ENERGY STORAGE DEVICES IN SPACE CRAFT - RADIOISOTOPE THERMO-ELECTRIC GENERATOR

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Abstract - A radioisotope thermoelectric generator (RTG, RITEG) is an electrical generator that uses an array of thermo couples to convert the heat released by the decay of a suitable radioactive material intoelectricity bythe Seebeck effect. RTGs have been used as a power sources in satellites and space probes. RTGs are usually the most desirable power source for unmaintained situations that need a few hundred watts (or less) of power for durations too long for fuel cells, batteries, or generators to provide economically and in places where solar cells are not practical. Safe use of RTGs have no moving parts and are very simple: fundamentally, they consist of a fuel cell, thermocouples and shielding. These compact, reliable systems provide basic mission fuel and keep critical spacecraft components warm enough to function in the cold, dark reaches of deep space.ISRO is about to use Nuclear Technology/Radioisotope thermoelectric generators(RTGs) to power Chandrayaan-2. The mission was planned to fly on a geosynchronous satellite launch vehicle MK-II (GSLV) with an approximate lift-off massof 2650kg from SatishDhawan center on Sriharikota Island. India might have been the first country to reach moon but our tricolor was the 4th national flag to be planted on the moon's surface.Radio isotope power systems are a nuclear powered system to generate electric power to feed communication and scientific systems on a space craft. The first RTG system developed for space situation was the system for Nuclear Auxiliary power (SNAP)

Keywords - Radioisotope thermo-electric generator (RTGs), fuel cells, thermocouples, satellites.

I. INTRODUCTION

Spaceflight presents unusual challenges for storing and collecting electrical power. Electrical power is required to operate instruments in the spacecraft and support equipment. In addition to the modest power requirements of computing, communications, and sensing electronics, some spacecraft components require large amounts of electrical power. Large peak power levels allow for radars to achieve better range or penetration through materials. It can also be used for propulsion in the form of ion drives, which improve efficiency over regular rockets by separating the storage of energy from the storage of reaction mass.

Energy storage on the Space Station and satellites is currently accomplished using chemical batteries, most commonly, nickel hydrogen or nickel cadmium.Today, energy is possibly one of the most critical sources for humanity. On Earth, we make use of different energy resources such as fossil fuels (coal, oil, etc.), nuclear power, and renewable energy (solar, wind, geothermal, etc.). Similarly, space missions require power at different stages of their life cycle, and they require their own power sources.[2]

NASA POWER SYSTEM TECHNOLOGY CAPABILITIES [1]

TECHNOLOGY ELEMENT	CAPABILITY
POWER SYSTEM	DIRECT ENERGY TRANSFER: 5 TO 20 KW SHUNT REGULATOR / RADIATOR: 28- 120 V dc
POWER ELECTRONICS	22- 120 V dc -55 to 75C, up to a 1Mrad >85% converter efficiency
RADIO ISOTOPE POWER SOURCES	GPHS RTG 4-5 W/kg; 6.5 % eff
SOLAR CELLS	Si cells 9-15% eff , TJ Cells 24-26% Rigid Panel 30-40 W/kg Flexible Fold Out Array : 40-60 W/kg
RECHARGEABLE BATTERIES	30-100 Wh/kg >30,000 Cycles (30% DOD >10 years -10 to 30 C

II. ENERGY SOURCES FOR SPACE MISSIONS

However, because the intensity of sunlight decreases with the square of the distance from the Sun, solar power becomes too weak beyond a certain distance and the spacecraft that are sent off to the outer solar system and beyond need a different source of energy to power up their systems. (The Juno spacecraft, launched in 2011, will be the first mission to observe Jupiter using solar power; however it will need to employ three huge solar panels of 2.7 m x 8.9 m size to meet its power requirements.) Also for Landers and rovers that must operate on dusty surfaces or on the dark side of planets in long-duration shadows, solar power is not an option.

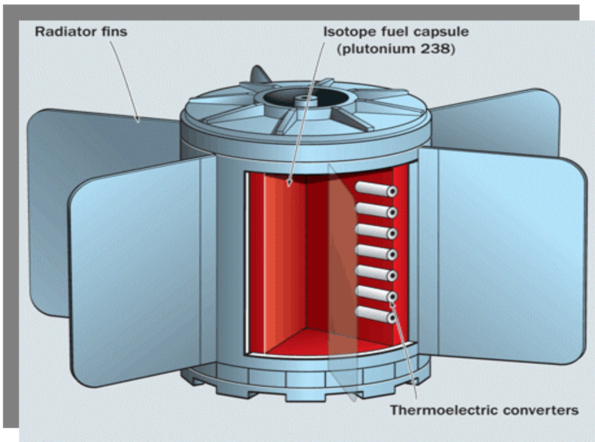


Fig 1: Radioisotope Thermo Electric Generator

The two basic types of nuclear power supply used in space are “nuclear reactors” and “radioisotope sources.” In a nuclear reactor system, the energy source is the heat generated by the controlled fission of uranium. This heat is then transferred by a heat-exchange coolant to either a static or dynamic conversion system, which transforms it into electricity. Rather, this technology relies on thermoelectric materials—special kinds of semiconductors that generate an electric current when one end is kept hotter than the other end. The greater the temperature difference, the more electricity is produced. These systems, generally referred to as Radioisotope Thermoelectric Generators (RTGs), are known to be simple and very reliable since they do not involve any moving parts.

RADIOISOTOPE SYSTEMS TECHNOLOGY:

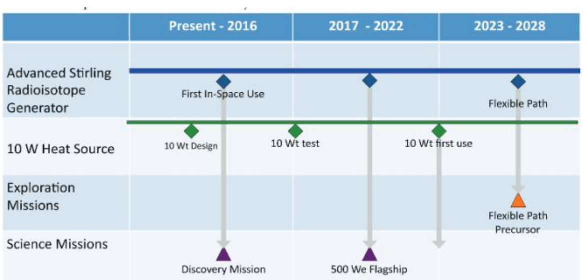
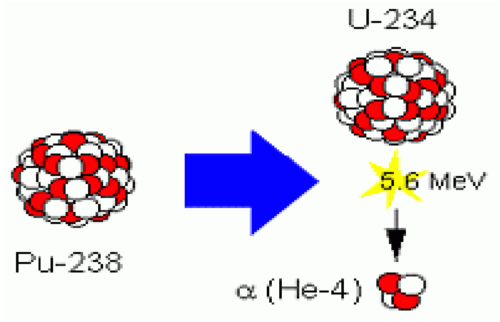


Fig 2: Radioisotope systems technology Roadmap

RADIOACTIVE FUEL SOURCE:

In a conventional nuclear reactor, one kilogram of Pu-239 can produce sufficient heat to generate nearly 8 million kilowatt-hours of electricity. The radioactive material has been chosen to be Pu-238, a standard RTG fuel type asit is a powerful alpha emitter. It has a half-life of 88 years, meaning it takes that long for its heat output to be reduced by half hence it works well as a space power source. It emits relatively low levels of radiation that is easily shielded, so mission –critical appliances and equipment are not affected. It can generate substantial heat in small amounts as it is stable at high temperature.



This Pu-238 has also been used in many space RTG applications .The most common plutonium isotope formed in a typical nuclear reactor is the fissile Pu-239, formed by neutron capture from U-238 (followed by beta decay), and which when fissioned yields much the same energy as the fission of U-235. Well over half of the plutonium created in the reactor core is 'burned' in situ and is responsible for about one-third of the total heat output of a light water reactor (LWR) and about 60% of the heat in a pressurized heavy water reactor (PHWR) such as CANDU. Of the rest in the LWR, about one-third through neutron capture becomes Pu-240 (and Pu-241). In a fast reactor this proportion is much less.

The approximately 1.15% of plutonium in the spent fuel removed from a commercial LWR power reactor (burn-up of 42 GWd/t) consists of about 53% Pu-239, 25% Pu-240, 15% Pu-241, 5% Pu-242 and 2% of Pu-238,bomb (see section on Plutonium and weapons below). Reactor-grade plutonium is defined as that with 19% or more of Pu-240. This is also called 'civil plutonium'.Plutonium-238, Pu-240 and Pu-242 emit neutrons as a few of their nuclei spontaneously fission, albeit at a low ratewhich is the main source of heat and radioactivity. [3].

Plutonium-240 is the second most common isotope, formed by neutron capture by Pu-239 in about one-third of impacts. Its concentration in nuclear fuel builds up steadily, since it does not undergo fission to produce energy in the same way as Pu-239. (In a fast neutron reactor it is fissionable' which means that such a reactor can utilize recycled plutonium more effectively than a LWR.) While of a different order of magnitude to the fission occurring within a nuclear reactor, Pu-240 has a relatively high rate of spontaneous fission with consequent neutron emissions. This makes reactor-grade plutonium entirely unsuitable for use in a thermoelectric generator. They and Pu-239 also decay, emitting alphaparticles and heatRadioisotope power systems based onplutonium-238 and thermoelectric converters have been used in space since 1961, with a typical performance of 3-5 We/kg, 6% efficiency, and over 30 yr (demonstrated) life. RPS's operate independent of solar proximity or orientation. In addition to enabling sophisticated science missions (e.g. Pioneer, Viking, Galileo, Ulysses, Cassini, and New Horizons) throughout the solar system, RPS's were used on Apollo missions 12-17 and the Viking Landers.

Examples of the types of variation in plutonium composition produced from different sources:

REACTOR TYPE	Mean fuel burn-up (MW d/t)	PU 238 (percent age)	PU239 (percent age)	PU240 (percent age)	PU241 (percent age)	PU 242 (percent age)
PWR	33000	1.3	56.6	23.2	13.9	4.7
	43000	2.0	52.5	24.1	14.7	6.2
	53000	2.7	50.4	24.1	15.2	7.1
BWR	27500	2.6	59.8	23.7	10.6	3.3
	30400	N/A	56.8	23.8	14.3	5.1
CANDU	7500	N/A	66.6	26.6	5.3	1.5
AGR	18000	0.6	53.7	30.8	9.9	5.0
Magnox	3000	0.1	80	16.9	2.7	0.3
	5000	N/A	68.5	25.0	5.3	1.2

Looking forward, RPS's in the 0.1 – 1000 wepower range could continue to enable exciting science missions and could also be useful in supporting human exploration missions. High specific power RPS's could enable radioisotope electric propulsion for deep space missions, enhancingor enabling numerous NASA missions of interest Specifically, there are three types of radioisotope power systems that need to be developed: 1) advanced Radioisotope thermoelectric generator(10-15 W/kg, 15-20% efficiency, 15 year life); 2) advanced Stirling radioisotope generator (ASRG) (10-15 W/kg, 35% efficiency, 15 year life); and 3) small (1-10W) RPS's that can survive a 5000-g impact, including both the heat source and power conversion system. The radioisotope of choice is plutonium-238, which has excellent power density and lifetime, and minimal radiation emissions. The use of a more readily available isotope (e.g., 241Am) instead of 238 Pu would result in a performance penalty for most RPS missions and would require an extensive qualification effort. However, the use of alternative isotopes (in addition to 238Pu) could potentially allow higher power (>1 kWe) radioisotope systems to be developed and utilized and allow more extensive use of radioisotope systems. NASA's Science Mission Directorate is continuing to develop advanced radioisotope power systems for future space science missions. The ASRG is making excellent progress towards the goals of efficiency greater than 28%, specific power of 6-8 We/kg, and life exceeding14 years.

The major challenges for RPS's are: (1) to create high efficiency power conversion systems with very long life capability, (2) the severe impending shortage of 238Pu, which is no longer being produced in the U.S. (if the 238Pu availability issue is not resolved, there is a need to develop and qualify alternative nuclear heat sources); and (3) to invent RPS's which can survive a 5000-g impact. Foremost is the need for a new program to establish U.S. plutonium-238 production facilities, or the development and production of alternative nuclear heat sources. NASA is working with other government agencies to implement this new program. Flight validation of the ASRG and other radioisotope power systems is very important to ensure the acceptability of these systems on future missions. This new program must also focus on developing small, impact-resistant radioisotope power systems and life-prediction models and experimental testing techniques. Advanced RPS's could be used on Discovery, Flagship, and Flexible Path precursor missions.

ISRO TO USE RADIOISOTOPE THERMOELECTRIC GENERATOR:

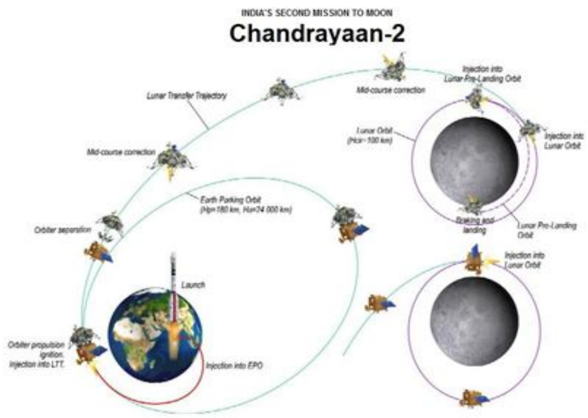
Developed by the Indian Space Research Organization(ISRO), the mission is planned to be launched to the Moon by a Geosynchronous Satellite Launch Vehicle (GSLV Mk II). [4].It includes a lunar orbiter, Lander and rover, all developed by India. The ISRO is planning to launch Chandrayaan-2 in the first quarter of 2018.[5].According to ISRO, this mission will use and test various new technologies and conduct new experiments.[6][7][8]. The wheeled rover will move on the lunar surface and will pick up soil or rock samples for on-site chemical analysis. The data will be relayed to Earth through the Chandrayaan-2 orbiter.[9]

Unlike Chandrayaan-1's Moon Impact Probe, which impacted the Moon's surface, the Lander will make a soft landing to then deploy the rover. [11] The Lander will not perform any scientific activities. The approximate mass of the Lander and rover is 1,250 kg (2,760 lb). Initially, the Lander was slated to be developed by Russia in collaboration with India. When Russia stated its inability provide the Lander to meet even the revised time frame of 2015, Indian officials decided to develop the Lander independently. The cancellation of the Russian Lander also meant that mission profile had to be changed. The preliminary configuration study of the indigenous Lander was completed in 2013 by the Space Applications Centre (SAC) in Ahmadabad. [10] .

The research team identified methods for a soft landing on the lunar surface, as well as the associated technologies that would be needed for such an event. Amongst these technologies are a high resolution camera, navigation camera, hazard avoidance camera, an 800 N throttle able liquid main engine and attitude thrusters, altimeter, velocity meter, accelerometer, and the software needed to run these components.[1][12] The Lander's main engine has successfully undergone a high altitude test for a duration of 513 seconds, and closed loop verification tests of the sensors, actuators and software are planned for the middle of 2016.[13]. Engineering models of the Lander began undergoing ground and aerial tests in late October 2016, in Challakere in the Chitradurga district of Karnataka. The ISRO created roughly 10 craters in the surface to help assess the ability of the Lander's sensors to select a landing site. [14]

Subsystem	Quantity	Mass (kg)	Power (W)
INS[15]	1	20	100
Star tracker[15]	2	6	15
Altimeter[15]	2	1.5	8
Velocimeter[15]	2	1.5	8
Imaging sensor[15]	2	2	5

The Indian Space Research Organization started a series of ground and aerial tests linked to the critical Moon landing of Chandrayaan-2 on Friday, as its new site at Challakere in Chitradurga district 400km from Bangalore.ISRO Satellite Centre or ISAC, the lead centre for the second Moon mission, has artificially created close to ten craters to simulate the lunar terrain and test the Lander's sensors. A small ISRO aircraft has been carrying equipment with sensors over these craters to plan the tasks ahead. ISRO, along with a host of other scientific and strategic agencies, owns vast land for its future missions at Challakere, in a 'Science City.



ISAC Director M.Annadurai told The Hindu, "The campaign for the Lander tests of Chandrayaan-2 has started. Tests are conducted over the simulated craters at Chitradurga. We are using an aircraft to assess whether the sensors on the Lander will do their job [later] of identifying the landing spot on the Moon." Chandrayaan-2 is tentatively set for late 2017 or early 2018 and includes soft-landing on Moon and moving a rover on its surface. Landing on an alien surface is very complicated, said Dr. Annadurai, who was also the Project Director for the successful Chandrayaan-1 lunar exploration mission of 2008. The Lander's success hinges on sensors. As it descends from the mother ship or Orbiter, they must correctly judge the distance to the lunar surface, the required speed and the time to hover over the location, for a few seconds.

CONCLUSIONS

RTGs are most desirable power source that need a few hundred watts of power in places where solar cells are not practical. RTG is a radioactive isotope, provides a supply of electrical power in the range of tens to hundreds of watts. It isan electrical power source based on thermoelectric conversion but which utilizes a nuclear reactor as a source. RTGs enable spacecraft to operate at significant distances from the sun or in other areas where solar power systems would not be feasible. They remain unmatched for poweroutput; reliability and durability by any other power source mission'sNASA power system capabilities are discussed.

Radioactive material Pu-238 is chosen and types of variation in plutoniumcomposition produced from different sources are given.ISRO to use nuclear technology/Radioactive isotope thermoelectric generator to power Chandrayaan-2. It can be a promising technology to run indigenous energy sources to save energy.

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