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Advanced Fuel Cycle Programme

Coated Particle Fuel – The context and Kernel Manufacture

Nick Barron

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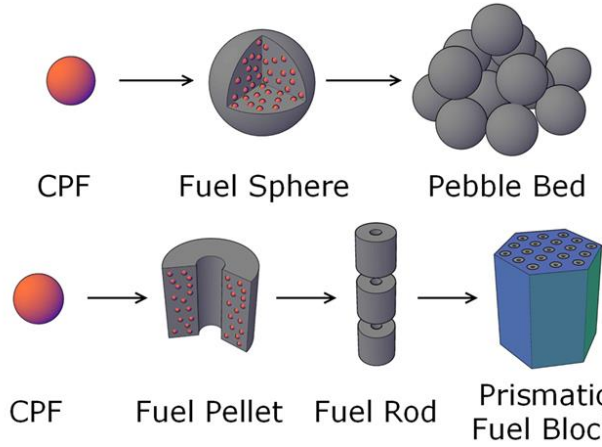
Background

- Coated Particle Fuels (TRISO fuels) are a specific type of fuel used in High Temperature Gas cooled Reactors (HTGRs).
- Fuel is extremely robust enabling high operating temperatures which:
  - **Increases efficiency of electricity generation**
  - **Permits high outlet temperatures suited to co-generation (e.g. H_2 production)**
- Particle fuel technology is mature
  - **First used in Dragon Reactor in 1964**
- HTGRs selected by government as preferred technology for AMR demonstration



	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-9	2010-14	2015-19	2020-21
Dragon Reactor, UK												
Peach Bottom, US												
Fort St. Vrain, US												
AVR, Germany												
THTR, Germany												
HTTR, Japan												
HTR-10, China												
HTR-PM, China												

International Interest

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UK

Potential demonstrator programme with fuel supply.

Poland

Plans for new nuclear including interest in HTGR technology.

Canada

A number of HTGR vendors have started licence review with CNSC.

Japan

HTTR first operated 1998-2011 and re-started in 2021.

NFI 400kgU/yr fuel capability. Dormant since circa 2006.

USA

BWXT – Qualified “UCO” fuel, expanding 100kgU/yr capacity.

X-energy - $80m USDoE support to develop the Xe-100 reactor and fuel capabilities.

China

Operated HTGRs since 2000 (HTR-10) and 2020 (HTR-PM twin unit).

~ 3teU/yr fuel capability at Batou.

GEN IV International Forum
Expertise | Collaboration | Excellence

Background

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Our work

- Develop UK capabilities and expertise through operation of *"engineering"* scale facilities to:
  - **ensure UK can be an intelligent customer to commercial fuel supply propositions; and/or**
  - **develop a UK fuel supply sufficient for a small demonstrator core (de-risk demo programme) and support domestic suppliers as they scale-up to build commercial supply.**
- Innovate to improve production methods
- Support UK supply chain to realise scale-up opportunities

Our team

Academia

Prifysgol Bangor University
University of Bristol
The University of Manchester
Manchester Metropolitan University
Imperial College London
Lancaster University
University of Strathclyde Glasgow

International

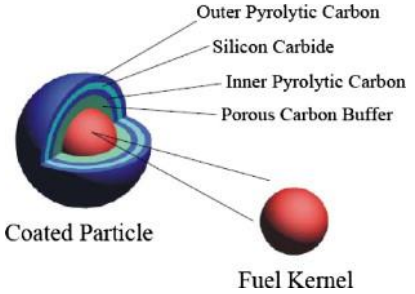
JAEA Japan Atomic Energy Agency
Lucid Catalyst

Supply Chain

ATL Advanced Coating Solutions
BRACE GmbH The Microsphere Company
Wissen
LUCIDEON
Jacobs

Department for Business, Energy & Industrial Strategy
National Nuclear Laboratory

Kernel Manufacture



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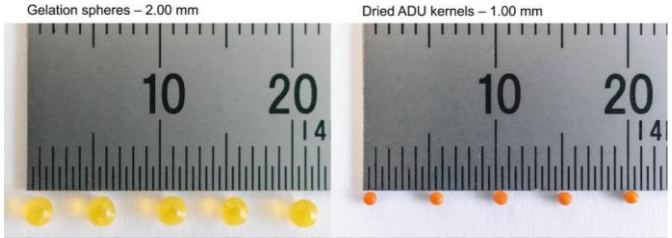
Our work

- Casting
  - **Lab scale capabilities operation at NNL Preston and Lancaster University with research ongoing to optimise**
  - **Active commissioning of "*engineering scale*" capability**
  - **Alternative routes under development at Bangor**
- Washing and Drying
  - **Research ongoing to enhance efficiency of process**
  - **Active commissioning of "*engineering scale*" capability**



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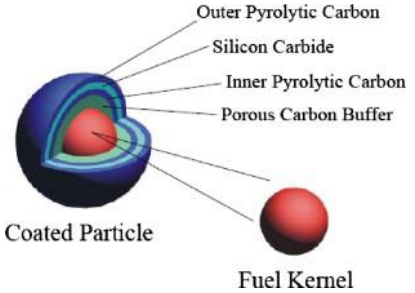
Kernel Manufacture



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Our work

- Calcining
  - **Optimisation ongoing to support operation of "*engineering scale*" capability**

- Reduction and Sintering
  - **Established technique in-place**
  - **Innovations also being supported – "*Flash Sintering*"**
- Quality Assurance

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Fluidised Bed Chemical Vapour Deposition in CPF manufacture

Mathieu Delmas

Department for Business, Energy & Industrial Strategy

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Background

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Our work

- ATL, specialists in Chemical Vapour Deposition (CVD) for 40 years
- Involved in many materials research programmes for nuclear fusion & fission
- Building a new CVD reactor to coat uranic kernels to manufacture TRISO particles that will aid the enhancement of domestic understanding of this process

Our team

ATL Advanced Coating Solutions

HENRY ROYCE INSTITUTE

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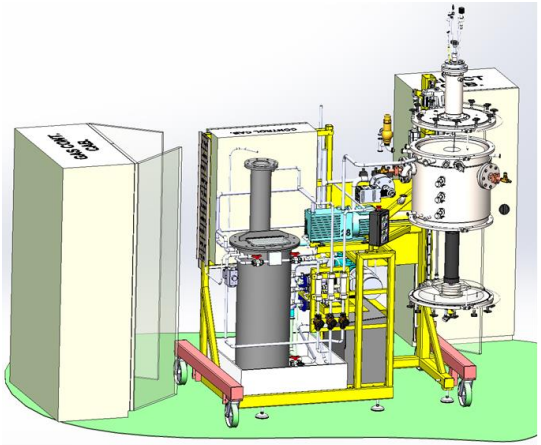
Find more about ATL at www.cvd.co.uk

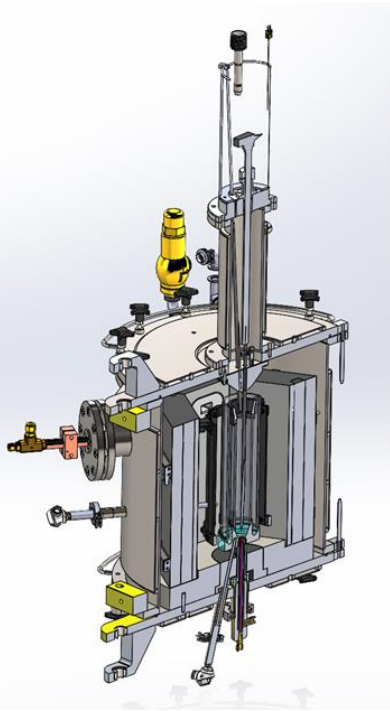
Context

- TRISO particles, initially developed in the 1970s, are required for modern High Temperature Gas-Cooled Reactors (HTGRs)
- Beyond clean energy applications, they are also under consideration for other nuclear projects
  - **Space**
  - **Thermal nuclear propulsion**

Highlights & Impact

- Pilot reactor nearing completion and FAT schedule confirmed
- First fluidised bed reactor built by ATL
- Various technical challenges solved (access to load/unload crucible, safety containment for any stray UO_2 kernels, etc.).
- System able to apply 4 layers of 3 different coating types in one continuous batch
  - **Carbon and SiC**
- Fitted with many measurement tools to improve the process and its understanding
  - **Sampling probes, thermocouples, camera**





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Matrix Graphite and Pyrocarbon (PyC) Materials in Coated Particle Fuels

Nassia Tzelepi

Department for Business, Energy & Industrial Strategy

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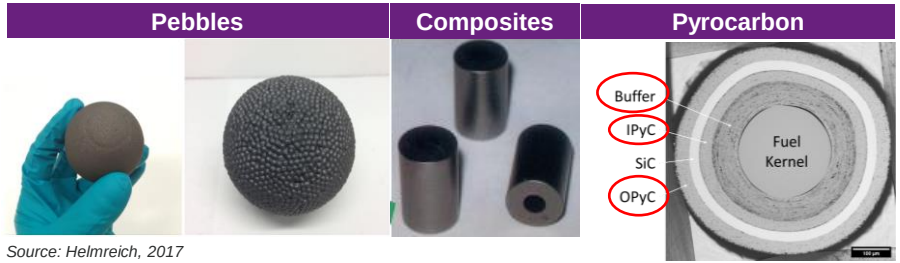
Background

Our work

- Graphite matrix: the material in which the coated particles are embedded to produce spherical (pebbles) or cylindrical (compacts) fuel elements
- Pyrocarbon: The buffer, IPyC and OPyC layers used in coated particles to protect the fuel kernel and the SiC layer
- Key challenges:
  - **Limited available data of properties that affect fuel performance**
  - **Properties depend on manufacturing process**
  - **Micro-size of buffer and PyC samples**
- Two main objectives:
  - **Understand manufacturing parameters that affect fuel performance**
  - **Provide new data representative of the UK fuels**

Our team

Matthew Jordan
Samantha Wilkinson
James McGladdery
John Dinsdale-Potter
Glen Copeland
Michael Crelling
Dave Goddard
Dong Liu
Alex Leide
Eric Jiang
Haiqi Huang



Source: Helmreich, 2017

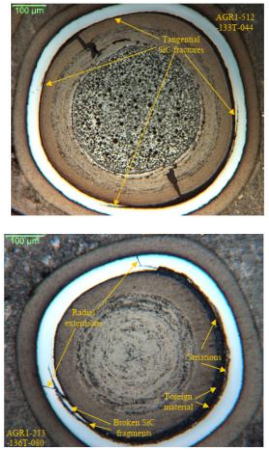
Context

- *Graphite Matrix*: Moderator and main structural material
- *Pyrocarbon*: Protective layers for the fuel kernel and the SiC (pressure vessel)
  - **accommodating fission gas pressure and kernel swelling**
  - **providing chemical, thermal and mechanical stability barriers**
- Manufacturing parameters affect the properties of the as-manufactured material
- All properties change under irradiation
- Good understanding is required to manufacture high quality and reliable fuel pebbles/compacts
- *However, the UK has unparalleled experience and capability in nuclear graphite that can be extended to satisfy the requirements of AFCP*

Pebbles in the reactor

Source: Jiang, 2019

Examples of PyC failures



Source: Ploger, 2012

Highlights & Impact

- Reports
  - **Graphite Matrix for TRISO Fuel: Review of Properties and Production Methods**
  - **Stress, Strain, and Slicing: Stress Redistribution caused by Hemisection of a Spherical Shell**
  - **Stresses and Strains in Spherical Shells Part 2: Analysis of Irradiation Creep**
  - **Review of TRISO-Relevant Pyrolytic Carbon Properties**
  - **Review of Measurement Techniques for Micro-sized Samples**
- Experimental: Development of measurement techniques for micro-sized PyC samples
  - **Sample preparation/machining**
  - **Mensuration**
  - **Elastic moduli (Resonant Ultrasound Spectroscopy (RUS))**
  - **Coefficient of Thermal Expansion (CTE)**
- Excellent collaboration with UoB
  - **Comparison of NNL theoretical analysis of stresses in manufactured and irradiated PyC layers with UoB residual stress measurement**