Rolls-Royce
LSIC Surface Power Monthly

October 26, 2023

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Rolls-Royce business groups

Civil

35
types of commercial aircraft powered by us

15,400
installed base around the world

17,900
total employees

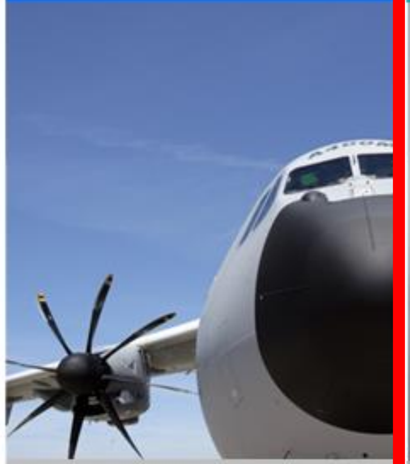
Power Systems

40,000
customers in 13 different industries

20,000
reciprocating engines sold per year

9,000
total employees

Defence



160
customers in over 100 countries

16,000
engines in service around the world

11,100
total employees

Electrical

NEW MARKET

£52m
Research & Development

≈ 400
total employees

SMR

NEW MARKET

£16m
R&D to enter the UK GDA process

≈ 255
total employees

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Defense

Our Defense business is a market leader in aero engines for military transport and patrol aircraft with strong positions in combat and helicopter applications.

It has significant scale in naval and is the technical authority for through-life support of the nuclear power plant for the Royal Navy’s submarine fleet

Aero Engines

With more than 16,000 military engines in service with 160 customers in over 100 countries, Rolls-Royce is a powerful player in the Defence aero engine market.

Naval Engines

We play an active role in most of the world’s major naval defence programmes.

Submarine Propulsion

We design and support the nuclear propulsion plant on board the current fleet of Trafalgar and Vanguard class submarines and new Astute class submarines.

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LibertyWorks

- RR LibertyWorks (RRLW) develops new technology in support of the US defense business
- Based in Indianapolis, IN
- Technologies are often applicable to wider applications

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Nuclear Power Conversion Projects at LibertyWorks

1. Project Pele

- DOD project (OSD SCO) to build a prototype mobile terrestrial power plant using a multi-MW microreactor
- RRLW is the power conversion provider in support of the BWXT team
- Leverages open Brayton cycle system and a modified gas turbine
- Scheduled to begin demonstration at Idaho National Lab in 2025

2. NASA Power Conversion Technology for Fission Systems

- Recent award to RRLW by NASA Glenn Research Center
- 1 year, ~$1M research grant for closed Brayton cycle power conversion technology for next-generation space microreactor systems with a target output of 25 kWe
- RR is leading a team that includes Sandia National Labs, PCKA and University of Wisconsin

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Space Nuclear Power and Propulsion Market

Focus on:

- Near Earth operations to meet growing space access and power requirements
- Planetary mobility and infrastructure development
- Reusable deep space propulsion for crew, cargo, and exploration

Space Power and Propulsion Applications

Fission Surface Power

40kW microreactor

- Supporting Lunar Ops/NASA Commercial Service Agreement
- Multiple use cases including powering Infrastructure, Construction, Habitats, ISRU, etc.

Propulsion

Increased demand for on-orbit, cislunar & deep space maneuverability

- USSF Requires AGILITY
- Reduced launch costs to drive lunar economic activity
- Leverage FSP and future MW class reactors
- Leverage for exploration and science missions

On Orbit Power

Demand for power to enable new and emerging capabilities/markets

- Power ranging from 200kWe-Multi MW
- Edge Computing
- On Orbit Industrial Activity
- Mission Extension Vehicle
- Commercial LEO Destinations

Common Technologies

Cross cutting investments to support broader space power development

- Power Conversion
- CMC Materials
- Thermal Management/Rejection
- Control Systems
- Fuel
- Electric Propulsion

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Introduction and History

Space Nuclear Power - *A Strategic Advantage*

Sophie Hollinrake, Novel Nuclear Engineer, UK PONI 2023 Annual Conference

Introduction

The development of compact nuclear power systems for defence and exploration applications in space is growing exponentially, presenting strategic advantages for the UK. Nuclear systems provide high density power enabling opportunities for:

- Fission powered spacecrafts,
- Radioisotope power systems,
- Fission surface power.

The recent reignition of the 'space race' between the US and Russia/China sparked Lunar/Martian fission surface power declarations. The UK is uniquely positioned with governmental and industrial nuclear capabilities to collaborate with the US in this important area and could play a key role in technology development, providing a number of strategic advantages.

History

Nuclear powered spacecrafts have been previously used in the US (SNAP-10A, in 1965) and the USSR TOPAZ-I reactor in 1987 (Kosmos 1818 and 1867).

Current Programs

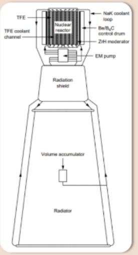
The identification of space nuclear power for defence applications has sparked the formation of multiple programs. After a development gap in nuclear powered spacecrafts, the US DoD and NASA have opened bids for projects:

- JETSON – Air Force Research Laboratory.
- DRACO – Defence Advanced Research Projects Agency[1].

Chinese CNSA and Russian ROSCOSMOS signed a MoU for the joint construction of an autonomous lunar permanent research base, identifying nuclear power as the primary energy solution.

Table 1 Operating Conditions of the USSR TOPAZ-II in 1987[2]

Reactor Thermal Power (kWth)	NaK Outlet Temp (°C)	NaK Inlet Temp (°C)	Fuel Form	Fuel Enrichment	Average Caesium Consumption g/day
~135	~600	~500	UO_2	96%	0.5



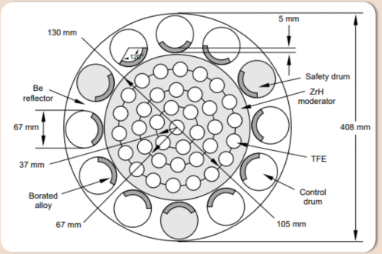


Fig.1 (left) shows the TOPAZ-II design with the radiator included[2]. Fig.2 (right) shows the core design of the TOPAZ-II reactor, note TFE; Thermionic Fuel Elements[2].

USSR TOPAZ-II Design

TOPAZ-I was flown twice by the USSR. TOPAZ-II was then developed (Table 1, Figs.1&2) which was sold to the US for $13 million for testing. With limited previous operating experience, the US and UK are up against Russia having the upper hand. After a long break in development, Russia has the potential to rapidly develop space nuclear power.

1958 Mutual Defence Agreement

Bilateral treaty between the US and UK allowing exchange of nuclear materials, technology and information. Most comprehensive agreement of all.

2021 AUKUS

Trilateral collaboration to support nuclear-powered submarines development. UK and Australia to develop 'SSN' and US sell Australia Virginia-Class subs.

2023 Atlantic Declaration

The UK and US are committed to cooperation on space nuclear power and propulsion in accordance with their respective domestic laws and consistent with international obligations and commitments

2023 UKSA Bilateral Fund Investments

- Rolls-Royce x BWXT novel space technologies.
- UoL/NNL x NASA radioisotope development.

Strategic Opportunities

UK-US collaboration is no new concept, with the Mutual Defence Agreement signed in 1958. Separately, the recent Atlantic Declaration explicitly states the intent for UK-US collaboration on space nuclear power, with collaborations already forming through the UKSA Bilateral Fund Investments.

Challenges

The reignited space race and rapid technology development presents a range of issues to overcome quickly and responsibly:

- Inflated risk of failures.
- Complex nuclear disposal methods.
- Development of inherently safe design features e.g. Accident Tolerant Fuels.
- Proliferation.
- Lack of HALEU supply chain.
- Public perception.

Essential Future Collaboration

It is evident Space Nuclear Power is becoming a key technology to the geo-politically important areas of space defence. Should Russia and China 'win' this new space race, the future prosperity of global democracies may be put at risk. UK involvement is therefore essential to maintain a strategic advantage.

- The UK government should rapidly evolve collaboration routes.
- Fruition of the Atlantic Declaration is imperative to the development of space nuclear power.

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[2] El-Genk, M.S. and Paramonov, D., 1993, January. An analysis of thermionic space nuclear reactor power system: I. Effect of disassembling radial reflector, following a reactivity initiated accident. In AIP Conference Proceedings (Vol. 271, No. 1, pp. 121-128). American Institute of Physics.

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Applications in Space

Intelligence, Surveillance and Reconnaissance satellites
Solar System exploration
Cis-lunar awareness
Space-based resource utilisation

	Propulsion	Power
Civil	Debris avoidance Mars transportation Wider solar-system exploration	In-Situ Resource Utilisation Commercial infrastructure Permanent human bases
Military	No regrets manoeuvre ASAT evasion Strategic Orbit utilisation	Scalable and futureproof More Satellite functionality

Increased Resilience

Smaller
Suitable for extreme environments
Robust to impact
Lower through-life degradation

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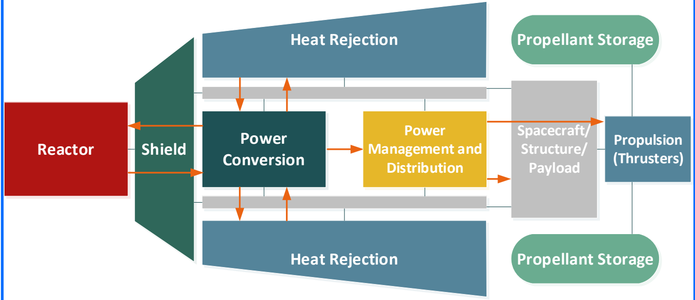
The Nuclear Advantage

Persistent and Resilient Power and Propulsion compared to Solar or Chemical propulsion

NEP



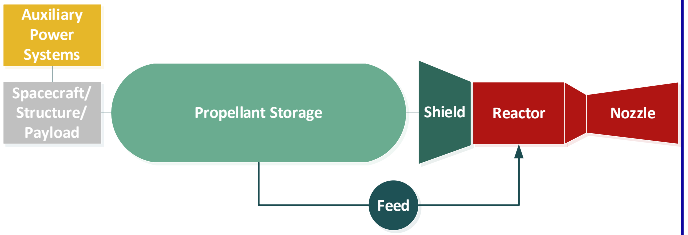
High I_{sp} and propellent efficiency

Low Thrust

Smaller, more resilient

Micro-Reactor overlap

NTP



Mid I_{sp} and propellent efficiency

High Thrust

Smaller, more resilient

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Existing Space Nuclear Programme Landscape

2020	2025	2030	2035	2040	2045	2050

- DARPA DRACO – BWXT/LM (2027)
- Nuclear power for China moon base (2028)
- AFRL NEP launch – BWXT/LM (2030)
- Artemis 6 & NASA FSP (2030)
- Russia NEP tug launch (2030)
- MW-scale commercial power requirements
- NASA Crewed Mars Mission

Low power proof of concept

Higher power solutions improve power to weight ratio compared to solar

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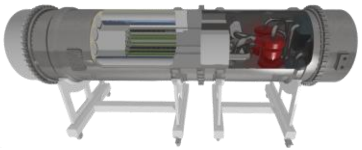
Rolls-Royce Micro-Reactor

UK SPACE AGENCY

Whole system model



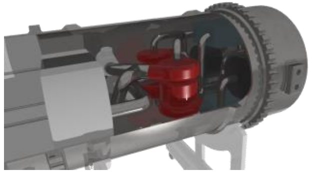
Coated Particle Fuel production

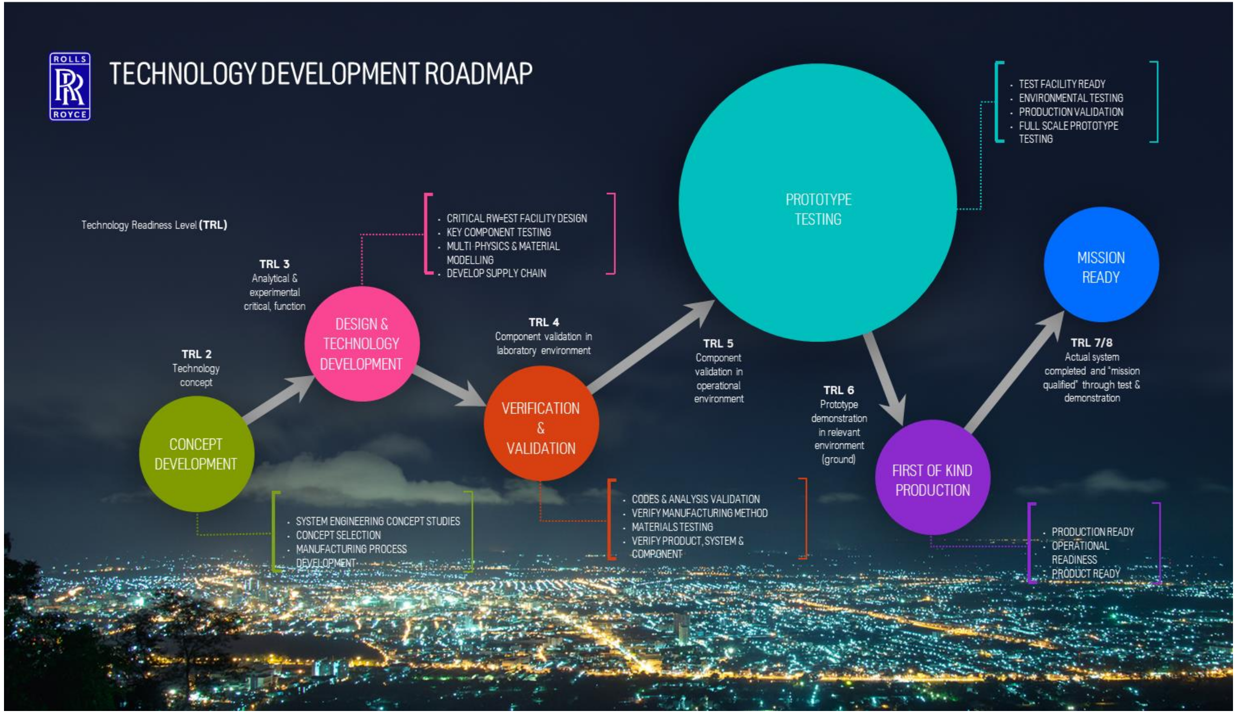
Images courtesy of Prof. S. Middleburgh, Bangor University

Heat transfer

Wall Block Cooling Rig
Images courtesy of Oxford Thermofluids Institute

Power conversion system





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Delivery

Current Programs

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- Rolls-Royce x BWXT novel space technologies.
- University of Leicester /National Nuclear Laboratory x NASA radioisotope development.

2027 AFRL Nuclear Electric Propulsion launch

2027 Demonstration Rocket for Agile Cislunar Operations (DRACO) launch

2029 NASA Fission Surface Power

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UK Nuclear Training Academy Vision

- A major driver of our long-term Skills Strategy – we have already started with the Skills Academy opened in September 2022.
- A flagship academy for training at all levels in the Nuclear Industry, governed by a partnership of key industry expertise, delivering a sustainable solution to the Nuclear skill deficit.

Operating Principles

Collaboration of leading industry experts, working in partnership, delivering nuclear skills for future industry opportunities in the area

Scalable operation accommodating minimum 200 Apprentices p.a.

Long-term sustainable funding through the Nuclear Sector Deal, local Government, local Council, local Universities, and Rolls-Royce

Provide a base for increased engagement with schools, improving the presence of Nuclear in the STEM curriculum

Continual utilisation of levies and investment to ensure facilities remain state of the art, containing latest techniques in education delivery

Strategic facility improving Nuclear skills in the Midlands

ROLLS ROYCE | NUCLEAR AMRC | NATIONAL COLLEGE FOR NUCLEAR | UNIVERSITY OF DERBY | Derby City Council

Industry Alignment (NAMRC & NCfN)	Industry Customer (Rolls-Royce)
• Nuclear content accreditation • Alignment with other Nuclear Courses across industry • Access to Catapult and other funding routes • Alignment of Nuclear STEM development	• Recruitment • Apprentice Line Management • Rolls-Royce Requirements • Placement Management • Learner salaries • Company culture and training • Rolls-Royce internal training
Facility Management (University of Derby) • Building Culture • Facility running & maintenance • Workshop maintenance • Classroom maintenance • Security • Shared space provision • Building Lease	**Course Provider (University of Derby)** • Course delivery • Course accreditation • End point assessment

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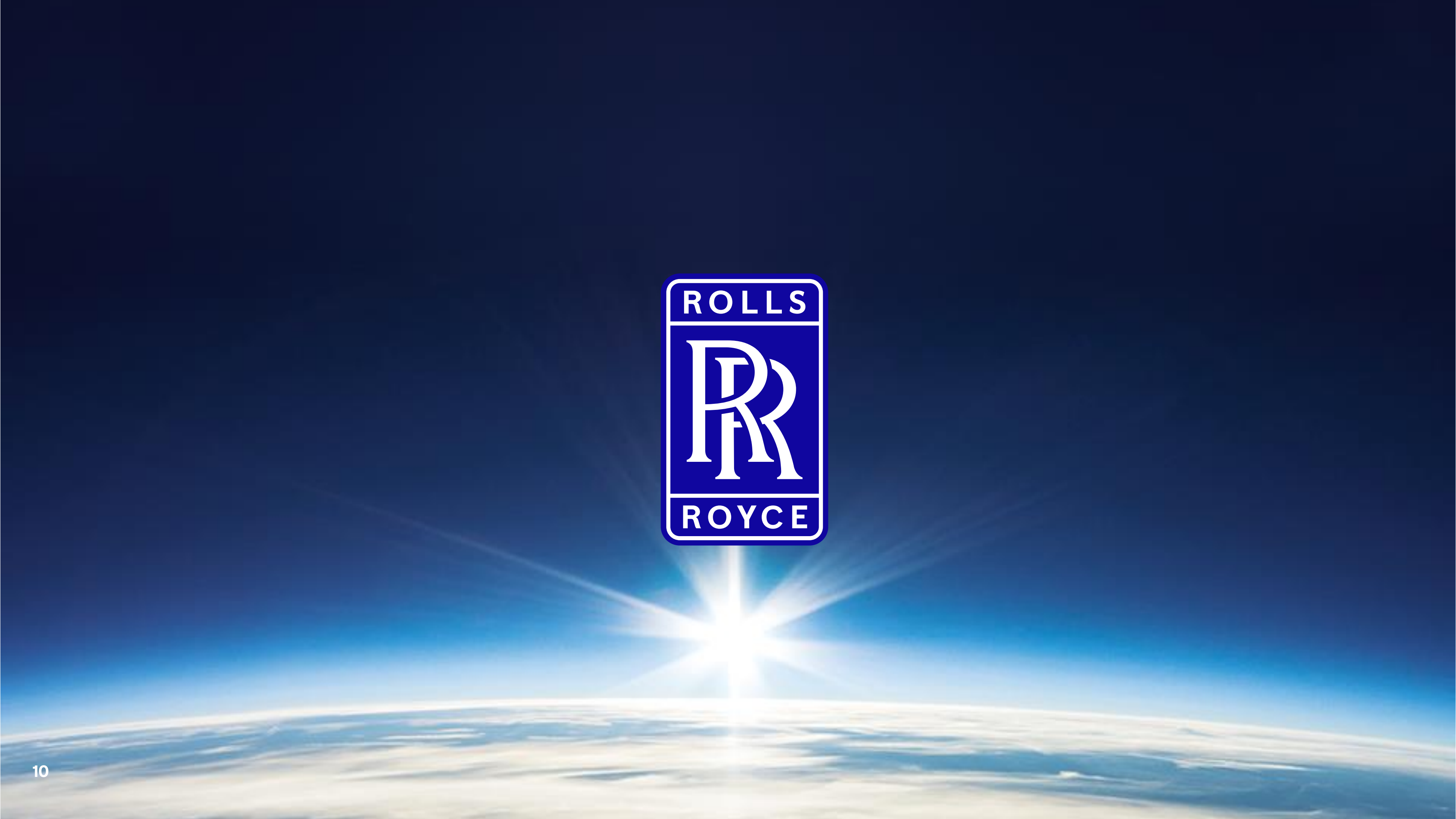
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