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European Space Nuclear Power Programme:
UK Perspective

INAC, Brazil, November 2013

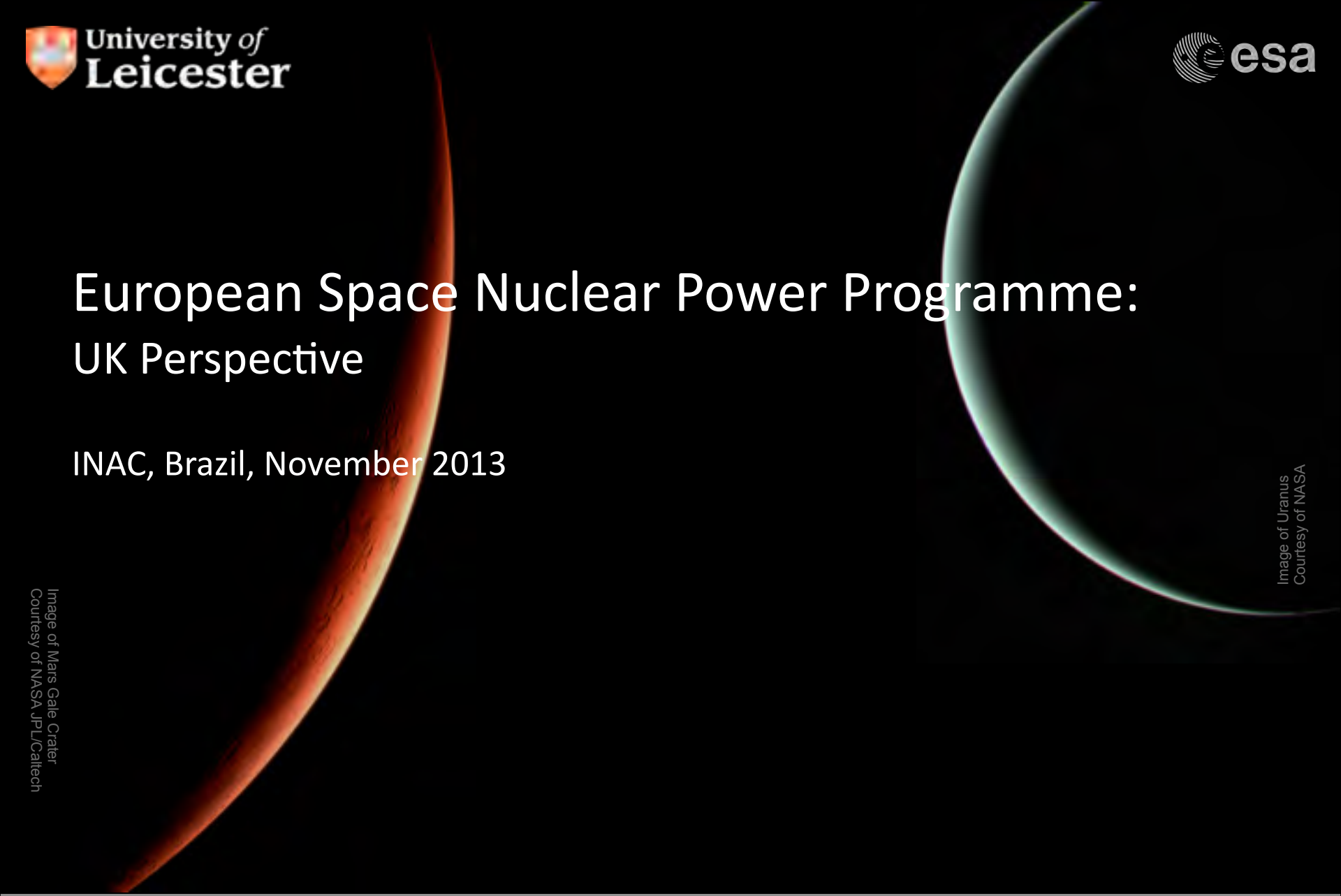

Image of Uranus
Courtesy of NASA

Image of Mars Gale Crater
Courtesy of NASA JPL/Caltech

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Context:

Department of Physics & Astronomy

- Sits in the College of Science and Engineering - Head of College, Prof. Martin Barstow
  - Seven departments:
    - Chemistry
    - Computer Science
    - Engineering
    - Geography,
    - Geology
    - Mathematics
    - Physics & Astronomy

- Head of Department of Physics and Astronomy - Prof. Mark Lester
- Six research groups:
  - Condensed Matter Physics
  - Earth Observation Science
  - Radio and Space Plasma Physics
  - Space Science & Instrumentation
  - Theoretical Astrophysics
  - X-ray and Observational Astronomy

- Space Research Centre - Director Prof. George Fraser
  - Two groups: Space Science & Instrumentation, Earth Observation Science

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Space Research at Leicester

1960, Prof. Ken Pounds establishes of a new group specializing in X-ray observations from space.

1961, Skylark rocket launch from Woomera in South Australia.

1962, launch of Ariel 1, from Cape Canaveral on a NASA Delta rocket. Payload included solar X-ray detectors developed at Leicester.

1972, Copernicus

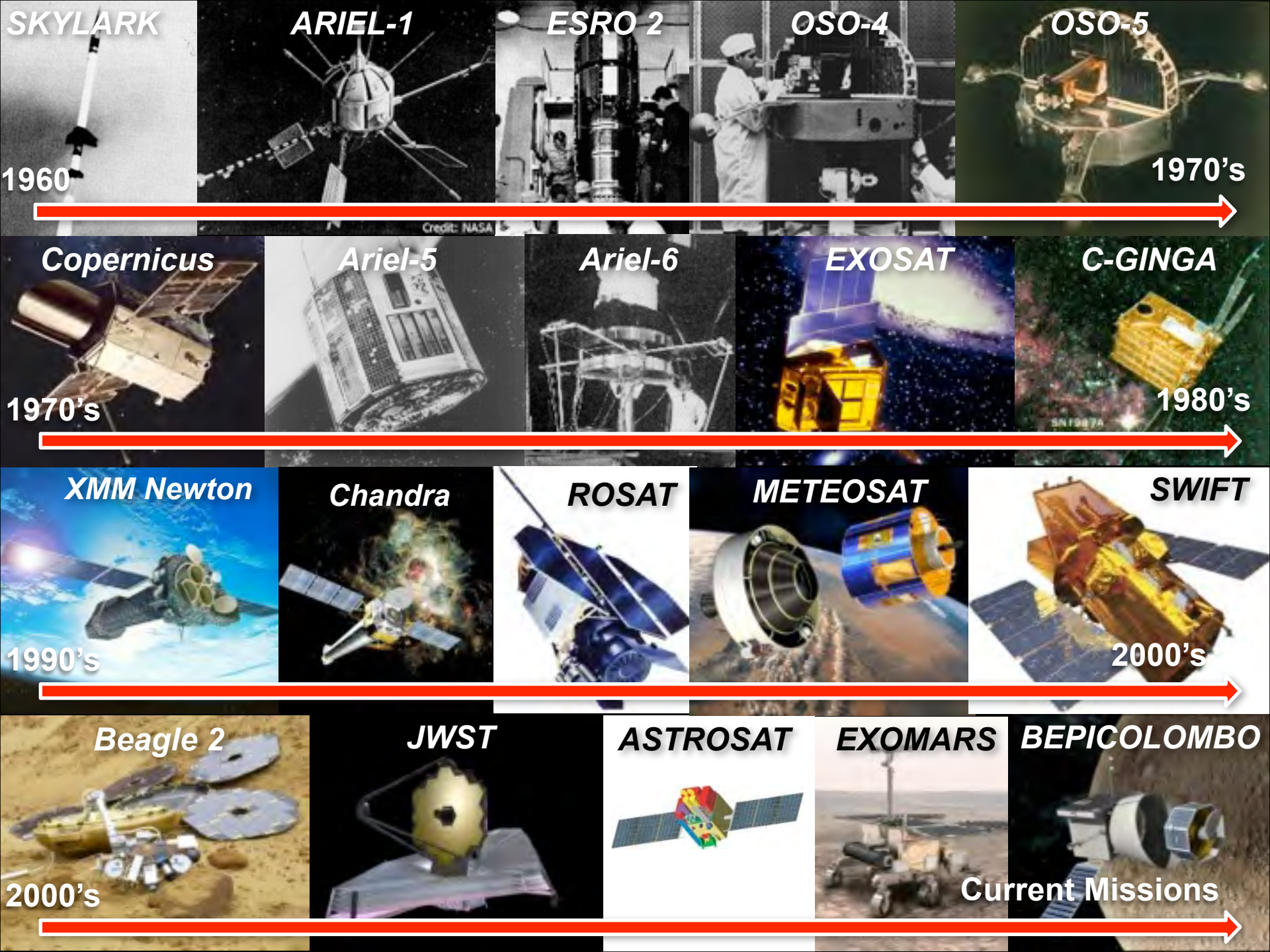
1983, EXOSAT

1999, XMM-Newton

2004, Swift, Beagle-2

SRC houses ~100 people (incl. students) in purpose built facilities.

2006, Research in space nuclear power systems starts.


SKYLARK
1960
ARIEL-1
Credit: NASA
ESRO 2
OSO-4
OSO-5
1970's
Copernicus
1970's
Ariel-5
Ariel-6
EXOSAT
C-GINGA
1980's
XMM Newton
1990's
Chandra
ROSAT
METEOSAT
SWIFT
2000's
Beagle 2
2000's
JWST
ASTROSAT
EXOMARS
BEPICOLOMBO
Current Missions

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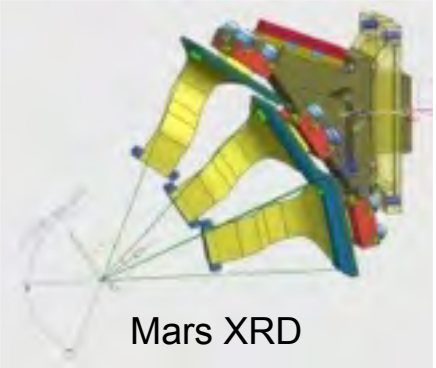
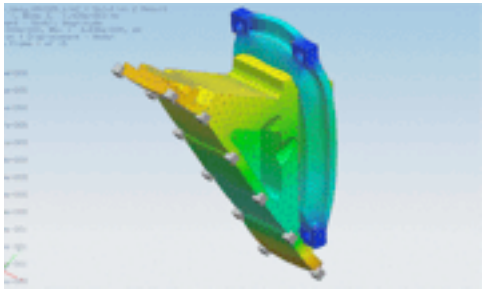
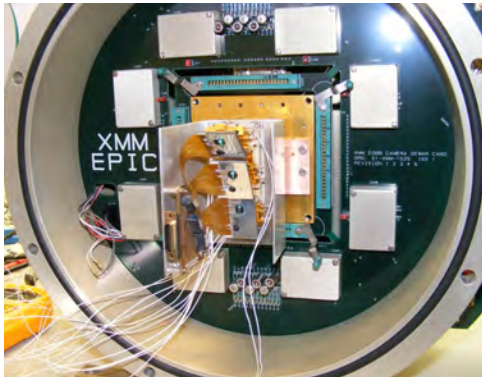
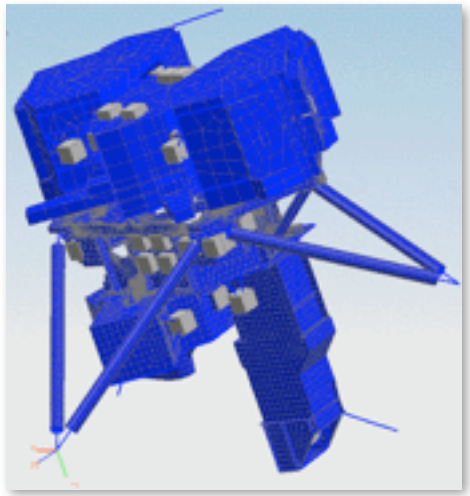
Concept to Production at the SRC









Design

Analysis

Manufacture,
Assembly & Test

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Space Nuclear Power:

Introduction

- In the context of the future European space science and exploration programme, radioisotope power and heat sources are enabling technologies for more challenging missions.
  - more capable spacecraft
  - extended lifetime,
  - continuous operation;
  - vehicles and probes that can access distant, and inhospitable environments;
  - near Sun operation.
- Value for money resulting from overall longevity.
- In Europe the focus is on Am-241 for the radiogenic heat source.
- Any European cross cutting technology programme must be based on structured and close collaboration with a number of participating nations.

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Space Nuclear Power:

Introduction

- In the longer term (~2012-2028) the aims are:
  - Develop a European space qualified radioisotope power systems (RPS).
  - Electrical power outputs of between 10 W and 100 W per unit.
  - Develop a European space qualified radioisotope heater unit (RHU) that uses Am-241 as the fuel source.
    - Producing 1W to 5W of heat.
  - Develop a European launch safety framework and infrastructure for RPS and RHU.

- In the short term (~2012-2016) the aims are:
  - Focus on a European capability in key technologies including:
    - Isotope production.
    - Isotope containment and safety.
    - Heat to electricity conversion (thermoelectric and Stirling).
  - Develop prototype systems targeting TRL 5.

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Future Missions

"In an effort to coordinate ideas in a fairly short amount of time, here in the UK we have been collectively preparing to respond to the ESA Call for White Papers for the L2/3 missions by coming up with a coherent list of priority science areas which we would like to see covered in the coming calls for missions." **UK Planetary Forum 19/03/13**

- European Space Agency L-class missions equivalent to US Flagships. Process is bottom-up with science community providing scientific drivers for missions.
- Recent call for white papers resulted in 32 submissions in a number of science themes.
  - Solar system exploration white papers accounted for ~20 white papers.
  - Many can only be achieved by using radioisotope power systems and/or radioisotope heater units.

Radiogenic Heat Source:
Americium-241

- National Nuclear Laboratory leading UK programme in isotope production by using chemical separation processes to extract Am-241 from 100 tons of stored reprocessed civil Pu.
  - Ingrowth of Am-241 from decay of Pu-241 implies a continuous supply (~25 g to 50 g per kg Pu)
  - Chemical separation process has been proven experimentally using a specifically designed process.
  - Scope of activity will include fuel form production.

- National Nuclear Laboratory's world class nuclear facilities are ideal for this programme.
- Builds on world class expertise in the civil nuclear sector & influence in the sector.
- Broad collaborative links across the globe.

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RTG

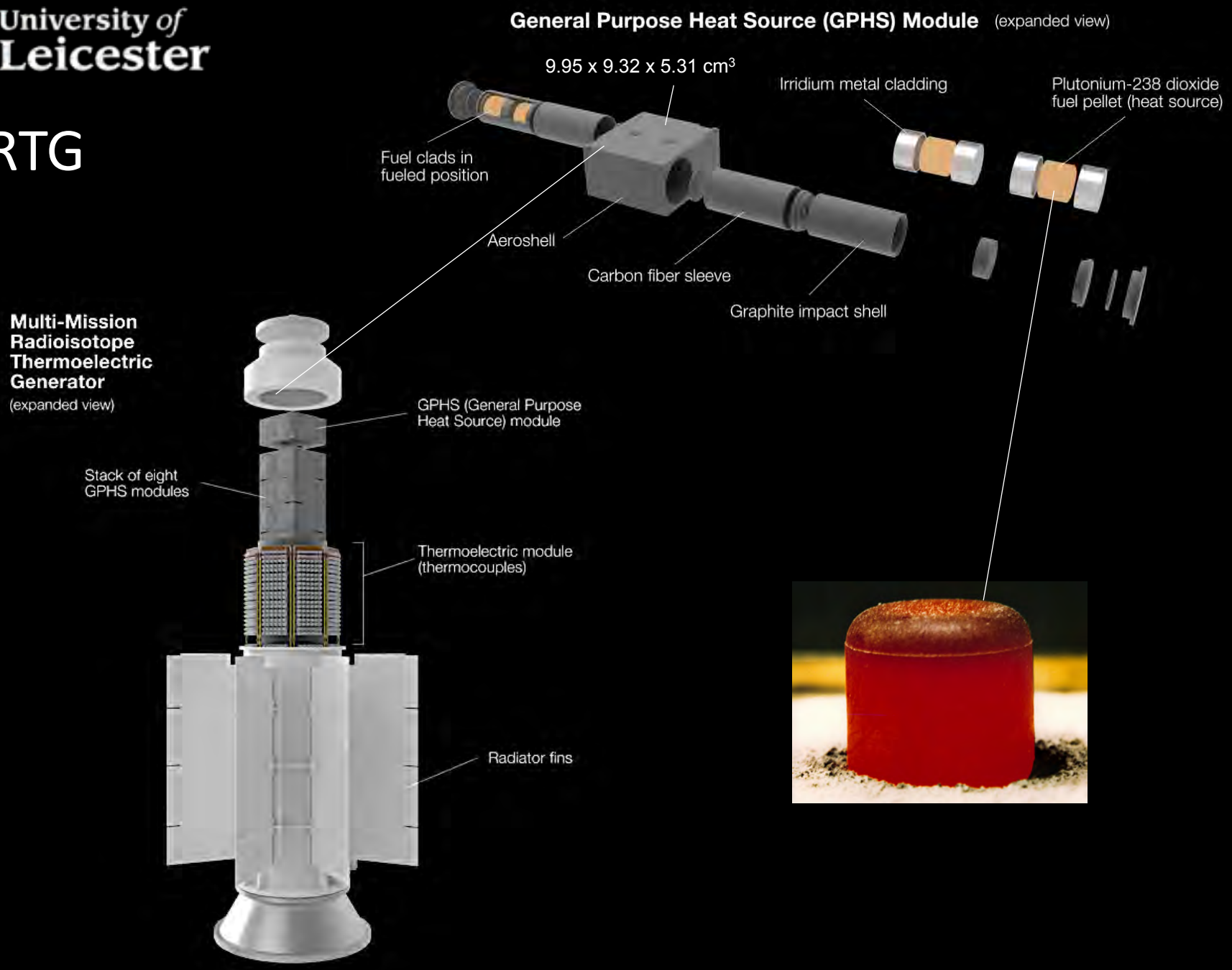

Image of MMRTG and GPHS Module Courtesy of NASA, US DOE

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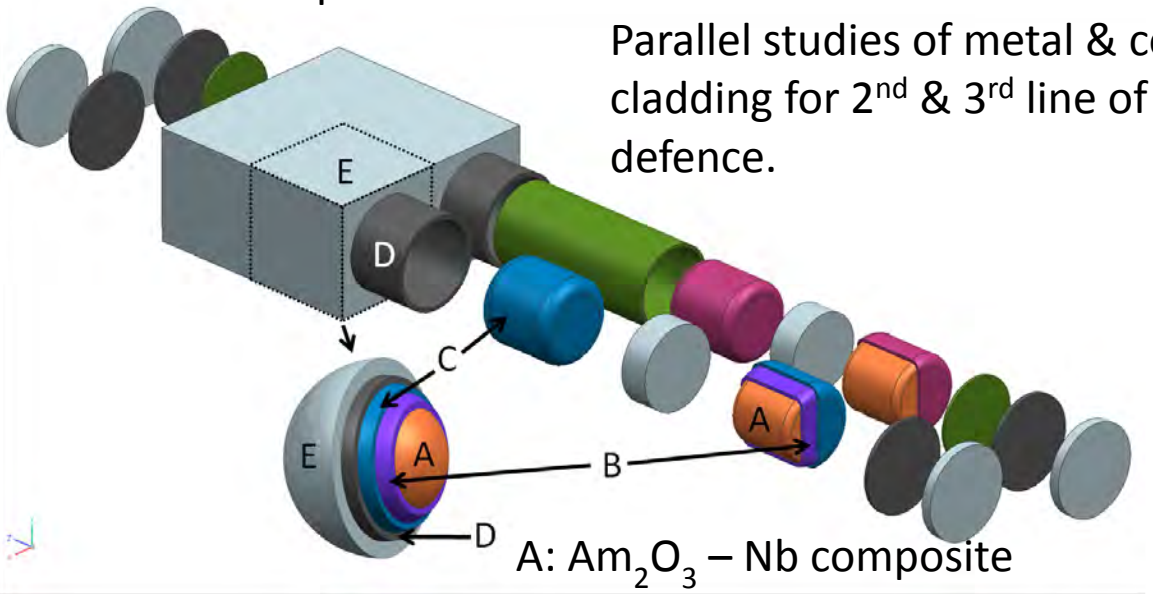
Containment

Outer heat-shield for re-entry heating and 1st line of impact defence.

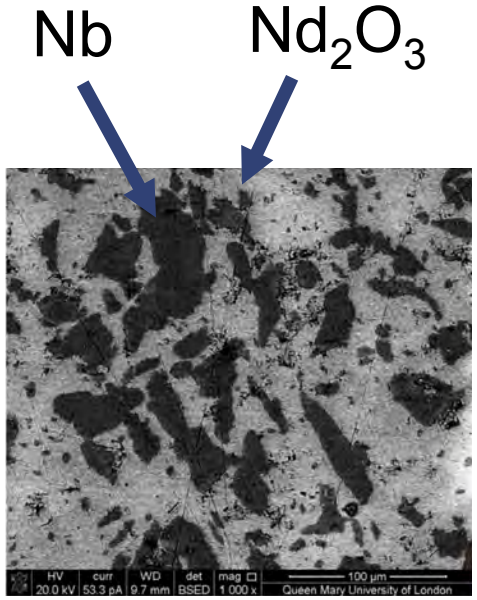


Parallel studies of metal & composite cladding for 2nd & 3rd line of impact defence.

A: Am_2O_3 – Nb composite

B: Niobium

C: ZrB_2-SiC composite



Mass fractions wt % Nd_2O_3 : Nb	Relative density %
70 : 30	99.7
50 : 50	98.7

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Radiogenic Heat to Electricity Conversion:

- European space nuclear power systems are focused on the conversion of radiogenic heat into 1-100 W of electricity using thermoelectric generators or Stirling engines.
  - Energy harvesting with thermoelectric generators has strong synergy with the renewables energy sector where this is a key element in applications that take advantage of waste heat.
  - Automotive applications amongst a number of examples.
- A small scale radioisotope thermoelectric generator prototype has been developed.
- Stirling engine development is also a key element in the programme which is underway and aimed at a prototype system.

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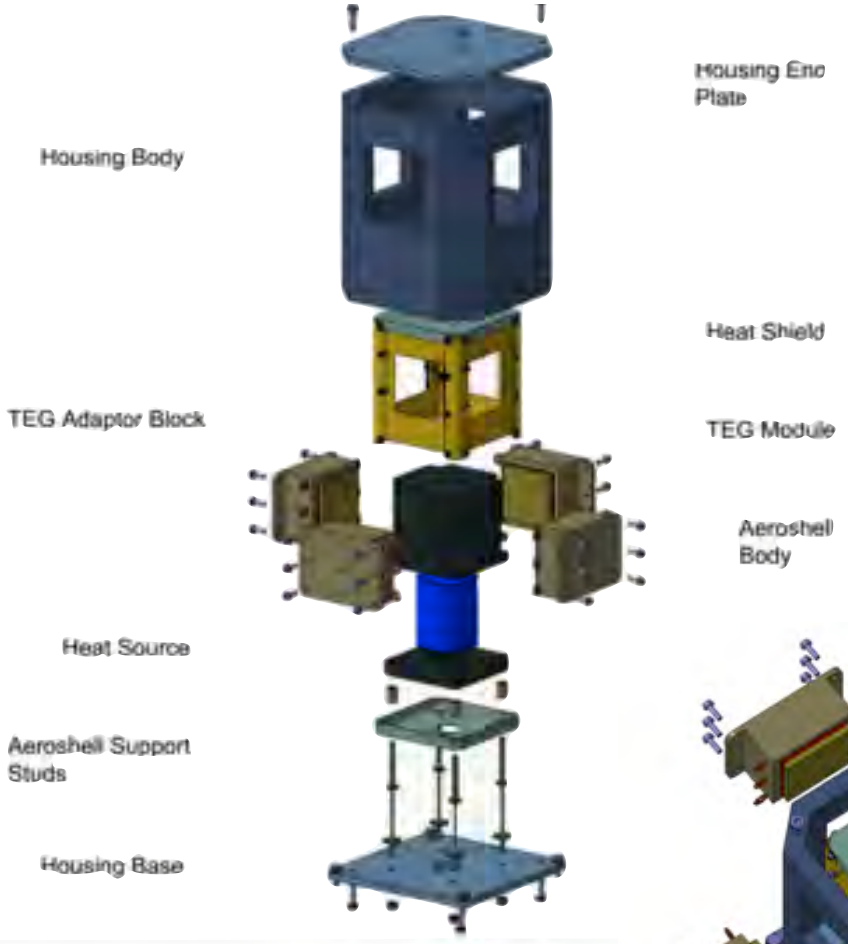
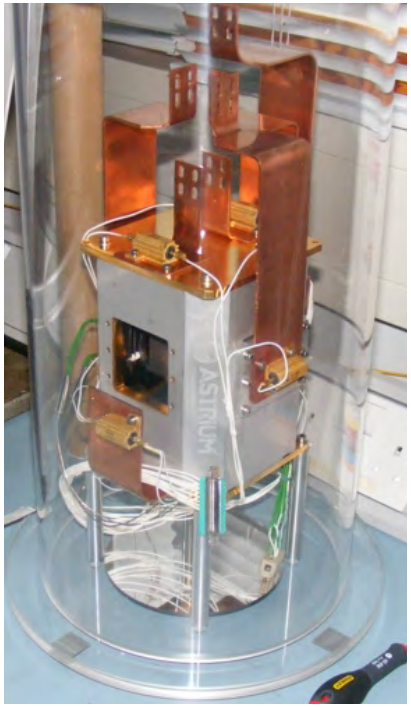
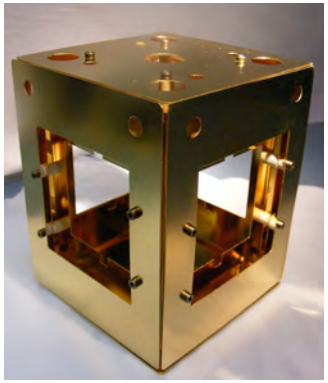
RTG Prototype

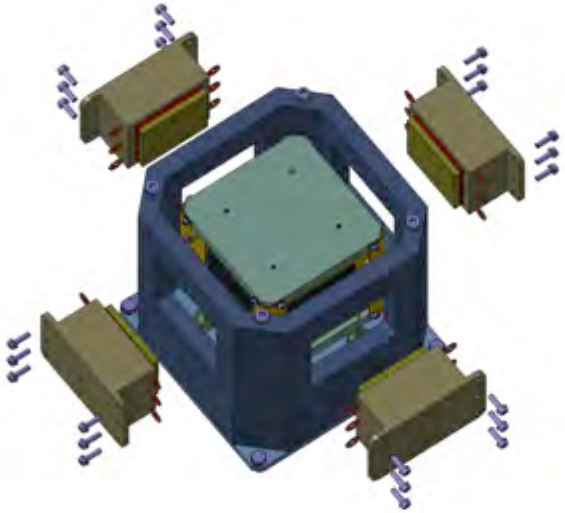




5 W prototype



Gold plated heat shield



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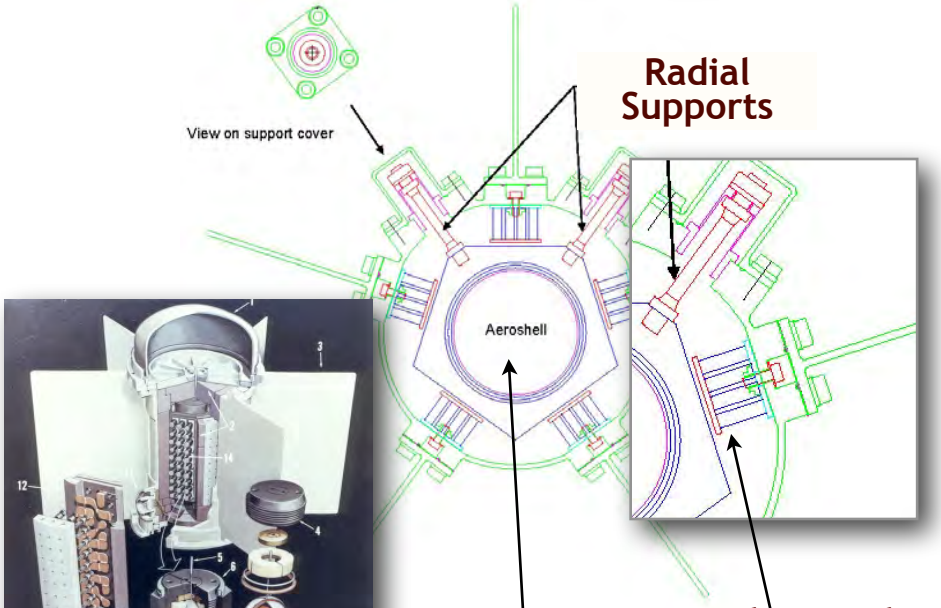
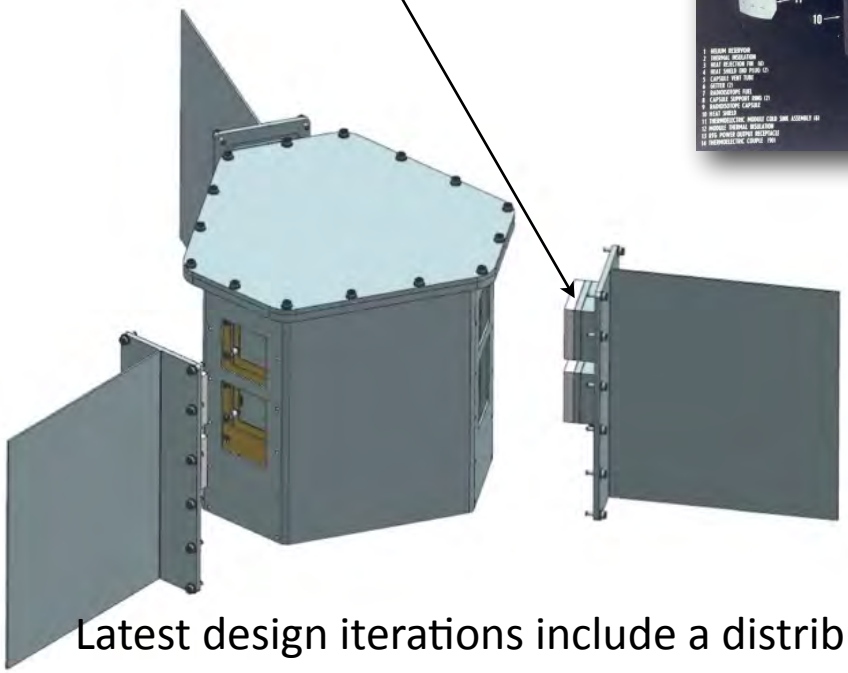
RTG:

Flight Design Iterations



First generation design used on axis fuel similar to the SNAP design.

Thermoelectric Generator (Conductive Coupling)



Latest design iterations include a distributed fuel arrangement increasing total power output per heat source

Image of SNAP RTG Courtesy of US DOE & NASA

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Stirling Conversion and Launch Safety

- Stirling conversion prototype system being developed by a team led by SEA Ltd (UK), which includes Oxford University and Rutherford Appleton Laboratory as well as other European partners.
  - ~100 W electrical power output.
  - Study to conclude in 2014.
- Metal cladding welding study being led by Gradel S.A. (Luxembourg) recently concluded.
- Launch safety and radiogenic heat source design study led by AREVA TA (France) was recently completed.

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Horizon 2020

- Enables Europe and international partners to target the technology challenges of future space exploration programmes.
  - Based around single technology projects or larger projects clustered around several technologies.
  - The budget for such a programme needs to be consistent with the objectives given that this is a new area of development for Europe.
- The space and nuclear industries working together to solve challenges facing space exploration fits perfectly in a number of the Europe 2020 priorities, part of the initiative to secure Europe's global competitiveness.
- It fosters the development of a knowledge-based, innovation-based, competitive and sustainable economy.
- It facilitates the entrance of highly qualified young people into the market with a positive impact local economies and social cohesion.This is strengthened by industry-academic partnerships.
- In this way, a third Europe 2020 priority is fulfilled in terms of inclusive growth, which reinforces the idea of high value job creation and investment in skills and competencies

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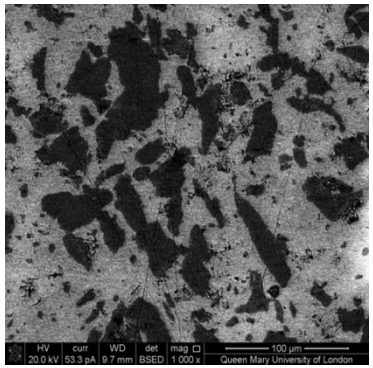
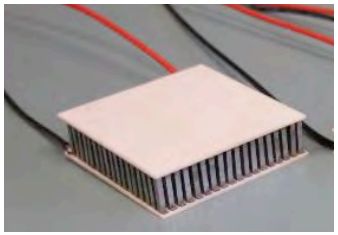
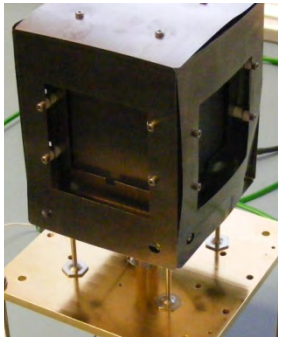
Spinoff







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Space Exploration Systems

UK SPACE AGENCY

www.le.ac.uk/departments/physics

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Concluding Remarks

- Since the programme kicked off in 2008, a lot has been achieved at a rapid rate of development.
  - Cost effective projects involving multidisciplinary teams.
  - Structured collaboration between academia and industry with clearly defined roles and responsibilities.
- There is still a lot of work to be done for what is cross-cutting technology development.
- Structured and close collaboration with a number of participating nations.
- Science community work more closely with teams working on this technology development programme in order to enable future more challenging missions.
- ESA programme focused on radioisotope systems.
- EU activities have focused on coordinated actions targeting fission systems.