Answers.com®

Radioisotope thermoelectric generator

Wikipedia:

Radioisotope thermoelectric generator

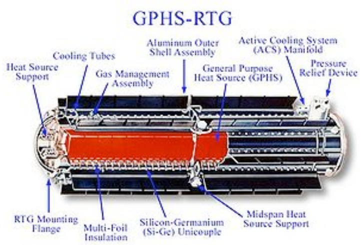


Diagram of an RTG used on the Cassini probe

A **radioisotope thermoelectric generator** (**RTG**, **RITEG**) is an electrical generator that obtains its power from radioactive decay. In such a device, the heat released by the decay of a suitable radioactive material is converted into electricity by the Seebeck effect using an array of thermocouples.

RTGs can be considered as a type of battery and have been used as power sources in satellites, space probes and unmanned remote facilities, such as a series of lighthouses built by the former Soviet Union inside the Arctic Circle. RTGs are usually the most desirable power source for unmanned or unmaintained situations needing a few hundred watts or less of power for durations too long for fuel cells, batteries and generators to provide economically, and in places where solar cells are not viable.

Contents [hide]

History

Image of a mostly thermally-isolated plutonium RTG pellet glowing red hot.

The first RTG launched in space by the United States was in 1961 aboard the SNAP 3 in the Navy Transit 4A spacecraft. One of the first terrestrial uses of RTGs was in 1966 by the US Navy at the uninhabited Fairway Rock Island in Alaska, where it remained in use until its removal in 1995.

A common application of RTGs is as power sources on spacecraft. Systems Nuclear Auxiliary Power Program (SNAP) units were used especially for probes that travel far enough from the Sun that solar panels are no longer viable. As such they are used with Pioneer 10, Pioneer 11, Voyager 1, Voyager 2, Galileo, Ulysses, Cassini and New Horizons. In addition, RTGs were used to power the two Viking landers and for the scientific experiments left on the Moon by the crews of Apollo 12 through 17 (SNAP 27s). Because Apollo 13 was aborted, its RTG now rests in the South Pacific ocean, in the vicinity of the Tonga Trench. RTGs were also used for the Nimbus, Transit and LES satellites. By comparison, only a few space vehicles have been launched using full-fledged nuclear reactors: the Soviet RORSAT series and the American SNAP-10A.

In addition to spacecraft, the Soviet Union constructed many unmanned lighthouses and navigation beacons powered by RTGs[1]. Powered by ^{90}Sr, they are very reliable and provide a steady source of power. However, critics argue that they could cause environmental and security problems, as leakage or theft of the radioactive material could pass unnoticed for years (or possibly forever: some of these lighthouses cannot be found because of poor record keeping). There has even been an instance where the radioactive compartments were opened by a thief[2]. There was also the case of three woodcutters in the nation of Georgia who came across one of these units and slept close to it as a heat source during a cold night. They were later hospitalized with severe radiation burns.[3] The unit was eventually recovered and isolated.[4]

There are approximately 1,000 such RTGs in Russia. All of them have long exhausted their 10-year engineered life spans. They are likely no longer functional, and may be in need of dismantling. Some of them have become the prey of metal hunters, who strip the RTGs' metal casings, regardless of the risk of radioactive contamination.[5]

RTGs are also utilized by the United States Air Force to power remote sensing stations for Top-ROCC and Save-Igloo radar systems predominantly located in Alaska.[6]

In the past, small "plutonium cells" (very small ^{238}Pu-powered RTGs) were used in implanted heart pacemakers to ensure a very long "battery life". As of 2004 about 90 were still in use. If the wearer dies and the generator is not removed before cremation the device will be subject to great heat. It is unlikely however, if the plutonium is in the form of the dioxide, that contamination will occur. Note that plutonium 238 is more able to disperse than plutonium 239, but the dioxide is an air stable solid which is normally sintered in air at a temperature much higher than that used in the cremation of human remains (although they are designed to survive cremation).

Although not strictly RTGs, similar units called radioisotope heater units are also used by various spacecraft including the Mars Exploration Rovers, Galileo and Cassini. These devices use small samples of radioactive material to produce heat directly, instead of electricity.

Design

The design of an RTG is simple by the standards of nuclear technology: the main component is a sturdy container of a radioactive material (the fuel). Thermocouples are placed in the walls of the container, with the outer end of each thermocouple connected to a heat sink. Radioactive decay of the fuel produces heat which flows through the thermocouples to the heat sink, generating electricity in the process.

A thermocouple is a thermoelectric device that converts thermal energy directly into electrical energy using the Seebeck effect. It is made of two kinds of metal (or semiconductors) that can both conduct electricity. They are connected to each other in a closed loop. If the two junctions are at different temperatures, an electric current will flow in the loop.

Fuels

Inspection of Cassini spacecraft RTGs before launch

New Horizons in assembly hall

Criteria

The radioactive material used in RTGs must have several characteristics:

- The half-life must be long enough that it will produce energy at a relatively continuous rate for a reasonable amount of time. However, at the same time, the half-life needs to be short enough so that it decays sufficiently quickly to generate a usable amount of heat. Typical half-lives for radioisotopes used in RTGs are therefore several decades, although isotopes with shorter half-lives could be used for specialized applications.
- For spaceflight use, the fuel must produce a large amount of energy per mass and volume (density). Density and weight are not as important

for terrestrial use, unless there are size restrictions.
The decay energy can be calculated if the energy of radioactive radiation or the mass loss before and after radioactive decay is known.

- It should produce high energy radiation that is easily absorbed and transferred into thermal radiation, preferably alpha radiation. Beta radiation can give off considerable amounts of Gamma/X-ray radiation through bremsstrahlung secondary radiation production, thus requiring heavy shielding. Isotopes must not produce significant amounts of gamma, neutron radiation or penetrating radiation in general through other decay modes or decay chain products.

Selection of isotopes

The first two criteria limit the number of possible fuels to fewer than 30 atomic isotopes within the entire table of nuclides. Plutonium-238, Curium-244 and Strontium-90 are the most often cited candidate isotopes, but other isotopes such as Polonium-210, Promethium-147, Caesium-137, Cerium-144, Ruthenium-106, Cobalt-60, Curium-242 and Thulium isotopes have also been studied.

^{238}Pu, ^{90}Sr

^{238}Pu has the lowest shielding requirements and longest half-life. Only three candidate isotopes meet the last criterion (not all are listed above) and need less than 25 mm of lead shielding to keep radiation. ^{238}Pu (the best of these three) needs less than 2.5 mm, and in many cases no shielding is needed in a ^{238}Pu RTG, as the casing itself is adequate.

^{238}Pu has become the most widely used fuel for RTGs, in the form of plutonium(IV) oxide (PuO_2). ^{238}Pu has a half-life of 87.7 years, reasonable energy density and exceptionally low gamma and neutron radiation levels. Some Russian terrestrial RTGs have used ^{90}Sr; this isotope has a shorter half-life, much lower energy density and produces gamma radiation, but is cheaper.

^{210}Po

Some prototype RTGs, first built in 1958 by USA Atomic Energy Commission, have used ^{210}Po. This isotope provides phenomenal energy density due to its high radioactive activity, but has limited use because of its very short half-life of 138 days, again due to its high activity. A kilogram of pure ^{210}Po in the form of a cube would be about 48 mm (about 2 inches) on a side and emit about 140kW. The heat of fusion is about 60kJ/kg, the heat of evaporation about 10 times larger. If there is no efficient cooling, the self heating power is sufficient for melting then partly vaporizing itself.

Cm, ^{241}Am

^{242}Cm and ^{244}Cm have also been studied well, but require heavy shielding from gamma and neutron radiation produced from spontaneous fission.

Americium-241 is a potential candidate isotope with a longer half-life than ^{238}Pu: ^{241}Am has a half-life of 432 years and could hypothetically power a device for centuries. However, the energy density of ^{241}Am is only 1/4 that of ^{238}Pu, and ^{241}Am produces more penetrating radiation through decay chain products than ^{238}Pu and needs about 18 mm worth of lead shielding. Even so, its shielding requirements in an RTG are the second lowest of all possible isotopes: only ^{238}Pu requires less.

Life span

Soviet RTGs in dilapidated and vandalized condition, powered by Strontium-90 ^{90}Sr.

Most RTGs use ^{238}Pu which decays with a half-life of 87.7 years. RTGs using this material will therefore diminish in power output by $1 - 0.5^{1 / 87.7}$ or 0.787% of their capacity per year. 23 years after production, such an RTG will have decreased in power by $1 - 0.5^{23 / 87.7}$ or 16.6%, i.e. providing 83.4% of its initial output. Thus, with a starting capacity of 470 W, after 23 years it would have a capacity of 0.834 * 470 W = 392 W. However, the bi-metallic thermocouples used to convert thermal energy into electrical energy degrade as well; at the beginning of 2001, the power generated by the Voyager RTGs had dropped to 315 W for Voyager 1 and to 319 W for Voyager 2. Therefore in early 2001, the thermocouples were working at about 80% of their original capacity.

This life span was of particular importance during the Galileo mission. Originally intended to launch in 1986, it was delayed by the Space Shuttle Challenger accident. Due to this unforeseen event the probe had to sit in storage for 4 years before launching in 1989. Subsequently, its RTGs had decayed somewhat, necessitating replanning the power budget for the mission.

Efficiency

RTGs use thermoelectric couples or "thermocouples" to convert heat from the radioactive material into electricity. Thermocouples, though very reliable and long-lasting, are very inefficient; efficiencies above 10% have never been achieved and most RTGs have efficiencies between 3-7%. Thermoelectric materials in space missions to date have included silicon germanium alloys, lead telluride and tellurides of antimony, germanium and silver (TAGS). Studies have been done on improving efficiency by using other technologies to generate electricity from heat. Achieving higher efficiency would mean less radioactive fuel is needed to produce the same amount of power, and therefore a lighter overall weight for the generator. This is a critically important factor in spaceflight launch cost considerations.

A thermionic converter -- an energy conversion device which relies on the principle of thermionic emission -- can achieve efficiencies between 10-20%, but requires higher temperatures than those at which standard RTGs run. Some prototype ^{210}Po RTGs have used thermionics, and potentially other extremely radioactive isotopes could also provide power by this means, but short half-lives make these infeasible. Several space-bound nuclear reactors have used thermionics, but nuclear reactors are usually too heavy to use on most space probes.

Thermophotovoltaic cells work by the same principles as a photovoltaic cell, except that they convert infrared light emitted by a hot surface rather than visible light into electricity. Thermophotovoltaic cells have an efficiency slightly higher than thermocouples and can be overlaid on top of thermocouples, potentially doubling efficiency. Systems with radioisotope generators simulated by electric heaters have demonstrated efficiencies of 20%[2], but have not been tested with actual radioisotopes. Some theoretical thermophotovoltaic cell designs have efficiencies up to 30%, but these have yet to be built or confirmed. Thermophotovoltaic cells and silicon thermocouples degrade faster than thermocouples, especially in the presence of ionizing radiation.

Dynamic generators can provide power at more than 4 times the conversion efficiency of RTGs. NASA and DOE have been developing a next-generation radioisotope-fueled power source called the Stirling Radioisotope Generator (SRG) that uses free-piston Stirling engines coupled to linear alternators to convert heat to electricity. SRG prototypes demonstrated an average efficiency of 23%. Greater efficiency can be achieved by increasing the temperature ratio between the hot and cold ends of the generator. The use of non-contacting moving parts, non-degrading flexural bearings, and a lubrication-free and hermetically sealed environment have, in test units, demonstrated no appreciable degradation over years of operation. Experimental results demonstrate that an SRG could continue running for decades without maintenance. Vibration can be eliminated as a concern by implementation of dynamic balancing or use of dual-opposed piston movement. Potential applications of a Stirling radioisotope power system include exploration and science missions to deep-space, Mars, and the Moon.

Safety

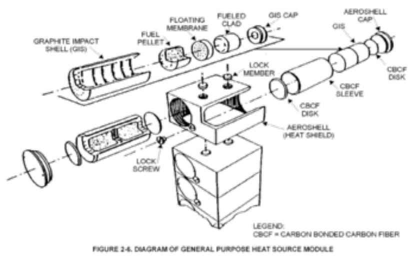


Diagram of a stack of general purpose heat source modules as used in RTGs

Radioactive contamination

RTGs may pose a risk of radioactive contamination: if the container holding the fuel leaks, the radioactive material may contaminate the environment.

For spacecraft, the main concern is that if an accident were to occur during launch or a subsequent passage of a spacecraft close to Earth, harmful material could be released into the atmosphere; and their use in spacecraft and elsewhere has attracted controversy.[7][8]

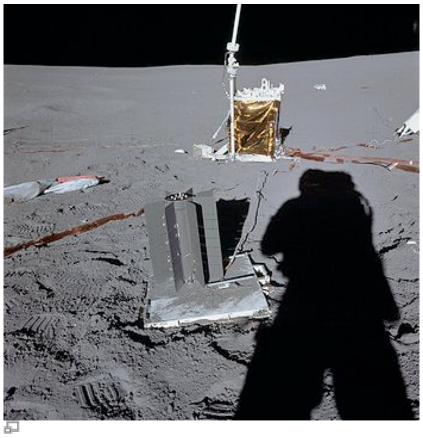
However, this event is not considered likely with current RTG cask designs. For instance, the environmental impact study for the Cassini-Huygens probe launched in 1997 estimated the probability of contamination accidents at various stages in the mission. The probability of an accident occurring which caused radioactive release from one or more of its 3 RTGs (or from its 129 radioisotope heater units) during the first 3.5 minutes following launch was estimated at 1 in 1,400; the chances of a release later in the ascent into orbit were 1 in 476; after that the likelihood of an accidental release fell off sharply to less than 1 in a million.[9] If an accident which had the potential to cause contamination occurred during the launch phases (such as the spacecraft failing to reach orbit), the probability of contamination actually being caused by the RTGs was estimated at about 1 in 10.[10] In any event, the launch was successful and Cassini-Huygens reached Saturn.

The plutonium 238 used in these RTGs has a half-life of 87.74 years, in contrast to the 24,110 year half-life of plutonium 239 used in nuclear weapons and reactors. A consequence of the shorter half life is that plutonium 238 is about 275 times more radioactive than plutonium 239 (i.e. 17.3 Ci/g compared to 0.063 Ci/g[11]). For instance, 3.6 kg of plutonium 238 undergoes the same number of radioactive decays per second as 1 tonne of plutonium 239. Since the morbidity of the two isotopes in terms of absorbed radioactivity is almost exactly the same[12], plutonium 238 is around 275 times more toxic by weight than plutonium 239.

The alpha radiation emitted by either isotope will not penetrate the skin, but it can irradiate internal organs if plutonium is inhaled or ingested. Particularly at risk is the skeleton, the surface of which is likely to absorb the isotope, and the liver, where the isotope will collect and become concentrated.

There have been six known accidents involving RTG-powered spacecraft. The first one was a launch failure on 21 April 1964 in which the U.S. Transit-5BN-3 navigation satellite failed to achieve orbit and burnt up on re-entry north of Madagascar.[13][14] The 17,000 Ci (630 TBq) plutonium metal fuel in its SNAP-9a RTG was injected into the atmosphere over the Southern Hemisphere where it burnt up, and traces of plutonium 238 were detected in the area a few months later. The second was the Nimbus B-1 weather satellite whose launch vehicle was deliberately destroyed shortly after launch on 21 May 1968 because of erratic trajectory. Launched from the Vandenberg Air Force Base, its SNAP-19 RTG containing relatively inert plutonium dioxide was recovered intact from the seabed in the Santa Barbara Channel five months later and no environmental contamination was detected. [15]

Two more were failures of Soviet Cosmos missions containing RTG-powered lunar rovers in 1969, both of which released radioactivity as they burnt up. There were also five failures involving Soviet or Russian spacecraft which were carrying nuclear reactors rather than RTGs between 1973 and 1993 (see RORSAT).[16]



A SNAP-27 RTG deployed by the astronauts of Apollo 14 identical to the one lost in the reentry of Apollo 13

The failure of the Apollo 13 mission in April 1970 meant that the Lunar Module reentered the atmosphere carrying an RTG and burnt up over Fiji. It carried a SNAP-27 RTG containing 44,500 curies (1,650 TBq) of plutonium dioxide which survived reentry into the Earth's atmosphere intact, as it was designed to do, the trajectory being arranged so that it would plunge into 6-9 kilometers of water in the Tonga trench in the Pacific Ocean. The absence of plutonium 238 contamination in atmospheric and seawater sampling confirmed the assumption that the cask is intact on the seabed. The cask is expected to contain the fuel for at least 10 half-lives (i.e. 870 years). The US Department of Energy has conducted seawater tests and determined that the graphite casing, which was designed to withstand reentry, is stable and no release of plutonium should occur. Subsequent investigations have found no increase in the natural background radiation in the area. The Apollo 13 accident represents an extreme scenario due to the high re-entry velocities of the craft returning from cislunar space. This accident has served to validate the design of later-generation RTGs as highly safe.

To minimize the risk of the radioactive material being released, the fuel is stored in individual modular units with their own heat shielding. They are surrounded by a layer of iridium metal and encased in high-strength graphite blocks. These two materials are corrosion- and heat-resistant. Surrounding the graphite blocks is an aeroshell, designed to protect the entire assembly against the heat of reentering the earth's atmosphere. The plutonium fuel is also stored in a ceramic form that is heat-resistant, minimising the risk of vaporization and aerosolization. The ceramic is also highly insoluble.

The most recent accident involving a spacecraft RTG was the failure of the Russian Mars 96 probe launch on 16 November 1996. The two RTGs onboard carried in total 200 g of plutonium and are assumed to have survived reentry (as they were designed to do). They are thought to now lie somewhere in a northeast-southwest running oval 320 km long by 80 km wide which is centred 32 km east of Iquique, Chile.[17]

Many Beta-M RTGs produced by the Soviet Union to power lighthouses and beacons have become orphaned sources of radiation. Several of these units have been illegally dismantled for scrap metal resulting in the complete exposure of the Sr-90 source, fallen into the ocean, or have defective shielding due to poor design or physical damage. The US Department of Defense cooperative threat reduction program has expressed concern that material from the Beta-M RTGs can be used by terrorists to construct a dirty bomb. [3]

The NASA claims 28 U.S. space missions have safely flown radioisotope energy sources since 1961.[18]

Nuclear fission

RTGs and nuclear power reactors use very different nuclear reactions. Nuclear power reactors use controlled nuclear fission. When an atom of U-235 or Pu-239 fuel fissions, neutrons are released that trigger additional fissions in a chain reaction at a rate that can be controlled with neutron absorbers. This is an advantage in that power can be varied with demand or shut off entirely for maintenance. It is also a disadvantage in that care is needed to avoid uncontrolled operation at dangerously high power levels.

Chain reactions do not occur in RTGs, so heat is produced at a fully predictable and steadily decreasing rate that depends only on the amount of fuel isotope and its half-life. An accidental power excursion is impossible. On the other hand, heat generation cannot be varied with demand or shut off when not needed. Auxiliary power supplies (such as rechargeable batteries) may be needed to meet peak demand, and adequate cooling must be provided at all times including the prelaunch and early flight phases of a space mission.

There are no nuclear proliferation risks associated with plutonium-238. The same properties, primarily its high specific power, that make it a desirable RTG fuel make it useless in nuclear weapons. Pu-238 is fissionable, not fissile. It will occasionally spontaneously fission instead of undergoing alpha decay or it can be induced to fission with an external source of fast neutrons produced by various fusion reactions, but it cannot sustain the chain-reaction needed in a nuclear weapon fission primary. Because of its relatively high spontaneous fission rate compared with that of the fissile bomb fuel isotope Pu-239, its presence even as a contaminant would degrade performance by increasing the likelihood of a fizzle, a low yield caused by premature initiation of the chain reaction before optimum conditions have been reached. Any significant amounts of Pu-238 would also generate heat that would have to be continually dissipated until the bomb was used.

Pu-238 could in principle be used as the tertiary stage to boost the yield of a fission-fusion-fission (thermonuclear) weapon, but there is no reason to use it in this way. Natural or even depleted uranium will also fission with fast fusion neutrons, is far more readily available, and generates essentially no heat in storage.

Pu-238 could conceivably be used in a radiological or dirty bomb to exploit the significant public fear of plutonium.

Models

Space

MHW = Multi-Hundred Watt

Name & Model	Used On (# of RTGs per User)	Maximum output		Radio-isotope	Max fuel used (kg)	Mass (kg)
		Electrical (W)	Heat (W)			
SRG*	in prototype phase, MSL	~110 (2x55)	~500	^{238}Pu	~1	~34
MMRTG	in prototype phase, MSL	~110	~2000	^{238}Pu	~4	<45
GPHS-RTG	Cassini (3), New Horizons (1), Galileo (2), Ulysses (1)	300	4400	^{238}Pu	7.8	55.9-57.8[19]
MHW-RTG	LES-8/9, Voyager 1 (3), Voyager 2 (3)	160[19]	2400[20]	^{238}Pu	~4.5	37.7[19]
SNAP-3B	Transit-4A (1)	2.7[19]	52.5[20]	^{238}Pu	?	2.1[19]
SNAP-9A	Transit 5BN1/2 (1)	25[19]	525[20]	^{238}Pu	~1	12.3[19]
SNAP-19	Nimbus-3 (2), Pioneer 10 (4), Pioneer 11 (4)	40.3[19]	525	^{238}Pu	~1	13.6[19]
modified SNAP-19	Viking 1 (2), Viking 2 (2)	42.7[19]	525	^{238}Pu	~1	15.2[19]
SNAP-27	Apollo 12-17 ALSEP (1)	73	1480	^{238}Pu	3.8	20

- The SRG is in fact not an RTG; it is a stirling power device.

Terrestrial

Name & Model	Used On (# of RTGs per User)	Maximum output		Radioisotope	Max fuel used (kg)	Mass (kg)
		Electrical (W)	Heat (W)			
Beta-M	Obsolete Soviet unmanned lighthouses & beacons	10	230	^{90}Sr	0.26	560
Efir-MA		30	720	?	?	1250
IEU-1		80	2200	?	?	2500
IEU-2		14	580	?	?	600
Gong		18	315	?	?	600
Gorn		60	1100	^{90}Sr	?	1050
IEU-2M		20	690	?	?	600
IEU-1M		120 (180)	2200 (3300)	?	?	2(3) × 1050
Sentinel 25 [21]		9 - 20		$SrTiO_3$	0.54	907 - 1814
Sentinel 100F[21]		53		Sr_2TiO_4	1.77	1234

See also

Sustainable development portal

- Radioactive isotope
- Atomic battery
- Betavoltaics
- Optoelectric nuclear battery
- Radioisotope heater units
- Alkali-metal thermal to electric converter

References

1. ^ Bellona report on Russian RTGs
2. ^ ibid. (See Reference 41 in the report.)
3. ^ *Nuclear Free Texas*, Dallas Peace Center, http://dallaspeacecenter.org/Nuclear/Civilian, retrieved 2009-05-09
4. ^ *IAEA Bulletin Volume 48, No.1 - Remote Control: Decommissioning RTGs*, Malgorzata K. Sneve, http://www.iaea.org/Publications/Magazines/Bulletin/Bull481/pdfs/r14.pdf, retrieved 2009-07-11
5. ^ *Report by Minister of Atomic Energy Alexander Rumyantsev at the IAEA conference "Security of Radioactive Sources," Vienna, Austria. March 11th 2003 (Internet Archive copy)*, http://web.archive.org/web/20030806043406/http://www.iaea.org/worldatom/Press/Focus/RadSources/statement_rus.pdf, retrieved 2009-10-10
6. ^ Alaska fire threatens air force nukes, WISE
7. ^ Nuclear-powered NASA craft to zoom by Earth on Tuesday, CNN news report, 16 August 1999
8. ^ Valley says pee-eww to plutonium plan, Idaho Mountain Express and Guide, 22 July 2005
9. ^ Cassini Final Supplemental Environmental Impact Statement, Chapter 4, NASA, September 1997 (Links to other chapters and associated documents can be found at [1])
10. ^ Cassini Final Supplemental Environmental Impact Statement, Appendix D, Summary of tables of safety analysis results, Table D-1 on page D-4, see conditional probability column for GPHS-RTG
11. ^ Physical, Nuclear, and Chemical, Properties of Plutonium, IEER Factsheet
12. ^ Mortality and Morbidity Risk Coefficients for Selected Radionuclides, Argonne National Laboratory
13. ^ astronautix.com
14. ^ , [www.icsu-scope.org/downloadpubs/scope50/chapter02.html#t2.1(
15. ^ A. Angelo Jr. and D. Buden (1985). *Space Nuclear Power*. Krieger Publishing Company. ISBN 0894640003.
16. ^ IASS Strategic Plan 2005-2009, page 39
17. ^ [illegible], NASA
18. ^ NASA: Enabling Exploration: Small Radioisotope Power Systems
19. ^ *a b c d e f g h i j k* http://www.fas.org/nuke/space/bennett0706.pdf "Space Nuclear Power" G.L.Bennett 2006
20. ^ *a b c* http://www.totse.com/en/technology/space_astronomy_nasa/spac
21. ^ *a b* *Power Sources for Remote Arctic Applications*, Washington, DC: U.S. Congress, Office of Technology Assessment, June 1994, OTA-BP-ETI-129, http://govinfo.library.unt.edu/ota/Ota_1/DATA/1994/9423.PDF

- Safety discussion of the RTGs used on the Cassini-Huygens mission.
- Bellona's report on RTG lighthouses.
- Nuclear Power in Space (PDF)
- Detailed report on Cassini RTG (PDF)
- Detailed lecture on RTG fuels (PDF)
- Detailed chart of all radioisotopes
- Stirling Thermoelectric Generator
- Toxicity profile for plutonium, Agency for Toxic substances and Disease Registry, U.S. Public Health Service, December 1990
- Environmental Impact of Cassini-Huygens Mission.
- Expanding Frontiers with Radioisotope Power Systems (PDF)

External links

Wikimedia Commons has media related to: ***Radioisotope thermoelectric generators***

- NASA JPL briefing, Expanding Frontiers with Radioisotope Power Systems - gives RTG information and a link to a longer presentation
- SpaceViews: The Cassini RTG Debate
- Stirling Radioisotope Generator
- DOE contributions - good links
- Idaho National Laboratory - Producer of RTGs

v · d · e **Nuclear technology** [hide]

Science		Physics · Fission · Fusion · Radiation (ionizing) · Nucleus · Chemistry · Engineering
Fuel		Fissile · Fertile · Thorium · Uranium (enriched • depleted) · Plutonium · Deuterium · Tritium · Isotope separation
Neutron		Temp · Thermal · Fast · Fusion · Cross section · Capture · Activation · Poison · Radiation · Generator · Reflector
Fission reactors by moderator	Water	Pressurized (PWR) · Boiling (BWR) · Supercritical (SCWR) · Heavy (PHWR · CANDU · SGHWR)
	Carbon	Pebble bed (PBMR) · Very high temperature (VHTR) · UHTREX · RBMK · Magnox · AGR
	FLiBe	Molten salt (MSR)
	None (Fast)	Breeder (FBR) · Liquid-metal-cooled (LMFR) · Integral (IFR) · Traveling Wave (TWR) · SSTAR Generation IV by coolant: (Gas (GFR) · Lead (LFR) · Sodium (SFR))
Power		By country · Economics · Safety · Fusion · **Isotope thermoelectric (RTG)** · Propulsion (rocket)
Medicine	Imaging	Gamma camera based: Scintigraphy · Positron emission (PET) · Single photon emission (SPECT) X-ray based: Projectional radiography · Computed tomography
	Therapy	Radiation therapy · Tomotherapy · Proton · Brachytherapy · Boron neutron capture (BNCT)
Weapon	Topics	History · Design · War · Race · Explosion (effects) · Test (underground) · Delivery · Proliferation · Yield (TNTe)
	Lists	States · Tests · Weapons · Free zones · Treaties · Pop culture
Waste	Products	Fission (LLFP) · Activation · Actinide: (Reprocessed uranium · Reactor-grade plutonium · Minor actinide)
	Disposal	Fuel cycle · Spent fuel (pool • cask) · HLW · LLW · Repository · Reprocessing · Transmutation

Learn More

GPHS-RTG

- Would it be legal to install a **radioisotope thermoelectric generator** in a residential home? *Read answer...*
- What are the types of radioisotopes? *Read answer...*
- What is the kinds of radioisotopes? *Read answer...*

Help us answer these

- What is the construction and working of a **radioisotope thermoelectric generator**?
- What are advantages to **thermoelectric**?
- Who improved Thermoelectricity?

Post a question - any question - to the **WikiAnswers** community:

Go