Air and Space this Week

Item of the Week

The Not-So-Notorious R.T.G.

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Humans have used a variety of power sources since recorded history and before. Almost all were forms of Nature-stored solar energy, the burning of wood, then coal, then oil. The one exception was the ingenious utilization of the power of falling water.

But there is no oxygen, wood, coal, oil, or falling water in Space.

Humans then learned to use the heat generated by nuclear fission to generate electricity.

But nuclear fission has many drawbacks, and has proved impractical for use in Space.

Then Humans learned how to directly generate electricity from radioactive decay.

And now Humans are exploring the outer Solar System and beyond.

THE AMAZING THERMOELECTRIC GENERATOR

Some materials have an amazing and extremely useful property: if one end is warmer than the other, an electrical current will flow within the material. No external power is required, and there are no moving parts. And, beneficially, the process works in reverse; if an electrical current is applied to a thermoelectric material, one end gets hotter and the other gets colder. It sounds too good to be true, but it's not. The generation part was discovered in 1821 in Estonia, and has historically been called the "Peltier-Seebeck Effect." The reverse phenomenon was discovered in 1851 by Lord Kelvin (William Thompson), and has historically been called, the "Thompson Effect."

Obviously, both Effects have tremendous potential in power generation and in temperature manipulation!

"Such systems are produced for the heating and cooling of a variety of things, such as car seats, food and beverage carriers, and computer chips. Also under development by researchers including MIT's Anantha Chandrakasan are systems that use the Peltier-Seebeck effect to harvest waste heat, for everything from electronic devices to cars and powerplants, in order to produce usable electricity and thus improve overall efficiency." [Quoted from here.]

Research into practical uses of both is being conducted aggressively.

POWER NEEDED IN REMOTE PLACES

Let us for a moment consider the lighthouse or other navigational aid from an engineering perspective. Most are located at ports or along established, easily accessible, transportation routes, and are therefore easy to fuel and tend.

But what about a lighthouse/aid in an area that is really remote? Getting fuel and service personnel to such a site is difficult, dangerous, and expensive.

And what if the intent is to robotically-explore the outer Solar System? There is no fuel, oxidizer, or long-term-enough battery power available, nor will there be. Solar power works fine, but only if the spacecraft is close enough to the Sun for power generation to be practical. With today's solar power technology, that limit is Jupiter; anything farther out, an alternative power source is needed.

While solar power works well for Earth-orbiting satellites, there are platforms for which solar panels are less-than-optimally desirable. For example, a long-duration military reconnaissance satellite needs to be more stealthy than a navigation, GPS, or other civilian satellite.

All three of the above scenarios can utilize a thermoelectric generator for their operational power. But what could generate enough heat to make one work satisfactorily?

The initial solution to military satellite power tried by the Russians utilized a fission nuclear reactor with thermoionic fuel elements in its core. Material would vaporize from the hot end of the elements in the core, then condense at the cooler end of the fuel element, creating a current. The operating temperature of the system made Earth-bound applications impractical, but for a space-borne system, it worked pretty well, until it didn't.

The USSR, USA, France, and Germany all conducted research into reactor systems for spaceborne power. The USSR launched a number of military satellites in the two decades from 1967-1988. On January 24, 1978, Russian military satellite *Kosmos 954* suffered an uncontrolled reentry over northwestern Canada. The casing of the reactor was breeched, but much of its highly-radioactive innards did not burn up. Radioactive debris was scattered over a wide area, from Great Slave Lake to Saskatchewan.

The USSR and Canada were signatories to the 1972 Space Liability Convention, which made the launching nation responsible for any damage one of their wayward spacecraft might cause. A joint Canada-USA team conducted a clean-up operation called Operation Morning Light. The task was daunting; the debris field covered ~48,000 square miles! Twelve pieces of Kosmos 954 were eventually recovered, ten of which were radioactive, and one of those was very radioactive. Canada billed the USSR over six million dollars (Canadian); the Russians eventually and grudgingly coughed up only half that.

Kosmos 954 was not the first satellite with this dangerous power system lost. A similar satellite went down in 1973 in the north Pacific. After *Kosmos 954*, *Kosmos 1402* also failed, crashing into the South Atlantic in 1983. The USSR then outfitted subsequent satellites of this type with a mechanism that could eject the core of a malfunctioning satellite into a “safe disposal orbit.” The new system received a successful acid test when *Kosmos 1900* failed in 1988.

A KINDER, GENTLER SYSTEM

Kosmos 954 and the satellites like it were RORSATs, Radar Ocean Reconnaissance satellites, whose primary purpose was to track naval ships on the high seas (metal ships give large radar returns). The radar system then in use required a lot of power, hence, the reactor system.

But there were many satellite applications that did not require as much power, and advances in radar and other technologies reduced the power requirements for ocean reconnaissance. At the same time the Kosmos system was in full use, an alternative heat source for generating electrical power directly was developed, one without the danger and complexity of using a reactor.

The result was the Radioisotope Thermoelectric Generator (RTG), and its first use by the USA was on the tiny Transit 4A subsatellite launched by the Navy on **June 29, 1961**, just over 60 years ago.

Radioactive substances were still involved, but in a much safer way. Instead of a fission reactor generating huge amounts of high temperatures, the RPG works by using the heat of the natural decay of a radioactive material to heat one side of a thermoelectric material relative to the other, causing a usable current to flow. There was no fission reactor and no vaporization/condensation of thermoionic material, making the system much safer. A number of radioactive materials could be used; the most effective is plutonium-238.

RTGs were a viable solution to the need to supply power in places other than Space. Any isolated location requiring electrical power over long time periods without human tending was a candidate for RPG utilization. For example, the USSR put a number of reporting stations on the shore of the Arctic Ocean to meteorological and navigational information. Well over 1000 RTGs have been deployed here on Earth; many are still functioning.

RTGs in SPACE

RTGs have been used on a variety of spacecraft for sixty years. Some of the satellites were military, but NASA has used them, too. Early inner Solar System probes to Venus and Mars could use solar panels to provide adequate power for spacecraft systems, but solar cell technology was not sufficiently advanced to allow travel beyond the orbit of Mars. RTGs were the answer. Solar cells technology has improved to the point where a Jupiter mission could use them instead of an RTG, but solar power is still ineffective at greater distances.

The instrument packages left on the Moon by *Apollo 11* was battery powered, and did not last more than a few days. Subsequent ALSEPs used RTGs successfully, except that on *Apollo 13* (more on that later). *Pioneer 10*, our first visitor to Jupiter, and *Pioneer 11*, our first visitor to Saturn, both used RTG power, and lasted long after their fly-bys. The Viking landers of 1976 were RTG powered, as were *Voyagers 1* and *2*, launched in 1977, which are still operating and returning some useful data (and they will continue to function well into the 2030s). Subsequent missions needed RTGs, too, including the *Galileo* Jupiter mission (1989), the *Ulysses* solar observer (1990), *Cassini* Saturn mission (1997), and the still-operating *New Horizons* Pluto (and beyond) mission (2006; functional into the 2040s), the Mars Science Laboratory (Curiosity; 2011), and *Perseverance* (2020). And, an RTG will power the *Dragonfly*, a robotic helicopter that will be sent to Saturn's moon, Titan.

Our initial Mars rovers used solar power, including *Sojourner* (*Mars Pathfinder*) and *Spirit* and *Opportunity*. Sojourner was tiny (the size of a bread box), and the Mars Exploration Rovers, *Spirit* and *Opportunity*, were golf-cart size, so it didn't take a lot of power to move them, but they did have to cease movement during the martian night. Were it not for a fortuitous dusting of their solar panels by a passing dust devil, both of their much-more-successful-than-expected travel would have been shortened significantly. [If your car performed as well against its warranty as the MERs did, you would enjoy over two million miles of maintenance-free travel, without stopping at a single gas station!]

Curiosity and *Perseverance* are much larger and heavier, and therefore require an RTG for their power and movement. Both are still going strong!

By the way, a simpler version of the RTG has been used on some spacecraft, not for power, but for the heat necessary to keep electronic and other systems functional. The amount of radioactive material needed to make a Radioisotope Heater Unit function is tiny. They were used on the *Galileo* spacecraft and the *Huygens* Saturn atmospheric probe, and on the solar powered Mars Exploration Rovers, *Spirit* and *Opportunity*.

RTG SAFETY

The RTG system is much safer than the earlier reactor power system, but the idea of launching plutonium still caused some concern among the public, based on the Russia-Canada issue above, and to the toxicity and cancer-causing potential of plutonium.

Such safety concerns are mitigated greatly by the construction of satellite-borne RTGs. They are constructed very heavily, greatly reducing the chance plutonium would be released, even if it was brought back to Earth in an uncontrolled reentry. Plutonium's primary cancer risk comes if one inhales plutonium dust (human skin is enough shielding to protect from plutonium's radioactivity), so the fuel for spaceborne RTGs is encapsulated as plutonium dioxide, a ceramic-like material that is extremely durable.

There have been two accidental crashes of USA spacecraft involving RTGs, neither of which caused a leak of radioactive material. In 1968, a US Nimbus weather satellite launched from Vandenberg AFB suffered a booster failure requiring destruction of the rocket. The satellite landed in the Santa Barbara Channel. The satellite remains were found and recovered five months later, and the RTG was recovered intact, with zero leakage of radioactive material. The Apollo 13 lunar module carried an RTG intended to be left on the Moon, but mission controllers were able to steer it to land over the Tonga Trench, one of the deepest parts of any ocean.

Subsequent monitoring has not detected any leak of radioactivity in the area (the water is too deep for recovery).

An RTG was carried on the Russian *Mars 96* spacecraft, which failed to leave Earth orbit and broke up over Chile. Its RTG has never been found.

The encapsulation of RTG plutonium oxide ceramic passed an unplanned test when the rocket it was aboard suffered a launch explosion at Baikonur Cosmodrome in 1970. Soviet soldiers found the RTG in the wreckage, and secretly kept it as a heater for their cold, cold guardhouse, without ill effect (at least from the plutonium, perhaps not from their brass…)!

There is one aspect of widespread use of RTGs that I worry about much more than the ones in spacecraft. As of 2005, there were ~1000 RTGs deployed in the former USSR. A good number of them are now out of service, either through old age or worse, scavenged for their metal. The plutonium remaining in them is extremely difficult to use in an atomic bomb, far beyond the capabilities of most terrorist organizations. Alas, however, the remaining RTG fuel could be used around a conventional explosive to make a dangerous "dirty" bomb….

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A Kinder, Gentler System

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