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A4_4 An RTG Powered Home

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Abstract

This article determines the feasibility of using radioisotope thermoelectric generators to power a household containing a working couple. It has been found that the amount of plutonium-238 required to supply sufficient energy to cover the needs of a working couple over the course of a year were 13.44kg. This amount of plutonium would be unreasonable due to the expense of this resource.

Introduction

One of the largest concerns facing the modern world is the effect of global warming and the need to find energy from sustainable sources. This paper assesses the feasibility of using a Radioisotope Thermoelectric Generator (RTG) as the means for powering a home, i.e. providing all the electrical needs. A radioisotope thermoelectric generator produces electricity using a series of thermocouples known as a thermoelectric generator. Each thermocouple consists of two types of semiconductor, one N-type and the other P-type; a number of these thermocouples are then connected electrically in series and thermally in parallel.

A thermocouple produces a current from a temperature difference applied across it; this is due to the free charge carriers flowing with the heat to the cold side of the thermoelectric generator. Thus 'by connecting an electron conducting (N type) and hole conducting (P type) semiconductor in series a net voltage is produced' [1]. The basic design of the RTG device in this paper would be the same as that used in space applications, i.e. a radioactive source surrounded by a casing and thermoelectric generators (refer to the design of SNAP 19 RTG [4]). This design will be used to estimate the usefulness of an RTG in the setting of a household, and whether they could be used to provide the electricity needs for a household, i.e. how much ^{238}Pu would be needed.

Radioactive Fuel Source

The radioactive material has been chosen to be ^{238}Pu, a standard RTG fuel type as it is a very powerful alpha emitter, but does not emit significant amounts of other more harmful radiations. This means that the isotope is relatively easy to shield, and as such would not require expensive casing. This isotope has also been used in many space RTG applications, thus its use and design is well established and would not require significant changes.

Household Consumption

This feasibility study will be based on the estimated electricity consumption of a full time working couple (i.e. they will not use electricity during the day on weekdays). The electricity consumption has been estimated for a working couple to be 4117kWh per year [2], therefore in the units of watts, 469.977W.

Power output from the decay of ^{238}Pu

^{238}Pu is produced from the decay of ^{238}Np following neutron capture by ^{237}Np. It releases 5.6MeV of energy per disintegration [3], which for the purposes of this paper will be assumed to be entirely in the form of heat.

^{238}Pu has a decay rate of

$$\frac{dN}{dt} = \lambda N, \qquad (1)$$

where, $\lambda = -\frac{\ln 2}{t_{1/2}}$ is the decay constant, $t_{1/2}$ =87.7 years, is the half life and $N = \frac{N_A}{m}$, the initial number of atoms present, $m = 238\, g\, mol^{-1}$, and $N_A = 6 \times 10^{23}$ is Avogadro's number. Hence,

$$\frac{dN}{dt} = 6 \times 10^{11} s^{-1} g^{-1}. \qquad (2)$$

Each decay releases E = 5.6MeV, so the total power output P is

$$P' = \frac{dN}{dt} E = 0.538 \, W \, g^{-1}, \quad (3)$$

So therefore 1 gram of ^{238}Pu will release 0.538 J of energy per second.

The Efficiency of the Thermoelectric Generator

The design for the RTG that has been assumed in this paper is that of the SNAP 19 device, used during the Pioneer 10 and 11 missions among others [4]. The reason for this choice is due to its relatively simple design, and well established history. The SNAP RTG device has a quoted efficiency of 6.5% [4], this value will be assumed as the efficiency of the device used to convert the thermal energy from the ^{238}Pu into electricity to power the household.

Powering an Average Household

The overall power output (P_{output}) of the (RTG) is calculated as the product of the conversion efficiency (η_{TEG}) of the thermoelectric generator and the power output of the radioisotope (*P'*- i.e. the power output per gram, multiplied by the mass (*M*) of the radioisotope). For the sake of this paper this is the required power to supply an average household over the course of the year;

$$P_{output} = P' M \eta_{TEG} \, . \qquad (4)$$

Rearranging this equation to find the required mass of the radioisotope and then substituting in the values reveals that a total of 13.44Kg of ^{238}Pu would be required.

Conclusions

In the search for alternative energy sources the feasibility of an RTG is unfortunately unlikely. The amount of radioisotope required to power a two person household is 13.44Kg of ^{238}Pu. This is a very large amount of plutonium, since the entire inventory of the US reserve (in 2004) was only 39.51 Kg. Not only would the RTG be very expensive but the production of enough plutonium to power more than a couple of houses would be very expensive [5]. The laws regarding nuclear material and the possession of the substance would also make 13.44Kg of ^{238}Pu impossible. The major flaw with the feasibility of the RTG is the very low efficiency. RTGs produce a significant amount of waste heat. To improve this, the waste heat could also be harnessed as another source of energy for the household. Overall this feasibility study has proved that conventional RTGs are not an alternative source of power for the working couple.

References

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