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Use of nuclear power sources in outer space

Space Nuclear Power Systems: Update on Activities and Programmes in the UK

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Introduction

- Radioisotope power sources are an important technology for future European space exploration missions resulting in:
  - More capable spacecraft.
  - Probes that can access distant, cold, dark and inhospitable environments.
  - Probes that can operate more effectively close to the Sun.
  - Missions using nuclear power can provide higher science return given the extended operational lifetimes.
  - In many cases nuclear systems can enable missions that are very challenging.

- Focus is on ^{241}Am for the radiogenic heat source.

Current UK Activities

- The UK is a major contributor to the ESA nuclear power programme.
- A consortium of UK companies and Universities working on the ESA Programme together with other European partners.
- UK organisations include: National Nuclear Laboratory, University of Leicester, Airbus Defense and Space UK, Lockheed Martin UK, Thales Alenia Space UK, Rutherford Appleton Laboratory, University of Oxford, Queen Mary University of London, European Thermodynamics Ltd.
- Nuclear is seen as an enabling technology.
- Key requirement is supply of radioisotope source material.
- UK has abundant supplies of ^{241}Am that can be extracted from stored civil plutonium.
- UK Government is supportive of the programme.
- NNL's Laboratory at Sellafield will house any future ^{241}Am separation facility.

Isotope Selection

- Research contracts were placed by ESA to identify and assess radioisotopes with potential use in European radioisotope power system.
- Independent studies concluded that for Europe ^{241}Am was the isotope of choice for the following reasons:
  - Although ^{238}Pu was determined to be the best choice for specific power (W/kg), implementing its production in Europe was determined to be too expensive.
    - Requirements including: Neptunium target fabrication, availability of high flux reactors and reprocessing facilities, were all considered in the tradeoff.
  - UK's stored separated civil plutonium provides a source of ^{241}Am that can be efficiently separated, with benefits to both the nuclear and space sectors.
  - ^{241}Am thermal power output is one-quarter of ^{238}Pu but with manageable impact on system mass and relatively affordable production route.

Isotope Separation and Fuel Form Development

- National Nuclear Laboratory has recently completed a 2 year contract for ESA to research and design a production facility for ^{241}Am.
- Outline design and costs were delivered.
- Continued positive discussions with the UK Government and Nuclear Decommissioning Authority on feed material supply (civil Pu) and general programme.
- Study on the criticality of ^{241}Am is underway with data provided to IAEA.
- First experimental runs completed, Am separated from civil Pu.
- Contract extension granted to NNL for a 30 month programme:
  - To increase the quantity of americium separated by order of magnitude.
  - Develop the fuel form using surrogate materials.
  - Explore solutions for pellet formation using surrogates.
  - Produce a radioisotope heater unit sized pellet with ^{241}Am oxide fuel.

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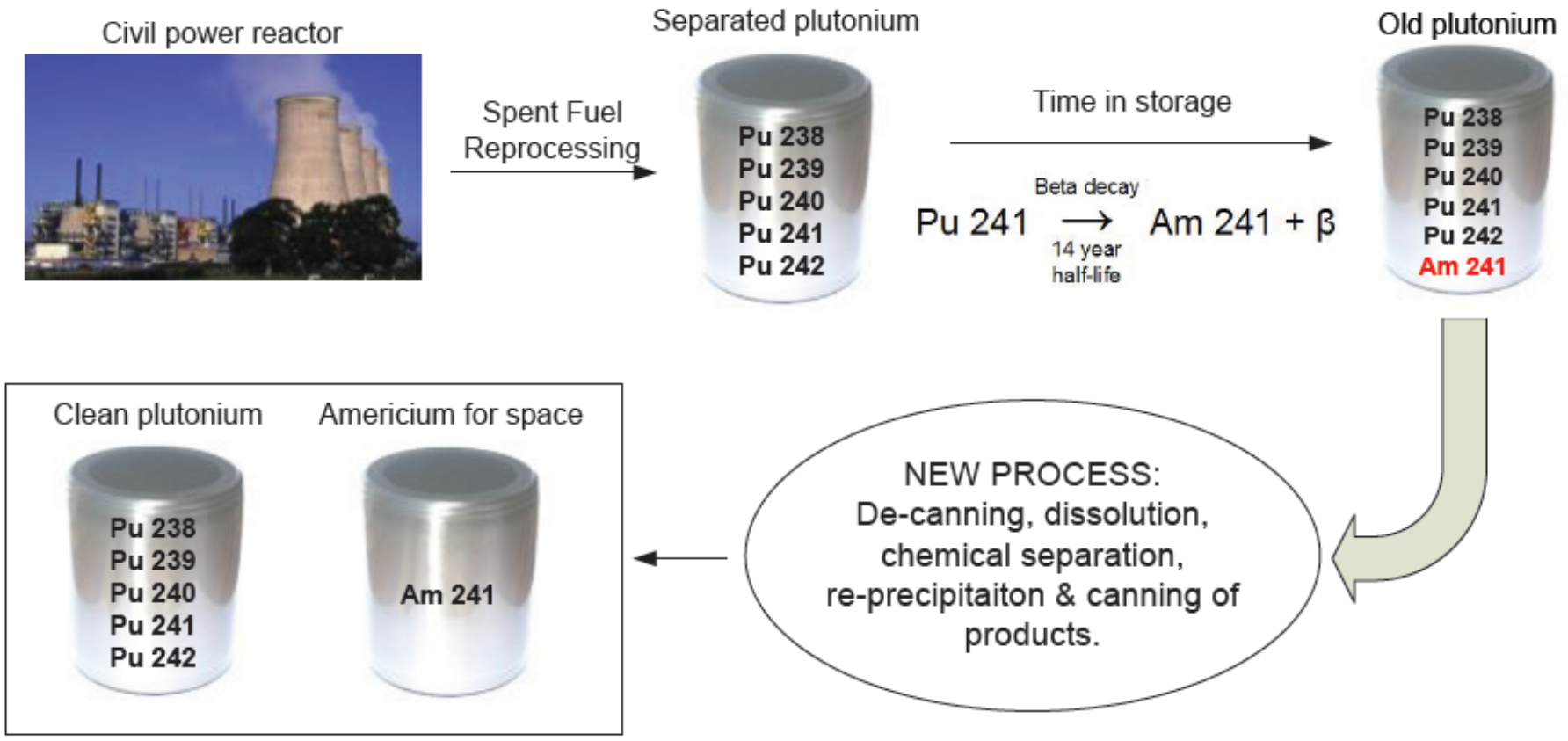
Fuel Production



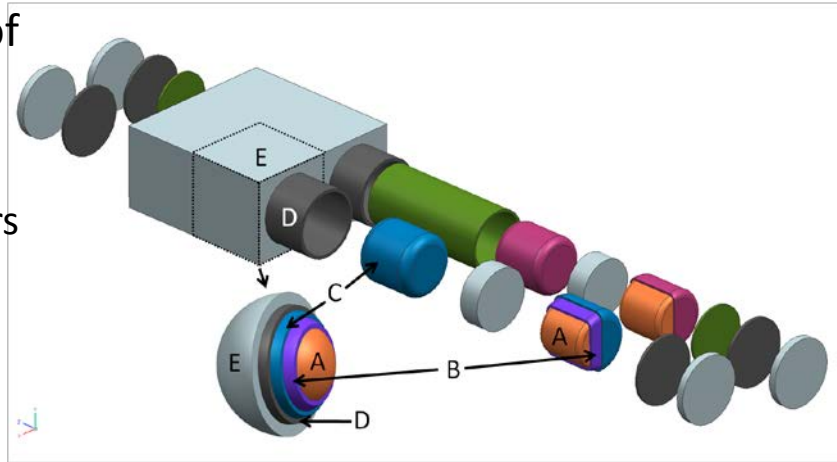
- 120 tons of separated reprocessed Pu.
- Approximately 2-3 tons of ^{241}Am.

Image Courtesy of ESA

Isotope Containment

- Containment of fuel in a multilayer system of physical barriers.
- Fuel dispersal prevention under accident conditions (e.g. projectile impact. launcher explosions, re-entry, Earth surface impact).
- Nuclear Fuel Capsule and Aeroshell Design Study:
  - Contract with Thales Alenia Space UK (previously SEA Ltd), National Nuclear Laboratory, University of Leicester, Lockheed Martin UK.
- Nuclear Power Systems Architecture for Safety Management & Fuel Encapsulation Prototype Development (NPSAFE)
  - Wider scope study led by Areva TA of France has been completed.

- Parallel approach for the preliminary development of a European ^{241}Am containment system:
  1. Analogue to the US multilayer system of using refractory metals, carbon impact and insulation layers and carbon-carbon aeroshell.
  2. Metal matrix composite fuel with carbon impact and insulation layers and carbon-carbon aeroshell.

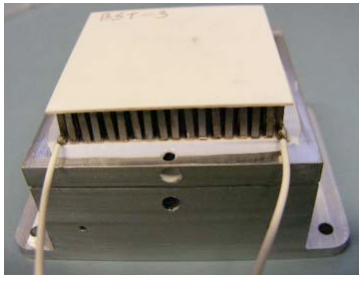


RTG Development

- Parallel R&D contracts:
  1. **University of Leicester**, Airbus Defense and Space UK, Fraunhofer IPM, Queen Mary University of London, European Thermodynamics Ltd.
  2. **Areva TA**, Ecoles des Mines de Nancy, Thales Alenia Space UK and Italy, Babrow Consulting.
- Contracts successfully developed, manufactured and tested electrically heated RTG prototypes.
- Successful development of thermoelectric generators using both silicide and telluride based thermoelectric materials.
- Systems targeting the 5 W to 50 W electric power range with no moving parts and acceptable specific power.

RTG Development in the UK

Innovative Mg-Si/Mn-Si-Ge Thermoelectric Module (Ecole des Mines de Nancy)



Bismuth Telluride Boron Carbide Composite Based Thermoelectric Materials and Modules (University of Leicester)

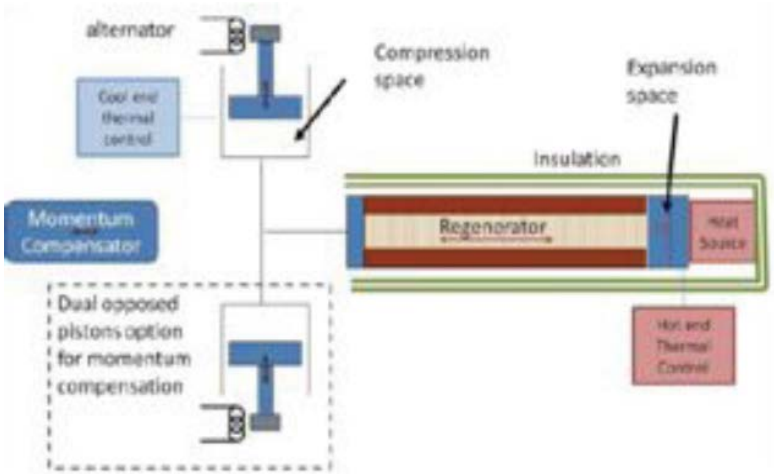
Electrically Heated 5 W RTG Laboratory Prototype (University of Leicester)

Image of Silicide Thermoelectric Module Courtesy of ESA & AREVA

University of Leicester

Stirling Radioisotope Generator Development

- In the larger power range (~100 W) Stirling engine can be used to efficiently convert heat to electrical power particularly given the lower power density of ^{241}Am compared to ^{238}Pu:
  - Consortium led by **Thales Alenia Space UK (Formally SEA Ltd)** also includes Rutherford Appleton Lab, Oxford University .
  - **Stirling Engine Radioisotope Power System Requirements Study** derived the detailed system requirements for a European SRG and highlighted the potential to use UK expertise in long-lived Stirling coolers for space applications that use the flexure bearding system developed by Oxford.
  - **Stirling Converter Technology Development Phase 1** to take the system to TRL 3 is currently underway.
  - This second study is led by **Thales Alenia Space UK (Formally SEA Ltd)** also includes Rutherford Appleton Lab, Oxford University, QinetiQ Space (NV), CSL (B) .



Stirling converter in gamma configuration (one option under evaluation)

Image Courtesy of ESA & TAS-UK

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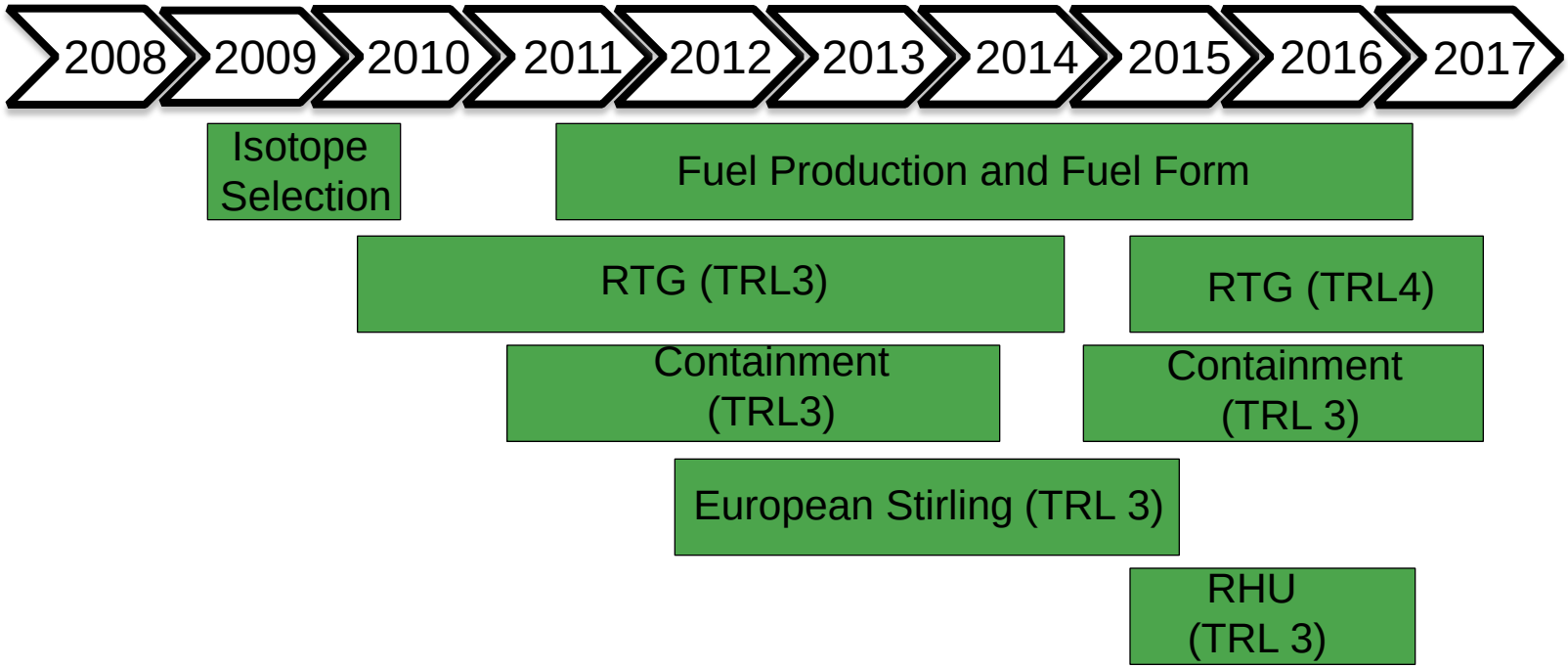
Radioisotope Power Programme in Europe



- Activities continue to be funded by ESA.
- Technology de-risking in incremental steps.

Interaction with US

- NNL and the University of Leicester have received valuable support and guidance from US DOE, NASA, US institutes and universities.
- Specifically in understanding the approach to radioisotope manufacturing, facilities and safety framework.
- Several facility and institute/university visits have taken place both in the UK and the US including recent visit by NNL and Leicester to NASA JPL.
- Positive interactions between UK's Department of Energy and Climate Change and US DOE.
- Exploratory discussions on US launch safety procedures including work and data requirements that underpin US ^{238}Pu launch safety approach.

Summary

- UK is active on behalf of ESA in exploring the viability of using ^{241}Am as a power source for space use.
- Development work on isotope separation and fuel form development continuing through to the pelleting stage.
- UK Government support, enabling availability of feed materials.
- UK knowledge base on radioisotope systems has been increased significantly, positioning UK as intelligent user of the technology to support future European utilisation of radioisotope systems .
- UK has key technical expertise and capabilities to work with other European states to enable future deployment of radioisotope systems
- We welcome interest and collaboration from any other states.