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Analysis on Radioisotope Thermoelectric Generators and Power Systems

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Abstract:- Radioisotope Thermoelectric Generators, or RTGs, provide electricity to the atmosphere by converting heat generated by the decomposition of plutonium-238 (Pu-238) gas into electricity using devices called thermocouples. Since they do not have moving parts that can be damaged or worn out, RTGs have historically been considered the most reliable electrical power. Thermocouples have been used in RTGs for a combined period of more than 300 years, and not a single thermocouple has stopped producing energy. The purpose of this research is to study the radioisotope energy generation and power systems. Study power generation capacity and efficiency when compared to nuclear fission and solar arrays. To learn about Electric Ion propulsion drive and its power consumption. To get the energy needed for future Manned and unmanned space missions or interplanetary space explorations. Merits and demerits of Radioisotope Power Systems in the context of power supplying capacity and electric power needed for future explorations. It is found that RPS and RTG are capable of generating energy for a long time but cannot generate high levels of energy i.e. RTG generates only 100-400 KW of electrical power whereas Nuclear fission generates fairly high levels of energy by splitting neutron from atoms. It is expected that energy needed for manned space missions are in tens of megawatts. On comparing Radioisotope Power Systems (RPS) with the nuclear fission and solar arrays power generation, It seems that having Nuclear reactor with the spacecraft could be the first step towards the Megawatt energy generation for Space explorations.

Keywords:- *Thermoelectric Generation, Radioisotope, Power Systems, Thermal Energy, Nuclear Fuel, Alpha Particles, Nuclear fission, solar arrays, Electric Ion Propulsion Drive.*

I. INTRODUCTION

Thermocouples are common in everyday objects that must monitor or regulate their temperature, such as air conditioners, refrigerators and medical thermometers. The principle of a thermocouple involves two plates, each fabricated from a separate electric conductor. Joining these two plates to make a closed circuit while keeping the two compounds at different temperatures produces electricity. Each of those couple's pairs forms each thermocouple. In RTG, radioisotope fuel burns one in every of these compounds while the opposite combustion is unheated and cooled by the atmosphere or planetary atmosphere. In the context of RTG's it is prerequisite to know about fundamental aspects of nuclear science, material science and Thermocouples. Advancement in RTG's can only be done when we start from the first step i.e. fuel. Generally, Fuel used for MMRTG's (Multi Mission RadioIsotope Thermoelectric Generators) is Plutonium dioxide which is a radioactive material, due to radioactive characteristics it produces alpha particles which particularly are ionizing radiations. Furthermore the nuclear fuel commonly Uranium 234 and plutonium-239 isotopes which are used in nuclear weapons wouldn't be work well in nuclear reactors for power generation [1]. However after the selection of fuel, the next step is the selection of material for thermoelectric generator (TEG). As we know the thermoelectric effect i.e. conversion of heat flux into electrical energy, Heat flux is the temperature difference between two different materials [2]. The greater Heat Flux results in large electrical energy, after the selection of material for the TEG the next step is to store that electrical energy. For dissipating the heat energy radiating fins are used. However, the RTG fuel i.e. plutonium-238 is a specialized fuel for the controllable Nuclear fission process.

Plutonium-238 is an Isotope of plutonium-239, which is processed at Oak Ridge National Laboratory (ORNL) and It is shipped from ORNL to Los Alamos National Laboratory (LANL) and then it is shaped to Heat source Pallets, Pallets are then transferred for the fuel storage [3]. Nuclear fission is the process of splitting of atoms which could generate power in the range of 100KW to few Megawatts for space missions. It is one way to power the Manned Space missions and for the planetary explorations. High energy High power is needed to power megawatt electric propulsion and on-board computer systems which can be obtained with the nuclear fission. Fission is the neutron splitting from an atom into radioactive isotopes generally 2 isotopes. Nuclear fission reactors are able to generate high levels of electric power so that it can fuel its electric energy to an EPID's [4].

Besides this, Radioisotope Thermoelectric Generators are the primary subject for the further Research proceedings which might be proven as an efficient and reliable source of energy for long time power supply system i.e. For many lunar and Inter-planetary missions, which in turn may help us to explore the different planets which are at a farther distance from Earth.

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II. COLLECTED DATA FROM NASA RADIOISOTOPE POWER SYSTEM

A. Radioisotope power systems convert heat from the natural decay of the isotope plutonium-238 (used during a ceramic kind of plutonium dioxide) into power to control the computers, science instruments, and other hardware aboard NASA missions like the Curiosity rover on Mars and also the New Horizons spacecraft flyby of Pluto and beyond. It's already published add the identical field [5].
B. US production for RPS fuel have been ceased in 1980's. The production Line by Department of Energy (DOE) for space exploration continue its operation after 30 years since it was ceased [6].
C. New Plutonium-238 is prepared at ORNL and then transferred to Los Alamos National Laboratory (LANL) where these pallets are then turned into pallets which are used for the general purpose heating source (GPHS) then shipped to INL to store it up for space missions [7].

III. STUDIES AND FINDINGS

Now it is the time to articulate the research work with ideas gathered in above steps by adopting any of below suitable approaches:

A. Plutonium Dioxide (Pu238) as Direct Fuel:

In this approach we are going to use direct fuel, as plutonium dioxide is a radioactive material which releases heat energy as it breaks or decays in the form of alpha matter or particles. Alpha matter or Particles are a type of Ionizing radiation that can be shielded by any this material like paper. In order to be used as a RPS fuel the plutonium should meet certain properties like they should have long half-life i.e. 20-95 years approximately also it should have high power density as well, In case of plutonium dioxide it is a really big unstable atom and it likes to decay into alpha particles in the form of heat energy and turning into Uranium (U234) atom. In this process it gives heat and according to Einstein's law:

$$E = mc^2 \quad (1)$$
$$energy\ (joules) = mass\ (Kg) x\ (speed\ of\ light)^{\ 2} \quad (2)$$

Plutonium atom weighs more than the Uranium and alpha particle i.e. because mass was lost when the decay happened, mass that lost is turned into energy. If we look at the mass (m) that was decayed multiplied by the speed of light squared that turns out to be small amount of mass loss and a huge amount of energy released in the form of HEAT. This energy is fed to the Radioisotope Power Systems (RPS) for the generation of Electrical power. So now let us understand what actually RPS is doing with the energy, The RPS is embedded with Thermoelectric Modules (for electricity generation) and Radiator Fins (for cooling purposes). We shall now focus on Thermoelectric Modules (TEM), each TEM module contains a bunch of Thermoelectric Peltier (TP).

Now TP is a device which works on the principle of thermoelectricity i.e. a voltage developed between two dissimilar conductors is proportional to their temperature difference. Thermoelectric Peltier is a two face device which is fitted into the Radioisotope Power System such that one of its face is towards the released Heat Energy and other side faces away from it, so that the temperature difference between both the faces could develop a significant amount of voltage and this generates useful electrical power.

$$^{238}PuO_2 \rightarrow U_{234} + \alpha\ \text{Particles} \quad (3)$$

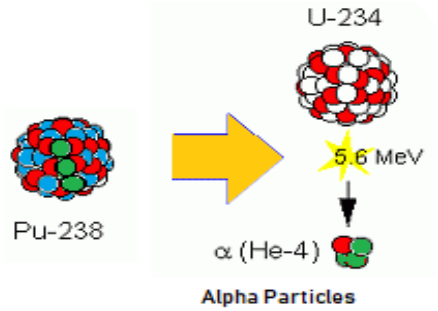

Fig1. Extraction of Alpha Particles from plutonium-238.

The extracted form of plutonium cannot be used directly for RTG's as for decaying of alpha particles and generation of thermal energy the natural form of plutonium needs to be treated and covered with the thick layer of Iridium due to its sustainability with the temperatures as high as 2000°c, also Iridium is also corrosion resistant metal which implies a long Life.

However, the plutonium-di-oxide which is used as a fuel in RTG is in form of ceramic disc like structure which is then covered with cladding and iridium. It is also capable to generate 292W of electrical energy with a 1.5kg of disc for a longer time span i.e. for years. Furthermore, General Purpose Heating Source (GPHS) Modules are installed in form of stacks.

B. General Purpose Heat Source Module (GPHS):

Each GPHS Module is having plutonium-di-oxide pallet, which is in group of 8 modules in total. Each pallet is a ceramic disc form of plutonium-di-oxide and with the coating of protective layer of Iridium forming the clad. In fig. 2 GHPS module is having measured dimensions of 4x4x2 (inches) and having weight of three pounds and layered with graphite aero shell covered with carbon fiber sleeve.

Fig2. General Purpose Heating Source Pallet (Pu^{238}).

1) Each GPHS module can generate 292 W of electric power in the mission's beginning [8].
2) For GPHS RTG the number of module may vary from 8 to 18 modules till now. Fig 2. General Purpose Heat Source Pallet

3) A working life of GPHS RTG is upto 19 years of exploration [9].

C. Thermoelectric Couple Assembly (TE couple Assembly):

The TE Couple assembly module is a set of Thermoelectric Peltier connected in series around the circular span of RTG to use the every joule of heat energy efficiently. When Plutonium-238 decays alpha particles in the form of heat radiation, the heat energy is directly transferred to the couple assembly which then converts Heat Energy to Electrical Energy directly. The TEC assembly is attached with Heat Distribution Block which is

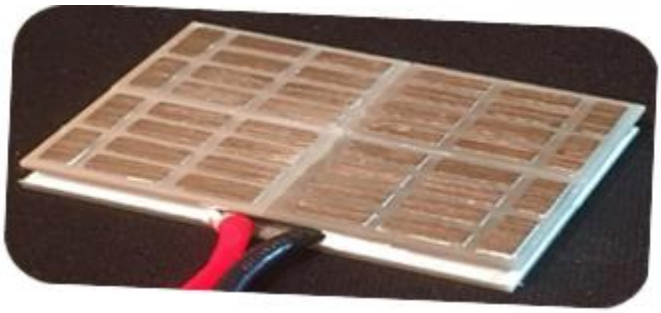

Fig 3 Pb/te lead thermoelectric Peltier.

Layered with mica, microthermal insulation and then thermoelectric couple assembly is placed having TEG cascaded and a Module Bar is formed. This all is covered with the cooling

Tube and yoke of MMRTG.

In fig. 3 lead thermoelectric Peltier is shown with its outer layering and covering. It has two terminals, positive terminal and negative terminal.

1) It is found that skutterudite (SKD) thermocouples have better efficiency than pb thermocouples.
2) Various factors are to be considered for Thermoelectric Generators:
a) Hot Junction Temperature.
b) Cold Junction Temperature.
c) Beginning of mission power.
d) End of mission power.
e) Potential implementation for future missions.

Materials used till now are Lead TE (Pb/te) thermocouples and skutterudite (SKD) Thermocouples. Both thermocouples served in NASA Space Missions.Enhancement of TE couples could be with the addition of oxidation layer at the heat source liner [4].

NASA RPS is having two versions of Thermoelectric Modules i.e. MMRTG and eMMRTG [10]. MMRTG uses Pb/TE thermocouples whereas eMMRTG uses skutterudite (SKD) thermocouples. It had been found that skutterudite (SKD) thermocouples are having greater efficiency than Pb/te thermocouples.

Fig. 4 Skutterudite Thermoelectric Peltier.

In fig. 4 skutterudite thermoelectric Peltier with its outer covering is shown. It is surface mounted type device and has greater efficiency.

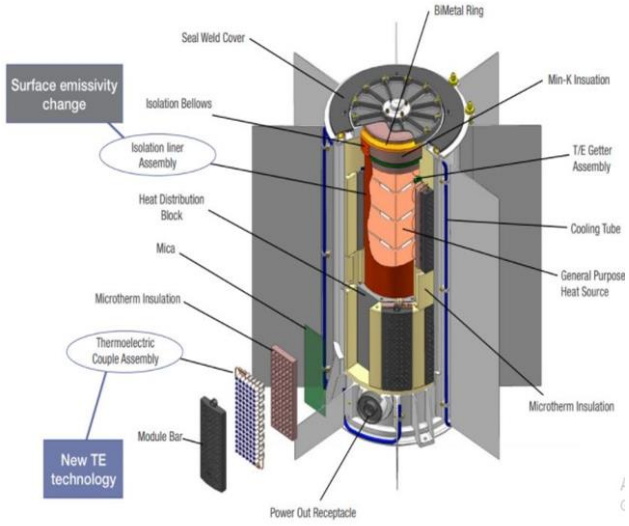

Fig. 5 Power-out Receptacle (MMRTG) Internal Structure.

D. Power out Receptacle:

In fig.5 MMRTG Power Out receptacle is shown, the power out receptacle is the power out terminal of RTG. It is the only exit point of the whole RTG. RTG can generate upto 2.36 KWapprox. for eight GHPS module. These improved performance attributes of the GPHS-RTG made it attractive for use on the Galileo mission [10].

Subsequently, the GPHS-RTG was selected to power the Cassini spacecraft which is currently orbiting Saturn, and the New Horizons spacecraft which is on its way to Pluto. Truly, the GPHS-RTG is a "general-purpose" space RTG.It is

the power out receptacle for the Electric Ion Propulsion Drive which consist of xenon rays.

In figure 4, Multimission RTG (MMRTG) Internal Structure is shown with the Layering and EMMRTG's additional feature is also shown with New TE Technology i.e. thermoelectric couple assembly. Besides this, to power a Space mission needs approximately 400 Watts to 2.5 KW of electric power to run onboard systems and this power is increased for manned space missions which could be upto 5 to 10 MW. Radioisotope power systems limited to generate approximately 100-300 watts electric power, for a long period of time which is alone isn't enough to power onboard systems when high levels of power is needed. For the rest of the High levels of power solar power and nuclear fission are used.

Solar arrays are used to power both onboard systems and Electric Ion Propulsion Drive (EIPD). EIPD's are the propulsion drive for the space craft which is powered through solar arrays which are used to ionize the atoms of Xenon. Orbiter slowly gains speed once ions expelled by a robust electric field at the back. Many orbiters have powered with the solar arrays upto 7.5 KW electric energy can be drawn from these type of solar arrays with the increased efficiency from 14% to 23.2% by using collectors and concentrating lenses which are used to concentrate the sunlight on the solar panels.

IV. CONCLUSION

A. It is concluded that Radioisotope Thermoelectric Generators and Power Systems may led the Conventional power systems towards the efficient generation of power, given that the thermoelectric elements needs to be more efficient. For the Solely purpose of space missions, To power a research rover or powering a space station RTG & RPS are the most efficient fuels as they can generate maximum energy with minimum mass of fuel.

B. For Nuclear fission reactor power generation Method, It is important that how the nuclear waste can be decomposed because decomposition of nuclear waste is limited by the same characterstics which is the reason behind huge power generation i.e. Radioactivity.

C. Electric Ion Propulsion Drive would be the efficient electric propulsion system but Energy needed for the Distant explorations and Interplanetary Manned Missions are so great that attaining much electrical power from RTG's or Solar Arrays are difficult.Here, Nuclear fission comes into play for the reason that "Nuclear Fission would be able to generate Megawatts of power in the upcomig years for manned missions." [10].

V. APPENDIX

1) Atomic mass (Pu) = 244u.
2) Atomic mass (U) = 238.03u.
3) Energy released = (decayed mass) x (speed of light)^2.

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