that the control system was extensive. Having 64 control clusters and having 7 control rods. Most of the control rods were made of lithium to make tritium. Originally the reactors ran on natural uranium fuel and were only able to make tritium in those rods. After 1959 however SRNL switched to use highly enriched uranium fuel. This allowed the process to produce more tritium and run at higher powers. For comparison a natural uranium fuel reactor produces 375 megawatts and heavy water reactors produce 2500megawatts. One megawatt per day will produce 1 milligram of tritium a day likewise one megawatt per day will produce 1 gram of Pu-239. The flux pattern of SRNL reactors is beneficial. A traditional reactor cycle will have a traditional tear drop flux pattern influencing radial fuel movement during irradiation cycles to get an even "burn." However, in SRNLs reactors the control clusters each with seven rods were capable of movement. With only half the rods in a cluster the radial and lateral flux pattern could be fine-tuned to get a much better uniform burn.

Pu-238 is produced rom successive neutron capture during the irradiation process in a reactor. To irradiate U-235 to U-236 to Np-237 to finally Pu-238. The SRNL reactors make a good amount of Np-237 because SRNL recycles the highly enriched uranium through the reactor gaining more U-236 each time it is passed through. The Np-237 is stock pilled and when more Pu-238 is needed the Np-237 is made into an oxide by adding oxalic acid to precipitate Np oxalate. The oxalate was calcined to the oxide in the furnace.

SRNL produced 35% of the United States' plutonium. Other byproducts include neptunium, curium, americium, and californium. The byproducts are taken out of the reactor and separated using a nitric acid solution. This solution oxidizes the isotopes. The oxide is blended with aluminum powder, compounded, and extruded out into a cylinder. Cold aluminum is then put on the inside and outside of the core acting as a shield to the radiation. This core is then left for several months to cool. When the core is taken out, it goes into a frame dissolver where the oxides undergo four cycles of ion exchange, making a nitric acid mixture. "In chemical engineering there are three technologies, Solid Extraction, Precipitation, and Ion Exchange" (Odum. Joseph 6/22/2023); in this context an ion exchange is performed. The solution is loaded onto tiny resin beads that undergo a chemical treatment. These beads have pores that are important to a successful ion exchange. When the acid concentration that the beads are in increases its acidity and strips the solution of its products except for Pu-238 and neptunium. This happens because the acid makes the plutonium and neptunium into anions and the other products into cations causing the cations to let go of the resin beads and the anions to cling to the pores on the beads. The beads are loaded onto a resin rod where neptunium and plutonium are separated with nitric acid solutions. This product is then sent to another building where oxalic acid is mixed in with the nitric acid, where it precipitates plutonium oxalate 238. Lots of heat is produced, causing the plutonium oxalate to self-calcine from an oxalate to an oxide. The same is done to the neptunium.

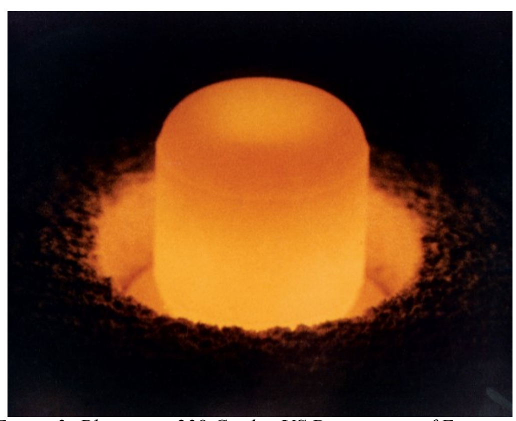


Figure 3: Plutonium-238 Credit: US Department of Energy

The plutonium is then a light brown dust, and because it is highly radioactive, it moves on its own becoming airborne. If the researcher is not careful it can crawl out of the glovebox it is contained in. The Pu-238 is placed into a stainless-steel (SS) container that is put into another SS container that is welded at the top. There, it has time to fission out from Pu-238 to Pu-235 PUFF (pulsed fission-fusion propulsion).

The plutonium is then taken out of containment and put into a ball mill, which is a tumbler with SS balls that grind up the Pu-235. This is done because the plutonium is in a polycrystalline structure, and the crystals needed to be smaller. The Pu is then taken out of the ball mill and compressed into a pellet causing it to glow red. The first time this was done, the pellet was made, and a picture was taken. When it unexpectedly the pellet started to wobble and move on its own due to thermal stress. To which it disassembled into a powder and plutonium shards. To avoid this in the future, when the process was done the plutonium is put back into the ball mill to get the crystalline structure smaller. It is then compacted into the pellet where it is encased into an iridium hemisphere and capped. This is the form of Pu-238 that is assembled into RTGs.

One of the big safety questions involved with this process is what to do with the waste that the reactor produces. This has a billion-dollar solution. There are three main ways SRNL has dealt with it now and in the past. One effective way for liquid waste is to make glass out of the sludge. The sludge is neutralized with sodium oxide to get sodium nitrate and cooled with cooling coils. Keeping in mind that half-lives are logarithmic, the sludge goes from salt to glass. This is a good solution as the sludge cannot leak out it is contained in its glass structure, and you can't dissolve glass. In addition, this radioactive glass cannot contaminate water. This is one of the main ways SRNL delt with their waste. Another was solid waste; this is a low waste form compared to the liquid waste which is a high-level waste form. Solid waste is anything that has been contaminated such as gloves, masks, or clothes. That waste is placed into a concrete vault. Another way is to put the waste into black boxes with a vent placed on top and filed with concrete. This is relevant to understanding the process, why it is such an expensive project, and why the political barriers exist to prevent production of Pu-238. And the complication of what to do with spent nuclear fuel in space. In place of RTGs Pu-238 can be used more efficiently in a Stirling generator.

5. *Advanced Stirling Radioscopic Generator (ASRG)*

So, one new design concept uses Pu-238 as efficiently and effectively as possible. There was a design created in the 2010s for an Advanced Stirling Radioscopic Generator (ASRG.) Unlike the RTG this is a dynamic system. This comes with its own challenges. On one hand the design can utilize Pu-238 more effectively than an RTG but because it is a dynamic solution the movement could potentially damage instruments onboard through vibrations. And through time the wear and tear of the movement will shorten its life span.

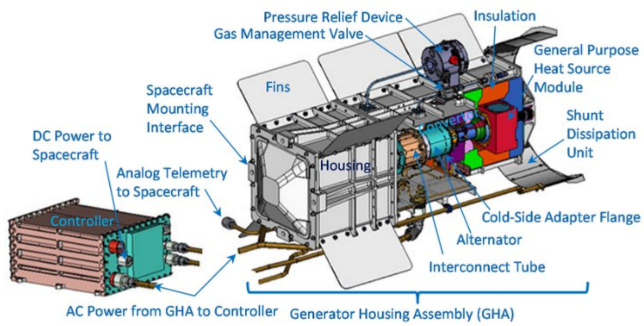


Figure 4: NASAs Advanced Stirling Radioisotopic Generator [Karacalıoğlu, Göktuğ, January 16th. "Energy Resources for Space Missions." Space Safety Magazine, 16 Jan. 2014]

The way an ASRG works is by producing electricity by triple energy transformation. By turning thermal energy from hot radioisotope fuel to high-speed kinetic motion. The ASC has two sets of pistons. These are aligned end to end and surrounded by helium gas. The helium acts as a hydrostatic between the ASCs and the walls diminishing gradual wear and tear. The pistons oscillate through coils of wire generating a flow of electricity by way of Faradays law: when magnetic flux linking a circuit changes, an electromotive force is induced. This is proportional to the rate of change of flux linkage. The ASC osculates at over 100times a second. The piston forces the helium gas back and forth between the hot side and the cold. The hot sides temperature is generated by plutonium dioxide in its ceramic non soluble form. The cool side is insulated with rugged heat resistant carbon-carbon material, graphite, and iridium metal. The ASC is configured just so to minimize complications with the vibrations produced by the two synchronized ASCs. A controller is used to synchronize the pistons and to transform the AC power produced to 140 watts of DC power.
This system uses the Stirling thermodynamic cycle in which two Isochoric (volume) processes and two Isothermal (temperature) [4] processes are used to move and generate energy. Acting like a piston. This method generates 4x more energy for the same

amount of plutonium as used in the original system. However, we move from having a static system to having a dynamic system with moving parts. The vibration from the movement could damage sensitive instruments inside the satellite. Moreover, this project was shelved [5] in 2016 due to budget constraints.

6. Reactors

A. Small Modular Reactors

Small modular reactors, a class of nuclear fission reactors, could also be used for deep space exploration. These reactors work by using the energy produced in a controlled nuclear fission process to create steam. This powers a turbine that produces electricity. They rely on coolants such as light water, gas, liquid metal, or molten salt. These reactors can be factory assembled and harness fission generating heat to produce energy. Making them more efficient in cost and construction time [6]. These rectors produce 300MW of power and use U238. The National Security and Defense department put an executive order out on January 12th of 2021 to promote small modular reactors for national defense and space exploration. However, the speed at which these are developed and implemented depends on whether or not the public view of nuclear power has softened. Micro Reactors

B. Micro modular nuclear reactors:

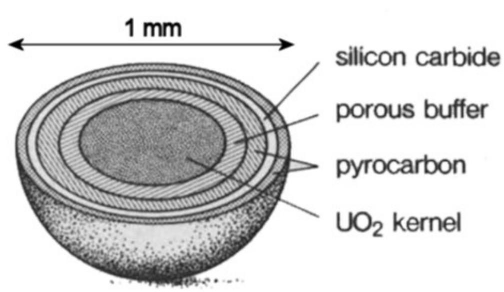
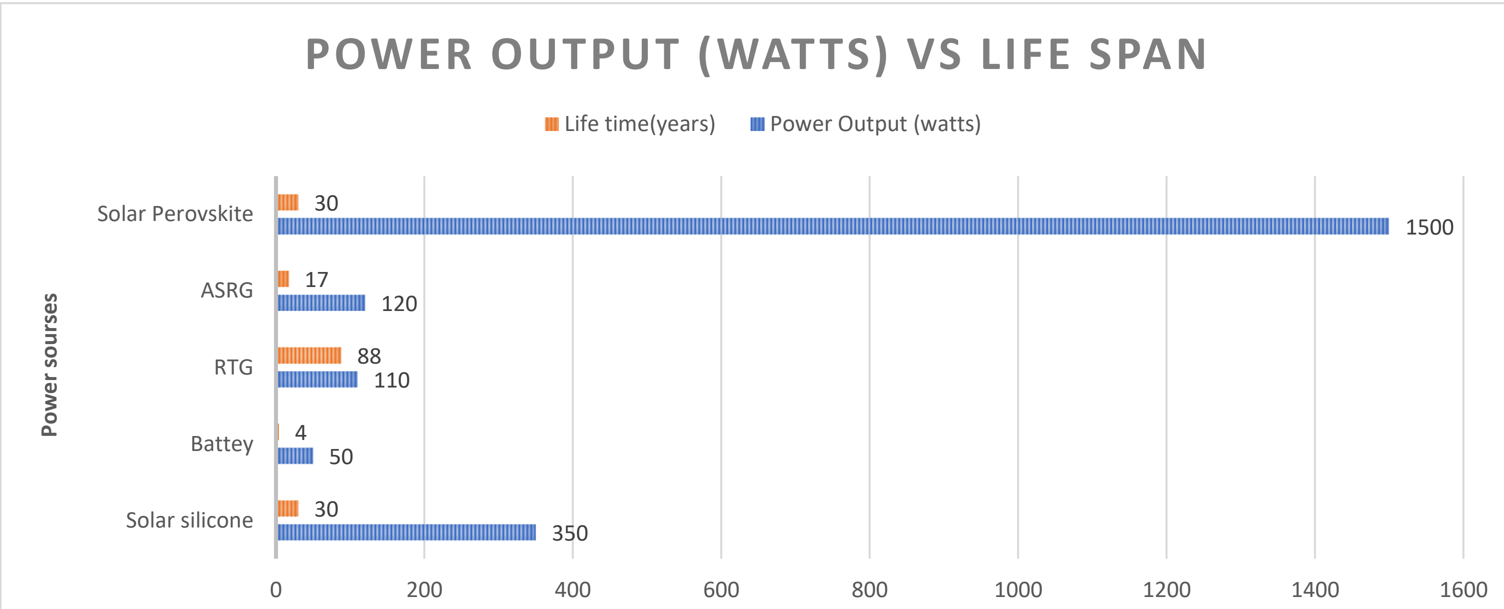


Figure 5: TRISO fuel kernel [Becker, Bjorn. (2010). On the influence of the resonance scattering treatment in Monte Carlo codes on high temperature reactor characteristics.]

Their core is about the size of a walnut. Micro Reactors make use of TRISO fuel. This is TR-structural Isotropic particle fuel producing up to 10 megawatts. Each particle is made of uranium, carbon, and oxygen, called a kernel. This kernel is then encapsulated by three layers of carbon and ceramic based materials. These layers start with Uranium dioxide, then a buffer layer, IPyC, Silicon Carbide, OPyC, and everything is finally contained within a cylinder of cylinder silicon carbide matrix which has a melting point of 2000degC. TRISO fuel are structurally more resilient to neutron irradiation, corrosion, high temperatures, and oxidation. This makes it to where it can retain all of its fission products under all reactor conditions, making it very safe to use. The TRISO fuel cannot melt in the reactor because its fully ceramic core can dissipate heat. In addition, helium is used to carry heat out of the reactors core. The cylinders are then placed into graphite blocks where it facilitates self-sustaining fission reaction.

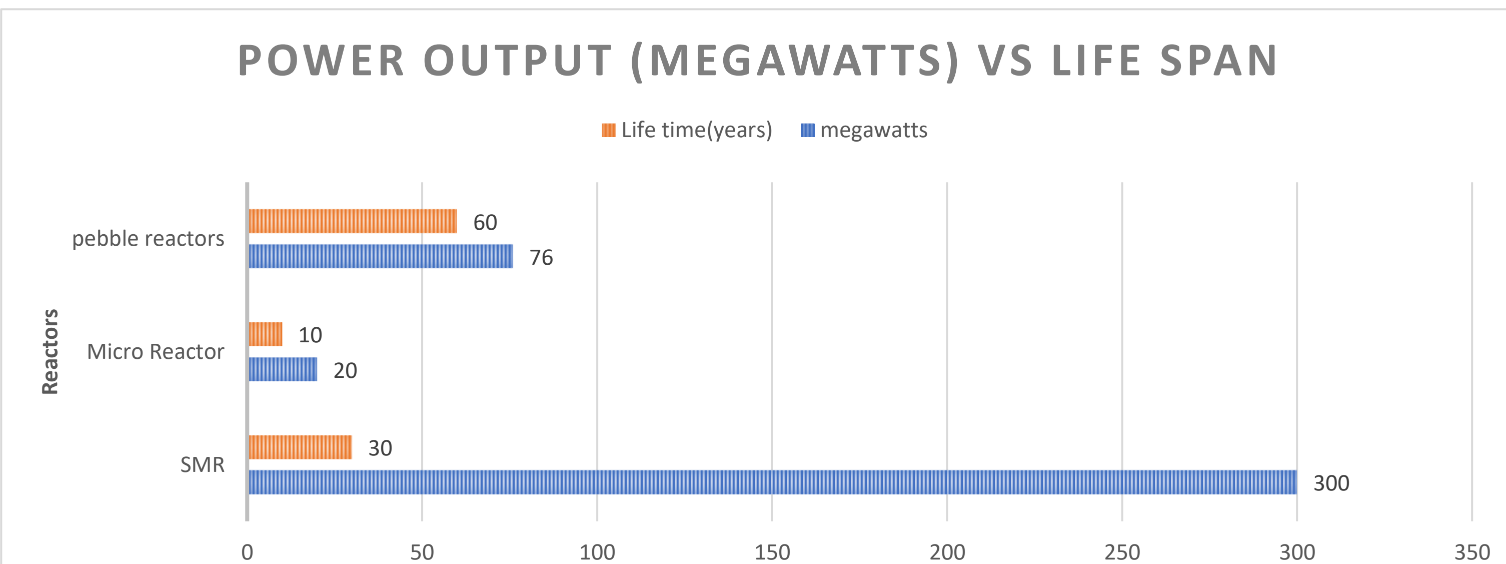
C. Pebble bed Reactors

Xe-100 produces 76megawatts of electric power. The reactor core is made of graphite which is filled with 15.5%enrivhed fuel pebbles. These pebbled contain TRISO fuel cells. The construction time for this kind of reactor is 1.5-4 years. The benefit to using the pebble bed reactors or the micro reactors is their size as well as their use of the TRISO fuel. Here there is the possibility for accidents to happen without major complications such as a nuclear melt down. The encasement of the uranium's fission process keeps its waste products contained. So not only are they safer from a scientific standpoint but also from a nonproliferation safeguard's standpoint of reactors in space. In addition, in the event that it is stolen, the waste products cannot be refined or repurposed into plutonium without being expensive, time consuming, and resource consuming. In this form uranium is increasingly difficult to extract from its shell to be used for other purposes.



	Solar silicone	Battey	RTG	ASRG	Solar Perovskite
Life time(years)	30	4	88	17	30
Power Output (watts)	350	50	110	120	1500

Figure 6: Graph Power Output (Watts) Vs Life Span



	SMR	Micro Reactor	pebble reactors
Life time(years)	30	10	60
megawatts	300	20	76

Figure 7: Graph Power Output (Megawatts) Vs Life Span

II. Propulsion

1. Nuclear Thermal Rocket (NTP)

Nuclear thermal propulsion (NTP) would only be used in space, chemical combustion would still be used to escape Earth's atmosphere. There are many advantages that NTP has over chemical combustion such as the following: for one, NTP is more energy dense and twice as efficient. Impulse combustion is 450sec for chemical and 900sec for nuclear [7]. They are better for deep space missions, cutting travel time to mars by 25% limiting the flights crew exposure to cosmic radiation. It also provides broader launch windows that aren't dependent on orbital alignments.

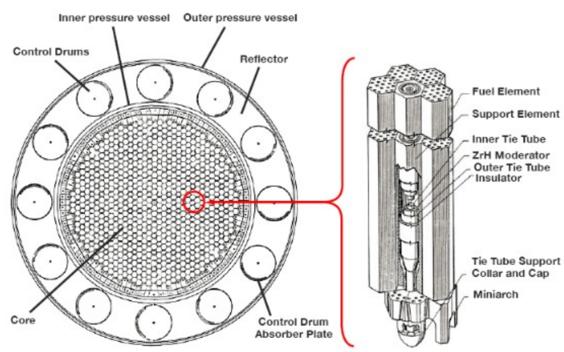


Figure 8: Nuclear Thermal Rocket Core [M. Houts et al., NASA's Nuclear Thermal Propulsion Project, NASA Marshall Space Flight Center, August 2018, ntrs.nasa.gov/citations/20180006514]

The Kiwi Rocket [8] was the first attempt at a nuclear propulsion rocket. The Kiwi was tested nozzle up for a burn lasting a few minutes. From this there was a proof of concept. In the next development stage, there are a few requirements such as extending lifetime and putting it into an engine configuration. This stage was known at NERVA. The core of the engine was a solid core in a cylindrical shape consisting of many graphite elements infused with uranium 235. The core is surrounded by a Beryllium reflector and has channels (coated with niobium carbide to prevent corrosion) that run down its length. Liquid hydrogen runs through the channel picking up heat produced by the fission process (acting as a coolant) and converting hydrogen into its gaseous state. Rotatable beryllium rods are placed around the core. One side of each rod is coated with Boron. This is done because the Boron absorbs neutrons [9]. When the boron side of the rod faces the core, the fission prosses stops and the core cools because those neutrons are being absorbed. Vice versa. When the boron side is facing away, the fission prosses starts and heats the core and the angle of the boron to the core determines the level of activity the neutrons have-- like a dimmer on a light switch. These rods are controlled by a remote control. After this, Phoebus 1B was tested with 7500lb of thrust, and then NRXA6 ran at full power for one hour.

This system works much like a chemical combustion engine were hydrogen and oxygen combine to create light, heat, and water. The heat turns the water to steam, and it expands until it is too big for the chamber and escapes downstream creating thrust [10]. Again, the main hurtle of using NTP is that it uses U-235 which was commonly used in weapons. Even though this system uses low enriched uranium, the public view is still very low. NTP is a preferable option to small modular reactors because instead of using a uranium graphite mix, low enriched uranium can be used, reducing security related costs that come with highly enriched fuel. NTPs will bring us much closer to deep space exploration taking it one step further to human space travel.

2. Thermionic Experiment with conversion (TOPAZ) or Thermionic Energy Conversion (TEC)

This is the direct conversion of heat into electricity by thermionic emission. A space based nuclear reactor was developed by the Soviet Union in 1969. This process takes advantage of the spontaneous ejection of electrons from a heated surface. When heat is added to the cathode, the temperature increases. Electrons then have enough energy to escape the solid and move freely within a vacuum, moving across an electrode gap to contact the anode [11]. This makes a complete circuit [12]. There are many different heat source possibilities for this kind of system: anything from fossil fuels to nuclear reactors to solar heat.

3. VASIMR Electrothermal Plasma Thruster

Variable specific impulse magneto plasma rocket (VASIMR) is a nuclear propulsion system that uses a nuclear electric engine design to power radiofrequency couplers. This RF [13] coupler heats a gas, either Argon, Helium, hydrogen, or Deuterium to produce a plasma. This plasma is then energized by another RF coupler. The plasma is then converted to high exhaust velocity using electricity and a magnetic nozzle to eject the plasma out of the engine [14]. This process gives a thrust of 123000mil/hour. This engine can turn a 7-month chemical combustion trip to Mars into a 45-day trip with the help of VASIMR.

4. *Ion Propulsion*

Ion Thrusters are mainly used for course corrections or to move a space system in space. They are low power systems. Ion thrusters use xenon, krypton, or argon as a propellent. These thrusters generate electrons through the discharge cathode. The electrons move out of the discharge cathode and are attracted towards the walls of the cathode. The electrons then collide with the propellent, and positive ions escape the chamber through a mesh grate. When you increase the time that electrons and the propellant stay in the chamber, the chance that ionization occurs also increases. These thrusters provide 0.5N of thrust, meaning that it needs to stay on for longer to accelerate to the desired speed. This eats up fuel. However, it can reach speeds over 200000mph and are 90% fuel efficient, whereas chemical rockets are 35% fuel efficient [15]. To increase the thrust of the ion thrusters, the power source could change from solar to nuclear, increasing thrust and longevity.

For low orbit satellites there is a new idea being researched: ABEP atmospheric breathing electric propulsion [16]. This works in a way to where the thruster uses the oxygen and nitrogen in the atmosphere taking those particles into itch chamber ionizing them and using that to maintain low orbit. These thrusters are the hall thruster model which outputs a higher thrust than regular ion thrusters. chamber ionizing them and using that to maintain low orbit. These thrusters are the hall thruster model which outputs a higher thrust than regular ion thrusters.

5. Nuclear Pulse Propulsion

This is a theoretical form of space travel. The first attempt to design one of these was Project Orion. Small nuclear explosions would be set off directionally to a large steel pusher plate that is attached to the craft and equipped with shock absorbers. The benefit to this kind of travel would be reducing travel time. However, this technology most likely will not advance because of the 1965[17] test ban treaty which bans detonation of nuclear explosives in space. Another attempt was made in 1973, Project Daedalus, in which pellets of lithium deuteride were placed into the reaction chamber and hit by lasers from all sides. The heat of the laser beams explosively compresses the pellet until fusion begins and we get a plasma and a small explosion. This process is contained in large electromagnets, and it had a funnel out the back where the explosions would propel the craft. The idea was to have helium3 as the fuel source because it could hypothetically be mined from Jupiter's atmosphere. These are very theoretical forms of space travel and are untested for obvious treaty violation reasons.

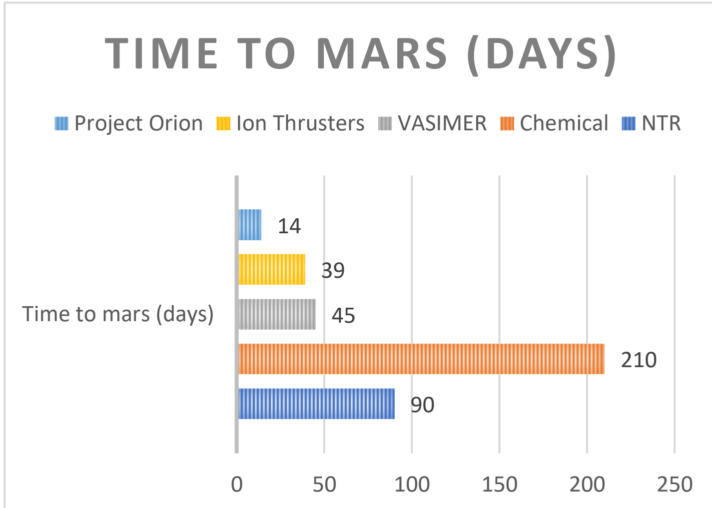


Figure 9: Graph, Time to Mars (Days)

Conclusion

There are many ways to power satellites, such as solar panels, batteries, RTGs, ASRGs, small modular reactors, and nuclear reactor systems. They all have their advantages and their limitations. More research into these systems and new possibilities need to be done to create something safe, reliable, and long lived.

A question was proposed to the researchers interviewed for this paper; however, their research connects to power in space systems, how would safeguards be used in deep space? In other words, where is the line? When does the government stop caring where the nuclear materials are? For example, countries are responsible for sea-space 12 nautical miles off the coast into the ocean. Therefore, where is the line drawn when it comes to space? A great example of this is Voyager One, that has left our solar system. As we advance there will be more space systems that will go that far if not farther. Some say the line is Jupiter, others say when the system is deemed unrecoverable or no chance of return, and others say it is unnecessary to track. With ever growing innovations and advancements in technology deep space travel is tangible however it is the political climate of the time that will decide the speed of progression.

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