Developments in Advanced Recycle and Sustainability for Future Fuel Cycle Options

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SNETP, 03 February 2021

Advanced Fuel Cycle Programme

Department for Business, Energy & Industrial Strategy

National Nuclear Laboratory

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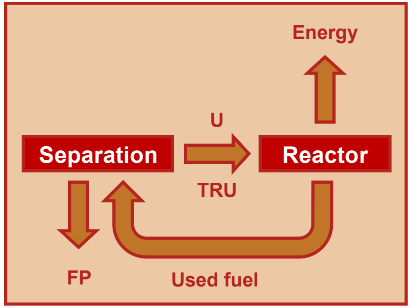
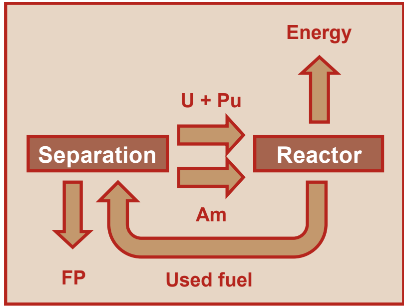
- Drivers for optimisation of advanced recycle processes & UK's AFCP
- (U,Pu) advanced aqueous reprocessing
- Heterogeneous recycling option for minor actinides
- Homogeneous recycling option for U and transuranic actinides together
- Results from NNL's *Sim Plant*
- Summary



HOMOGENEOUS



HETEROGENEOUS

Current state of the art: commercial scale fuel reprocessing

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Can we do better...?
Can we find 21st Century solutions for SF recycling…?
To realise the benefits by addressing the perceived problems…?

⇒ *"Advanced Fuel Cycle Programme" part of UK Government's £505m "Energy Innovation Programme"*

AFCP is funded by the UK Government's Department of Business, Energy and Industrial Strategy (BEIS) and led by the UK National Nuclear Laboratory (NNL) who are delivering the work in partnership with around 100 other organisations from industry and academia

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Needs for process optimisation

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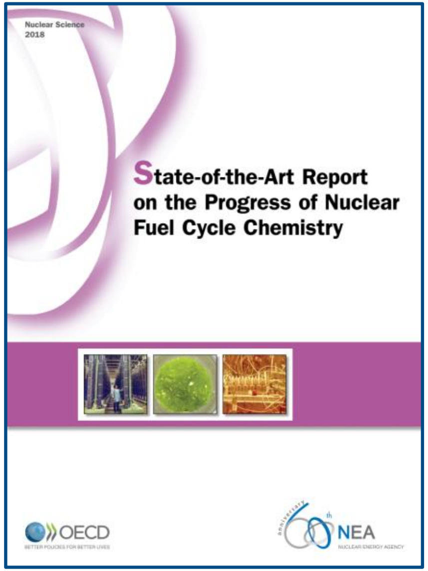
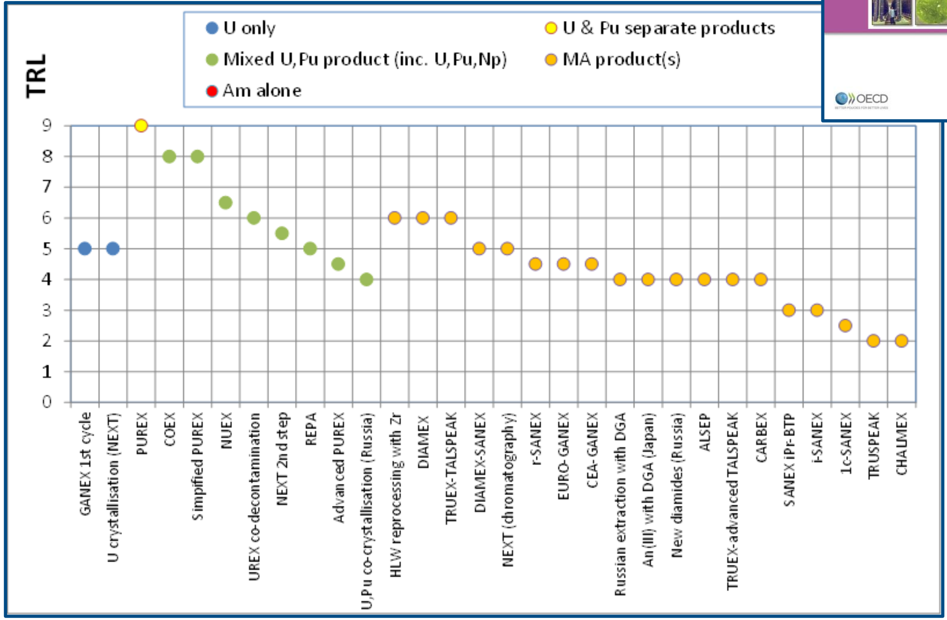
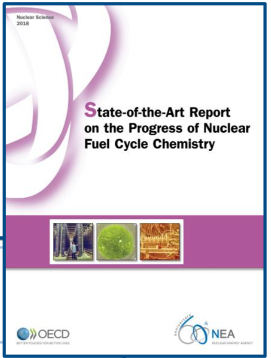
Objective	Fuel cycle requirement	Impact on separations process
Process safety	• Geometrically safe • Safer process	• Avoid specific reagents • Improve understanding • Modelling & simulation • Engineering design
Sustainability	• Plutonium multi-recycling	• High Pu concentrations in SX • Increased radiolysis • FP decontamination in short cooled or HBU fuels
Waste management & environmental impact	• Pu & MA multi-recycled • Reduced impact on DGR • Reduced waste & environmental impacts	• Recovery of Np • Options for MA separations • Reduced effluents • CHON reagents
Non-proliferation	• Increased physical safeguards & monitoring • Integrated reprocessing & recycling	• U+Pu co-processing &/or less pure Pu products • Real time accountancy
Economic	• Reduced capital cost • Greater flexibility	• Process intensification • Single SX cycle • Less effluent streams • Process wider range of fuels



Technology readiness





NEA
NUCLEAR ENERGY AGENCY

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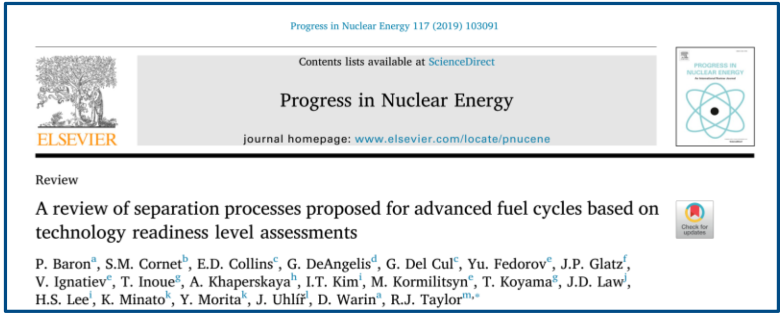
⇒ Mainly in development phase

⇒ Proof of Principle

⇒ Demonstration

i.e. Raising TRLs from ~3 to 6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ELSEVIER

Review

A review of separation processes proposed for advanced fuel cycles based on technology readiness level assessments

P. Baron[a], S.M. Cornet[b], E.D. Collins[c], G. DeAngelis[d], G. Del Cul[c], Yu. Fedorov[e], J.P. Glatz[f], V. Ignatiev[e], T. Inoue[g], A. Khaperskaya[h], I.T. Kim[i], M. Kormilitsyn[e], T. Koyama[g], J.D. Law[j], H.S. Lee[i], K. Minato[k], Y. Morita[k], J. Uhlíř[l], D. Warin[a], R.J. Taylor[m,*]

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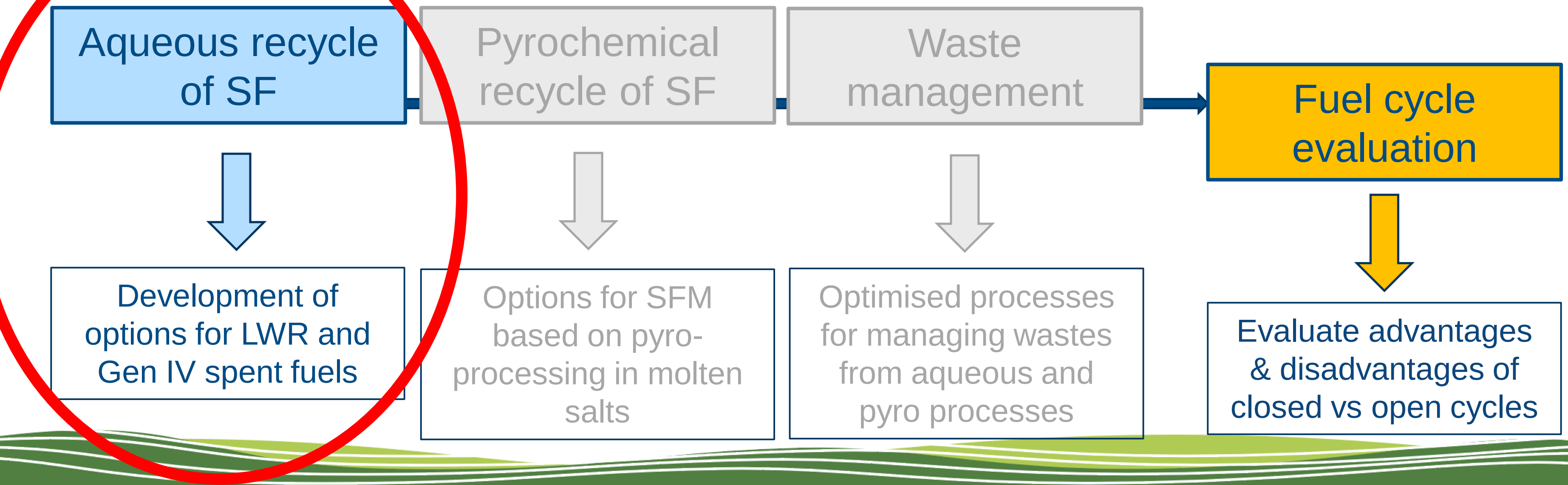
AFCP Recycle & Sustainability Project Areas

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

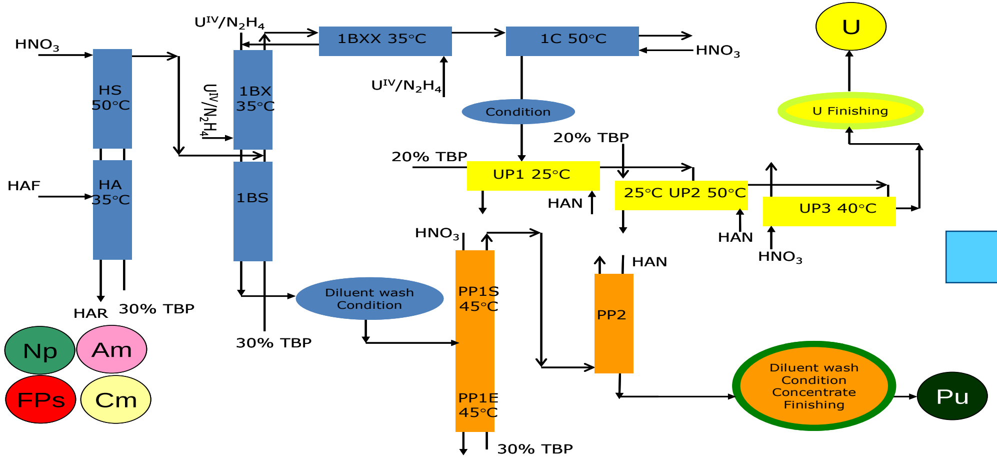


Advanced Aqueous Recycle

Simplified actinide separations for future reprocessing:

Advanced Fuel Cycle Programme

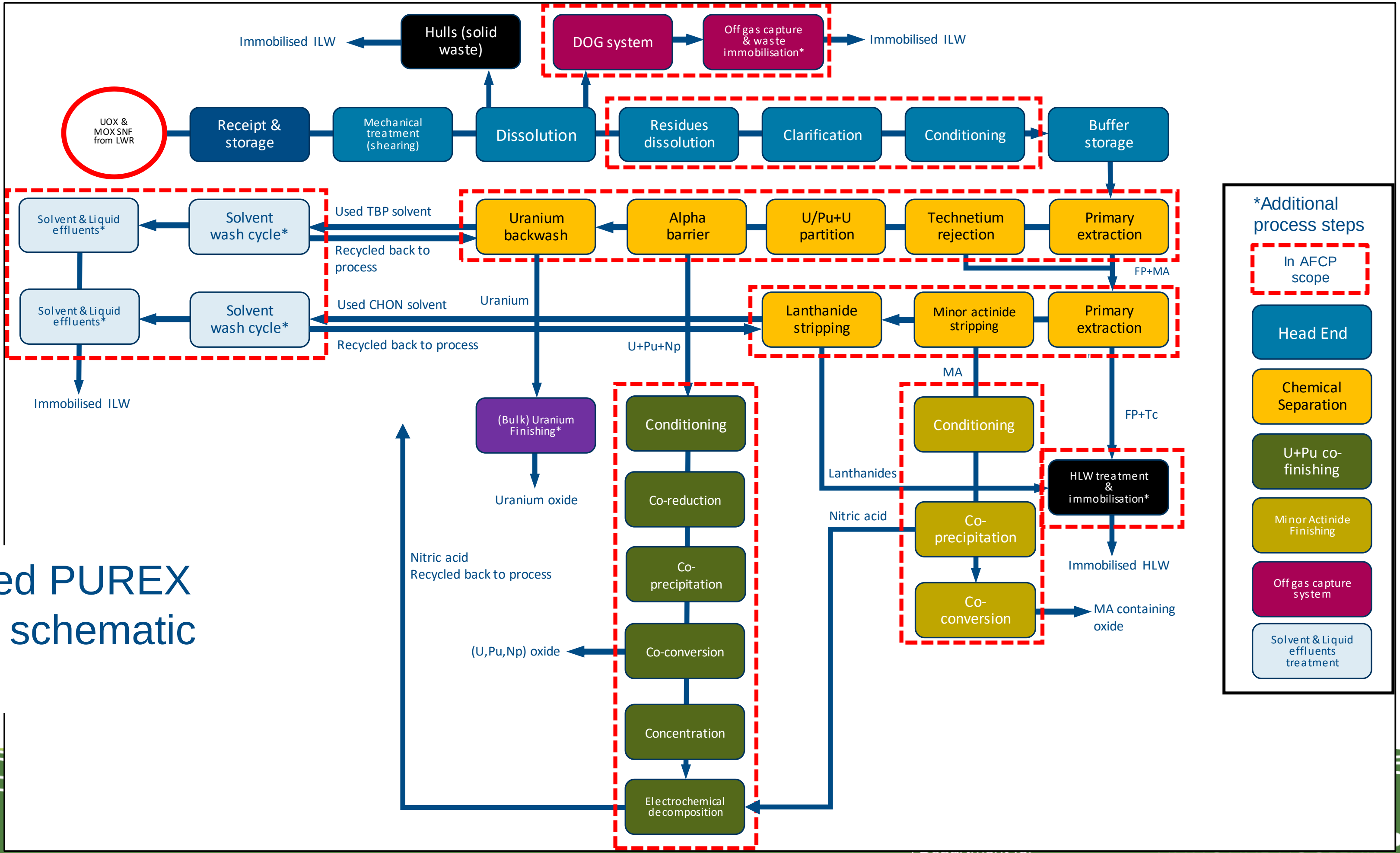
Current reprocessing (Thorp SX)



Advanced aqueous recycling

CHALLENGE

- 1 SX cycle (core process)
- Smaller footprint
- Reduced hazards
- Less wastes at source
- Lower cost
- Added proliferation barriers
- Real time process control
- Mixed products (no separated Pu)
- Can process range of future fuels
- Flexible/modular
- Integrated with waste management & fuel fabrication



Advanced PUREX process schematic diagram

Key highlights: Advanced PUREX process

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- Capability to handle MOX feeds
- U+Pu co-processing
- U+Pu separation by reduction with U(IV)-hydrazine replaced by complexation with organic ligand
- Full Np control proven
- Technetium rejection stage (current focus)
- Dynamic process models on modern platforms
- Compatible with centrifugal contactors
- Reducing wastes at source
- Proving flowsheet meets product specifications (ongoing)

Lancaster University
MANCHESTER 1824
The University of Manchester
UNIVERSITY OF LEEDS
University of Strathclyde Glasgow

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Heterogeneous recycling – MA separation options

GENIORS
GEN IV integrated oxide fuels recycling strategies

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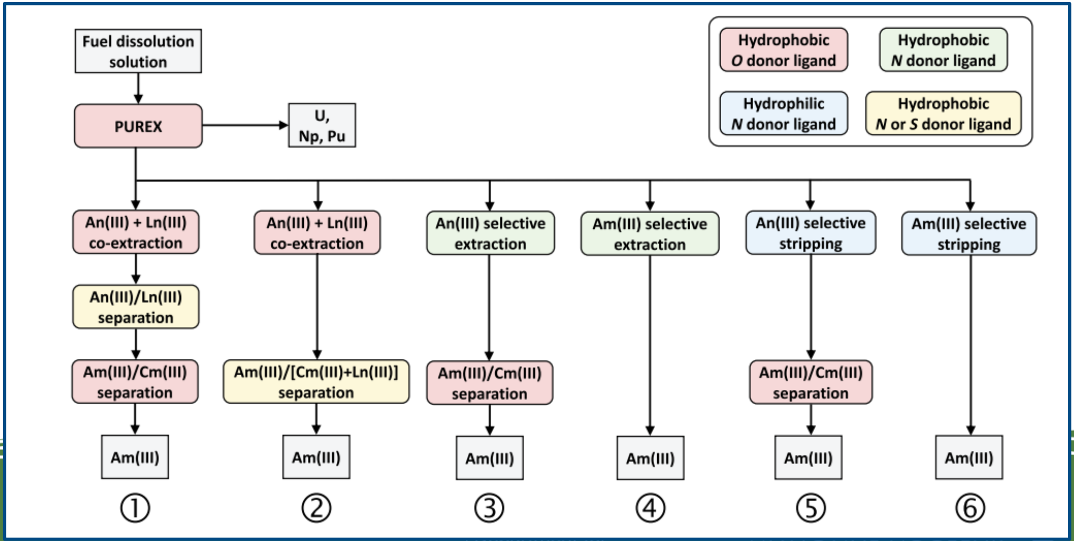
- 25+ years of MA partitioning research in Europe
- New ligands discovered (organic and aqueous phases)
- High selectivities for An(III)/Ln(III) separations
- Reference SX processes developed & tested for range of strategies
- Rationalisation towards 1-cycle SX processes

SEPARATION SCIENCE AND TECHNOLOGY
https://doi.org/10.1080/01496395.2020.1795680
Taylor & Francis
Taylor & Francis Group
Check for updates

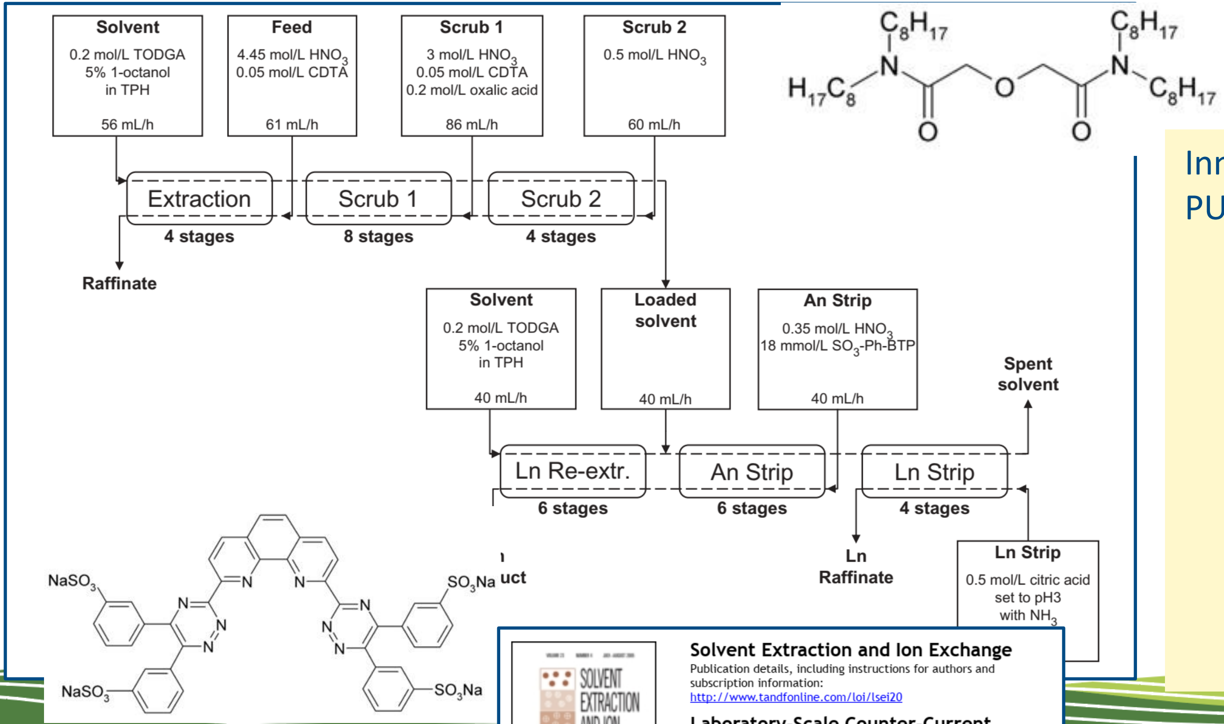
An overview of solvent extraction processes developed in Europe for advanced nuclear fuel recycling, part 1 — heterogeneous recycling

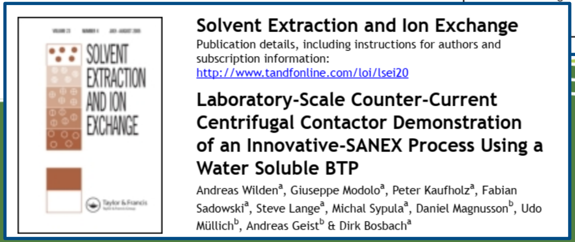
Andreas Geist[a], Jean-Marc Adnet[b], Stéphane Bourg[b], Christian Ekberg[c], Hitos Galán[d], Philippe Guilbaud[b], Manuel Miguirditchian[b], Giuseppe Modolo[e], Chris Rhodes[f], and Robin Taylor[f]



Current focus (i-SANEX)

Minor Actinides Separations processes




Solvent Extraction and Ion Exchange

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lsei20

Laboratory-Scale Counter-Current Centrifugal Contactor Demonstration of an Innovative-SANEX Process Using a Water Soluble BTP

Andreas Wilden[a], Giuseppe Modolo[a], Peter Kaufholz[a], Fabian Sadowski[a], Steve Lange[a], Michal Sypula[a], Daniel Magnusson[b], Udo Müllich[b], Andreas Geist[b] & Dirk Bosbach[a]

Innovative-SANEX ("bolt on" to Advanced PUREX):

- SANEX = Selective Actinide Extraction
- Recovers MA (Am+Cm) from HLW
- 1 cycle, CHON extractant
- Developed & tested at FZJ on spiked simulant (SACESS, GENIORS projects)
- Testing with realistic Am concentration planned at NNL
- Improved actinide strip to be tested (avoids S-containing ligand)
- Interfacing with conversion process

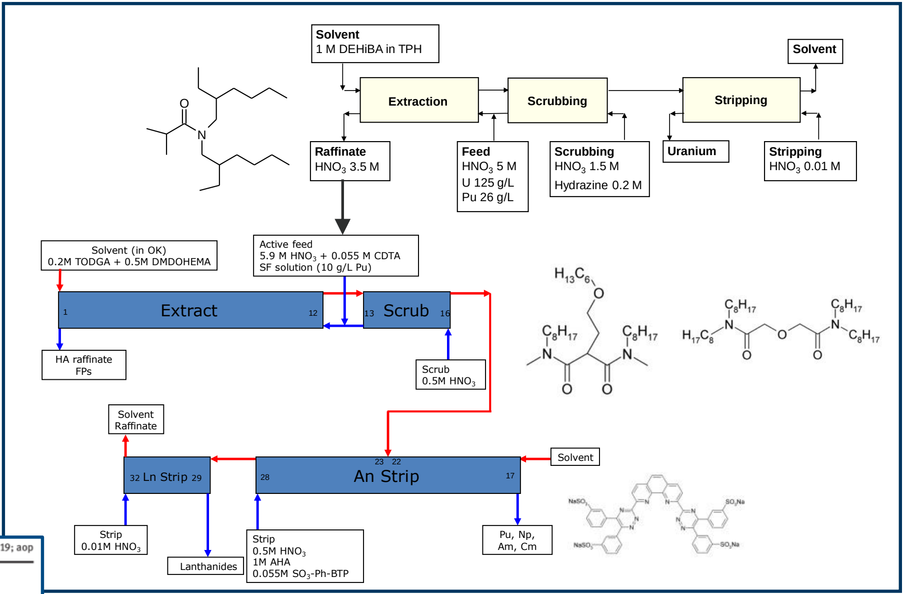
Aqueous Recycle

Homogeneous recycling

Current focus is GANEX (recovers U & all TRU)

GANEX (alternative to Advanced PUREX & i-SANEX):

- **GANEX = Grouped Actinide Extraction**
- **U extraction cycle (based on monoamide) [*developed by CEA*]**
- **TRU extraction cycle (similar to i-SANEX) – EURO-GANEX**
- **Developed under ACSEPT, SACSESS, GENIORS projects**
- **Fundamental chemistry explored**
- **Improved complexing agents developed (aqueous & organic phases**
- **Flowsheet testing of GANEX-1 and EURO-GANEX**
- **Hot test with SF proved concept**
- **Impacts of radiation doses on solvent**
- **Interfacing with conversion process**



DE GRUYTER Radiochim. Acta 2019; aop

Rikard Malmbeck, Daniel Magnusson, Stéphane Bourg, Michael Carrott, Andreas Geist*, Xavier Hérès, Manuel Miguirditchian, Giuseppe Modolo, Udo Müllich, Christian Sorel, Robin Taylor and Andreas Wilden

Homogenous recycling of transuranium elements from irradiated fast reactor fuel by the EURO-GANEX solvent extraction process

GENIORS GEN IV integrated oxide fuels recycling strategies

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NNL's *Sim Plant*

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Developing range of tools & techniques to evaluate fuel cycle options

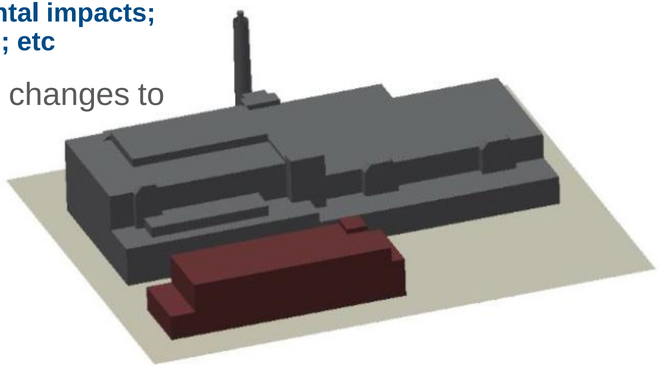
- **Electricity supply; environmental impacts; economics; proliferation risks; etc**

Sim Plant quantifies the benefits of changes to reprocessing flowsheets:

- **Waste production**
- **Plant size**
- **Nuclear materials flow**
- **(Costs)**
- **(Dose)**

Demonstrate impact of R&D at the plant and site scale

Identify key focus areas for future R&D that maximise impacts on wastes, plant size, costs etc



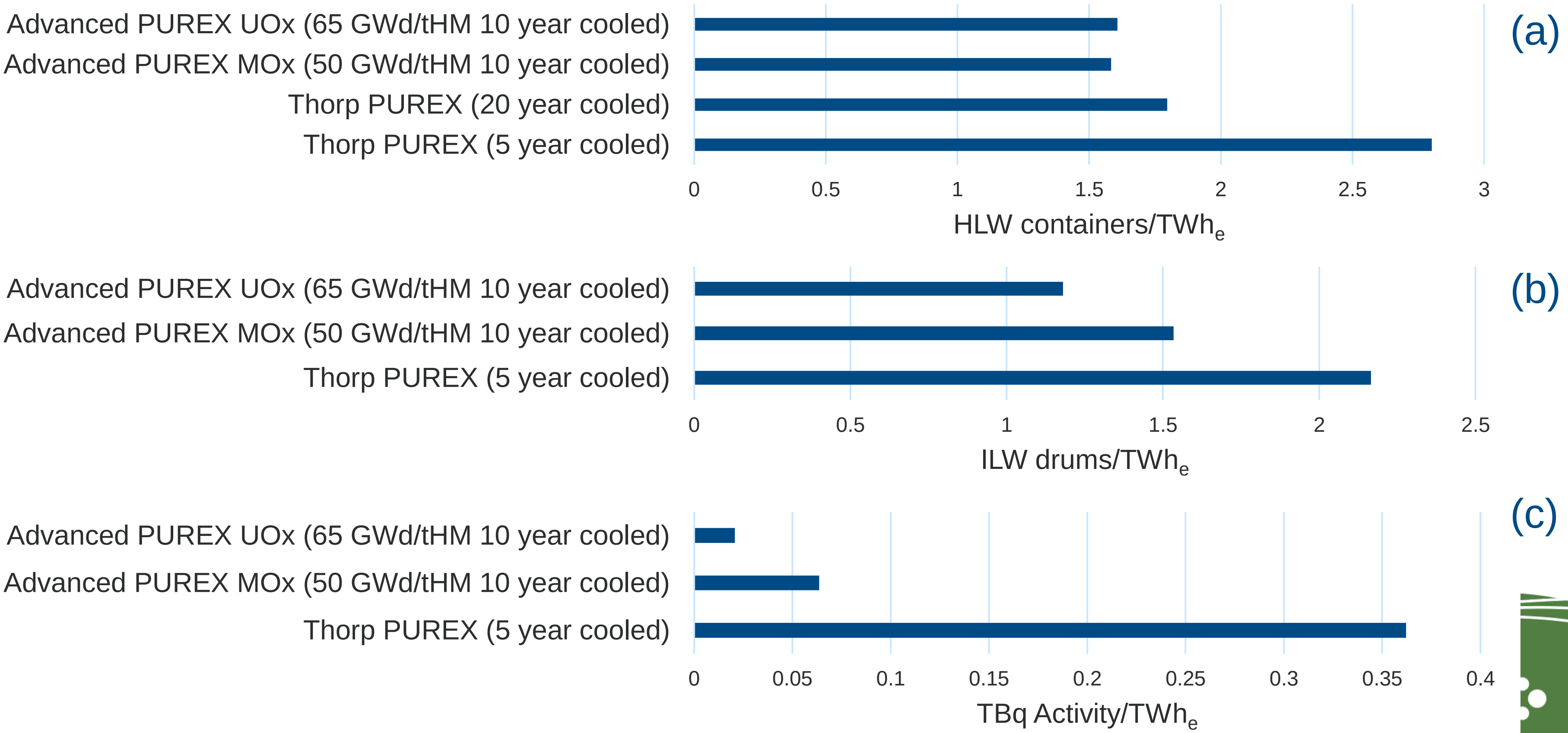
Approach:

- A suite of mass flow models to compare the new processes relative to conventional reprocessing operations
- Flowsheets for reprocessing and waste management (ILW, HLW, solvent)
- Inclusion of plant sizing models

Relative calculations!

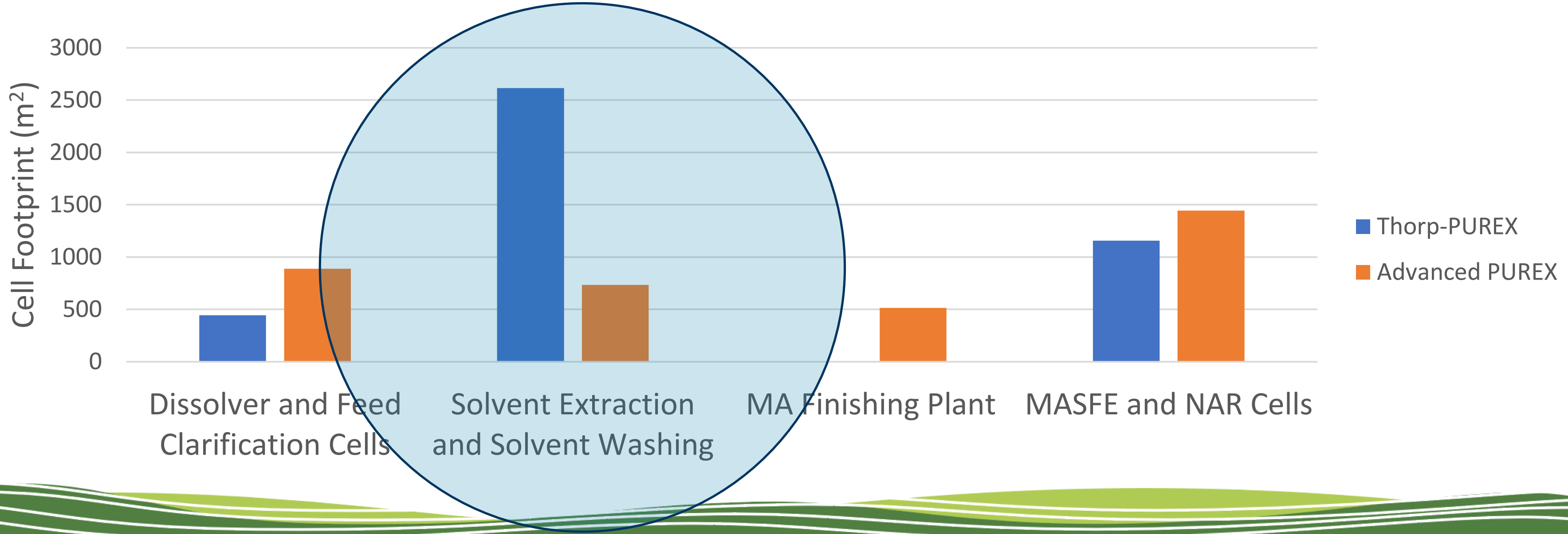
NOTE: the results use the Advanced PUREX process but conventional WM processes, i.e. (as yet) no account for process development in WM technologies

(a) HLW, (b) ILW & (c) liquid effluents normalised per TWh_e



Sizing and Footprint Evaluation: Reprocessing

Impact of R&D: The Advanced PUREX flowsheet, using centrifugal contactors, results in a much smaller Solvent Extraction process footprint



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Summary

AFCP is maintaining UK fuel cycle skills

- **And building new capabilities and wider UK networks at the R&D level**

AFCP is developing options that promote sustainability and de-risk deployment of ANT

- **Collaborating internationally, including European projects (GENIORS, PUMMA & PATRICIA)**

Advanced recycle options under development in UK & internationally

- **Flexible, advanced processes that reduce costs, wastes, environmental impacts & add proliferation barriers**
- **Trends in separations towards single cycle concepts, use of centrifugal contactors, mixed actinide products and complexation rather than redox reactions**
- **Separation processes are in the TRL range 3-6 (development through to demonstration)**
- **Interfacing with upstream, downstream & ancillary processes important next step towards industrialisation**

AFCP is developing modelling tools to evaluate fuel cycle options

- **E.g. NNL Sim Plant highlights reductions in wastes & plant size achievable through R&D**