The Evolution of Radioisotope Thermal Generators

Introduction

The advancement of space exploration started in 1957 with the launch of Sputnik 1 which was quickly followed by the launch of Explorer 1 in 1958. The advancement in space exploration had much to do about the development of nuclear power in space. Enabling satellites to draw more power than before and carry out long term mission. The Radio Isotopic thermal generator (RTG) was first invented in 1954 and earned its place in the inventor's hall of fame in 2015. The RTG has been the key to our success in the exploration of deep space. With in this paper the evolution of the RTG will be covered including the missions they facilitated. In addition, the ever present political and public view of nuclear material will play a role in the history of the RTG and the modern possibilities for nuclear power in space.

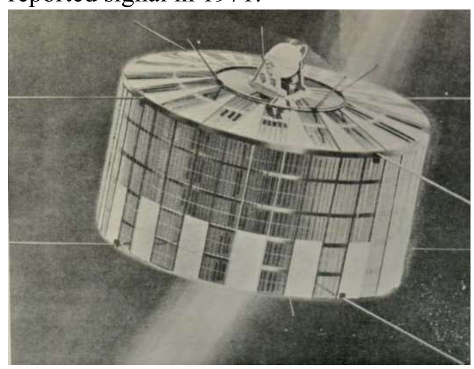
History

What is an RTG and how does it work?

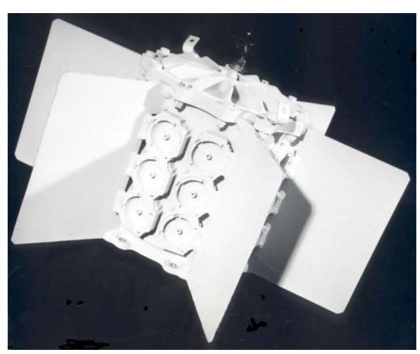
Radioisotope Thermal Generators is a power source that was developed for space in 1954 by Kenneth C. Jordan. An RTG is a kind of "nuclear battery" with a life span of 88 years. The RTG structure is manly comprised of thermocouples. Thermocouples are a thermoelectric material that conducts electric current. This current is produced when there is a temperature difference, on ether end of the couple. For example, in an RTG one end of the couple is exposed to the decay of Plutonium 238 (Pu-238), which emits intense heat, and on the other side, the couples are exposed to the freezing temperatures of outer space. This process produces a flow of electrons resulting in a voltage output. The greater the temperature difference the stronger the power output. The RTG core pu-238 can get up to 600°C, for any access heat produced the RTG has Radar fins that distribute the heat for self-regulation. The advantage of RTGs is that it's a long-lived static operation that results in minimal complications. Kenneth C. Jordan however had the advantage in 1954 having the ability to use Pu-238 without the political upset we have today. Unfortunately, Pu-238 is no longer being produced post cold-war and there is little in store. However, despite this modern hurtle, RTGs have made deep space and time heavy missions possible. Accomplishing things many people doubted. The RTG was inducted into the inventor's hall of fame in 2013 and has been used in more that 23 space systems since its debut in 1961.

RTGs in space past and present

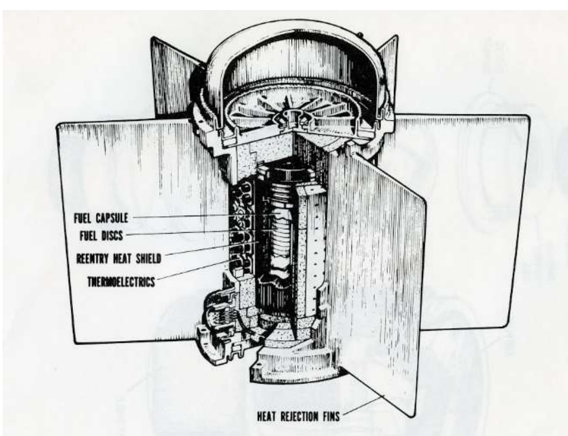
The first RTG launched into space in 1961. Transit 4A, was used as a navigational satellite for ships and aircrafts. Using a SNAP 3 RTG. SNAP 3 was among the first configurations of the RTG being smaller than our modern RTGs it was designed to last for 5 years producing 52.5W with a power conversion efficiency of 5-6%. Transit 4A operated for 15 years with its last reported signal in 1971.



In 1963 Transit 5BN-1 was launched sporting the newest RTG configuration SNAP-9A. With a power capacity of 26.8W it was designed to run continuously for 5 years. In addition, in this configuration heat displacing magnesium fins were added. The SNAP-9A catalyzed the beginning of formal launch safety reviews. The Transit 5BN-1 series were also navigational satellites. Unfortunately, in April of 1964 the launch of Transit 5NB-3 the mission was aborted after reaching an altitude of 1000 miles. Fortunately, as designed the Pu-238 burned up to particles small enough not to be a health hazard. This was confirmed a few years later after balloon sampling. This led to a series of policy and meticulous safety review being established.

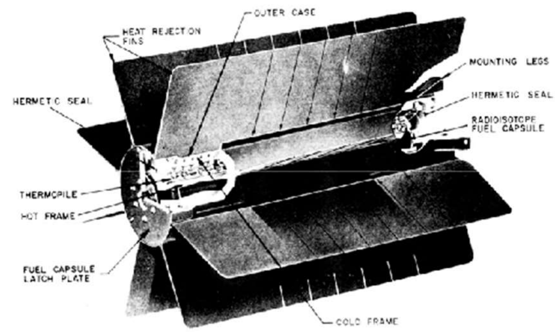


1968 Nimbus B-1 was launched carrying the RTG SNAP-19B2. Nimbus was the first weather satellite to take global temperature measurements 24-7. SNAP-19 used an auxiliary system, the Intact Impact Heat Source (IIHS), and led telluride thermocouples. The IIHS contained the fuel and limited the probability of environment contamination in the event of an accident such as what happened with Transit 5NB-3. In addition, the fuel form was modified from plutonium metal to plutonium oxide meaning the plutonium particles were encapsulated in microspheres. An additional precaution in the event of an accident. The microspheres will be large enough to prevent the inhalation of the particles. Preventing health risks. When Nimbus-B-1 launched in 1968 it veered off course this forced NASA to self-destruct. Landing in the Santa Barbara channel it was found 4 months later and sent back to the laboratory for further research. Nimbus-B-2 was launched in 1969 operating for 2.5 years. Its decline in performance was attributed to the loss of the heat junction bond between the thermocouples brought on by the sublimation of the lead telluride. The Nimbus series was the first and last time RTGs were used by NASA in earth orbit.

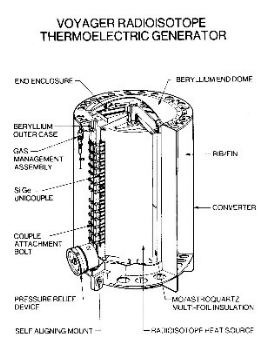


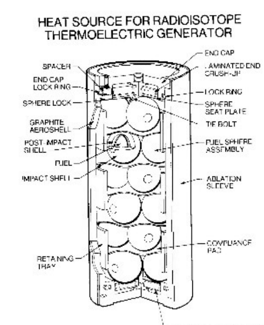
1969 SNAP-27 was launched in the Apollo 12s Luner Excursion Module (LEM) for the Apollo Lunar Surface Experiment Package (ALSEP). As the SNAP-27 was to be used on the Luner surface it required modifications from the SNAP-19 configuration. One being a separate storage for the heat source in a graphite Luner modal fuel cask. In addition, thermal energy was transferred from the generator by radiative coupling. Five units were deployed and implemented without hiccup. They preformed their task for eight years.

1972 Pioneer 1975 Viking

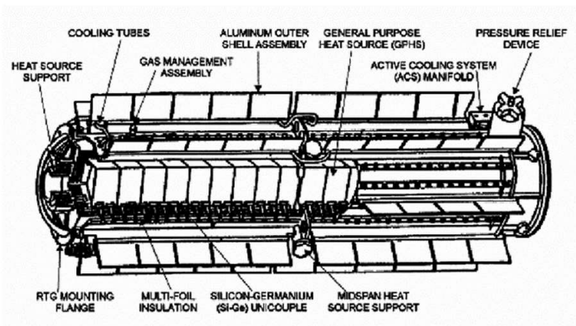


1976 Multhundred Watt (MHW) RTG was launched in LES 8 and Les 9. LES 8 and 9 were geostationary communication satellites used to experiment with different communication terminals for the Department of Defense (DOD). The MHW was built for missions needing more power in the capability range of several hundred wats hence the name. This resulted in a dramatic change in how the RTG was initially designed. Instead of using lead telluride for the thermocouples they used silicon-germanium this enabled the use of a higher temperature heat source. Which meant a greater power conversion efficiency was achieved, so the size of the RTG was able to be much smaller. In addition, the silicon-germanium does not sublimate significantly which mitigates the issues found on SNAP-19. The design was also modified to house the converters in beryllium. And individual spherical metallic iridium shells held the fuel and a graphite impact shell. Not only were MHW used for the LES series but also for Voyager 1 and 2 launched in 1977 who have now entered interstellar space.





1989 Galileo was launched carrying a General-Purpose Heat Source (GPHS) RTG. The GPHS iteration needed to be modified for the International solar Polar Mission (Ulysses 1990) and for the Jupiter orbital probe (Galileo 1989) to function effectively in a vacuum environment. Initially the design proposed using selenide thermocouples however, it was decided they were not suitable for long term missions. As such they continued the use of silicon-germanium. The converter casing changed from beryllium to the more cost-effective Aluminum 2219-T6. In addition, the casing for the fuel and the graphite impact shells remained as iridium but in pellet form. Galileo was equipped with two GPHSs for warmth whilst its power came from batteries. Both RTGs met their mission end date. Ulysses launched in 1990 with one GPHS RTG exceeding its mission time and continued operation until 2008.



In 1997 Cassini was launched with a MHW RTG. A 6-year transit into Saturn's orbit.

And in 2006 the New Horizons mission to Pluto was launched using a GPHS-RTG. This is currently the last satellite RTG launched by the USA.

Discussion

RTGs come with their angels and demons. On the one hand RTGs may continue to be the key to our success in space exploration because of their power capabilities and their longevity. However, on the other hand in 1994 the public was widely pro nuclear but after 2001 public opinion flipped. Though the engineers behind the RTGs have gone through great length to make sure that ensure the safety of the fuel in the event of complications. The RTG will still have to conform to ease public tensions. Meaning other alternatives to Pu-238 should be explored. Such as using low enriched uranium, americium, or even curium. The evolution of the RTG is full of innovation and perseverance.

Conclusion

In conclusion the RTG started in the 1950s as the SNAP 3. Through perseverance we have the modern version of SNAP 3 in the form of a GPHS RTG. These power sources have been at the forefront of many groundbreaking discoveries in space. To continue to progress in space the RTG will need to continue to adapt to support our ever-growing ambitions.

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