THE ASOF PROJECT - ADVANCED SEPARATION FOR THE OPTIMAL MANAGEMENT OF SPENT FUEL

BRUGGEMAN CHRISTOPHE, CARDINAELS THOMAS, VAN HECKE, KAREN, VERGUTS KEN, VERWERFT MARC, LEINDERS GREGORY, LEMMENS KAREL, FERRAND KARINE, QUOC TRI PHUNG, FREDERICKX LANDER, WEETJENS EEF, GEYSMANS ROBBE

Belgian Nuclear Research Centre SCK CEN, Boeretang 200, 2400 Mol, Belgium

With the help of the Belgian Energy Transition Fund under the FOD/SPF economie

Introduction

- Since 1975: nuclear energy as energy source in Belgium
  - Irradiated (spent/used) nuclear fuel (SNF)
    - < 1993: Reprocessing + reuse (MOX-fuel)
    - > 1998: De facto moratorium for reprocessing of commercial SNF
      - 672 ton irradiated fuel reprocessed
      - ~4000 ton not reprocessed (wet + dry storage)

- Management options for irradiated fuel: direct influence on amount and radiotoxicity of final radioactive waste inventory
  - Direct disposal (open cycle)
  - Disposal of VHLW after reprocessing (closed cycle)
    - Full or partial reprocessing
  - Advanced separation/partitioning → Project ASOF
  - Burning/transmutation

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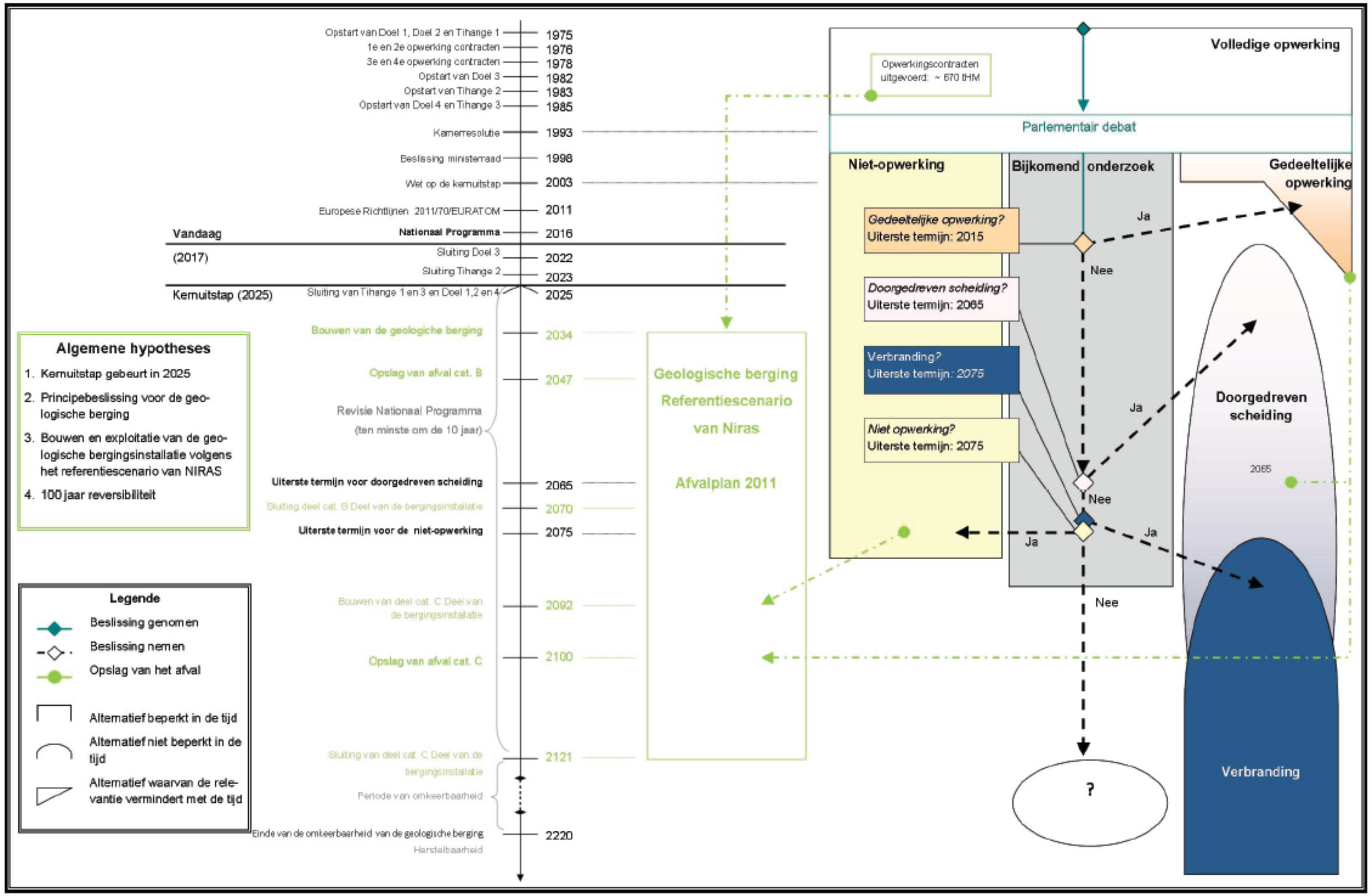
FOD Economy, Vergelijkende studie van de beheersstrategieën van de Belgische splijtstof, 2017

Introduction

Window of opportunity to study and implement different management options



FOD Economy, Vergelijkende studie van de beheersstrategieën van de Belgische splijtstof, 2017

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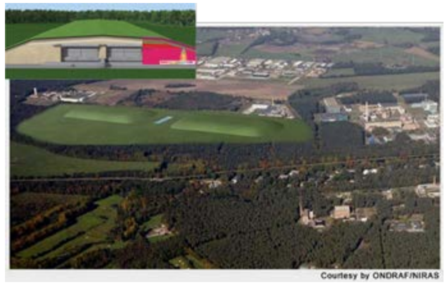
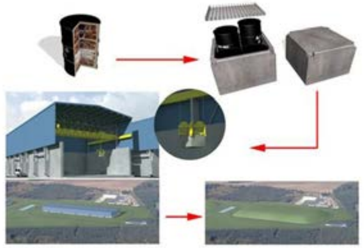
Management of Belgian radioactive waste

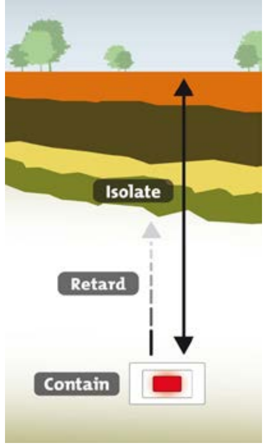
- Short-lived low and intermediate level waste (category A)

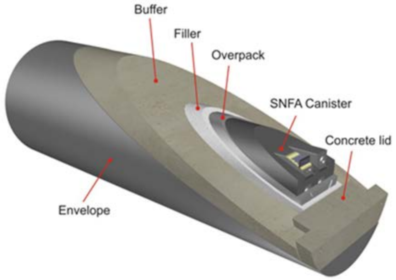


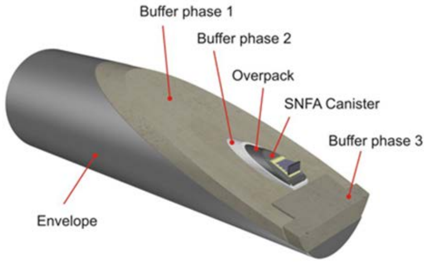


Near-surface disposal site in Dessel
Operations to be started 2027

- Long-lived and/or high-level waste (category B&C)







No decision yet
Reference = deep geological disposal in poorly indurated clay formation
Supercontainer design for HLW

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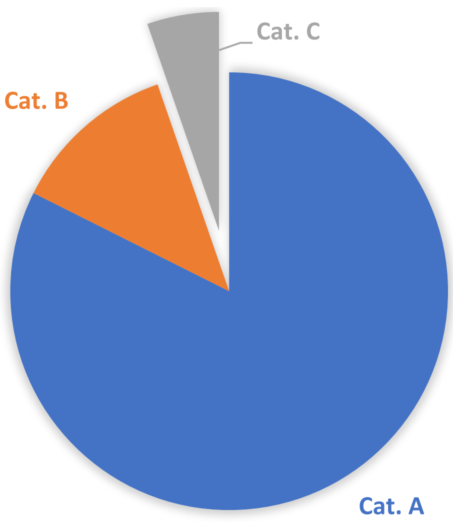
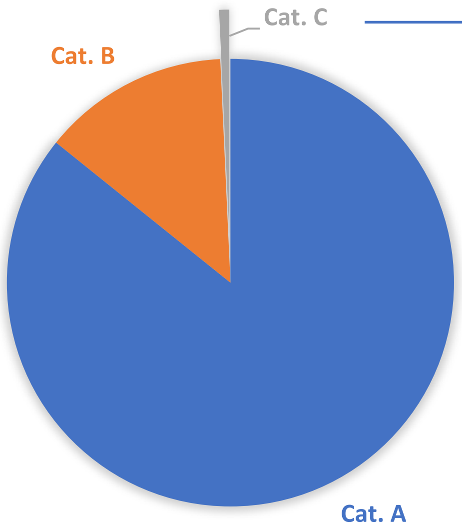
Management of Belgian radioactive waste

- Impact of spent fuel management options on final disposal
  - Impact on final inventory to be disposed

Without reprocessing



With reprocessing

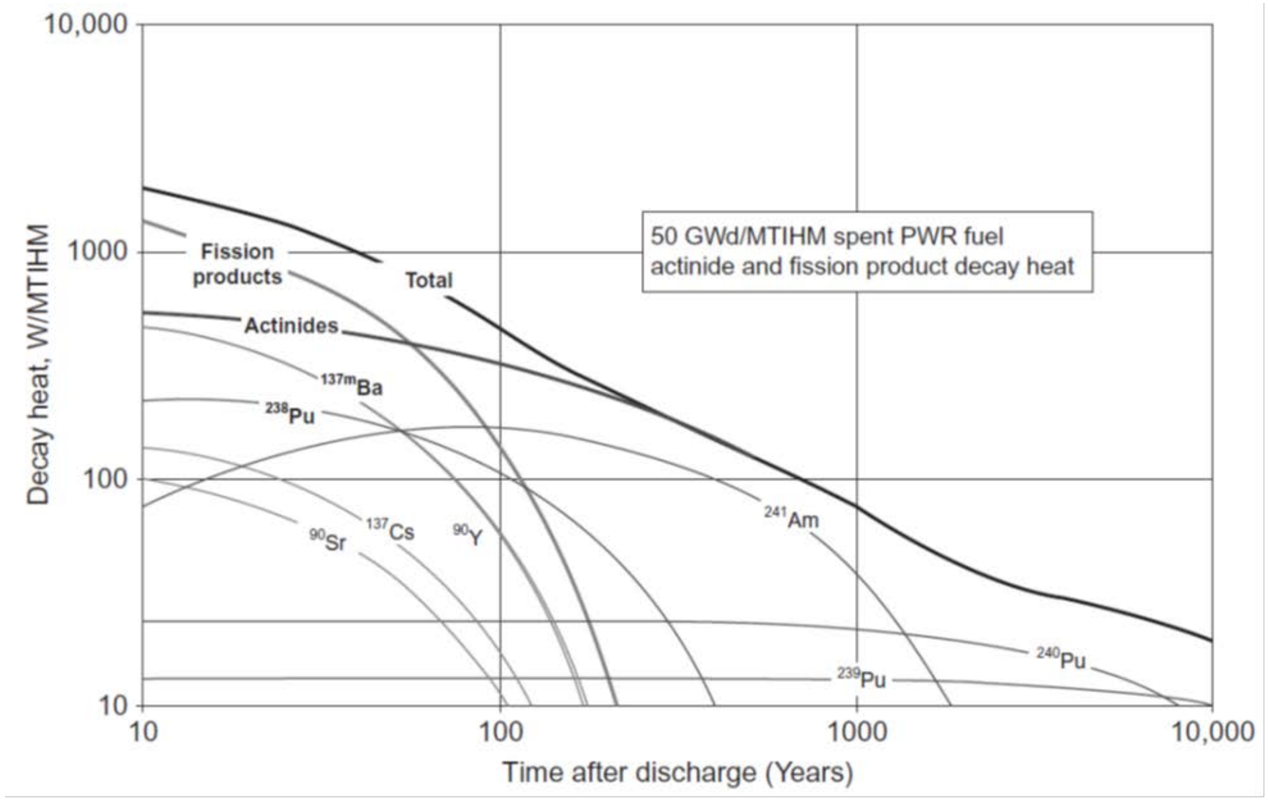


- Change in relative amounts of category B&C waste
- Decrease footprint

What would be the effect of advanced partitioning scenario?

Management of Belgian radioactive waste

- Impact of spent fuel management options on final disposal
  - Impact on residual decay heat of the final waste form



Adapted from Taylor, 2015

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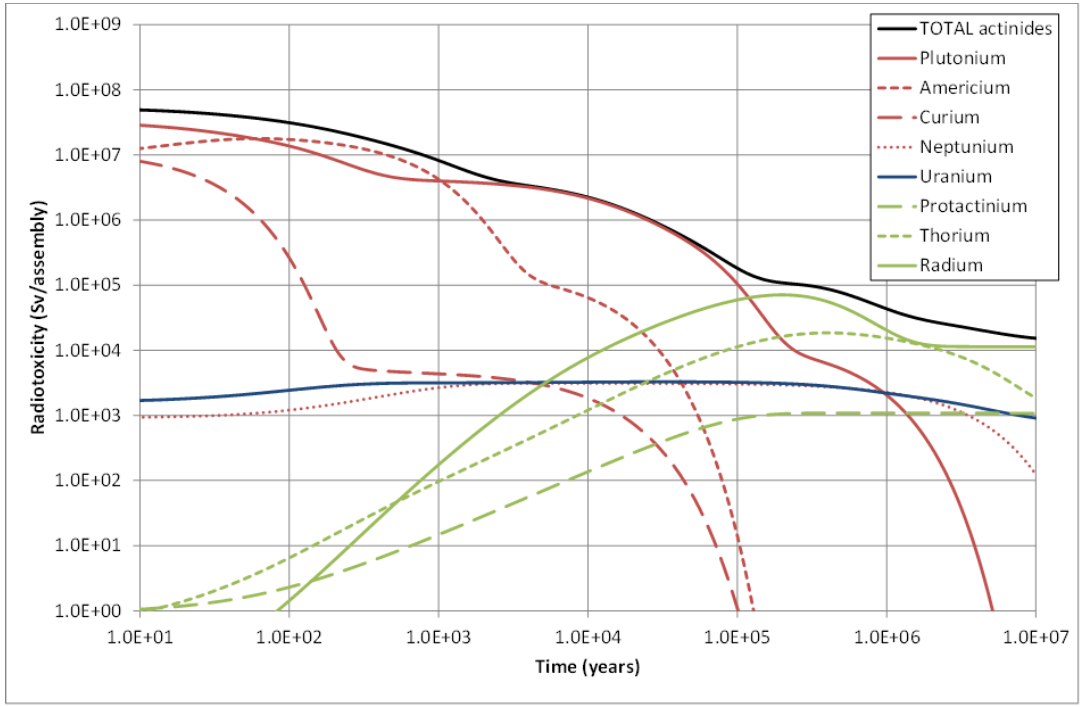
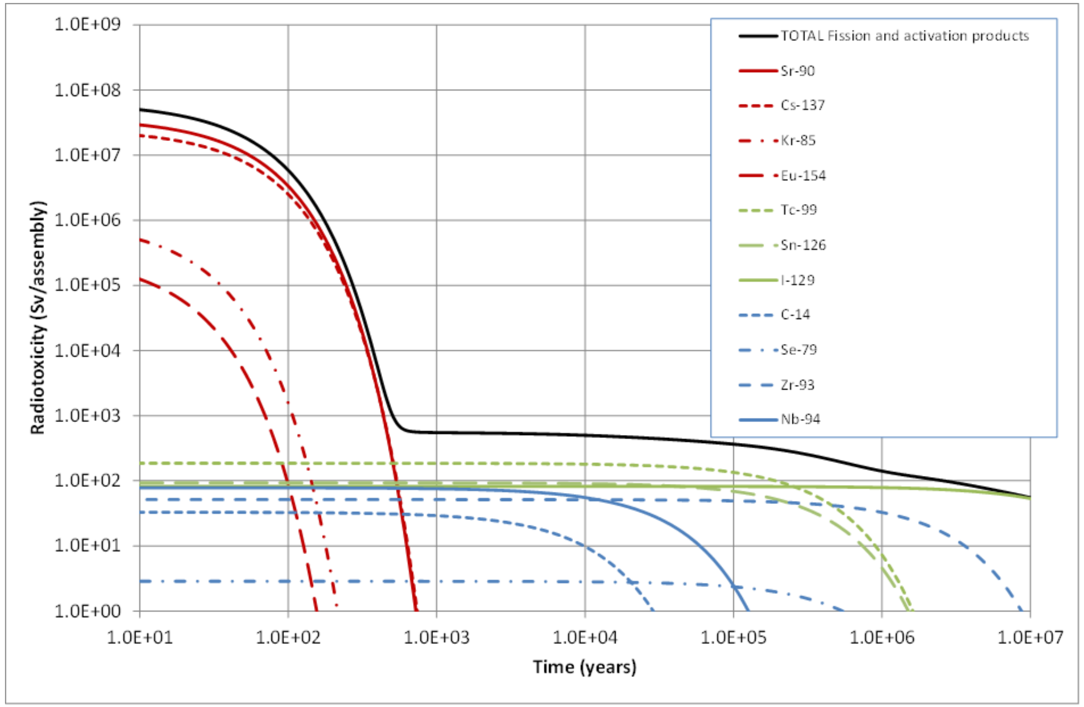
Management of Belgian radioactive waste

- Impact of spent fuel management options on final disposal
  - Impact on radiotoxicity of the final waste to be disposed of



Contribution of actinides



Contribution of fission products

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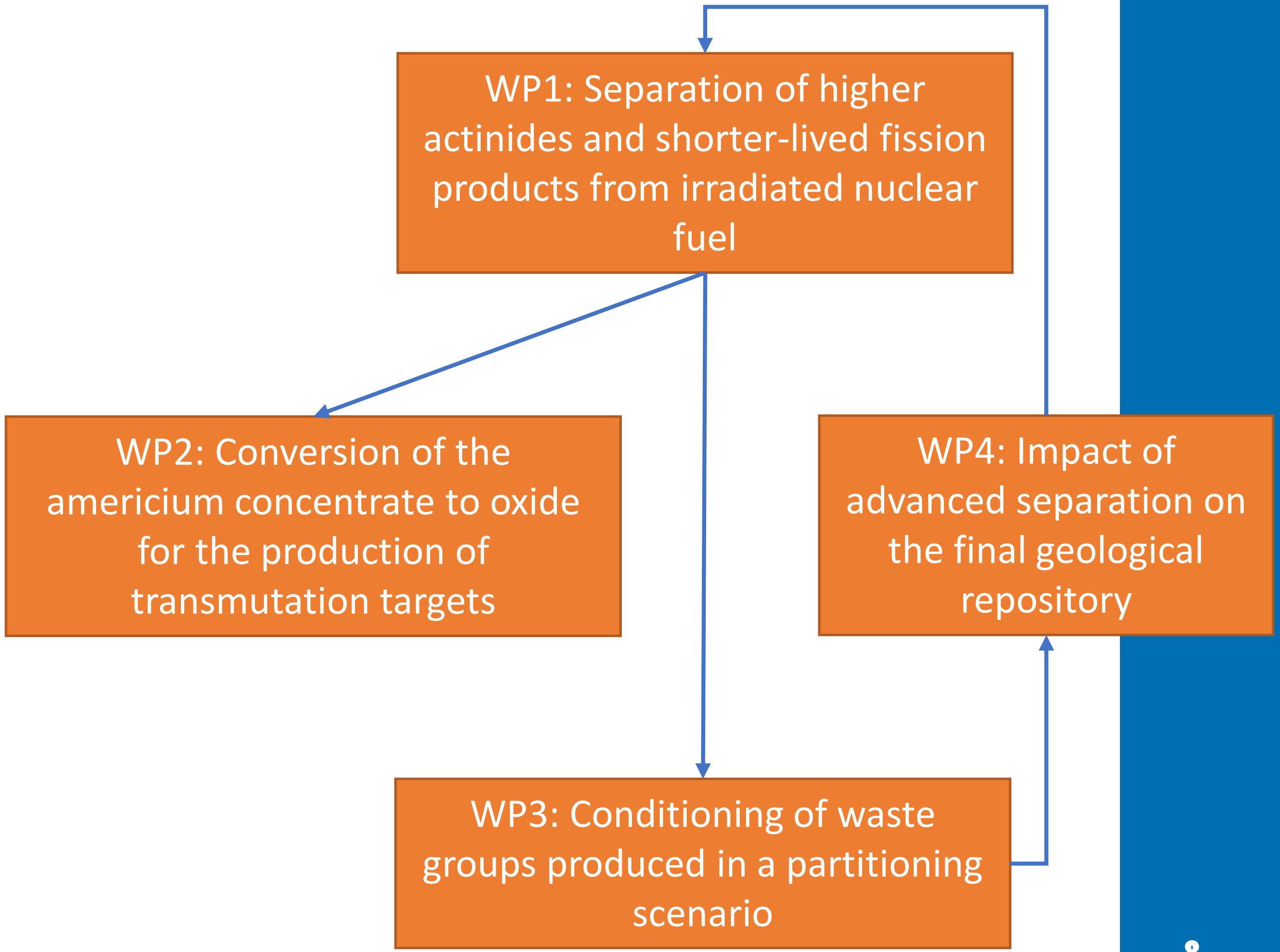
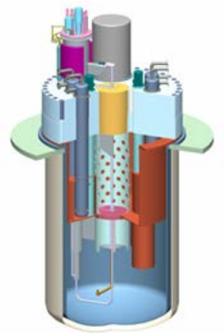
The ASOF project

- To build expertise and competency and advance fundamental R&D on Belgium level in order to make more informed decisions concerning the “advanced separation/partitioning” option for Belgian nuclear spent fuel.
- In line with the Belgian decision to build MYRRHA as a demonstrator transmutation facility





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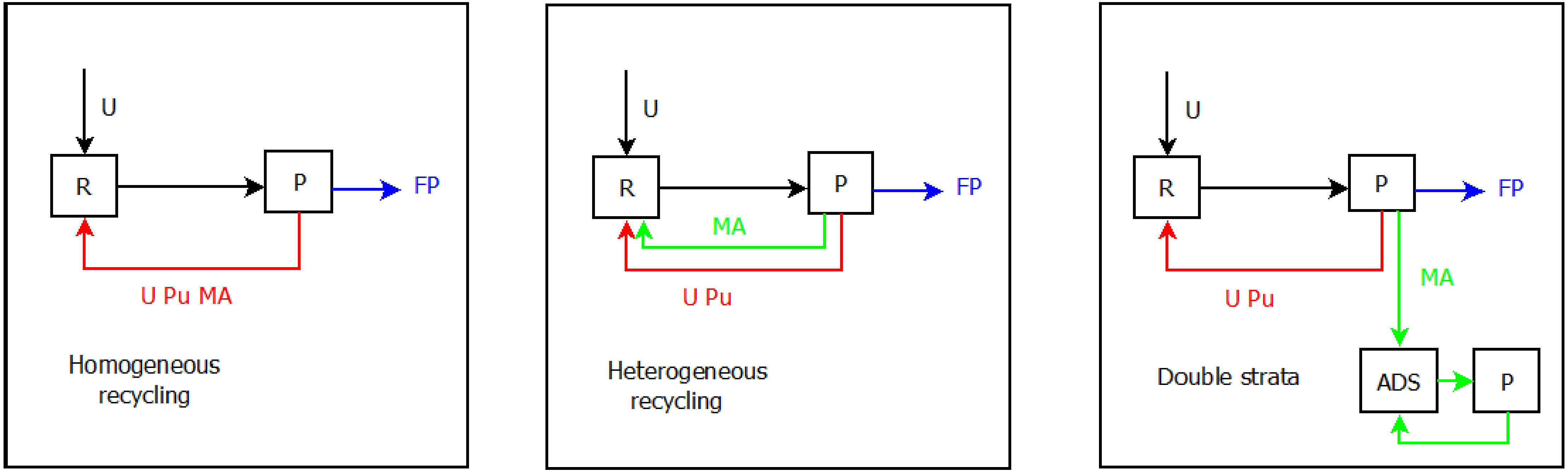
Transmutation strategies



Overview of the different partitioning (removal of U, Pu, MA and FP from spent fuel) and transmutation strategies in a fleet of nuclear reactors, adapted from [1]. The symbols R and P denote the reactor fleet and the partitioning process, respectively. (a) Homogeneous recycling: U, Pu and MA are recycled as MOX fuel with small amounts of MA. (b) Heterogeneous recycling: U and Pu are recycled as MOX fuel, while MA are fabricated as separate target materials and transmuted in the periphery of the reactor. (c) Double strata: U and Pu are recycled as MOX fuel, while MA (and some specific Pu isotopes) are fissioned and recycled in a dedicated ADS.

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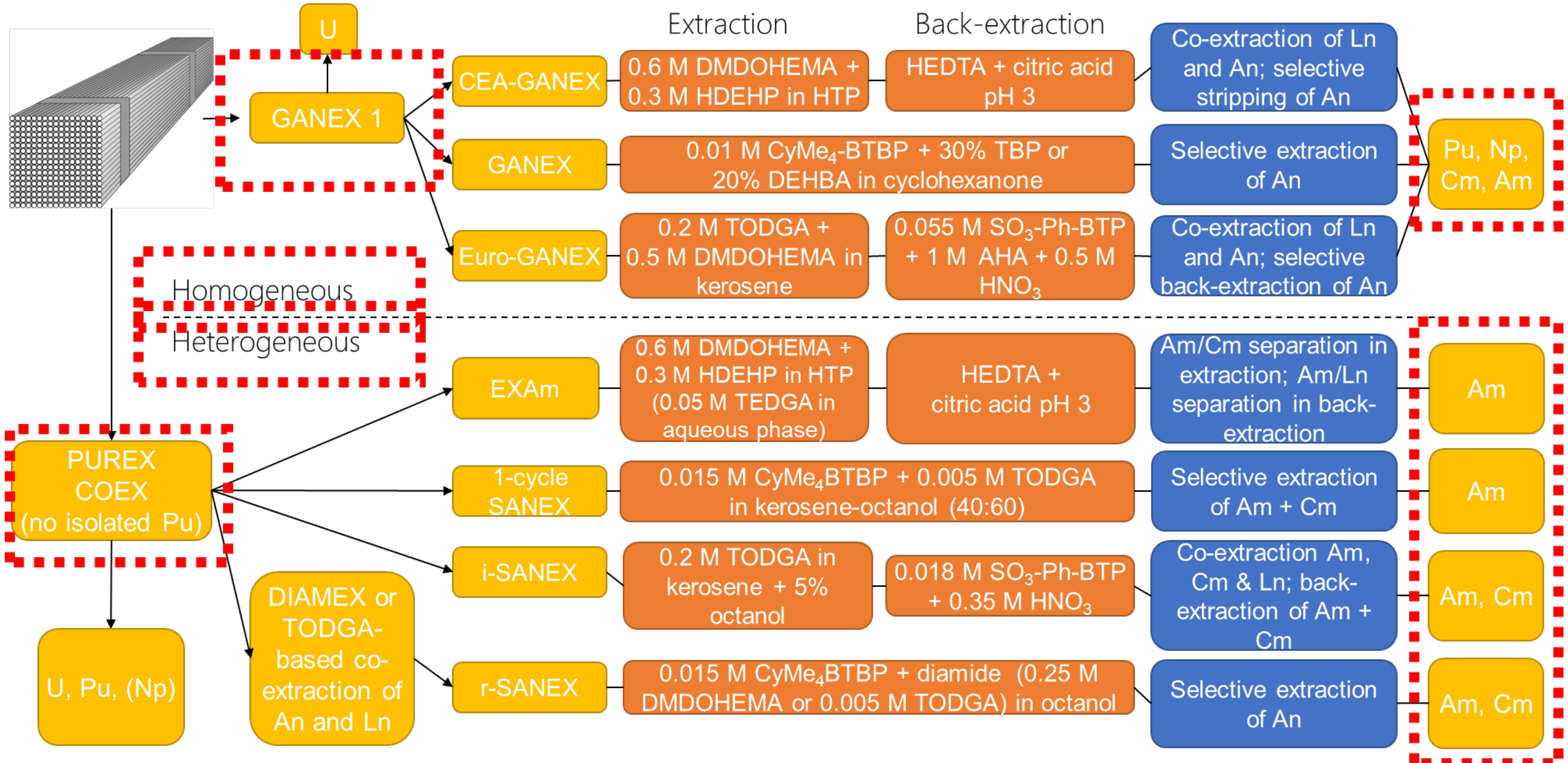
[1] Pillon, S., *3.05 - Actinide-Bearing Fuels and Transmutation Targets* in *Comprehensive Nuclear Materials*, Elsevier, Oxford, **2012**, pp. 109-141.

WP1: Advanced partitioning

- R&D on advanced separation processes following the (well-proven) UREX/PUREX process



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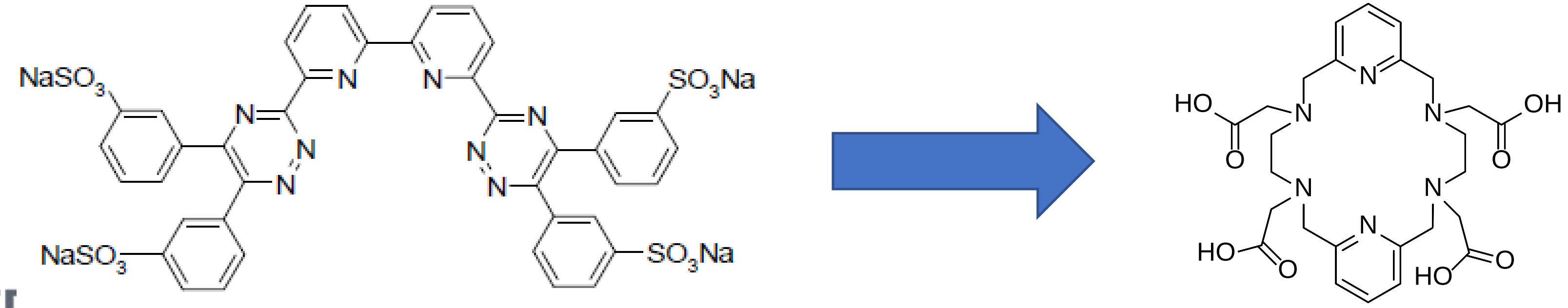
WP1: Advanced partitioning

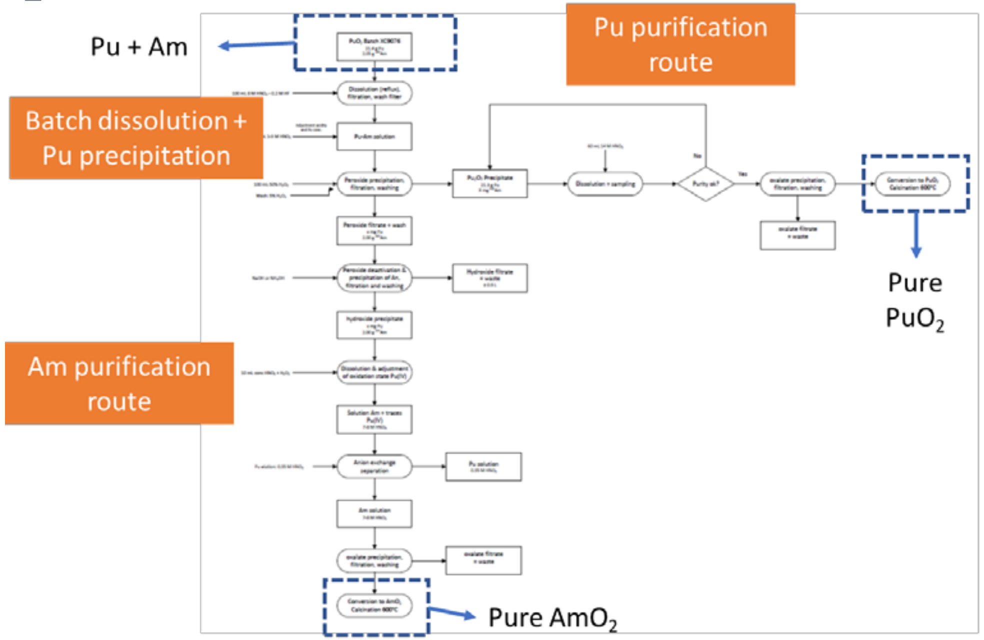
- Separation of actinides (→ Am)
  - Optimisation DIAMEX/SANEX processes in terms of radiation tolerance and stability by modification of the solvent (*e.g.* ionic liquids)
  - AmSel process: Extract Am, Cm and Ln first, then selectively strip Am



Development of new molecules

WP1: Advanced partitioning

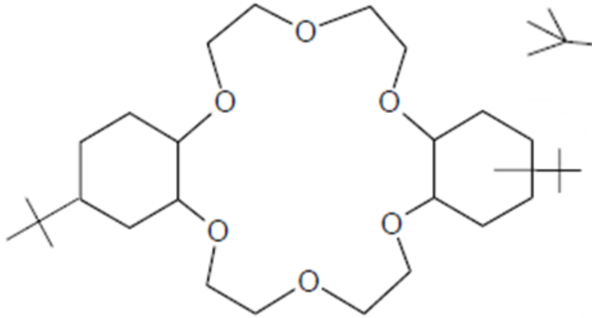
- Separation of actinides (→ Am)
  - Optimisation DIAMEX/SANEX processes in terms of radiation tolerance and stability by modification of the solvent (*e.g.* ionic liquids)
  - AmSel process: Extract Am, Cm and Ln first, then selectively strip Am
  - Separation of Am and Pu from an old PuO_2 batch
    - Batch dissolution
      - Selective Pu precipitation
    - Pu purification
      - Pure PuO_2
    - Am purification
      - Pure AmO_2



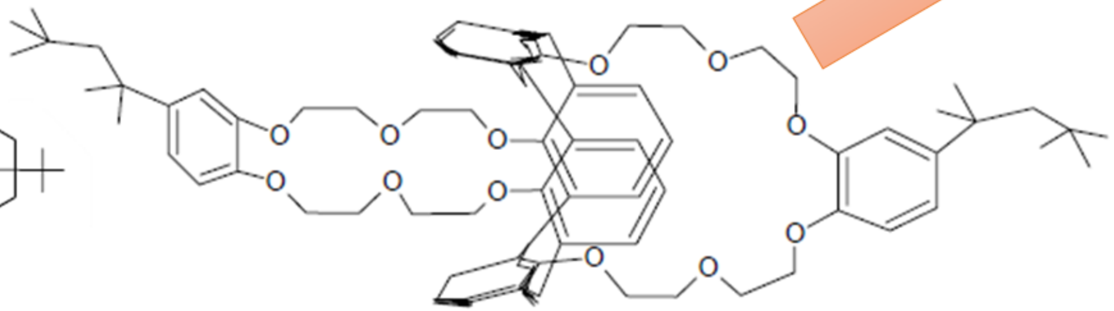
WP1: Advanced partitioning

- Study and development of innovative partitioning techniques for separation of Cs and Sr (FPEX process)
- SOTA developed by US DOE
  - Combined Cs and Sr extraction using two extractants:
    - Sr extractant: DtBuCH18C6 **(1)**
    - Cs extractant BOBCalixC6 **(2)**
    - Modifier: 'Cs-7SB' **(3)**

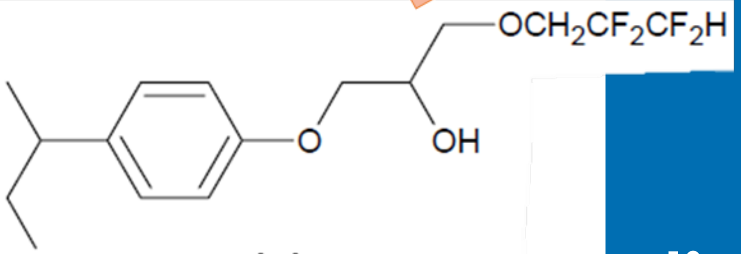
Replaced @ SCK by new, promising CHON compliant molecules



(1)



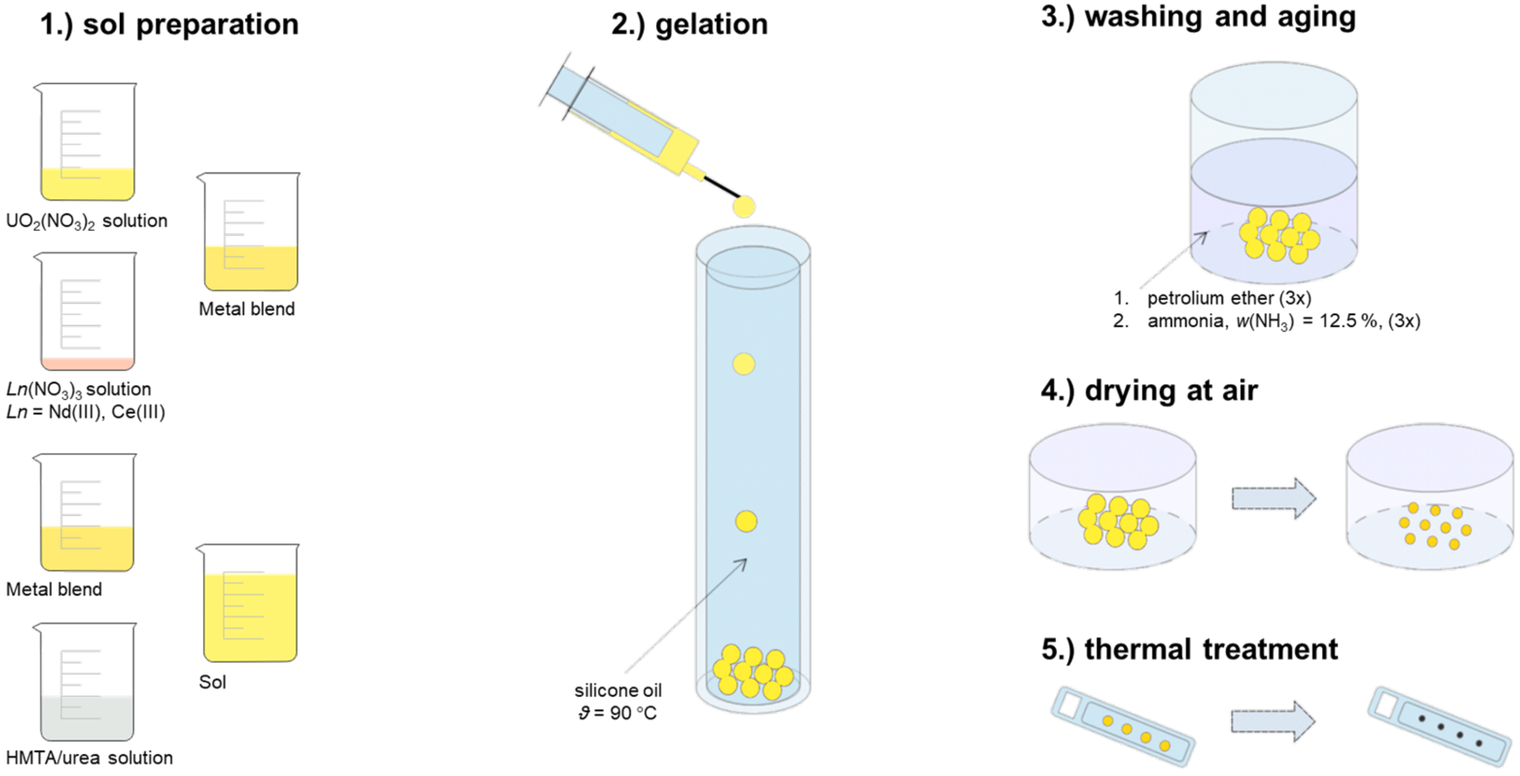
(2)



(3)

WP2: Conversion of Am

- Innovative fabrication of Am-containing targets through sol-gel process via internal gelation resulting in $(U, Am)O_{2-x}$ microspheres



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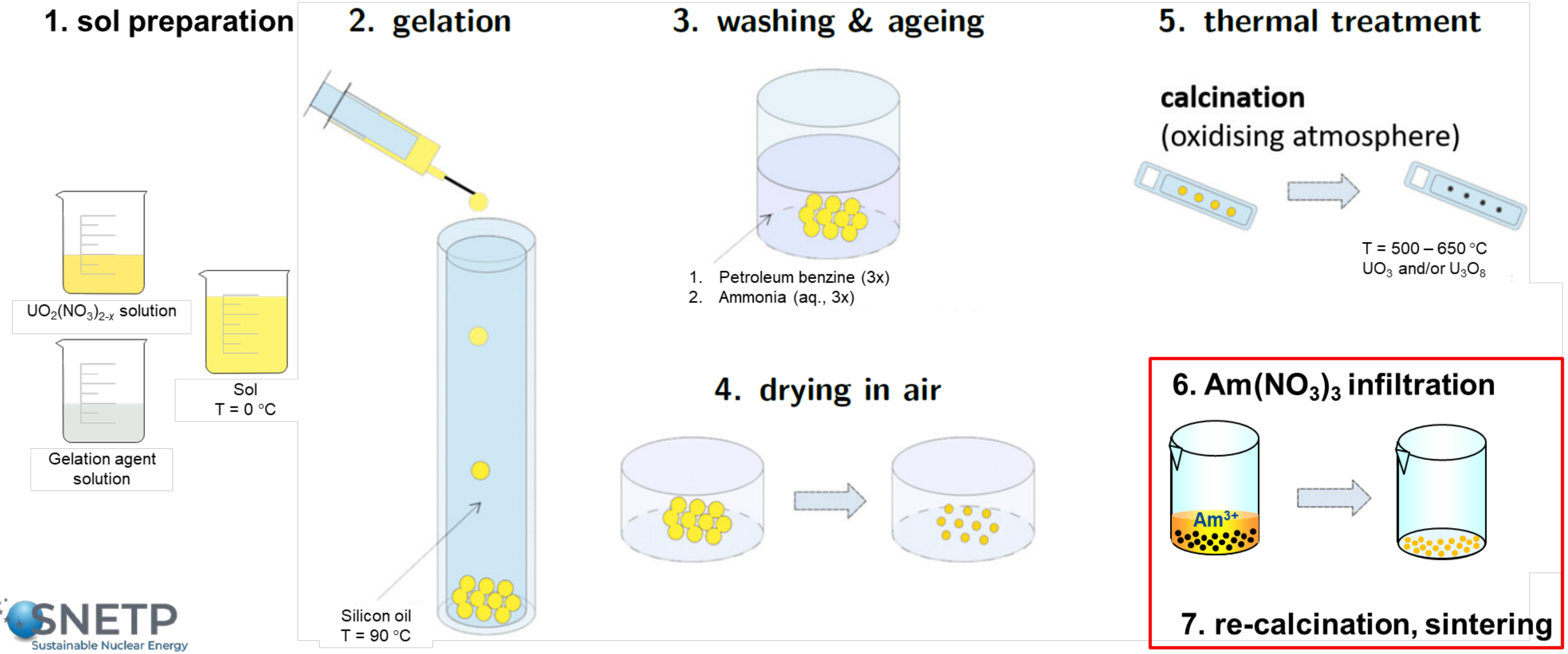
WP2: Conversion of Am

- Hybrid internal gelation + infiltration route



Shielded environment

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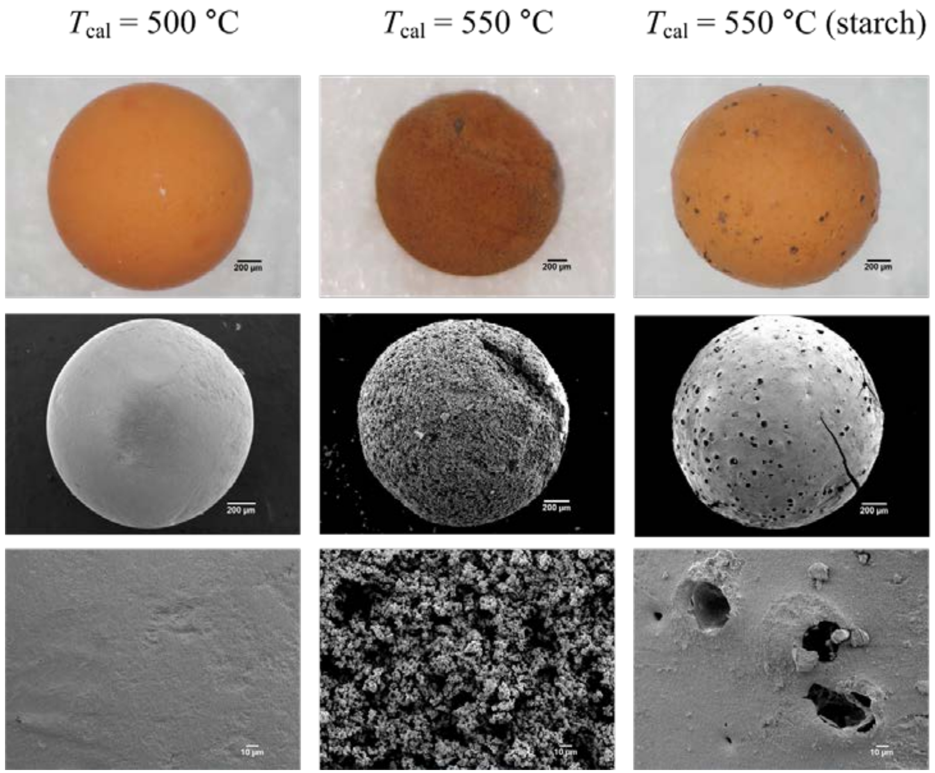
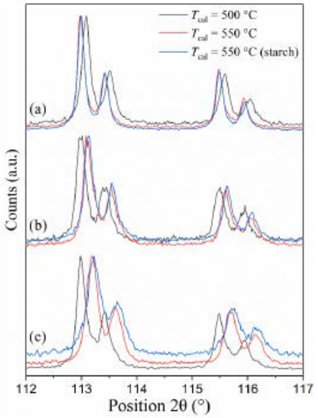
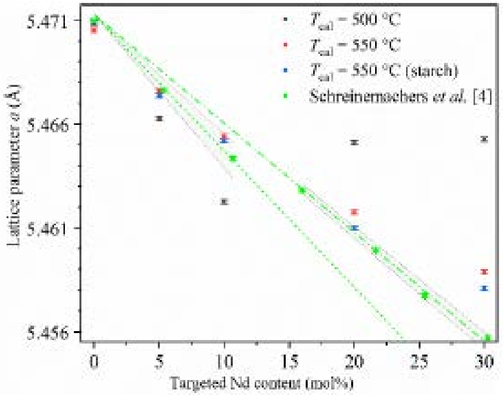
WP2: Conversion of Am

- From internal gelation to infiltration





T_{cal} (°C)	Pore former used	Target χ(Nd) (mol%)	Lattice parameter *a* (Å)	Actual χ(Nd) (*mol%*)
500	none	5	5.4663(1)	9.4
		10	5.4623(1)	16.9
		20	5.4651(1)	11.6
		30	5.4653(1)	11.3
550	none	5	5.4676(1)	6.9
		10	5.4654(1)	11.0
		20	5.4618(1)	17.8
		30	5.4589(1)	23.3
550	starch	5	5.4674(1)	7.3
		10	5.4652(1)	11.4
		20	5.4610(1)	19.3
		30	5.4581(1)	24.7



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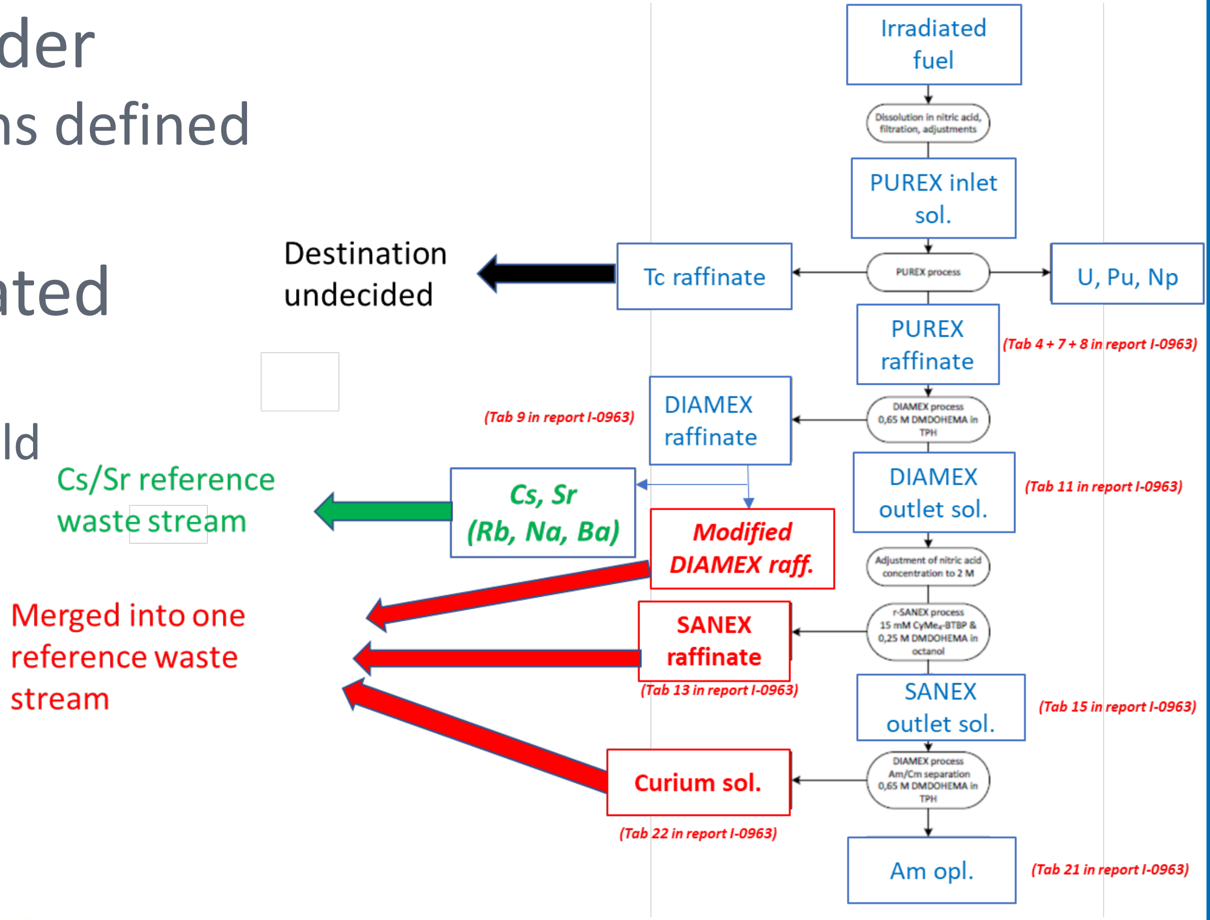
WP3: New conditioning routes

- 2 Main waste streams to consider
  - Simplified reference compositions defined
  - Mostly HNO_3 based
- 2 Conditioning routes investigated
  - HIPping/Synroc-type
    - Together with ANSTO+Univ Sheffield

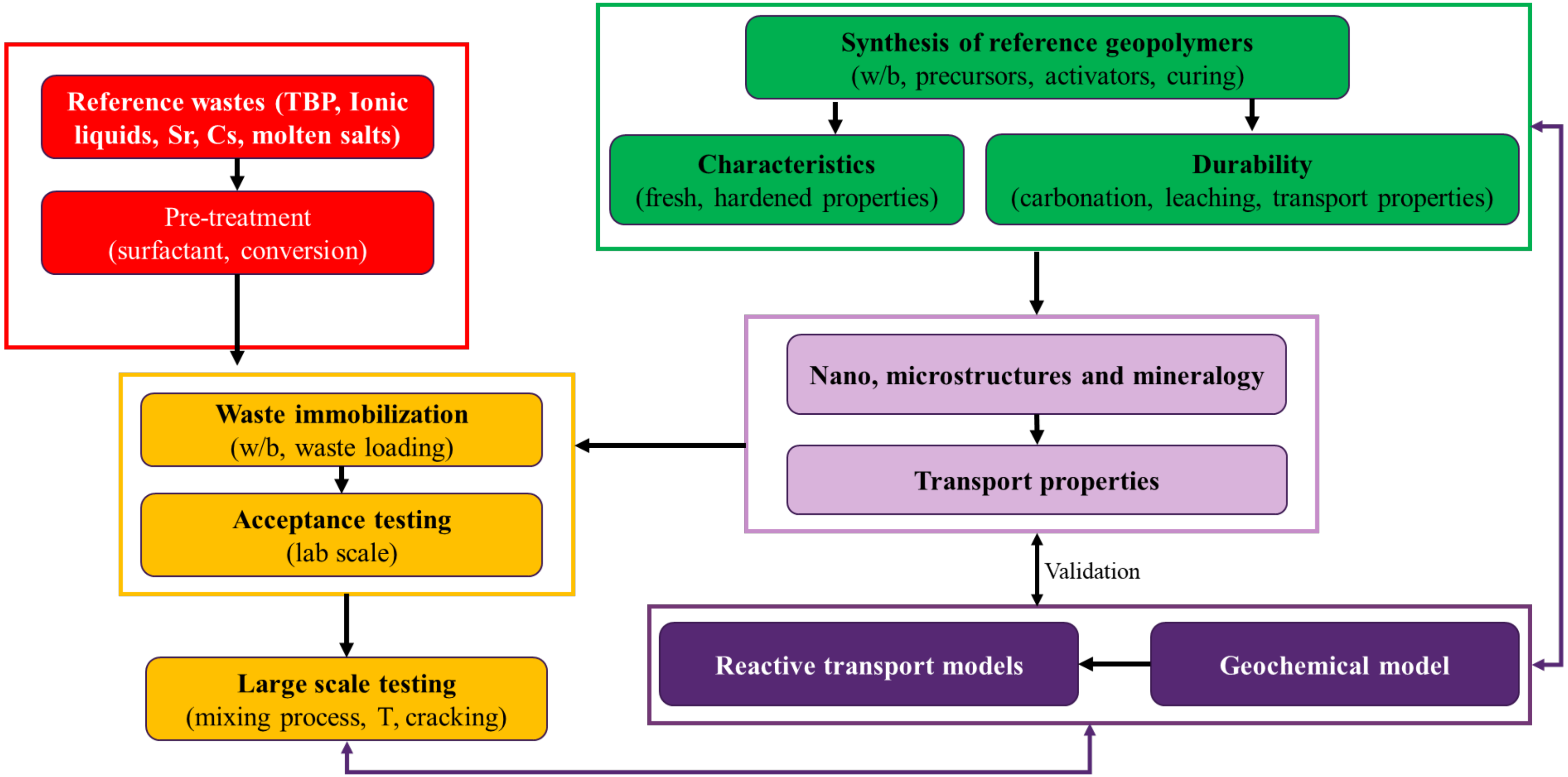
	Basic comp	Alternative comp
Cs+Sr	Low waste loading	Low waste loading
	High waste loading	High waste loading
Rest fraction	Low waste loading	Low waste loading
	High waste loading	High waste loading



  - Geopolymers

WP3: New conditioning routes

- Durability of geopolymers with potential for radioactive waste immobilization



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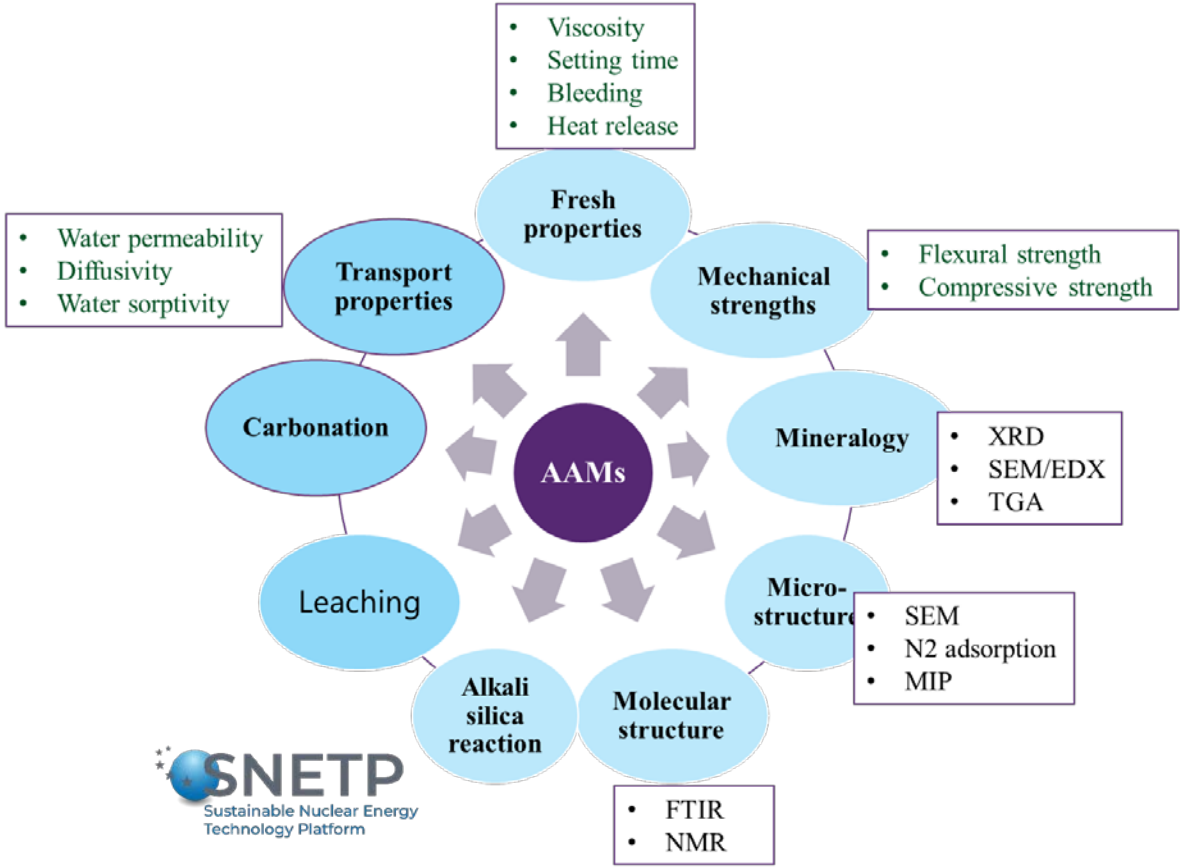
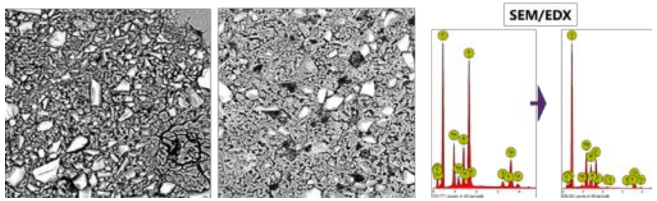
WP3: New conditioning routes

- Durability of geopolymers with potential for radioactive waste immobilization

Metakaolin-based geopolymers
BFS based alkali activated materials





7 days

14 days

28 days

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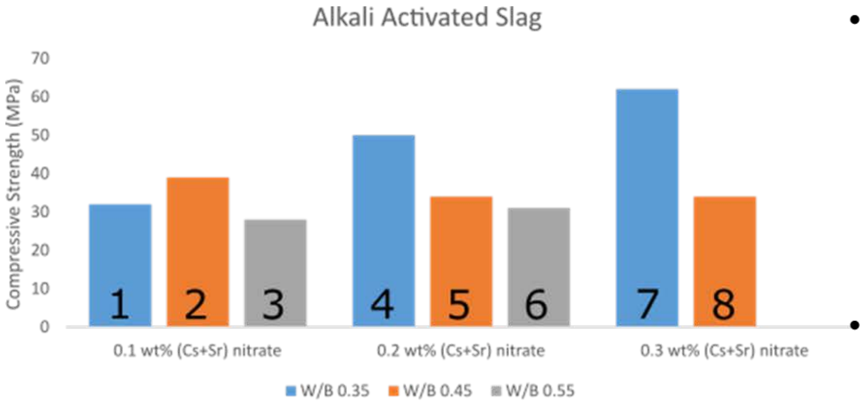
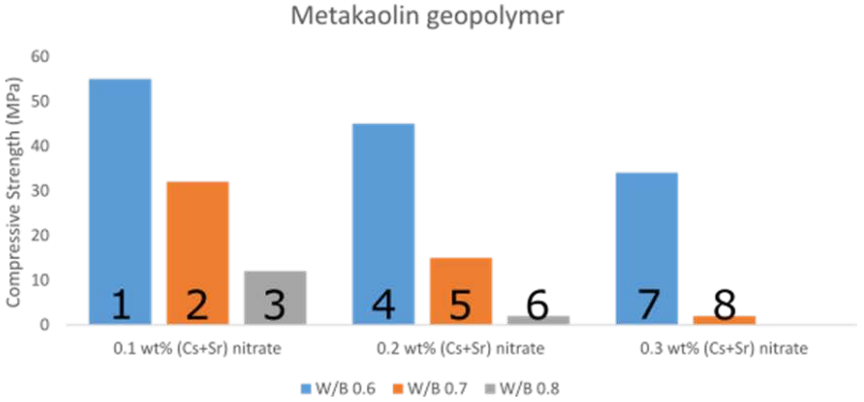
WP3: New conditioning routes

- Durability of geopolymers with potential for radioactive waste immobilization – incorporation of Cs+Sr



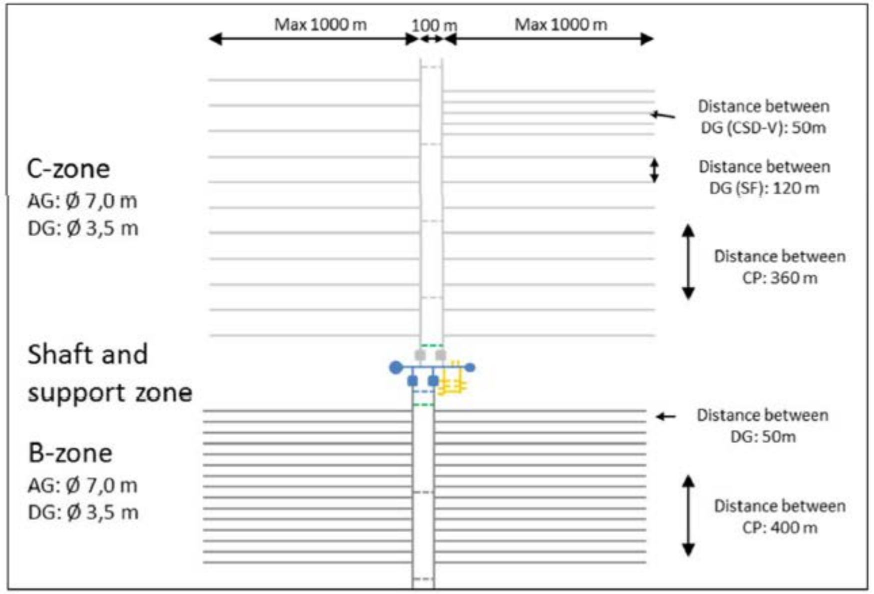


- Design of experiments to optimize the mechanical properties of alkali-activated materials in the presence of Cs- and Sr-nitrates
- Waste loadings were limited to 0.3 wt.% to contain the expected heat output in a storage scenario within acceptable limits

WP4 Impact

- Impact on GDF layout + footprint
  - Amounts of B+C waste
  - Heat ouput per can and/or m gallery
- Impact on final inventory radiotoxicity
  - No/limited effect long-term safety
    - LL mobile fission products
  - Radiotoxicity – intrusion scenarios
- Impact on societal parameters
  - Acceptability, fuel cycle policy and infrastructures, economics

Belgian ref GDF layout, 2020, NIRAS/ONDRAF



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Conclusion

Thank you!

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Contact us

www.snetp.eu

secretariat@snetp.eu

www.linkedin.com/company/snetp

@SNE_TP

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