RTT TECHNOLOGY TOPIC
March 2018

Nuclear SATS

Although space is nominally a vacuum, satellites in low earth orbit get slowed by small amounts of molecular mass hitting the solar arrays and other external surfaces. Drag increases as size increases and at lower orbital altitudes and gets greater when the sun is more active within its 11 year cycle. When the sun is quiet, satellites in low earth orbits need an orbital boost every three months. When the sun is active, a boost is needed every two weeks. The newer generation of electric satellites can maintain orbit by using their solar panel arrays to power ion thrusters but this reduces the power available for communication, sensing and imaging.

An alternative is to power satellites using nuclear energy. The benefits include lower launch weight and size (no solar panels in the pay load) and lower drag due to the reduced external surface of the satellite. It also supports very high power small satellites for communications, imaging and sensing, improves the manoeuvrability of the satellites, their pointing accuracy and their docking capability and supports an extended service life (solar arrays start to fog after a few years in space due to small matter impact erosion).

While the application of nuclear power to civilian communication satellites might seem hazardous, it is in reality a tried and tested option with economic benefits and is the subject of this month's Technology Topic.

Nuclear power for deep space operation, a necessity not an option

The relevance of nuclear power sources to modern communications systems may not be immediately obvious but for deep space communication where the sun does not shine there are no other available options.

The two Voyager spacecraft that have left the solar system after 40 years are on their way to the Oort clouds which they will reach in 300 years' time. It will be thirty thousand years before they emerge from the other side with still many thousands of years to go before the next galaxy appears on the horizon. The communication system will carry on working until at least 2025 which means the Voyager transceivers will have been operating for nearly 50 years.

Mr Musk's mission to Mars and other planned Mars missions (Lockheed Martin and NASA) will require a range of isotope based and fissile power systems for propulsion, on board power and for hydrogen and oxygen production to sustain life on Mars and production of liquid fuel for the return to Earth. NASA, China and Russia are all working on new generations of small nuclear reactors and isotope power sources.

Nuclear power for near earth satellite constellations

Mr Musk's very large rocket can either take a relatively small payload, a few astronauts and their baggage allowance to Mars or a very large payload, potentially several dozen big satellites or several thousand small satellites per launch into near low earth and medium earth orbit. It can be assumed that this will be the vehicle that takes low earth orbit satellites into space at a cost base several orders of magnitude below present launch options.

OneWeb and LEOSAT have similar plans for high count LEO constellations with multiple launch options courtesy of Mr Bezos and his rocket company (Blue Origin),Mr Branson (Virgin Galactic) and sovereign nation launch capacity (The USA, Russia, China, India and Europe) .

These new satellite constellations will co share spectrum with existing MEO and GSO satellites. They achieve this through angular power separation which requires the satellites to roll as they fly towards the equator and through angular selectivity achieved by using vertical VSAT antennas (see earlier tech topics).

This is a process made more cumbersome by the solar arrays. It will be easier to achieve if the satellites have an alternative power source to solar. Crucially the pointing accuracy will be improved; a critical parameter in meeting the required MEO and GSO protection ratios while also providing highly focused flux density in specific geographic areas.

It could also be useful in networks with very high beam counts. The upgraded O3b network for example will have 30,000 shapeable and steerable beams. Adaptive beam pointing can adapt for pointing inaccuracy but absorbs power and processor bandwidth.

https://www.ses.com/press-release/ses-opens-new-era-global-connectivity-o3b-mpower

This combination of performance and cost benefits opens up a new market for space optimised weight optimised nuclear power sources with a potential of thousands of units, similar in function to existing sources but very different in terms of potential production volume.

Including a radioactive payload as a power source on a rocket is not risk free but is not uncommon and the risks can be managed, and potential radiation minimised though the insurance costs implicit in any risk of accidentally irradiating America and adjacent continents can be prohibitive. However think of it as a taking a bit of the sun into space with you, and it can seem like a relativity benign option. Practically, it comes down to using radioactive isotopes to produce power from decay heat (thermo- electric generation) or from fission and fusion (the sun is effectively our local tele-fusion source of energy). The best option depends on the amount of power needed, the time scale over which it is required, the amount and type of gamma rays or x or y ray ionising radiation produced and the cost and complexity of containing that radiation.

Radio-isotopes have been used in space as a heat and power source for over fifty years and are known as RTG's, **R**adio-isotope **T**hermo-electric **G**enerators. When used just to warm up components they are known as RHU's (**R**adio-isotope **H**eating **U**nits).

Plutonium, specifically Plutonium-238 (Pu-238) has been widely used partly because it has been available as a by-product of the US and Russian and other country weapon programmes. It has a decay heat of 0.56 watts per gram and a half-life of 88 years. A typical RHU used to warm instruments to an efficient operational temperature would typically use just under 3 grams in a box about 3cm by 2.5 cm to produce a watt of power.

There are also many by-products of plutonium including Americium, produced when plutonium is bombarded with neutrons for example in a reactor or weapons test. Americium-241 is the most common flavour of Americium, manufactured from aging plutonium stocks. Because it is a by-product, Americium is significantly less expensive to manufacture. The cost of manufacturing a kilogramme of plutonium has been estimated as $8 million dollars. The European Space Agency is paying for AM-241 recovered from the UK's civil plutonium stocks where this cost has essentially been amortised over many years of (expensive) nuclear power generation. The cost is therefore high but already paid for by the UK tax payer.

For several decades there has been enough plutonium available from civil and military nuclear programmes including for example from the various nuclear missile reduction programmes for space use either in its raw state or processed into AM-241. In 2011, NASA and the US Department of Energy received $10 million of US tax payer funding to restart plutonium production with the intention of generating initially 1.5 kilogrammes per year at significantly lower cost. Throughout the 1990's the US bought Pu-238 from Russia, in total about 16.5 kilograms, a by-product of START, the Strategic Arms Reduction Treaty and Glasnost. When President Putin came to power, Russia decided it would no longer be a source of supply hence the focus on US based production capability.

There are several dozen RTG's presently powering US and Russian space vehicles. Cassini sent to explore Saturn's rings was powered by three RTG's providing 870 watts of power from 33 kilogrammes of plutonium oxide. As you may remember, there was a planned deorbit into Saturn's atmosphere on September 15 2017

The Pathfinder Mars robot lander launched in 1996 had three RTG's each with 2.7 grams of plutonium-238 oxide producing 35 watts of power and one watt of heat. Russian RTG's are apparently still operational in orbit on Cosmos navigation satellites launched in 1965. China's lunar lander apparently uses Pu-238 based RTG's. RTG's turn heat into energy by using simple thermocouples. These are almost completely reliable (no known or recorded in service failures) but inefficient, two kilowatts of heat produces 10 watts of electricity though the extra heat can also be useful.

The alternative is to use a Stirling engine. Stirling Engines can produce at least four times more electricity from a gram of plutonium when compared to a simple thermocouple. There is a hot end which could be for example at 650 degrees centigrade which heats up helium which then drives a free piston reciprocating in a linear alternator powered by the temperature difference either side of the piston. Two Stirling engines working on 500 watts of thermal power should produce about 140 watts of electric power from a kilogram of Pu-238.

Not content with radioisotope thermoelectric generators, Russia has invested significant development in fission reactors for space power systems. Just as a reminder, fission and fusion are both nuclear reactions that produce energy, but fission does it by splitting a heavy, unstable nucleus into two lighter nuclei, and fusion crashes two light nuclei combine together to release a vast amount of energy very quickly. Fission is recreating the sun in a small package; fusion is capturing the power of the big bang, an altogether more cataclysmic process.

Russia has used over 30 fission reactors in space; the USA has flown only one - the System for Nuclear Auxiliary Power in 1965. Ion engines powered by small nuclear reactors are theoretically capable of producing twenty kilowatts or more of propulsion power over a 7 to 10 year life time with high fuel efficiency. There are also plans to produce Megawatt power sources but the reactors weigh between 30 and 40 tonnes.

Regulatory issues of launching radioactive material into space

The regulatory issues associated with nuclear powered satellites are dealt with by the Office for Outer Space Affairs (UNOOSA) under the administration of the United Nations. UNOOSA implements policy decisions taken by the Committee on Peaceful Uses of Outer Space (COPUOS) set up in 1959 and now supported by 75 member states.

Risks associated with launching radioactive material into space

Environmental Groups are not always happy at the prospect of firing small or large amounts of radioactive material into space. When the Cassini-Huygens probe was launched in 1997 the United States Department of Energy estimated the chances of a launch accident that would release radiation into the atmosphere at 1 in 350, It was estimated that a worst-case scenario of total dispersal of on-board plutonium would spread the equivalent radiation of 80% of the average annual dosage in North America from background radiation over an area with a radius of 105 kilometres though the methodologies used in these calculations are open to interpretation and legal challenge. Assuming the payload gets into space successfully it is then necessary to minimise damage from space debris and to ensure satellites are deorbited in a controlled way. Surrey Satellite Technology Limited has a current mission to test possible options for managing this issue.

http://www.sstl.co.uk/Missions/RemoveDEBRIS/RemoveDEBRIS-Platform/RemoveDEBRIS-platform

Summary

While having nuclear powered satellites in low powered orbit might seem a scary proposition it is in practice realisable and achievable and potentially delivers many economic and performance benefits across a whole range of communications and imaging and sensing applications.

There would need to be sufficient fail safe systems in place to guarantee longer term environmental sustainability but essentially anything is possible provided there is sufficient market scale by volume and value to fund the protection procedures.

The shift to high count LEO and MEO constellations and shift to high power high throughout small satellites and very high power very high throughput bigger satellites including super-size satellites in geostationary orbit could deliver a step function increase in capacity and thoughput with nuclear power sources being a part of that critical shift in per bit delivery cost.

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http://uk.artechhouse.com/5G-and-Satellite-Spectrum-Standards-and-Scale-P1935.aspx

If you apply promotional code VAR30, an additional discount applies which brings the price down to £88.90 (list price £127). There is also a bundle discount promotional code VARRALL5G which allows you to order a copy of our previous book, 5G Spectrum and Standards. The two books together cost £177.80 including free shipping.

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