AFCP
Advanced Fuel Cycle Programme

Aqueous Recycle

Robin Taylor

Department for Business, Energy & Industrial Strategy

NATIONAL NUCLEAR LABORATORY

Group D – Breakout 4

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Coated particle fuel	Accident Tolerant Fuel	Fast reactor fuel and Pyro-processing	Aqueous recycle
1. Introduction: The Context and International Screen *Nick Barron, NNL*	1. Introduction: The context and the opportunity *Dave Goddard, NNL*	1. Introduction: The context and the opportunity: FRF & Fuel Cycle *Mike Harrison, NNL*	1. Introduction: The context and the opportunity: *Robin Taylor, NNL*
2. Making fuel kernels *James Gath, NNL*	2. Coated cladding *Peter Kelly, MMU*	2. MOX preparation & integrated recycle test *Hannah Colledge, NNL*	2. Testing flowsheets at NNL *Dan Whittaker, NNL*
3. Developing the coater design *John Yeatman, ATL*	3. High density fuels *James Paul, NNL*	3. Pyro-processing overview *Mike Edmondson, NNL*	3. Integrated Waste Management *Josh Turner, NNL*
4. Graphite *Nassia Tzelepi, NNL*	4. Westinghouse *David Eaves*	4. Pyro-wastes overview *Donna McKendrick, NNL*	4. On-line process monitoring *Catriona McFarlan, Strathclyde*
			5. PuMA-2 facility & opportunity *Rebecca Sanderson, NNL*

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Introduction

Robin Taylor, NNL

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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Background

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Our work

To provide **credible technical options** for advanced reprocessing of spent fuels that are competitive with other fuel cycle options available to decision makers

I. *Development of proliferation resistant aqueous reprocessing options …that generate less wastes and are more compact and cost effective, yet more flexible, than current reprocessing*

II. *Develop spent fuel management options for …innovative fuels*

III. *Minimise the supporting infrastructure needed for managing wastes arising from spent fuel recycle*

IV. *Develop the tools that enable the advantages and disadvantages of …spent fuel recycle to be evaluated and compared against other …options*

Our team

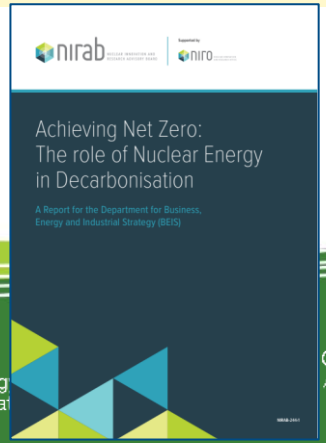
Extension Phase: Advanced Technology Light Water Reactor Fuels

- Development of the capability to sustainably recycle and supply future fuel materials with a better understanding of economics, environmental impacts, proliferation barriers and waste management options

Context

- Significant policy uncertainty in the longer term
- Some ANT (e.g. MSRs) rely on recycled products or need closed cycle
- Uncertainty with GDF – need to “hedge bets” with closed cycle options for the long term
- Any viable future deployment of closed cycles requires technology development now
- Expertise needed for UK to be a “top tier” nuclear nation
- Supports UK international influence, security & ability to respond
- Consistent with societal trends towards sustainability & the circular economy
- UK needs to retain minimum intelligent buyer capability in fuel cycle technologies
- Maintain world class R&D skills & facility base established through AFCP & deliver on commitments under US-UK Action Plan, EU programmes, IAEA & OECD-NEA

“a global expansion of nuclear energy could place an increasing strain on uranium supply and spent fuel storage / disposal facilities. This could result in a much greater emphasis on energy security and sustainability and the consequent closure of at least part of the fuel cycle”



Highlights & Impact

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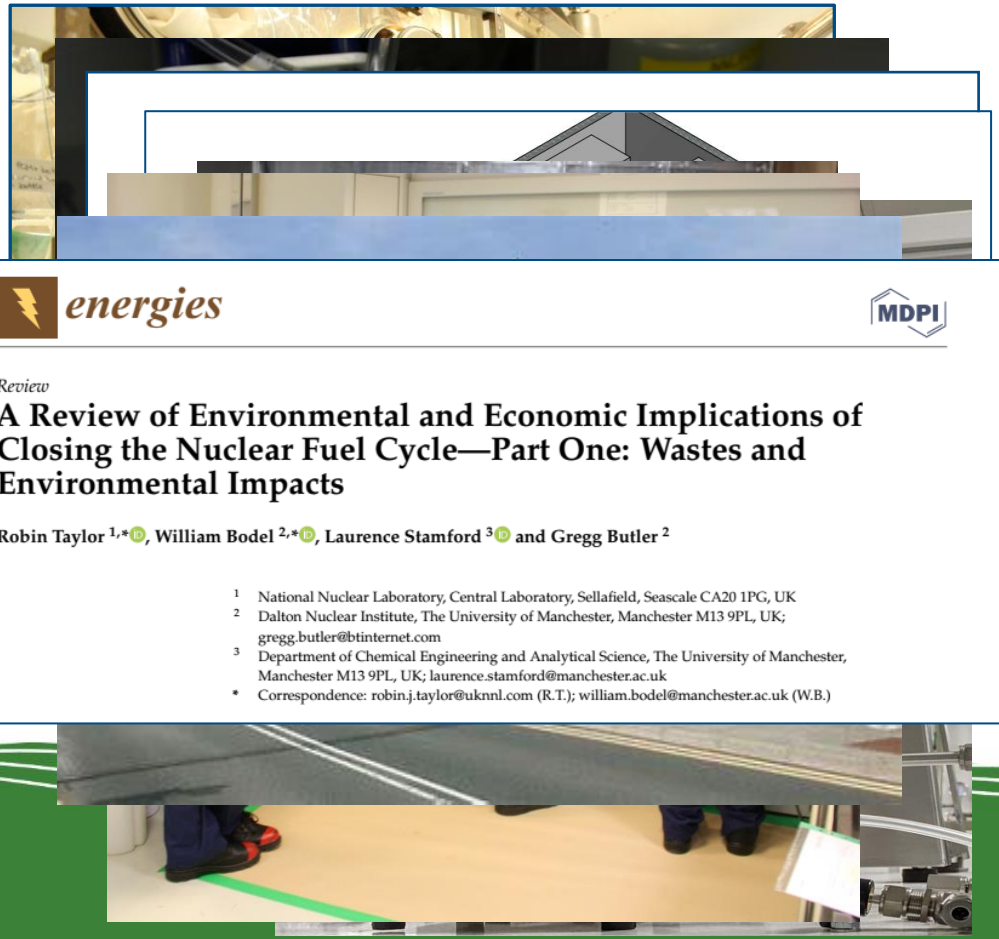

energies

MDPI

Review

A Review of Environmental and Economic Implications of Closing the Nuclear Fuel Cycle—Part One: Wastes and Environmental Impacts

Robin Taylor [1,*], William Bodel [2,*], Laurence Stamford [3] and Gregg Butler [2]

[1] National Nuclear Laboratory, Central Laboratory, Sellafield, Seascale CA20 1PG, UK
[2] Dalton Nuclear Institute, The University of Manchester, Manchester M13 9PL, UK; gregg.butler@btinternet.com
[3] Department of Chemical Engineering and Analytical Science, The University of Manchester, Manchester M13 9PL, UK; laurence.stamford@manchester.ac.uk
* Correspondence: robin.j.taylor@uknnl.com (R.T.); william.bodel@manchester.ac.uk (W.B.)

- Series of flowsheet rig trials in unique facility raising TRL of advanced aqueous separations to TRL 4
- Innovation & leading edge R&D. E.g. photo-reactor
- New tools developed to analyse sustainability issues such as Sim Plant & LCA
- New capabilities: PuMA-2 Lab design
- Pilot scale rigs such as ELENDES at Preston Lab for organics waste treatment
- New engineering-scale centrifugal contactor rigs
- Training apprentices in alpha skills & developing next generation SMEs
- Strong focus on knowledge management
- Growing body of impactful publications

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Testing Flowsheets at NNL

Dan Whittaker, NNL

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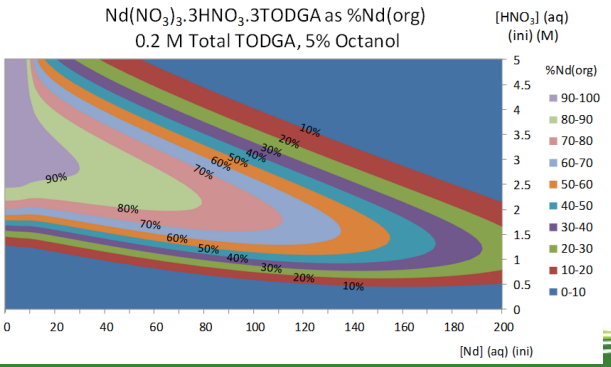
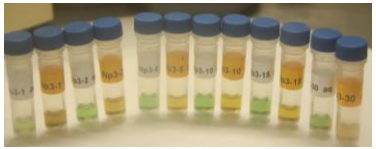
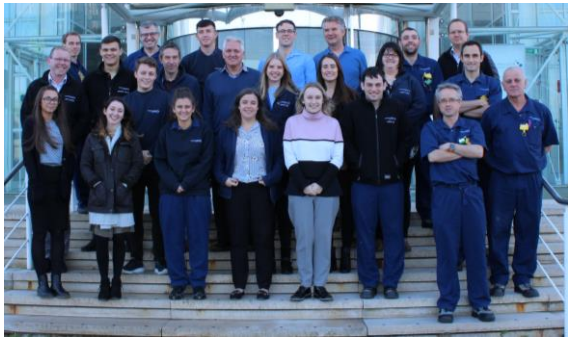
- Need "21st C" separations process for reprocessing:
  - **Advanced recycling NOT based on 1980's PUREX process**
- NNL has heritage of separations development:
  - **E.g. Low Acid flowsheet for Magnox saved ca £100M**
- Modelling and "test tube" experiments are important but:
- **Must test flowsheets**





Our team



- ~50 staff
- 14 apprentices
- ECWs
- SMEs

Testing flowsheets is our 'Flagship' work!

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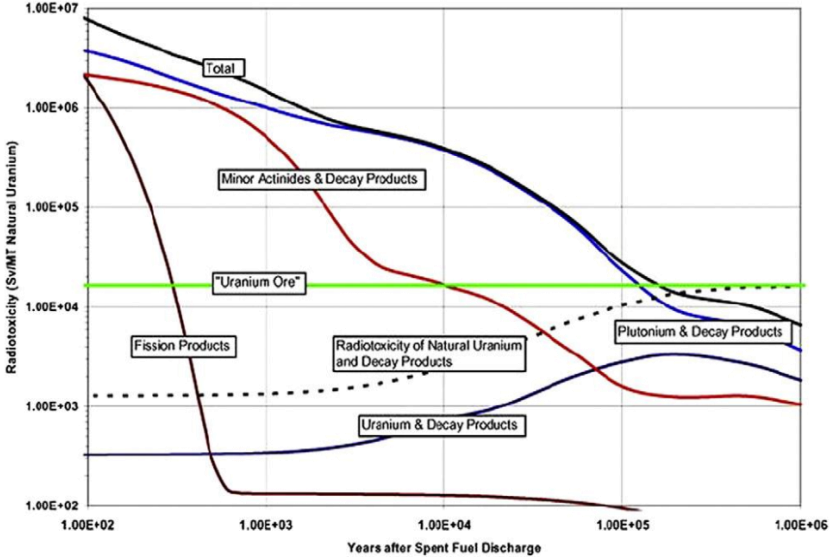
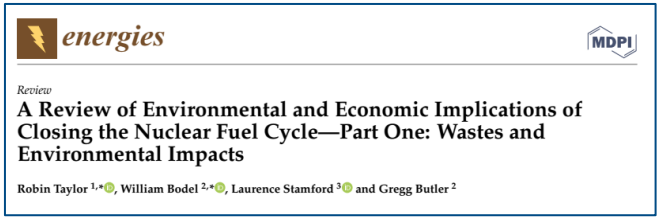
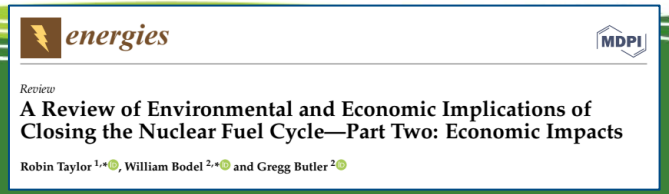
Context

- Aim: "*Development of proliferation resistant aqueous reprocessing options for spent nuclear fuels that generate less wastes and are more compact and cost effective, yet more flexible, than current reprocessing plants*"
- Separation & recycle of actinides enables:
  - **Waste volume & lifetime decrease**
  - **Waste repository size decrease**
  - **Robust bespoke engineered wasteforms**
  - **Re-use of materials as fuel (extends U resources)**
  - **Reduce global inventory of Pu & MA**
  - **Reduced environmental impact**
  - **Enhanced sustainability of nuclear**
- Aim: flexible range of options for various closed fuel cycle scenarios



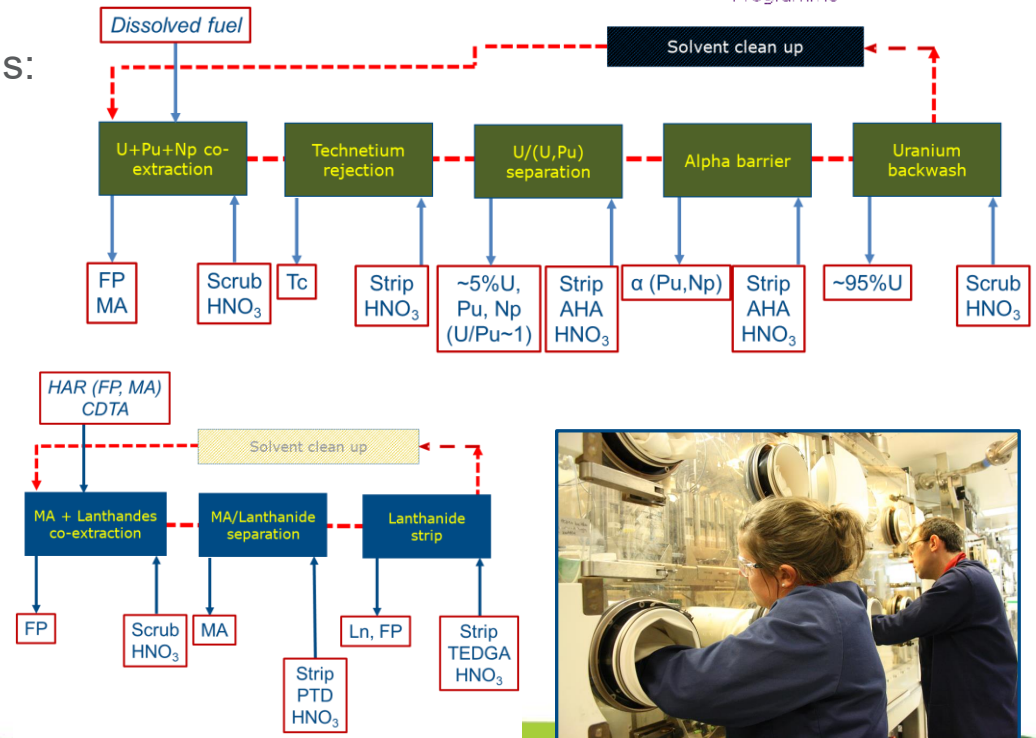




*From M. Salvatores and G. Palmiotti, Prog. Part. Nucl. Phys., 2011, 66, 144.

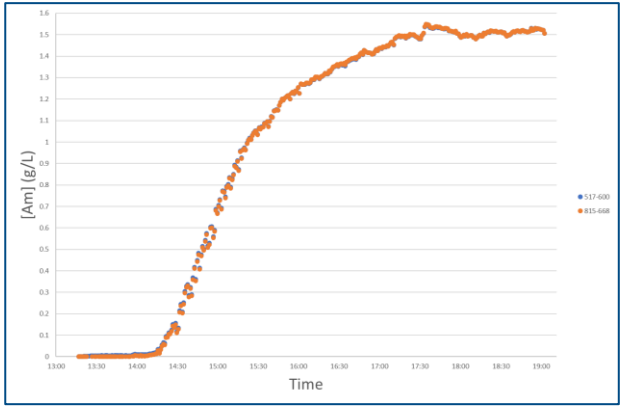
Highlights & Impact (1)

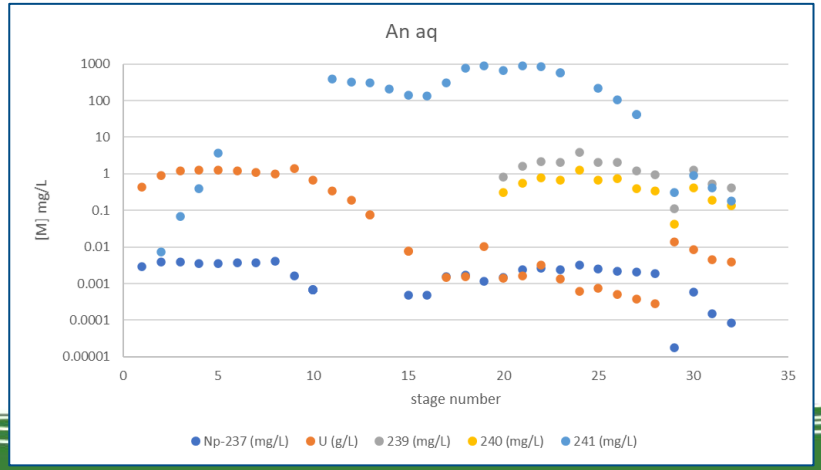
- Completed 5 AFCP ‘rig trials’ in 18 months:
  - **Advanced PUREX (2)**
  - **GANEX (2)**
  - **i-SANEX**
- Training opportunities:
  - **Chemistry degree(s)**
  - **New glove box & rig SQEPs (Alpha skills)**
  - **Development of next generation SMEs**
- New capabilities:
  - **Organic analysis**
  - **^{99m}Tc generator**



Highlights & Impact (2)

- *i*-SANEX rig trial
  - **First test of flowsheet with process levels of Am**
  - **First flowsheet test of new molecules that are decomposable (PTD and TEDGA)**
  - **Collaborating internationally with EU GENIORS project & US national labs**
- Flowsheet successfully demonstrated!
  - **On-line analysis of Am**
  - **Good decontamination factors & recoveries**
  - **Further optimization needed (lanthanide control)**
  - **Models being further developed to optimise design before any new test**
  - **Fundamental chemistry investigated via university partners**





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Integrated Waste Management

Joshua Turner, NNL

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Background

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Our work

- Co-developing waste solutions that enable advanced fuel cycles. Three main projects:
  - **Processing of Aqueous Wastes**
  - **Solvent and Effluent Management**
  - **Off-gas Capture**
- What does success look like:
  - **Increased sustainability**
  - **Reduced plant footprints**
  - **Target “near-zero” emissions**

Our team

Academia

UCL
The University of Manchester
UNIVERSITY OF LEEDS
Sheffield Hallam University
The University Of Sheffield.

SME

Finden
GRI LTD
C-Tech INNOVATION

International Collaboration

PNNL
OAK RIDGE National Laboratory
INL Idaho National Laboratory

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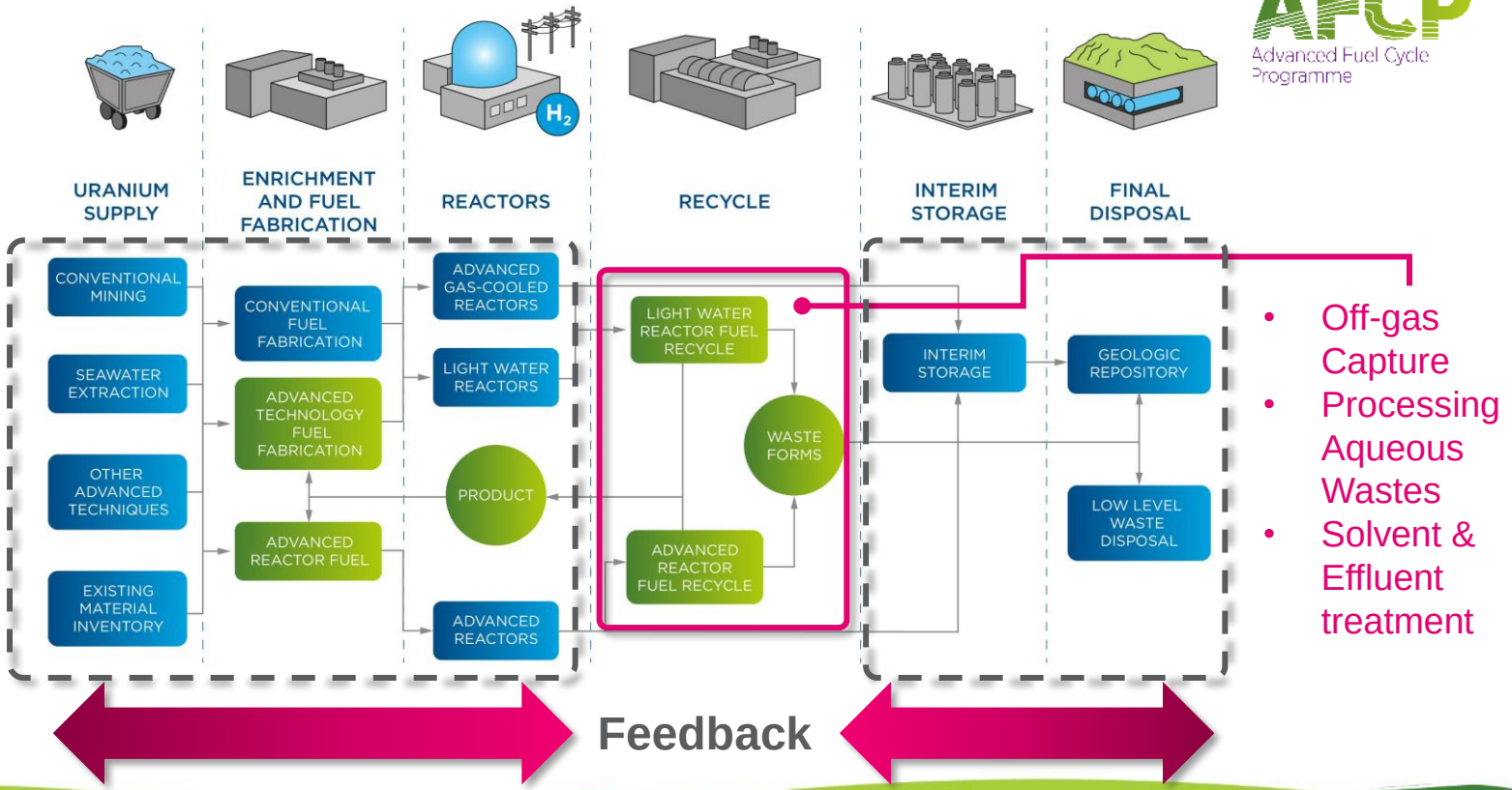
Context

Stages of the fuel cycle



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Other fuel cycle processes

- Off-gas Capture
- Processing Aqueous Wastes
- Solvent & Effluent treatment

The AFCP sustainability toolkit

Context

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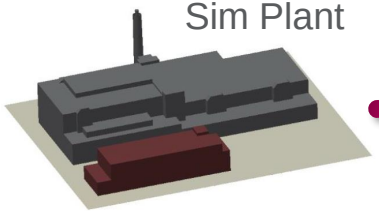
EXAMPLE
Sim Plant



EXAMPLE
Zircaloy Recycle

EXAMPLE
Panel on UK-US collaboration at WM2022
[PHOTO TO BE ADDED]

EXAMPLE
Solid sorbents

See: Nuclear Futures Nov/Dec 2021

Applying the Waste Hierarchy for Future Recycling of Nuclear Fuels

Integrated Waste Managem

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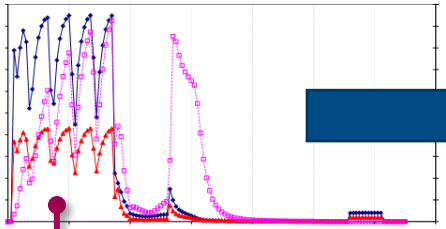
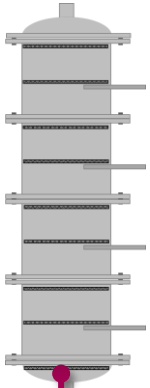
Highlights & Impact

Iodine

Plant data (UK)



Sorbent testing(US)



UK-US Action Plan Off-gas Collaboration

High Level Wasteforms: Comparing Synroc and glass

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Ag recycle

Installing ELENDES solvent destruction rig at NNL Preston

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On-line process monitoring

Catriona McFarlan, University of Strathclyde

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Background

Our work

- Aim: Provide on-line monitoring of advanced aqueous recycle processes using optical spectroscopy and chemometric techniques
- Ability to monitor and control process important
  - ➢ Fast – real-time measurements
  - ➢ Improved quality – deviations quickly detected
  - ➢ Optimisation and control – improved processes
  - ➢ Safeguards – accountancy of radioactive materials
  - ➢ Safety – remote analysis possible

Our team

University of Strathclyde:

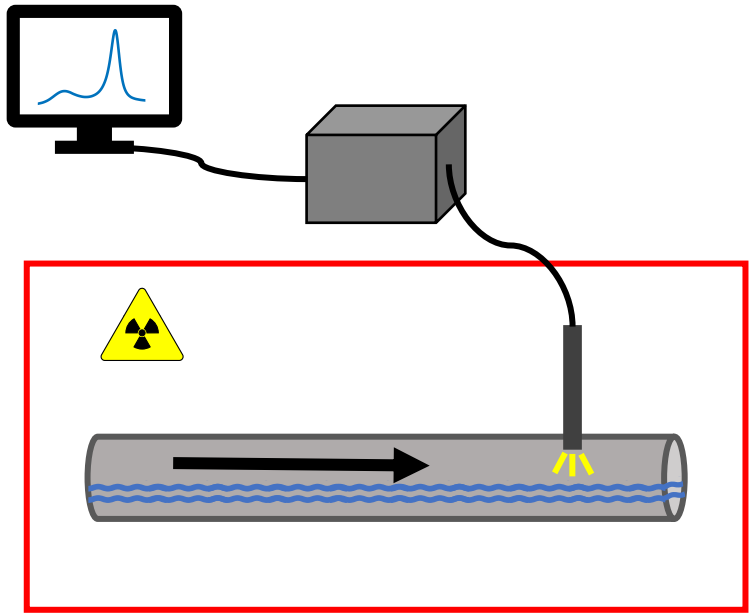
- Catriona McFarlan
- Alison Nordon

NNL:

- Mark Sarsfield
- Robin Taylor
- Gemma Mathers
- Matt Bye

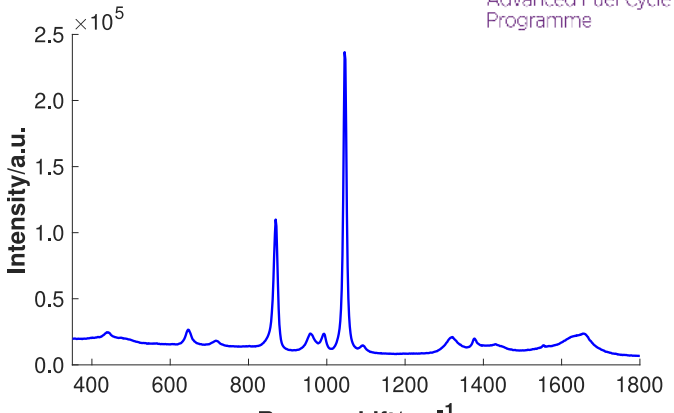
Context

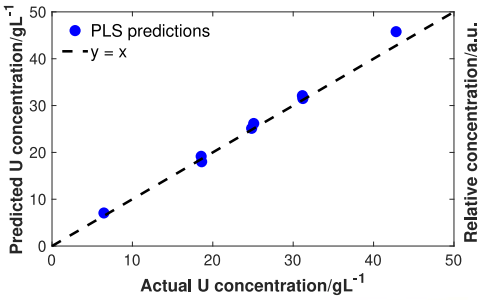
- Development and operation of advanced aqueous recycle processes requires on-line monitoring of key components
  - Developing methods for quantification of nitric acid, uranium and plutonium
- Methods can be applied on-line to rigs at NNL and across the UK
  - Facilitates future recycling of spent fuel
  - Increase sustainability of nuclear fuel cycle
- Reduces need for off-line analysis
  - Saves costs, time and resources
  - Minimises radioactive wastes generated

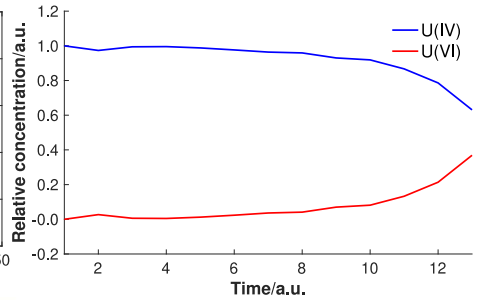


Highlights & Impact

- Measured concentration of U(VI) and nitric acid in presence of acetohydroxamic acid (AHA) by Raman spectroscopy
- Analysed UV-vis spectra to understand complexation of Pu(IV) to AHA
  - ➢ Impact – Control of U:Pu during plutonium stripping stage to add proliferation barriers
- Resolved UV-vis spectra of U(VI) and U(IV) in absence of calibration data
  - ➢ Impact – Monitor conditioning of U(VI) to U(IV) prior to finishing stage to improve recovery
- Identified opportunities for on-line monitoring of GANEX process
  - ➢ Impact – Facilitate proliferation-resistant extraction in Generation IV nuclear energy systems
- Opportunities to apply methods to coated particle fuel fabrication & other processes







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New “PuMA-2 Lab” – facilities and opportunities

Rebecca Sanderson, NNL

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Alpha Active Facilities

- NNL's PuMA Lab – Current facilities are research facilities for
  - **Small scale (medium active) plutonium & minor actinides facilities**
  - **Head-end Dissolution capabilities**
  - **Solvent Extraction (SX) & separations**
    - **Centrifugal contactor rigs in glovebox & fumehood**
  - **Finishing capabilities**
- Separate gloveboxes
- Supports – AFCP, ESA, SL, NDA, European projects
- PuMA 2 – flexible platform for future needs
  - **Concept & Preliminary designs in AFCP**
  - **Multi-disciplinary NNL Project**

Sellafield Ltd

esa European Space Agency

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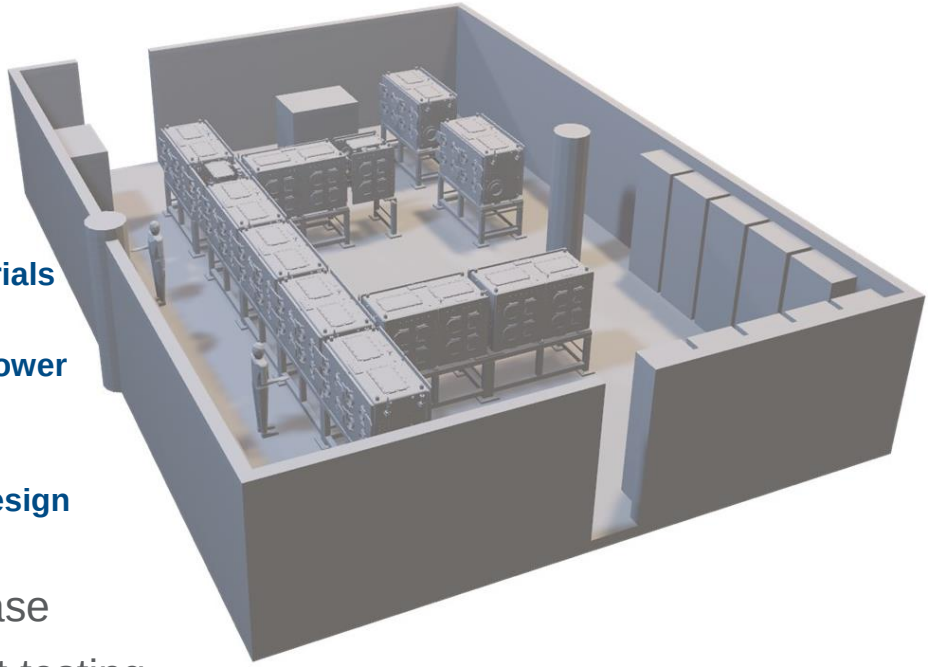
PuMA-2 Lab Design Detail

- Suite of integrated gloveboxes (process line)
- Test flowsheets end-to-end efficiently
- Extend the current capability of PuMA Lab
  - **Bespoke design processing facility for actinide materials**
  - **Safe, secure environment, optimised for purpose**
  - **Process isotopes at quantity e.g. Am-241 for space power**
  - **Temperature-controlled separations capability**
  - **Higher inventory flowsheets**
  - **On-line process monitoring & control integrated in design**
  - **Integration of waste management with operations**
- Engineering led development in the design phase
- Technical (user) support to design & equipment testing
- Unique capability in UK & world class facility



Highlights & Impact

- PuMA 2 will be a UK capability for multiple users:
  - **Future testing for reprocessing and recycling of fuels (up to TRL 5)**
  - **Pilot-scale studies**
  - **Small-scale production of isotopes (e.g. Am-241)**
  - **Capability for processing alpha wastes and residues from Sellafield or elsewhere**
  - **Manage residues from MOX fuel lines enabling return of Pu to Sellafield stores**
- Provide a unique R&D platform for range of customers (e.g. ESA, AFCP, European Union)
- Provide training opportunities for the next generation of Subject Matter Experts & glove box operators
- Opportunities to manage various plutonium residues in the UK
- Early technical input will ensure the design is user driven for the most efficient facility
- Workshops completed on the 4 main areas – HE, SX, Finishing, Analysis
  - **Research tasks to support the design**