SMALL-SCALE SPACE NUCLEAR POWER SYSTEMS

Enabling Technology for Space Exploration Missions

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NASA/JPL: Image of Uranus on cover page.

NASA/JPL/Caltech: Image of Mars, Gale Crater, page 2

NASA/JPL/ESA/SSI: Image of Saturn, page 4

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Introduction

Space nuclear power systems are under development in the UK in collaboration with European partners as part of a European Space Agency (ESA) programme. France has been a major contributor to this ESA activity.

This initiative brings the expertise of the space and nuclear industries together to create new technologies that benefit space exploration, the wider economy and new markets.

In order to drive back the boundaries of space exploration, innovations in power generation, robotics, autonomous vehicles and advanced instrumentation are needed. These will be the future space mission enabling technologies.

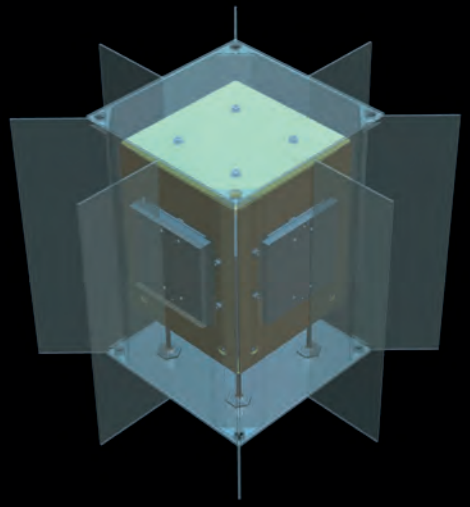
Challenges associated with space exploration and research promote economic growth through innovation, technology development and education. Sustained investment in science, engineering and high-tech manufacturing disciplines contributing to the development of space nuclear power systems and exploration technologies will aid in rebalancing the economy by developing high impact technology solutions for Europe. The interdisciplinary nature of the teams and the potential for technology transfer and knowledge transfer are the clear strengths of the programme.

Why Nuclear?

Radioisotope power sources are an important technology for European space exploration missions as their use would result in more capable spacecraft and landed probes that can access distant, cold, dark and inhospitable environments.

Missions using nuclear power present better value for money, with one mission delivering the science that might only be achieved from several missions using solar power, and offering considerably longer operational lifetimes (e.g. Pioneer, Voyager, Ulysses). In many cases nuclear systems can enable missions that would otherwise be impossible. Solar power is primarily used to provide electricity to space systems; however, difficulties arise:

- When operating close to the Sun (solar cell efficiency decreases with increasing temperature).
- When operating very far from the Sun (beyond Jupiter).
- When required to survive the lunar night or explore a lunar crater.
- When wanting to operate continuously (during eclipse periods, during day, night and in dusty conditions on planetary surfaces), carry a large complement of instruments, and travel over large distances at a fast pace for a long time.
- When requiring freedom to chose trajectories optimised for science, rather than for power generation.
- When deploying probes in subsurface or near-polar environments.



Mars: Daybreak Gale Crater NASA/JPL/Caltec

Status of Technology Developments

National Nuclear Laboratory will lead the extraction of americium-241 from the UK's stored, separated civil plutonium. This brings diversification to the civil nuclear sector and further extends the value that can be derived from nuclear R&D facilities fitting in with the Cumbria Economic Strategy and Britain's Energy Coast master plan.

System Engineering Assessment (SEA), National Nuclear Laboratory, University of Leicester, Lockheed Martin UK and others have completed a study on radioisotope containment and encapsulation technologies.

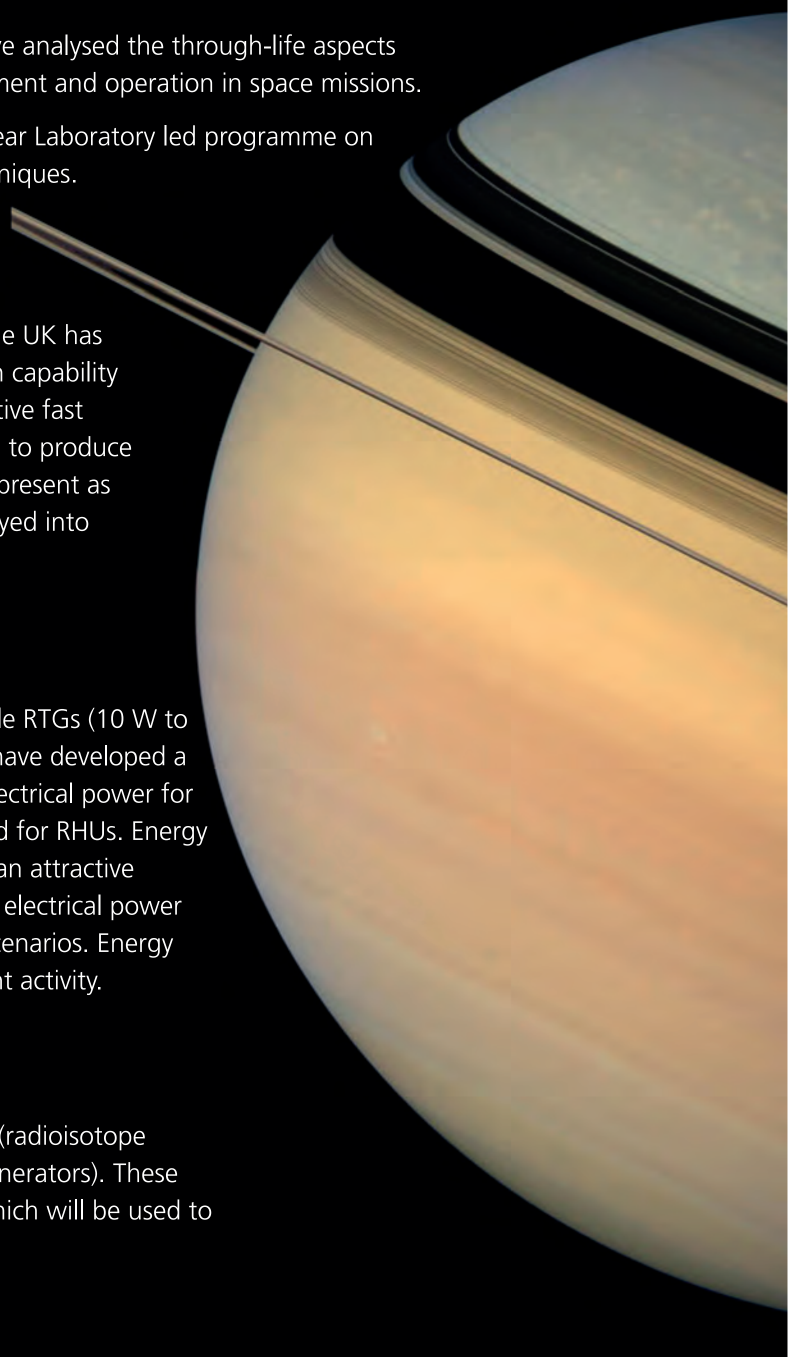
France are leading the launch safety framework and are extending the development of the radioisotope containment systems.

The University of Leicester together with Astrium Ltd and Fraunhofer IPM, Germany, Queen Mary University of London and European Thermodynamics have developed a prototype radioisotope thermoelectric generator. A parallel French-led development includes SEA.

SEA together with University of Oxford, Rutherford Appleton Laboratory and contributors from Europe are developing Stirling engine conversion technology.

Astrium Ltd together with SEA and University of Leicester have analysed the through-life aspects of nuclear power systems technology from factory to deployment and operation in space missions.

The University of Leicester will be supporting a National Nuclear Laboratory led programme on novel fuel production methods and materials processing techniques.



The Issue of Fuel

The European programme has focused on americium-241. The UK has unique resources on which to build an independent European capability in space nuclear power (using americium-241) at a cost effective fast pace. Part of the UK's stockpile of civil plutonium will be used to produce americium-241. Suitable amounts of ingrown americium are present as a result of it originally containing plutonium-241, which decayed into americium-241 during its considerable time in storage.

Small-Scale Power Systems

The European programme is focused on developing small-scale RTGs (10 W to 50 W of electrical power output). The University of Leicester have developed a design for a 200 W thermal heat source providing 10 W of electrical power for RTG systems. A 1-4 W heat source design has been developed for RHUs. Energy harvesting from RHUs using thermoelectric conversion offers an attractive option for low cost or small missions where small amounts of electrical power combined with heat sources could open a range of mission scenarios. Energy storage will be an essential element in any future development activity.

The ESA Plan

ESA plans to develop RHUs (radioisotope heater units), RTGs (radioisotope thermoelectric generators) and SRGs (Stirling radioisotope generators). These will use sealed pellets of americium-241 to generate heat, which will be used to generate tens to hundred watt levels of electricity.

Saturn: NASA/JPL/ESA/SSI

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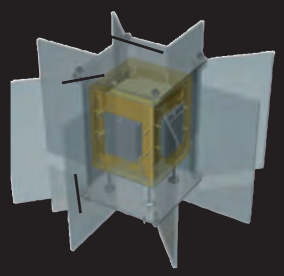
Space Nuclear Power

Radioisotope Thermoelectric Generators Powered by 241Am

Specific Power

Specific power 2.2 W/kg to 1-2 W/kg depending on the power output and operating environment (planetary surface or deep space).

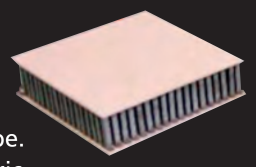


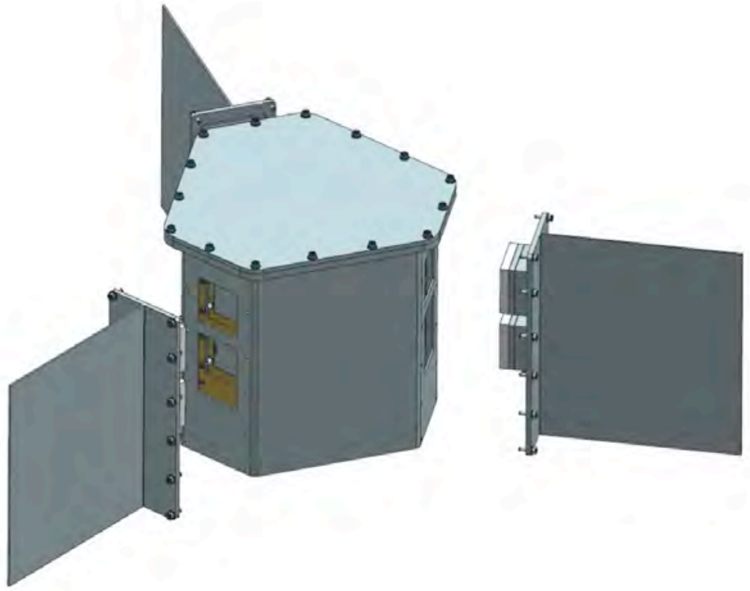
RTG Prototype

Tested in vacuum and inert argon atmosphere. Producing 4 W electrical from 83 W thermal. Total system efficiency of 4.8 %. Technology Readiness Level (TRL) 4.

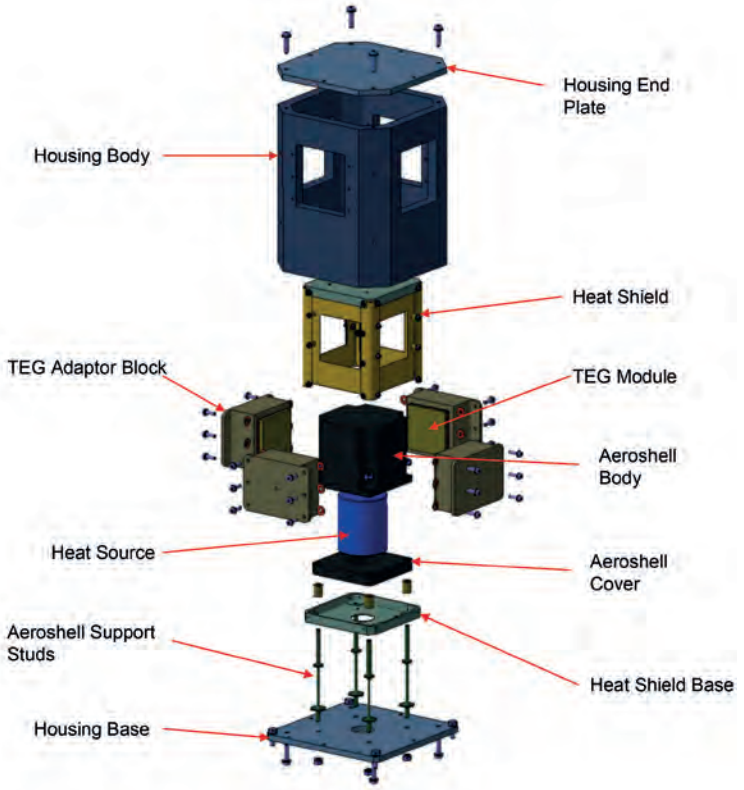
Thermoelectric Generators

Bismuth telluride custom commercial modules developed for the prototype. Lead telluride thermoelectric generators were also tested.

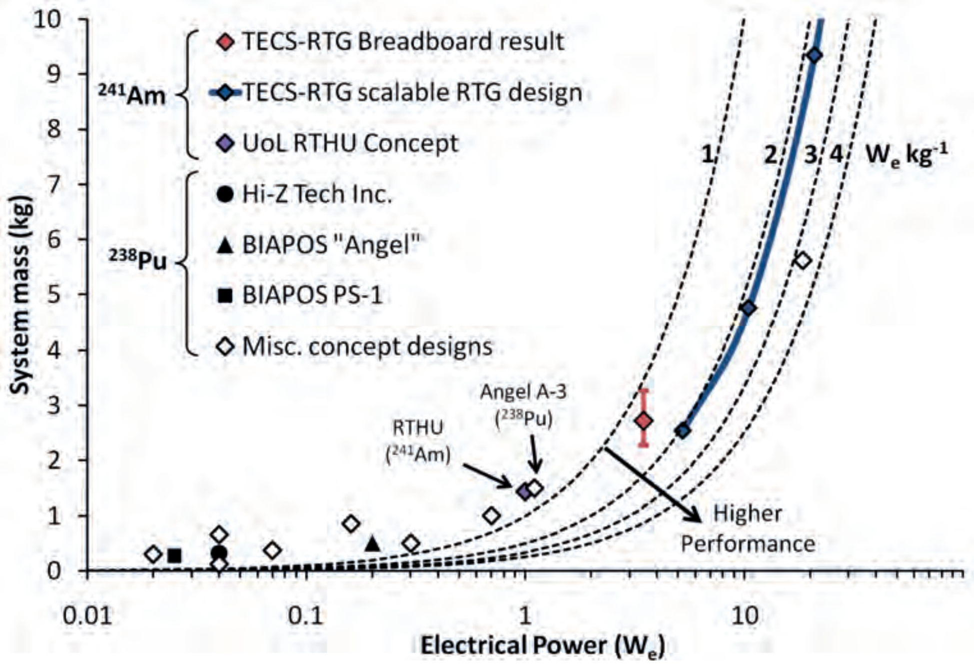




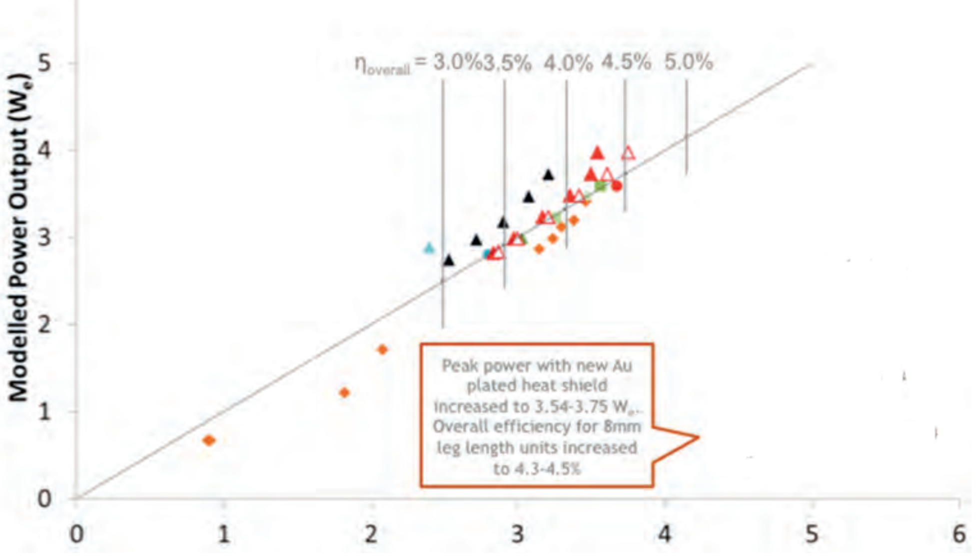
RTGs in 10 W to 50 W electric range. For a 10 W unit shown above, approximately 220 mm x 190 mm in size for the main body. Radiator fins are ~160 mm in length.



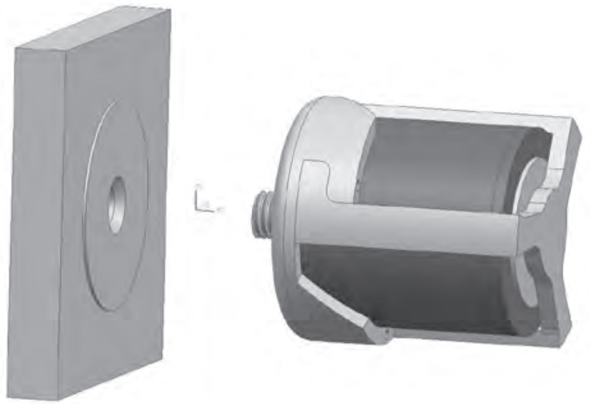
Radioisotope thermoelectric generator (RTG) prototype system.



Specific power of the RTG prototype system and flight architecture design.



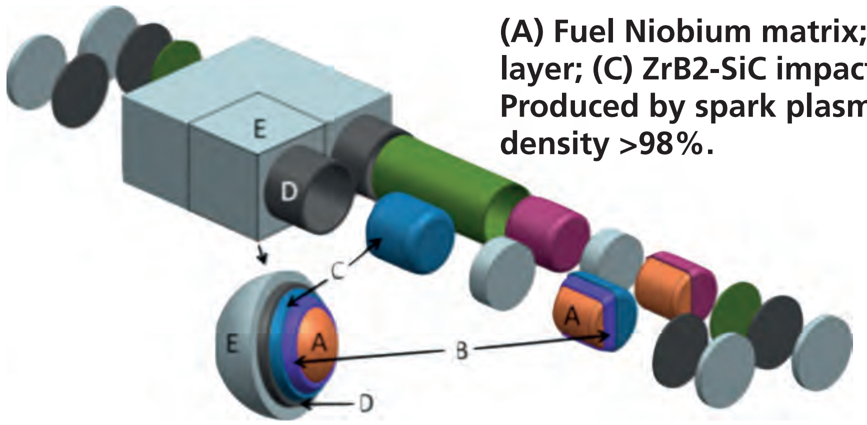
Experimental and calculated power output for a 5 W RTG prototype.



1 W radioisotope heater unit (RHU) for keeping systems warm.

Fuel containment system ensures highest safety requirements are met.

(A) Fuel Niobium matrix; (B) Niobium layer; (C) ZrB2-SiC impact shell. Produced by spark plasma sintering density >98%.



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