

Preliminary Analysis: Am-241 RHU/TEG Electric Power Source for Nanosatellites. Glen A. Robertson¹, David Young¹, Karen Cunningham¹, Tony Kim¹, Richard M. Ambrosi², and Hugo R. Williams², ¹Marshall Space Flight Center, Huntsville Alabama, 35812, USA, glen.a.robertson@nasa.gov; 256-544-7102, ²University of Leicester, Space Research Centre, Leicester, LE1 7RH, UK.

Introduction: The February 2013 Space Works Commercial report indicates a strong increase in nano/microsatellite (1-50 kg) launch demand globally in future years [1]. Nanosatellites (NanoSats) are small spacecraft in the 1-10 kg range, which present a simple, low-cost option for developing quickly-deployable satellites. CubeSats, a special category of NanoSats, are even being considered for interplanetary missions [2]. However, the small dimensions of CubeSats and the limited mass of the NanoSat class in general place limits of capability on their electrical power systems (especially where typical power sources such as solar panels are considered) and stored energy reserves; restricting the power budget and overall functionality.

For example, leveraging NanoSat clusters for computationally intensive problems that are solved collectively becomes more challenging with power related restrictions on communication and data-processing. Further, interplanetary missions that would take NanoSats far from the sun, make the use of solar panels less effective as a power source as their required area would become quite large.

To overcome these limitations, americium 241 (Am-241) has been suggested as a low power source option. The Idaho National Laboratory, Center for Space Nuclear Research reports [3] that:

- (Production) requires small quantities of isotope – 62.5 g of Pu-238; 250 g Am- 241 (for 5 We),
- Am-241 is available at around 1 kg/yr commercially,
- Am-241 produces 59 keV gammas which are stopped readily by tungsten so the radiation field is very low. Whereby, an Am-241 source could be placed in among the instruments and the waste heat used to heat the platform, and
- Amounts of isotope are so low that launch approval may be easier, especially with tungsten encapsulation.

As further reported in [4], Am-241 has a half-life that is approximately five times greater than that of Pu-238 and it has been determined that the neutron yield of a 241-AmO₂ source is approximately an order of magnitude lower than that of a 238-PuO₂ source of equal mass and degree of ¹⁶O enrichment. Also it has been demonstrated that shielded heat sources fuelled by oxygen-enriched 238-PuO₂ have masses that are up to 10 times greater than those fuelled by oxygen-enriched 241-AmO₂ with equivalent thermal power

outputs and neutron dose rates at 1 m radii. For these reasons, Am-241 is well suited to missions that demand long duration electrical power output, such as deep spaceflight missions and similar missions that use radiation-hard electronics and instrumentation that are less susceptible to neutron radiation damage.

United Kingdom Am-241 RHU/TEG: The authors propose using the Am-241 radioisotope heat unit and thermal electrical generator (RHU/TEG) being developed in the United Kingdom (UK) as the electrical power source (EPS) [5]. In Europe isotope selection studies have identified Am-241 as the isotope of choice for a European program. The Am-241 fuel can be produced economically and at high isotopic purity by separation from stored separated plutonium (Pu) produced during the reprocessing of civil fuel [5, 6].

Safe radioisotope thermoelectric generators and heat source for NanoSats: [4] evaluates several isotopes as alternatives to Pu-238 that is traditionally used in radioisotope thermoelectric generators (RTGs) and heating units (RHUs) and conclude that Am-241 is a good replacement for Pu-238 in space missions. To demonstrate this, a 5 We Am-241 RHU/TEG prototype breadboard model for low mass with a total system weight of 6.4 kg was developed. The model indicates that the outermost shield for neutrons would be composed of 5 cm thick boron loaded polyethylene [4, Table 3]; equating to a maximum outer diameter >16 cm.

The weight and volume of the 5 We Am-241 RHU/TEG plus shield will fit within the 1-10 kg range defined for NanoSat class spacecraft. CubeSats, on the other hand, are the only NanoSat exception, presenting a potential challenge to packaging due to the severe dimensional and mass restrictions of this NanoSat subclass. CubeSats range from 1 kg, 10 cm cubes (1U dimensions) up to typically 6U sizes (6 kg stack of 6 x 1U cubes) [7].

CubeSat Prototype Am-241 RHU/TEG EPS Design: To overcome the dimension limitation, part of the neutron shielding could be placed around the CubeSat while only in the carrier/launcher to provide adequate radiation safety during handling and ground operations, and left in the launcher after the CubeSat is deployed. For smaller Wattage (<5 We) RHU/TEGs, some reduction in the size would be expected. But the 5 cm thick boron loaded polyethylene neutron shielding required would still push the overall size outside CubeSat dimensions.

Figure 1 illustrates the 5 cm thick boron loaded polyethylene neutron shielding (green plus blue areas) packaging footprint for the 5 We RHU/TEG with respect to the 1U CubeSat footprint (blue area). As can be seen, the outer portion (green area) of the neutron shielding only extends a maximum of ~3 cm about the standard 1U CubeSat (blue area). Noting that, the weight of the 5 We RHU/TEG is more than 6 times that of the standard 1U CubeSat; requiring other considerations if flown as a purely CubeSat mission.

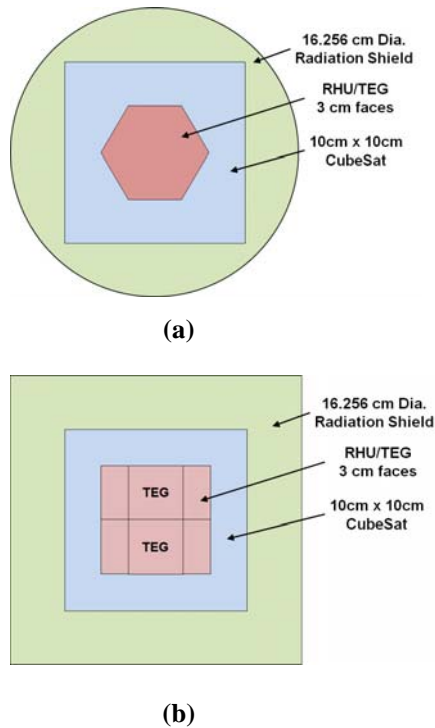


Figure 1. CubeSat and 241-Am RHU/TEG Footprints; a) top or bottom view and b) facial side view.

CubeSat Budget Analysis: With the design of Figure 1 in mind, a review of the power budgets considered for the CubeSat missions addressed in [8] is conducted to compare the EPS requirement toward the use of the 5 We Am-241 RHU/TEG prototype breadboard model of reference [4].

CubeSat power budgets for different modes of operation are used to estimate an overall energy reserve budget which equates the total energy produced by the EPS with the total energy consumed by key subsystems; Attitude Determination and Control System (ADCS), Command & Data Handling (C&DH); and payload. The estimate is the result of a detailed analysis that takes into account key components of these subsystems, including the power requirements of specific computational operations. However, sunlight cycles due to mission orbital patterns and their influence on the power budget estimates of [8] are not expected

to be a significant influence on the analysis to be presented and therefore will be ignored.

References: [1] DePasquale, D. and Bradford, J., Space Works: Nano/Mirosatellite Market Assessment, February 2013. [2] Staehle, R., *et al.*, “Interplanetary NanoSat: Opening the Solar System to a Broad Community at Lower Cost,” *JoSS*, Vol. 2, No. 1, pp. 161-186, 2013. [3] Howe, S. D., *et al.*, “Compact, Low Specific-Mass Electrical Power Supply for Hostile Environments,” presented at the 9th Annual Polar Technology Conference, 2-4 April 2013. [4] O’Brien, R. C., *et al.*, “Safe radioisotope thermoelectric generators and heat sources for space applications,” *Journal of Nuclear Materials*, 377, pp. 506–521, 2008. [5] Sarsfield, M. J. *et al.*, “Progress on 241Am production for use in Radioisotope Power Systems,” Paper 6750 in the Proceedings of *Nuclear and Emerging Technologies for Space 2013* Albuquerque, NM, February 25-28, 2013. [6] Ambrosi, R. M. *et al.*, “Development and Testing Of An Americium-241 Radioisotope Thermoelectric Generator,” Paper 6780 in the Proceedings of *Nuclear and Emerging Technologies for Space 2013* Albuquerque, NM, February 25-28, 2013. [7] Heidt, H., Turner, C., Twiggs, R., “CubeSat: A new generation of picosatellite for education and industry low-cost space experimentation,” in *Proceedings of the 14th Annual AIAA/USU Conference on Small Satellites*, SSC00-V-5, Logan, UT, Aug. 2000. [8] Arnold, S.S., Nuzzaci, R., and Gordon-Ross, A., “Energy budgeting for NanoSat with an integrated FPGA,” Aerospace Conference, 2012 *IEEE*, 3-10 March 2012.