DEVELOPMENT AND TESTING OF AMERICIUM-241 RADIOISOTOPE THERMOELECTRIC GENERATOR: CONCEPT DESIGNS AND BREADBOARD SYSTEM.

R.M. Ambrosi[1], H.R. Williams[1], P. Samara-Ratna[1], N.P. Bannister[1], D. Vernon[1], T. Crawford[1], C. Bicknell[1], A. Jorden[2], R. Slade[2], T. Deacon[2], J. Konig[3], M. Jaegle[3] and K. Stephenson[4]. [1]Space Research Centre, Dept of Physics and Astronomy, University of Leicester, Leicester LE1 7RH, UK. (rma8@le.ac.uk), [2]Astrium Ltd., Gunnels Wood Rd, Stevenage, UK. [3]Fraunhofer IPM. Freiburg, Germany [4]European Space Agency, ESTEC TEC-EP, PO Box 299 - 2200 AG Noordwijk, The Netherlands.

Introduction: The European programme to develop radioisotope space nuclear power systems includes the development of thermoelectric and Stirling power converters. Based on a number of industry academic partnerships other key technology areas under development include radioisotope fuel production and containment in the event of launcher failure or unscheduled spacecraft re-entry [1]. Thermoelectric conversion system studies are targeted at electrical power levels <50 W_e based on current thermoelectric conversion technology.

In Europe isotope selection studies have identified ^{241}Am as the isotope of choice for a European programme. ^{241}Am fuel can be produced economically and at high isotopic purity by separation from stored separated Pu produced during reprocessing of civil fuel [2].

This paper will outline the likely requirements for a European ^{241}Am fuelled Radioisotope Thermoelectric Generator (RTG), describe the concept designs prepared and the breadboard testing currently in progress which forms the first phase of a European Space Agency programme.

Requirements: Thermoelectric conversion systems are expected to be preferred for electrical power requirements below about 50 W_e, but detailed mission and RTG requirements are still under development, as are feasible performance targets. Studies currently focus on a requirement for modularity or scalability and operation under vacuum or cover gas for interplanetary or planetary missions.

The longer half life of ^{241}Am (433 y *cf* 88 y for ^{238}Pu) requires a greater mass of fuel for a given power, however does provide the advantage of more consistent power. For a 20 year timescale (nominal 15 year mission plus margin), the output of a ^{241}Am fuelled system would be expected to drop by ~3.2%, compared to a ^{238}Pu fuelled system which would fall by ~15%.Consequently the distinction between beginning and end of mission power outputs is less critical than in ^{238}Pu systems. The values quoted herein are for beginning of mission.

Flight design concepts: Preliminary designs were developed assuming an Am_2O_3 ceramic fuel in a conventional containment structure of equivalent thickness to the US General Purpose Heat Source GPHS system. A variety of structural, thermal and electrical design trade-offs were performed, concluding that a scalable or module designs could feasibly be produced for the range 5-50 W_e, but that very small power requirements of ~1 W_e required an alternative approach.

5-50 W_e scalable or stackable concepts. The design concept developed consists of on-axis cylindrical fuel pellets arranged in 5 or 10 W_e modules with lead telluride thermoelectric converters. In the scaled RTGs, the total aeroshell length, housing and radiator are varied with a fixed cross-section. In the modular concept individual modules are stacked which results in a more flexible design but with a lower specific electrical power output. The scalable concept design is predicted to achieve a specific electrical output of 2.0-2.2 W_e/kg.

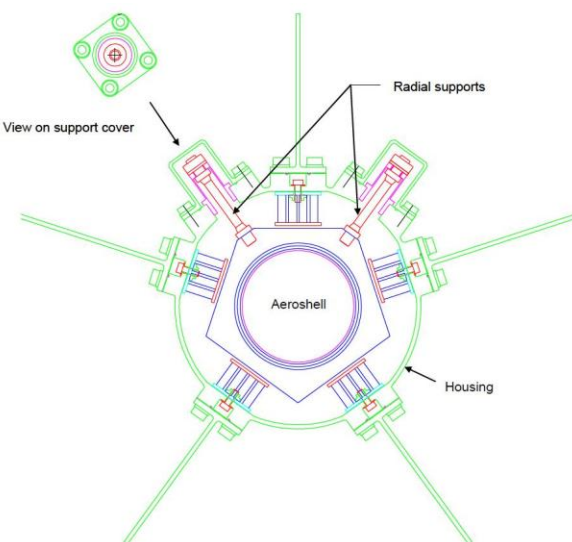

Figure 1 – RTG concept design illustrating cross-section of a scalable design.

1W_e Radioisotope Thermoelectric and Heater Unit (RTHU). For very low electrical power outputs, the conventional radiator solution was found to be too large for the thermal requirements due to the geometric constraints. An alternative approach was adopted using the spacecraft structure for heat rejection. At 1 W_e, a specific electrical power of 0.75 W_e/kg is estimated (budget mass of 1.3 kg inc. margins) with approximately 20 W_t conducted to the spacecraft structure. This concept uses bismuth telluride thermoelectric converters that are much closer to those currently available commercially, with attendant reduction in development cost and risk. Figure 2 shows that this concept is competitive with ^{238}Pu fuelled small RTG concepts because at these small scales the relative effect of the lower specific power of the fuel is reduced.

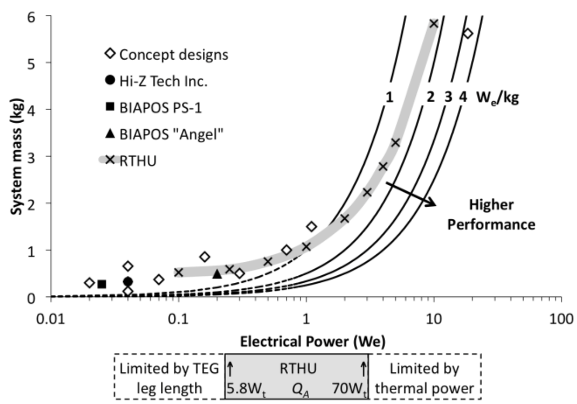

Figure 2 – Comparison of RTHU with ^{238}Pu fuelled small RTG concepts [3].

Breadboard: In order to further investigate the performance, detailed design features and challenges and start to validate the thermal modelling approaches, an electrically heated RTG breadboard was designed, manufactured and tested.

Design. The breadboard is mounted inside a bench-top vacuum chamber with cooling provided by liquid nitrogen. The unit itself is of cuboid form, with an aluminium alloy outer radiator structure coupled to a cold-finger by thermal straps. An electrical heater element is mounted inside a graphite aeroshell in the centre of the unit. The system can accept four thermoelectric generator modules. The thermoelectric generators modules can be thermally coupled to the aeroshell conductively or radiatively. The chamber can be operated in vacuum or with a variety of cover gases. The heater element size and capacity is equivalent to 83 W_t output of Am_2O_3 fuel. Thermal and electrical power management systems are included in the design and all monitoring and control is carried out by a dedicated software control package.

Test programme. The test programme underway encompasses testing of commercially-available bismuth telluride generator modules and bespoke lead telluride modules under vacuum, with argon cover gas and in conductively and radiatively coupled configurations. The breadboard is designed to produce a maximum electrical power output of to 5 W_e (6% overall efficiency), however in a development project of this kind, the headline performance is less critical than model validation and developing a thorough understanding of the performance, design features and development opportunities.

Conclusions: An RTG system breadboard has been developed and tested to validate designs and design methodologies for ^{241}Am-fuelled spacecraft power sources. This is the first stage in the development of radioisotope power systems within the European Space Agency funded programme.

While the specific power of a ^{241}Am fuelled RTG is unlikely to match that of ^{238}Pu fuelled units (except perhaps at small size) the design work undertaken provides confidence in the capability and performance of potential ^{241}Am systems for future space mission opportunities. Medium-sized RTGs in the range 5-50W_e are predicted to achieve an overall specific power output of around 2 W_e/kg. A novel scoping-study concept for a small RTG combining the function of a Radioisotope Heater Unit (RHU), termed an RTHU is predicted to achieve a specific power output of around 0.75 W_e/kg, which is very competitive with other low power concepts reported in the literature [4,5].

The RTG breadboard system developed by the University of Leicester, UK, Astrium UK and Fraunhofer IPM, Germany is the first hardware to be produced as part of the European Space Agency funded programme and to our knowledge this may be the first time integrated RTG system technologies have been tested outside the USA or Russia. This is therefore a major step forward for European deep-space and planetary exploration capabilities.

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References: [1] Summerer L. and Stephenson K. (2011) *Proc. IMechE. G. ,225,* 129-143. DOI: 10.1243/09544100JAERO7661151–1154. [2] Tinsley T. et al. (2011) *Proc. NETS 2011* Paper #3029. [3] Williams H.R. et al. (2011). *Int. J. Energy Res*. Published online ahead of print. DOI: 10.1002/er.1864. [4] Abelson R.D. et al. (2004). NASA JPL Pub #04-10. [5] Pustovalov A. (1999). *Proc 18th. Int. Conf. Thermoelectrics.*