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Modelling of a once-through MSR without online fuel processing

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The 4th Annual Serpent Users Group Meetings

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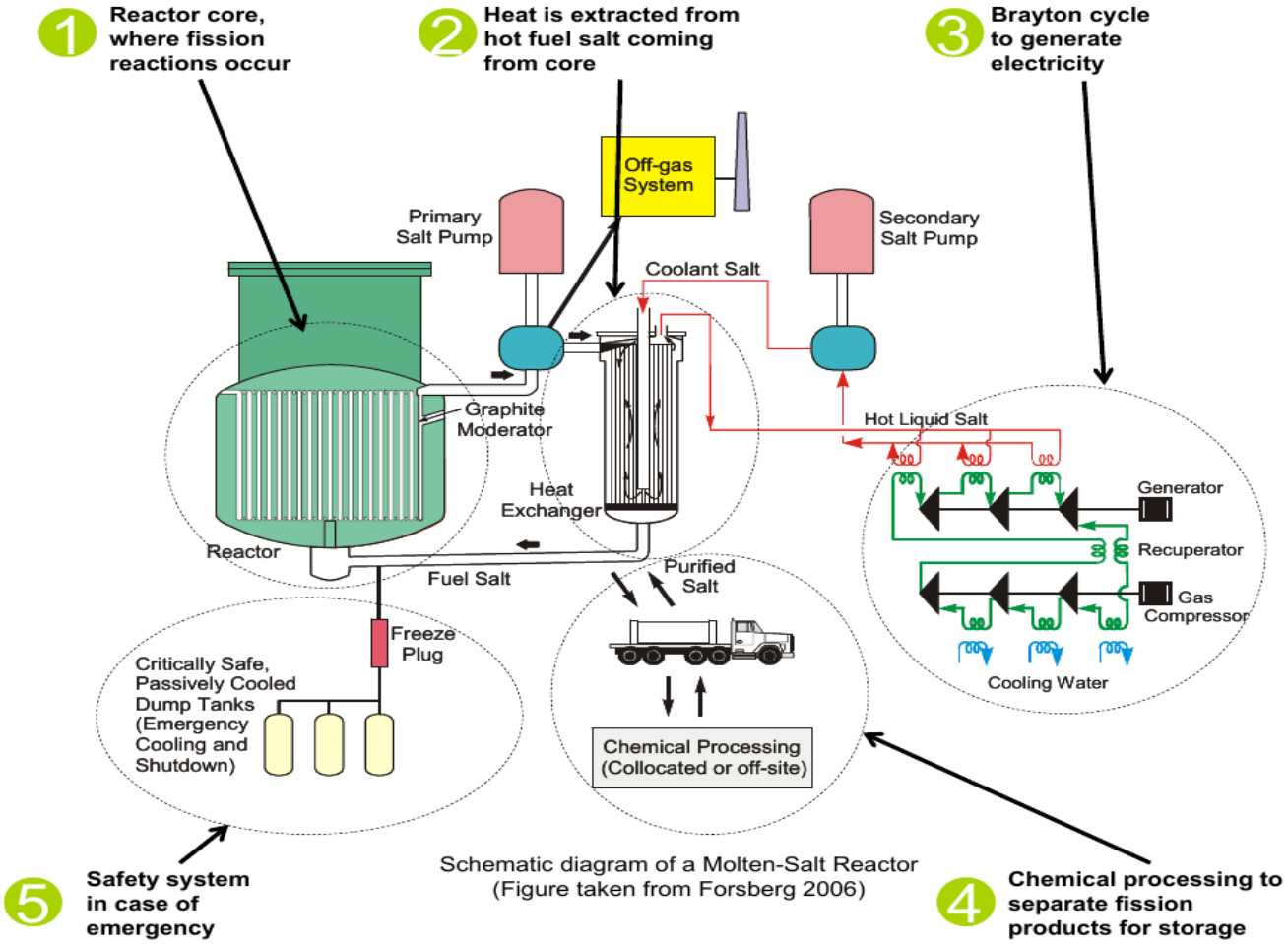
OUTLINE

1. Background & motivation
2. The Denatured Molten Salt Reactor (DMSR)
3. The Serpent model of the DMSR
4. Future work

Overview of the Molten Salt Reactor

- Fuel is in the form of molten halide salts(e.g. $^{233}UF_4/^{232}ThF_4$ dissolved in LiF & BeF_2 (FLiBe))

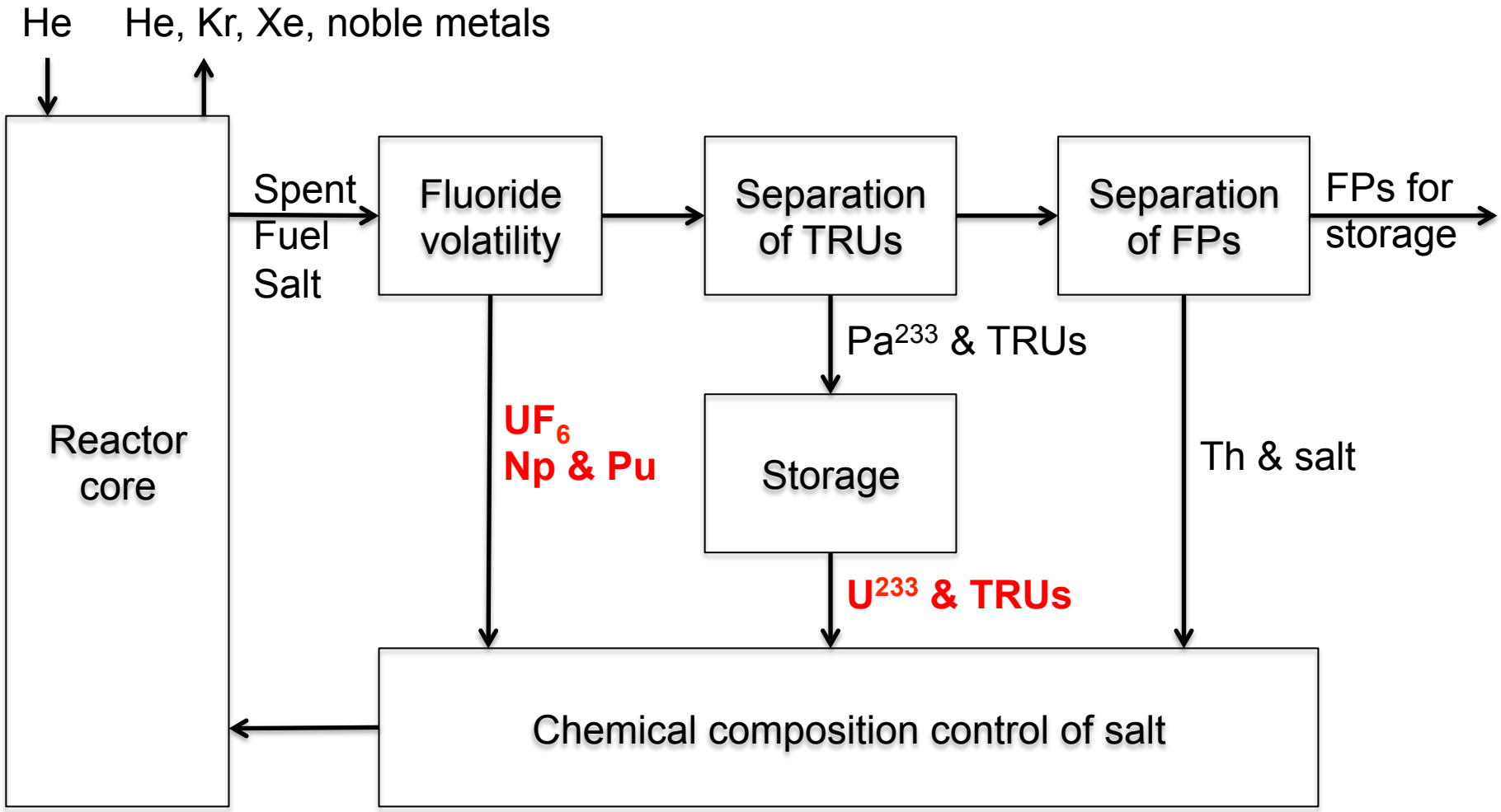
- Advantages include higher efficiency, higher fuel utilisation and improved safety



Schematic diagram of a Molten-Salt Reactor
(Figure taken from Forsberg 2006)

Forsberg, C W. (2006). Molten-Salt-Reactor Technology Gaps. In *2006 International Congress on the Advances in Nuclear Power Plants (ICAPP '06)*. Reno, Nevada.

Proliferation & hazardous risk of online fuel reprocessing



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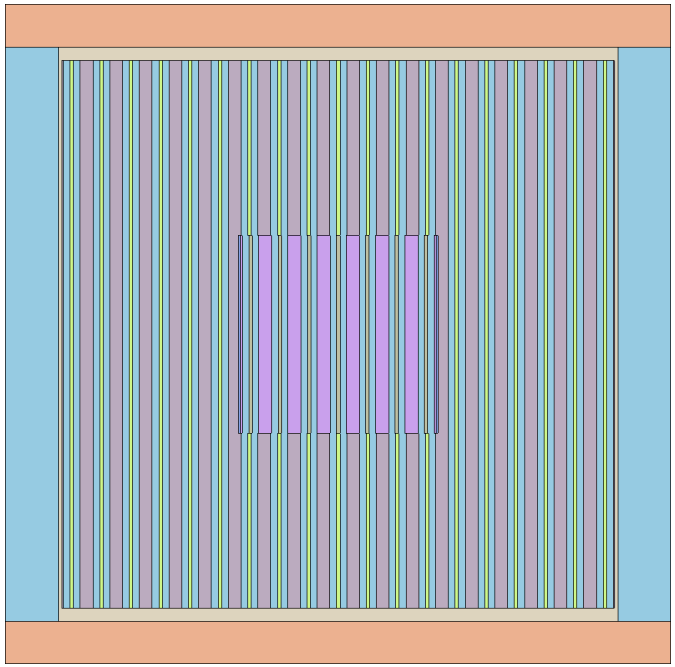
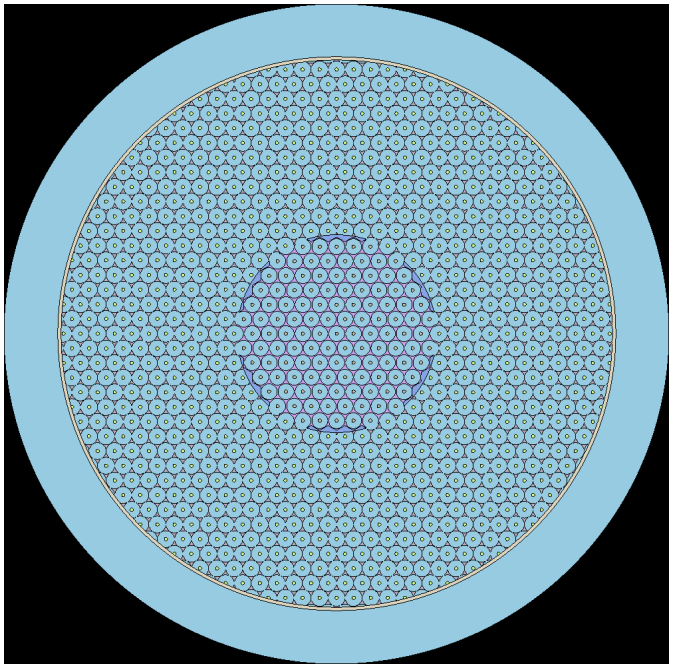
The Denatured Molten Salt Reactor: The simplest MSR design

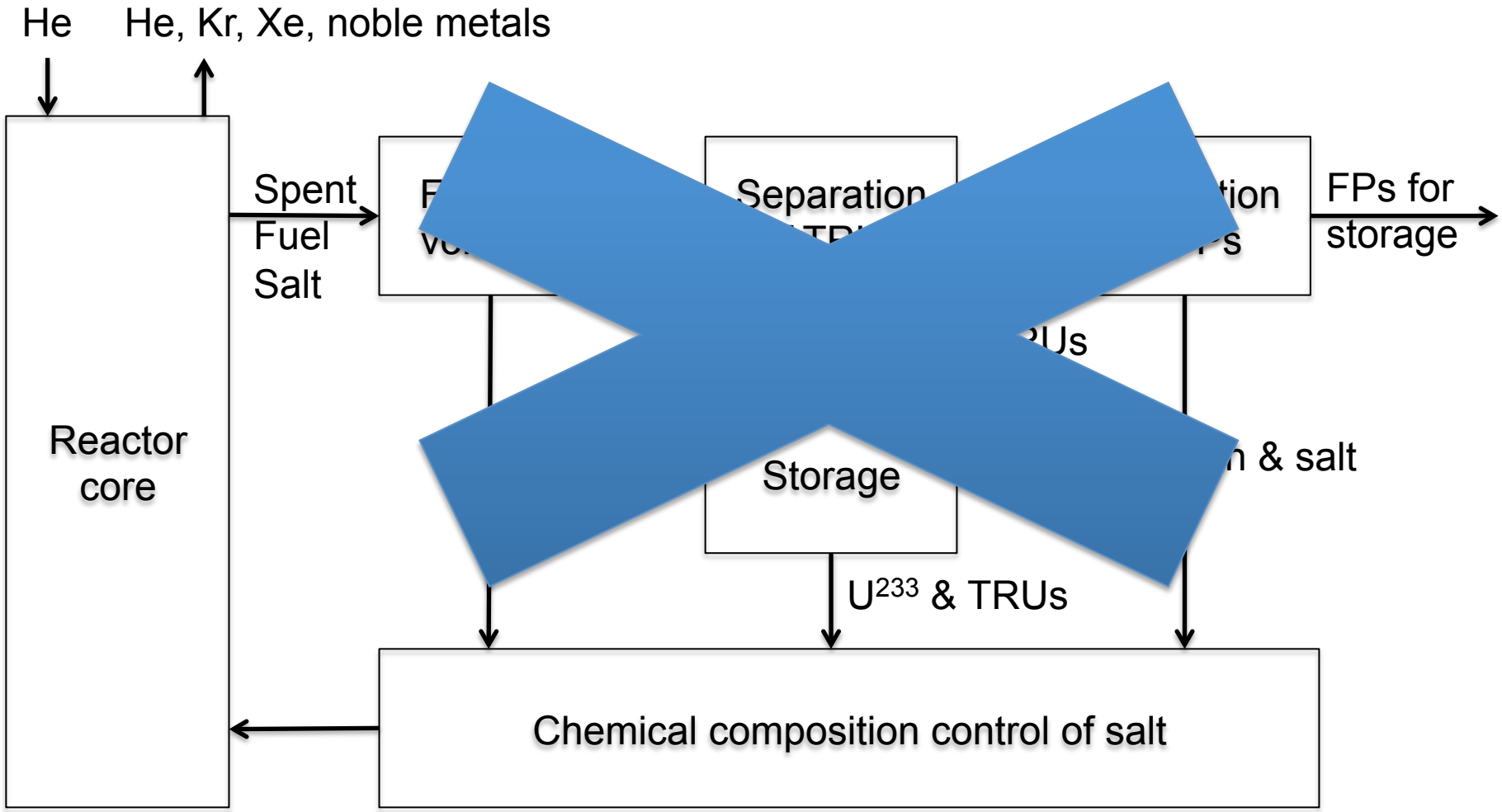




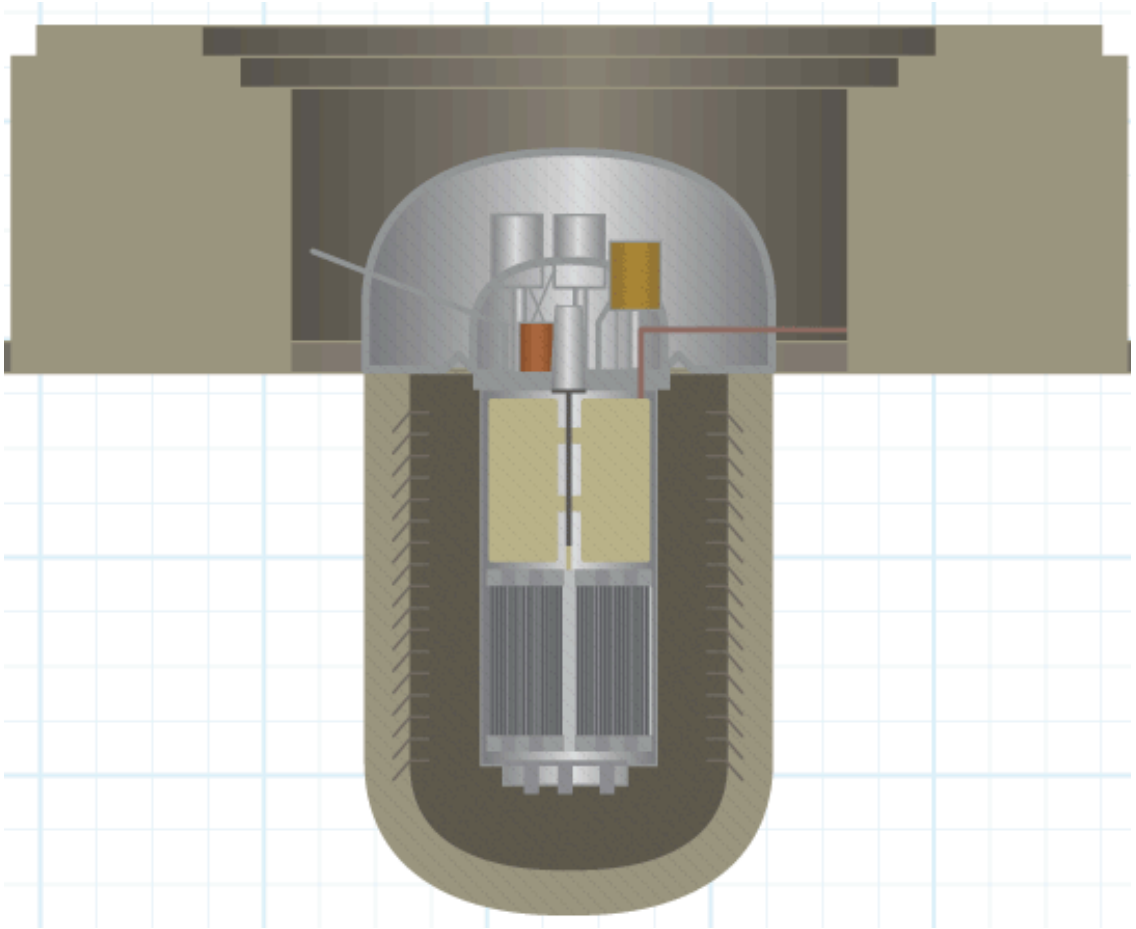
- Denatured uranium: $(m_{U233} + 0.6m_{u235}) < 0.12m_{Utot}$
- No fuel reprocessing required beyond He bubbling and chemical redox control

Engel, J.R. et al. (1980). Conceptual Design Characteristics of a Denatured Molten-Salt Reactor with Once-Through Fuelling. Technical Report, The Oak Ridge National Laboratory.

The Denatured Molten Salt Reactor: The simplest MSR design



The Integral Molten Salt Reactor: A small modular DMSR



- Small modular (80-600MWth)
- Completely sealed unit
- Removed & discarded after 7 years

Terrestrial Energy (2013a). Integral Molten Salt Reactor. http://terrestrialenergy. com/safety/. Accessed 2014-08-29.

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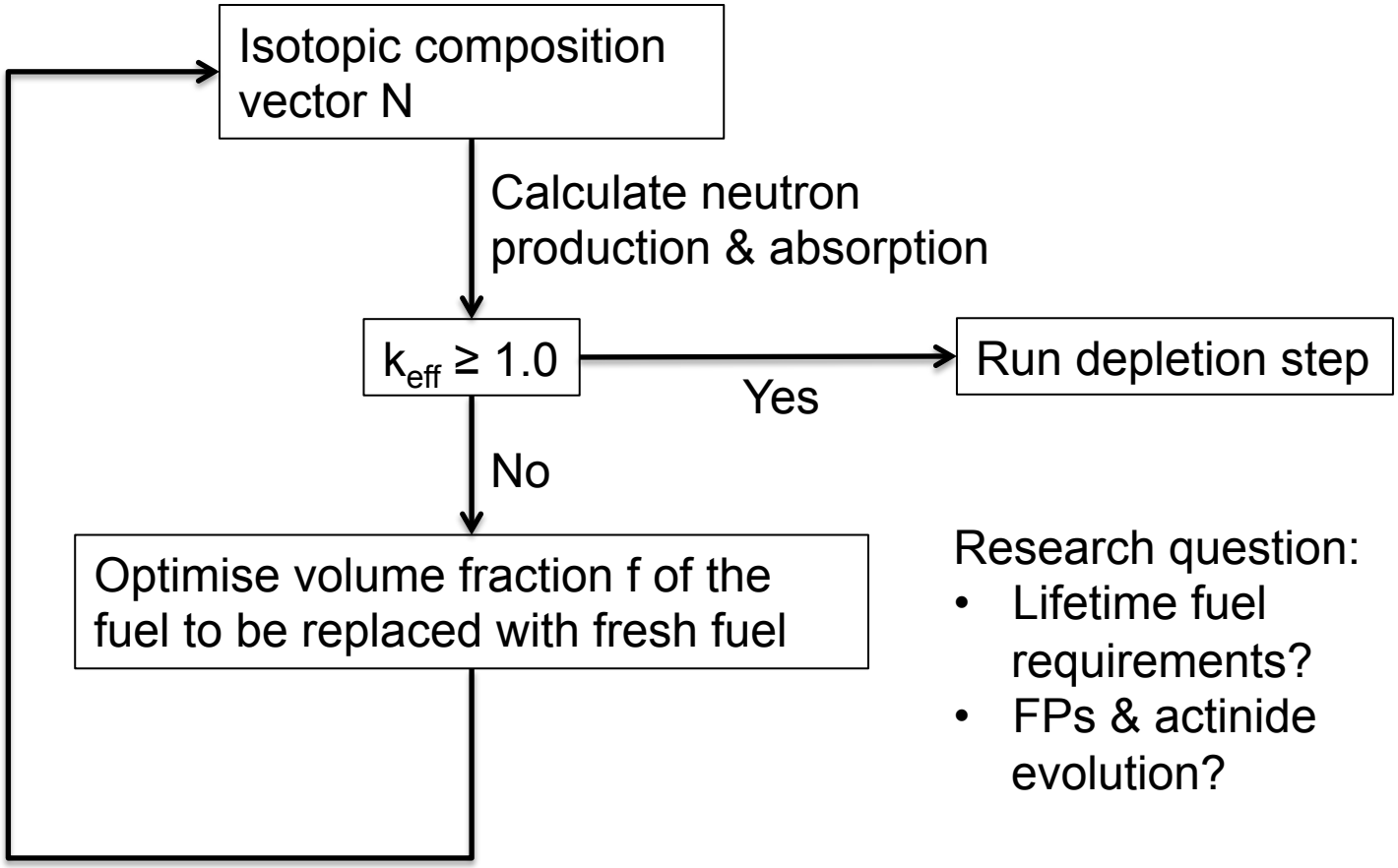
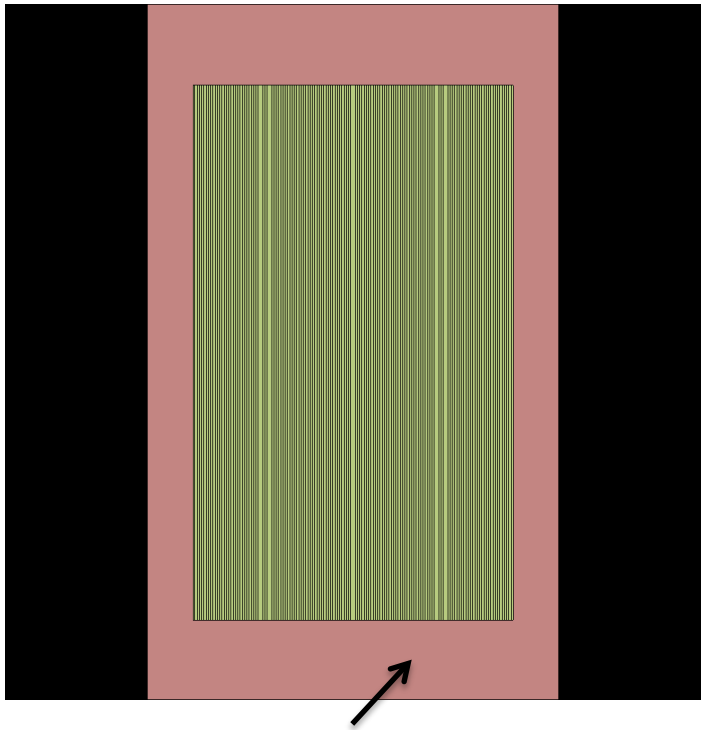
Modelling a multi-batch refueling scheme of the DMSR



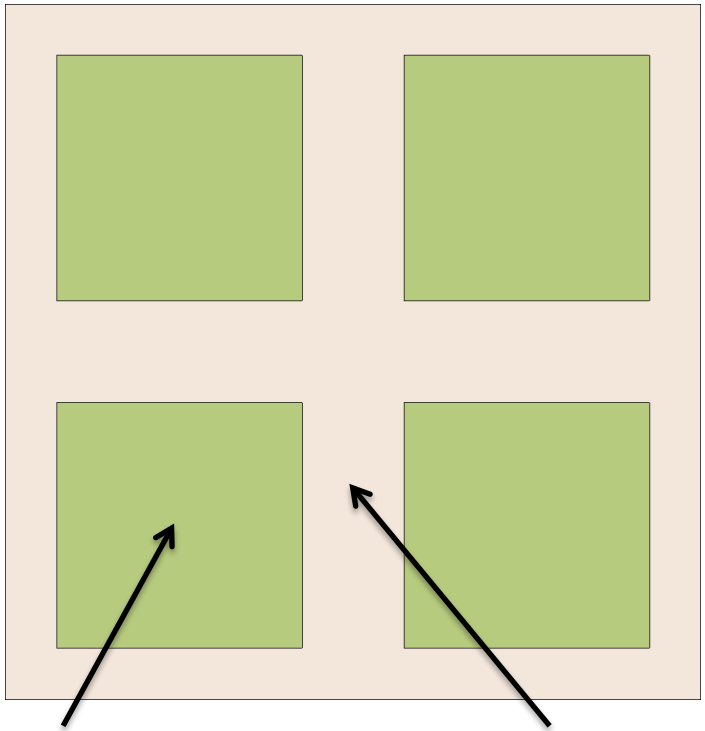
Research question:

- Lifetime fuel requirements?
- FPs & actinide evolution?

Validation of the SERPENT model: Replicating results from PSI



Hastelloy-N reflectors



Fuel salt

Graphite

- Salt volume from 5 to 100% core volume
- Constant power (1.5 GWth)
- Core dimension adjusted to reach BR = 1

Křepel, J. et al. (2014). Fuel cycle advantages and dynamic features of liquid fueled MSR. *Annals of Nuclear Energy* , 64:380-397.

Validation of the Serpent model: Differences in simulation of refuelling

SERPENT	ERANOS
Additional artificial decay term in the Bateman equation of FPs: $dN/dt = -\lambda N$ Where: $\lambda = \ln 2/30$ for gaseous FPs and noble metals (30s characteristics removal time) $\lambda = 1/(182.5*24*3600)$ for other FPs (6 months removal time)	Non-soluble FPs are removed every 30s (by applying a similar artificial decay term) All soluble FPs are removed every 6 month
Fuel is topped up with ^{232}Th: $dN_{Th232}/dt = +\Sigma\sigma_{f,i}N_i\phi$	The removed FPs mass was replaced by ^{232}Th

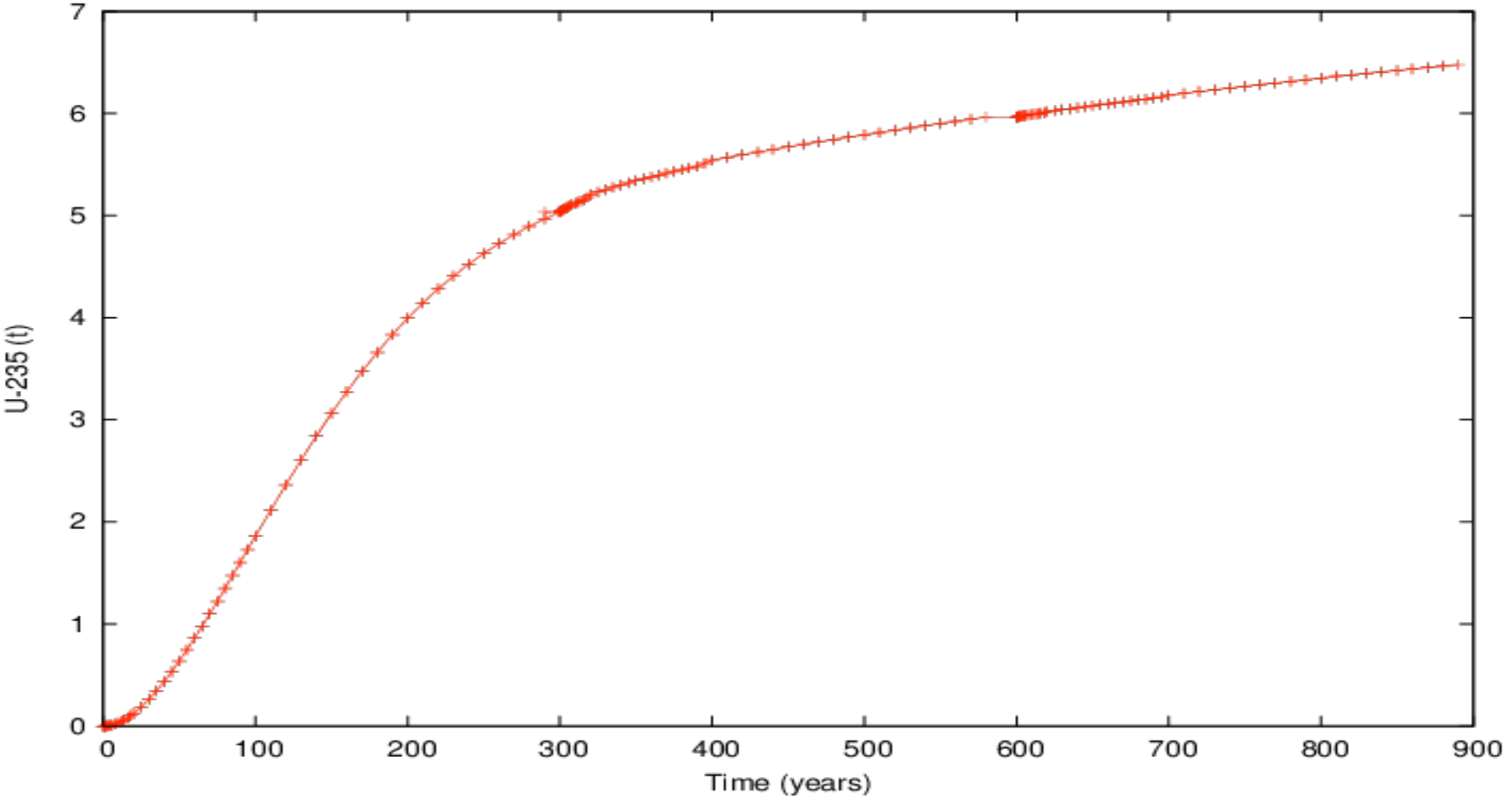
Křepel, J. et al. (2014). Fuel cycle advantages and dynamic features of liquid fueled MSR. *Annals of Nuclear Energy* , 64:380-397.

Discrepancies between Serpent and Eranos results

Actinide	90% volume salt			10% volume salt		
Mass (t)	SERPENT	ERANOS	%diff	SERPENT	ERANOS	%diff
Ra	6.75E-08	1.59E-07	57.54	3.80E-08	1.21E-07	68.50
Ac	1.57E-06	1.24E-06	-26.28	4.78E-08	4.26E-08	-12.23
Th	1.52E+01	1.51E+01	-0.59	9.14E+01	9.79E+01	6.62
Pa	6.05E-02	6.23E-02	2.95	6.16E-02	6.12E-02	-0.61
U	3.24E+00	3.17E+00	-2.16	3.39E+00	3.23E+00	-4.79
Np	6.05E-02	5.85E-02	-3.41	7.92E-02	6.76E-02	-17.22
Pu	1.18E-01	1.20E-02	1.37	9.84E-02	9.41E-02	-4.53
Am	2.18E-03	2.25E-03	2.68	6.17E-03	6.37E-03	3.10
Cm	2.32E-03	2.47E-03	6.13	1.96E-02	2.37E-02	16.98
Bk	2.79E-06	2.42E-06	-15.56	1.74E-05	1.49E-05	-17.16
Cf	8.45E-05	1.27E-05	-564.46	6.79E-05	9.01E-05	24.64

Křepel, J. et al. (2014). Fuel cycle advantages and dynamic features of liquid fueled MSR. *Annals of Nuclear Energy* , 64:380-397.

Slow conversion to equilibrium of the 30% volume salt case



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Future Work

- Validate Serpent model
- Quantify the effects of the multi-batch refuelling scheme: refuel volume versus frequency?
- Optimise start-up and top-up loads: ORNL proposed 74% LiF, 16.5% BeF_2 and 9.5% (ThF_4, $^{233}UF_4$, $^{238}UF_4$) and 20% enriched UF_4 top-up without further optimisation.
  - Use 5% enriched uranium and ^{232}Th as top-up?
  - Chloride instead of fluoride?