AFCP
Advanced Fuel Cycle Programme

Introduction: The context and the opportunity
Fast reactor fuel & fuel cycle

Mike Harrison

This work was funded under the £46m Advanced Fuel Cycle Programme as part of the Department for Business, Energy and Industrial Strategy's (BEIS) £505m Energy Innovation Programme

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NATIONAL NUCLEAR LABORATORY

Background

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Our work

Re-establish the UK capabilities for:

- **Research and manufacture alpha-active fuels to support re-use of the civil stockpile in fast reactors**
- **Development of pyro-processing as a complementary technique to aqueous methods for the treatment used nuclear fuel**

Investigate innovative manufacturing routes to fuel and cladding to enable advanced nuclear to contribute to the future net zero energy system

Demonstrate innovative options for the recycling of used nuclear fuel, especially pyro-processing, to enable the closure of an advanced fuel cycle

Develop and enhance skills, facilities and capabilities across UK nuclear supply chain

Our team

University of Cambridge
University of Cumbria
Imperial College London
The University of Edinburgh
HSE Health & Safety Executive
Lucideon
Manchester Metropolitan University
Manchester 1824 The University of Manchester
Nuclear Futures Bangor
The University Of Sheffield.
University of Birmingham
UCL
Sheffield Hallam University
University of Leeds
University of Bristol
Sellafield Ltd
IAEA International Atomic Energy Agency

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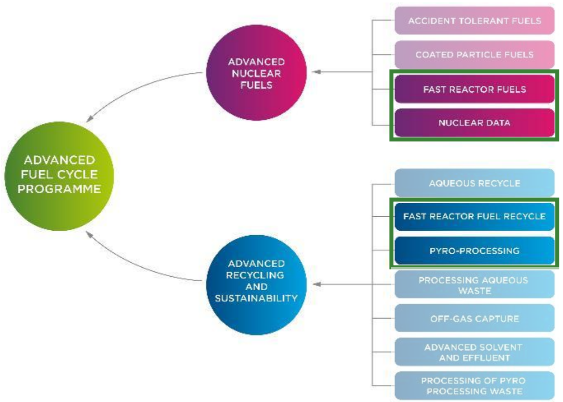
National Nuclear Laboratory

Context

- Liquid metal-cooled Fast reactors are…
  - **Technology Mature**
  - **Low pressure systems with high boiling coolants**
  - **More efficient (more heat converted to electricity)**
  - **Can be operated as actinide ‘burners’, an essential component of some advanced fuel cycle scenarios**
  - **Require fuels with high fissile material contexts**
- Pyro-processing is…
  - **Based on high temperature molten salts**
  - **Radiation tolerant**
  - **Ideal for metallic / high burn-up feeds**
  - **Well suited for recycle of used fast reactor fuel**
  - **Complimentary to aqueous (solvent extraction)**
  - **May be advantageous in some fuel cycle scenarios**
  - **Produces unconventional waste streams**



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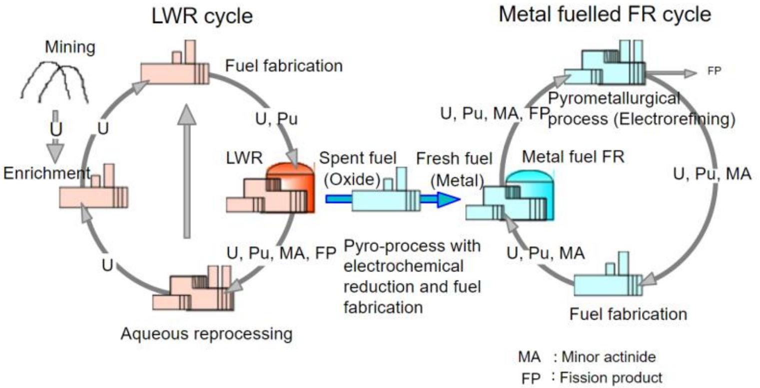
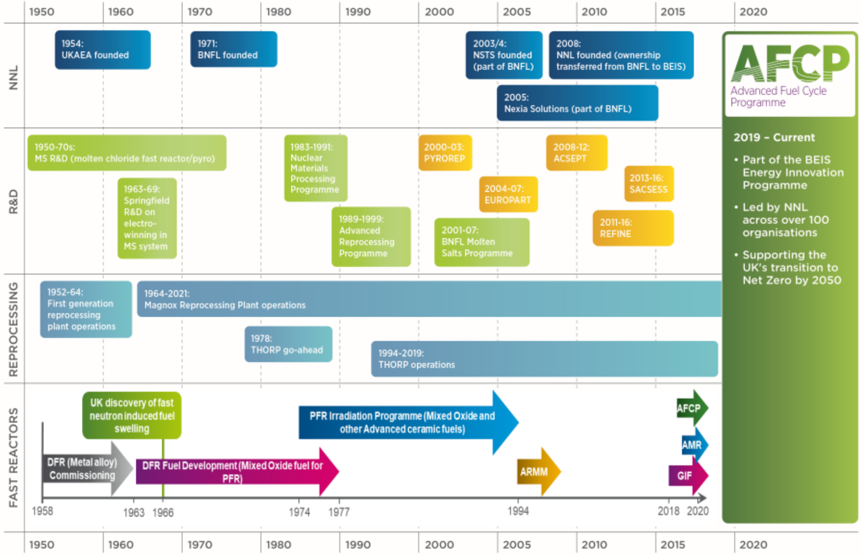


Highlights & Impact

UK re-establishing fast reactor fuel and pyro-processing research capability

- Captured and built on existing knowledge
- Developed and built new rigs and networks
- Re-establish UK facilities / capabilities for
  - **Pu-bearing fuel manufacture**
  - **Liquid-metal testing facilities**
  - **Investigate advanced manufacturing opportunities for fuel and cladding production**
  - **Molten salt chemistry, handling and characterisation**
  - **Experimental facilities including alpha-active molten salt electrochemistry**
  - **Pyro-processing engineering and flowsheeting**
  - **Pyro-waste salt treatment processes**
  - **Nuclear data**



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MOX Preparation & Integrated Recycle Test

Hannah Colledge

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Our work

Developing “21st Century” options for future reprocessing & recycling options

Co-Finishing of mixed actinides:

✓ Prepare fuel materials from reprocessed products

✓ Generate less wastes

✓ Added proliferation barriers

✓ Interface with recycle fuel manufacturing

✓ Improved efficiency / flexibility

- **✓Eliminate co-milling stages**
- **✓Homogeneous at the molecular level**

Our team

PuMMA

Lancaster University

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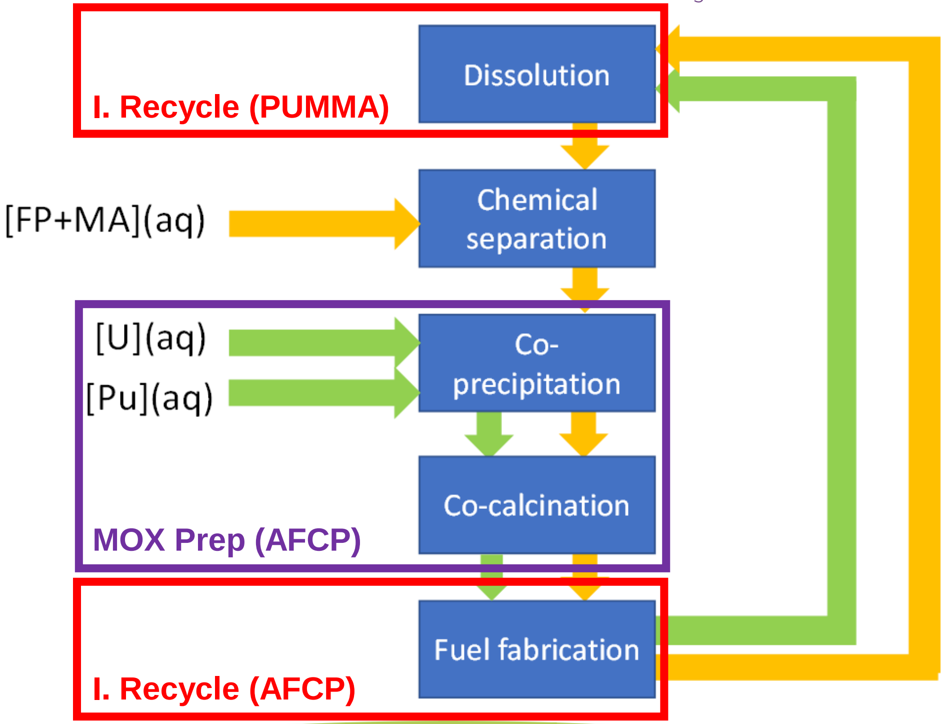
Context

Demonstrate the integration of advanced reprocessing, co-finishing and fuel fabrication processes to close the cycle:

- Various stages have only been tested in isolation to date (at TRL ~ 4)
- New pelleting capability expected in 2022
  - **Flexible Mini Fuel Line (FMFL)**
- Preparation of bulk quantities of MOX for manufacturing FR fuel pellets
- Collaborate on dissolution studies
  - **EU Horizon 2020 "PUMMA"**



Highlights & Impact

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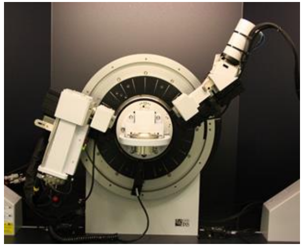
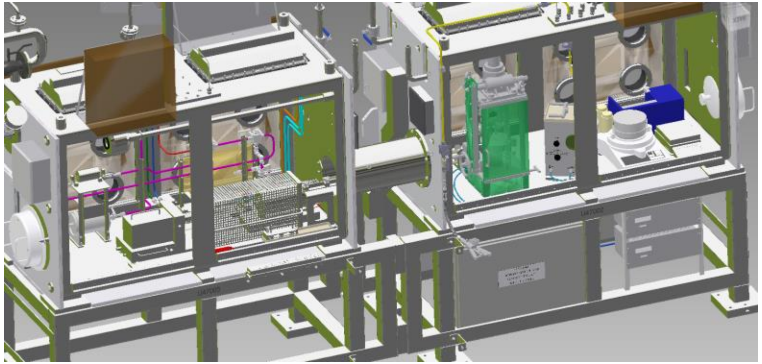
- Basic studies at NNL & Lancaster to optimise conditions for co-finishing
- Extension phase: Prepared bulk quantities of MOX via oxalate co-precipitation of U(IV)/Pu(III)
  - **45, 55, 70 % Pu**
  - **90% Pu**
- MOX material will be characterised & used for integrated recycle tests including:
  - **Pelleting (FMFL)**
  - **Dissolution Trials**
  - **Characterisation**
- Key step towards demonstrating an economic & closed cycle option for spent fuel management with enhanced proliferation resistance





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Pyro-processing overview

Mike Edmondson

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Pyro-processing

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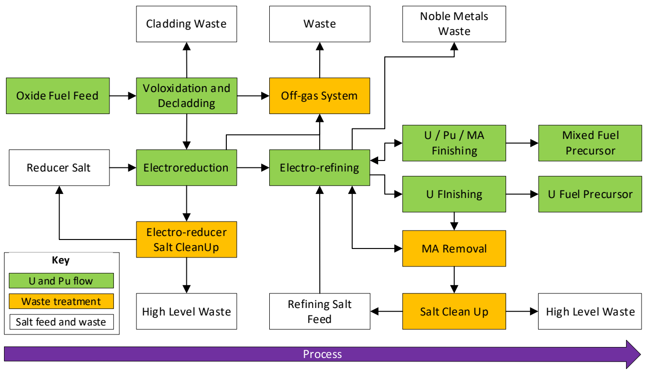
- Use of molten salt to dissolve fuel and application of current to separate reusable products from waste
- Pure U product and a Pu product also containing U and minor actinides
- Molten salts have other potential applications in nuclear:
    - **Molten salt reactors (salt fuel)**
    - **Molten salt reactors (salt coolant)**
    - **Thermal Storage**
- Pyro-processing offers a stepping stone to those technologies

The main aim of the area has been to rejuvenate the capability in this area.

- Network of 9 UK universities utilised
- Over 16 PDRAs and 20 new NNL researchers engaged
- Engagement with national labs in UK and US (Covid impacted)
- Conferences and publications
- Re-established knowledge and skills in this area

Pyro-processing Highlights



Understanding and knowledge

- Baseline flowsheet established
- Process monitoring instruments reviewed and tested
- Knowledge management – state of the art review and archive created

Capabilities

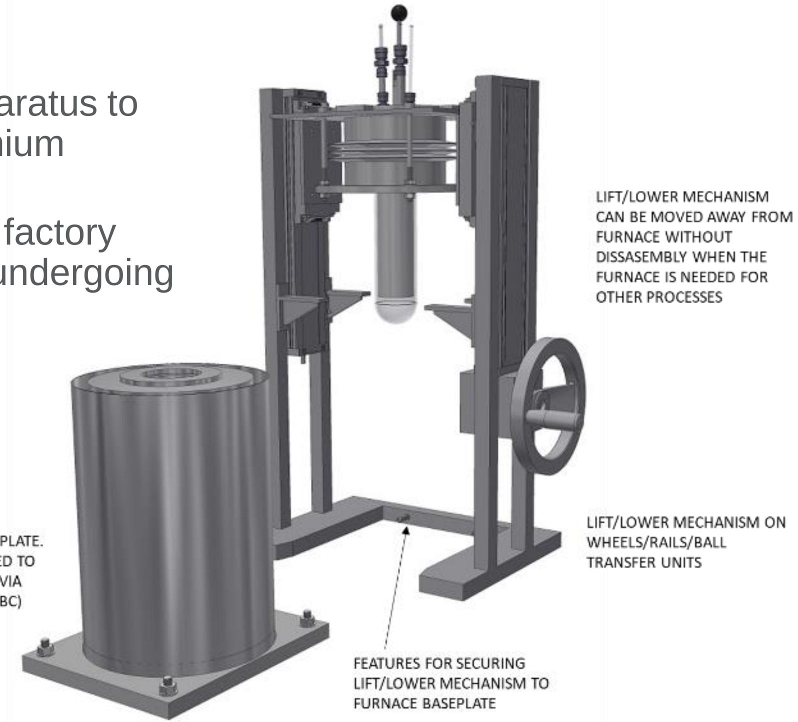
- Molten Salt Handling and Behaviour studied
- Rigs:
  - Alpha active glovebox rig (PAPA) in commissioning
  - Two molten salt flow loops.
    (UoB – in use / PRIME – concept design)
  - Refurbishment of specialist 'dry box' facility for handling molten salt

Way forwards

- Roadmap and 5 year plan in place.
- …and synergies with other molten salt applications for nuclear established (VMOST)

Pyrochemical Alpha-active Processing Apparatus (PAPA)

- Unique plutonium active apparatus to allow us to do work on plutonium containing salts
- Apparatus has been through factory acceptance and is currently undergoing inactive commissioning
- Active commissioning in Central Laboratory Glovebox culminating in Pu-active material experiments



Pyro-wastes overview

Donna McKendrick & Mike Harrison

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Pyro Waste

What is Pyro Waste?

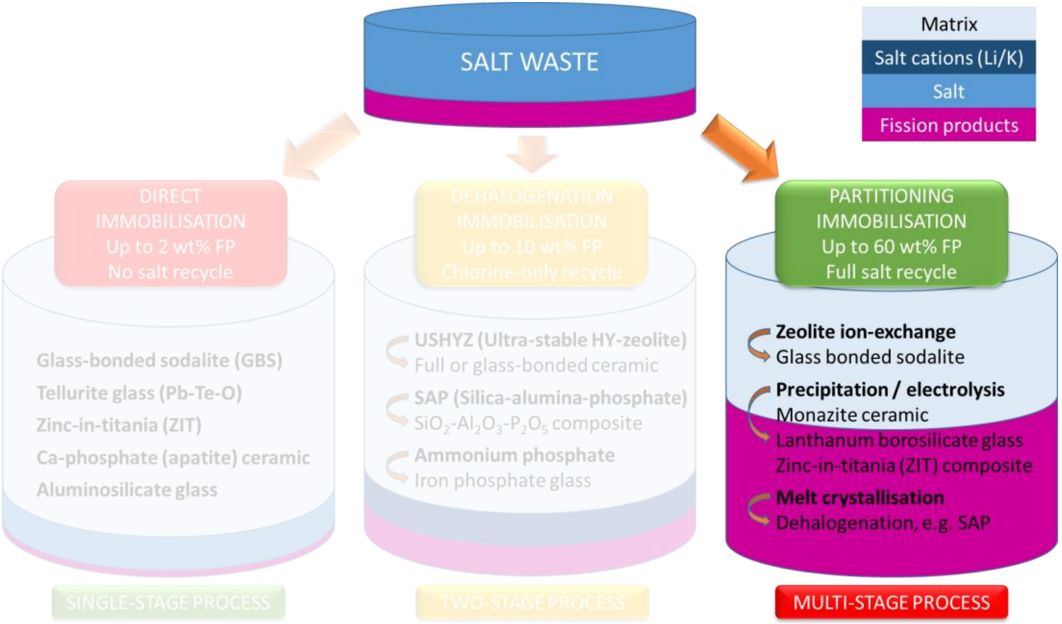
Clean-up technologies and the immobilisation of unrecyclable waste from pyroprocessing.

Two experimental programmes

- WP1.3 Salt Clean-up and Recycle
- WP1.4 Wasteform Development

Collaboration with

The University Of Sheffield. Sheffield Hallam University



Pyro Waste WP1.3 - Salt Clean-up and Recycle

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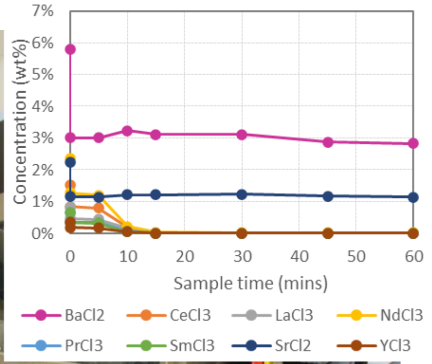
Aim: Assess FP removal from molten LKE salt by precipitation.

Phosphate and Carbonate Precipitation Experiments

- Rare earth and/or alkaline earth composition:
    1. Six $RECl_3$ mix,
    2. $BaCl_2$:$SrCl_2$ mix
    3. 50:50 by weight $ReCl_3$:$(Ba/Sr)Cl_2$ mix.
- Selection of precipitant reagents
- Temperature: 450, 550 and 650°C
- Agitation
- FP loading: 10 and 25 wt%

- Phosphate reagents effective at removing RE (RE-only experiments)
- Carbonate reagents effective:
    - Removing RE from RE-only & mixed AE/RE
    - Removing AE from AE-only
    - Only partial removal of AE from mixed AE/RE
- Generally, efficiency (yield & rate) improved
    - Using K-only reagents
    - Lower temperatures
    - Stirring



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Non-

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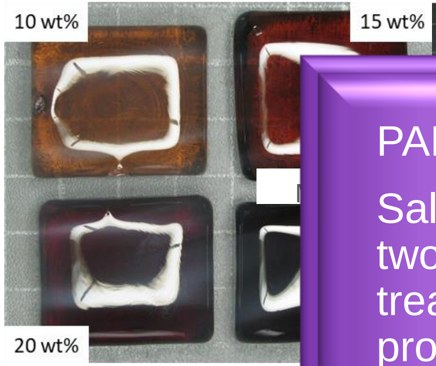
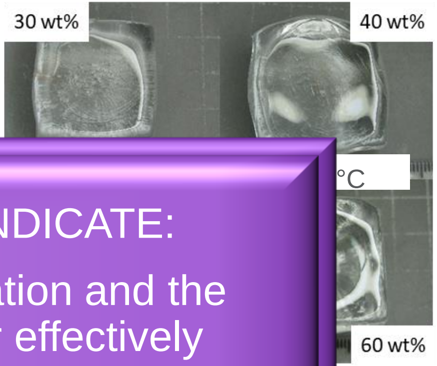
Pyro Waste WP1.4 – Wasteform Development

Aim: Develop novel wasteforms for the immobilisation of separated FPs

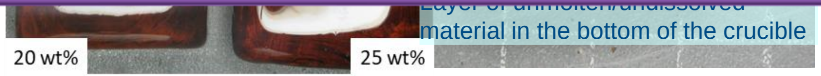
Testing Novel Wasteforms: Modified MW (MMW) glass formulation





PARTITIONING IMMOBILISATION EXPERIMENTS INDICATE:

Salt clean-up by phosphate and/or carbonate precipitation and the two novel wasteforms tested are strong candidates for effectively treating and minimising waste generated from pyrochemical processing.

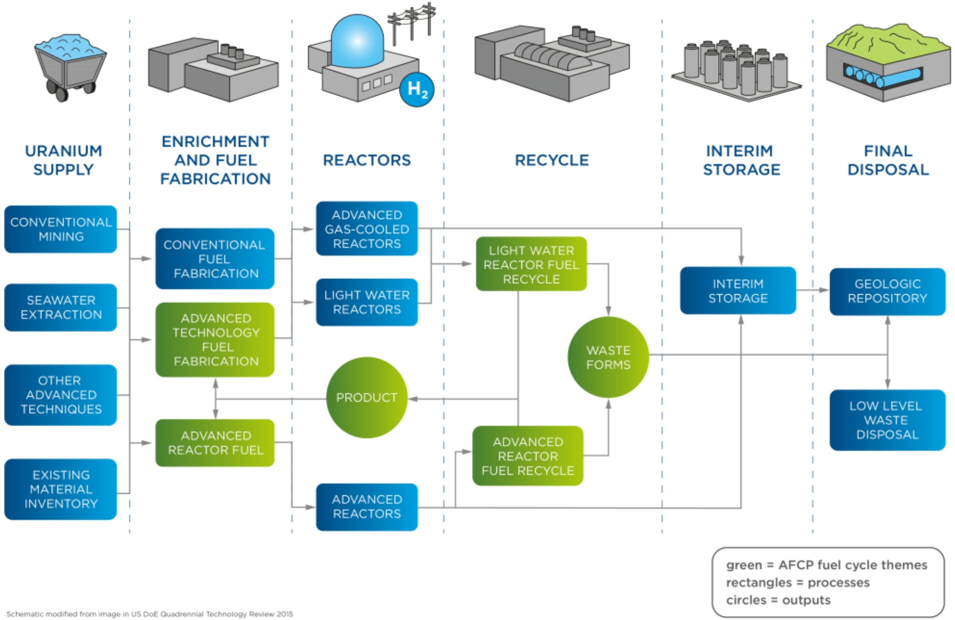


- AFCP was the RE_xO_y mix,
- BaSr was Ba/Sr mix (added as CO_3),
- AFBa was 50:50 by weight mix of AFCP and BaSr

Summary

Key Outcomes

- Re-established UK capabilities
  - **Liquid metal testing**
  - **Pu-bearing ceramic manufacture**
  - **Pyrochemical electrochemistry**
  - **Pu-bearing salt and waste**
- Consolidated and furthered our understanding in:
  - **Fast reactor fuels**
  - **Pyrochemical processing and wastes**
- Generated Roadmap to make a fast reactor cycle and / or pyro-processing a reality
- Leveraged international experience



Schematic modified from image in US DoE Quadrennial Technology Review 2015