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The role of thorium in UK nuclear R&D

Current trends and MSFR modelling

28th October 2013, ThEC 2013, CERN

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The role of thorium in UK nuclear R&D

- Analysis of UK nuclear R&D strategy.
- The role of fuel cycle modelling…and thorium within it.
- Fuel cycle modelling of molten salt fast reactor roll-out.

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UK nuclear R&D strategy

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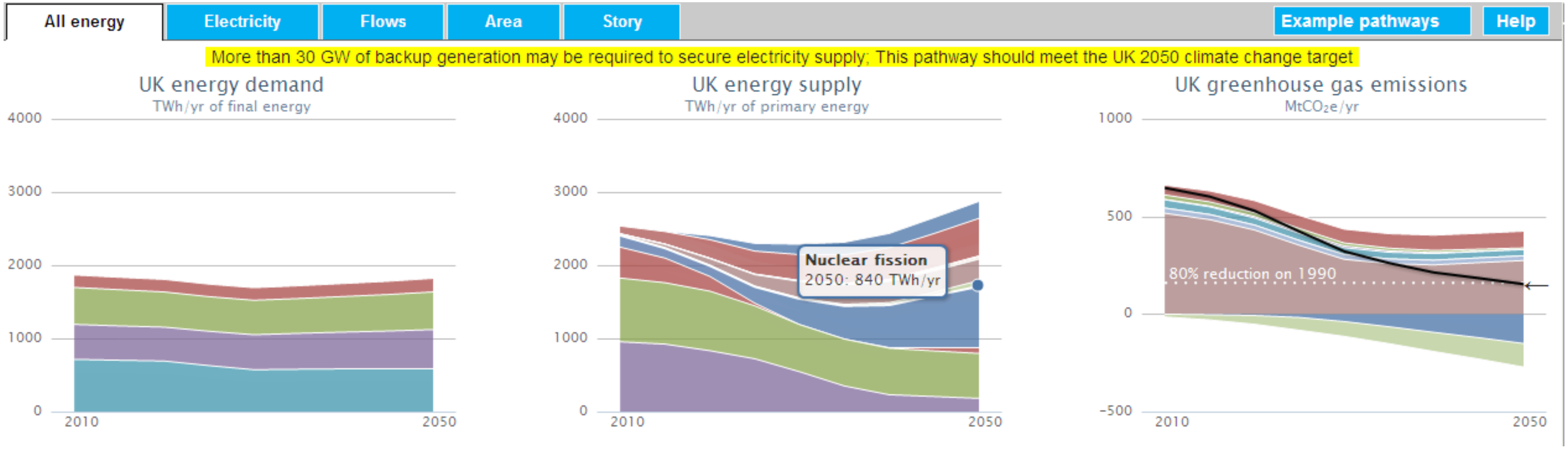
UK nuclear R&D need - history

2050 Pathways Analysis Tool was developed to analyse possible technology trajectories to decarbonisation on current consumption.

This and subsequent studies suggested up to around 75GW nuclear generation may be needed by mid-21st Century.



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UK nuclear R&D need - history

2008 – 2013 Decisions make new nuclear build and a significant share of UK electricity generation from nuclear seem increasingly likely.

Policy statements, type approval of new reactor designs, consortia bidding to build.

Dec 2011 House of Lords (UK's 2nd Parliamentary chamber) criticises UK nuclear R&D and skills retention. Government initiates a review of strategy and analysis of skills and technology needs for near and long term futures.

March 2013 Publication of an extended nuclear strategy, including a nuclear R&D roadmap.

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UK Nuclear R&D Roadmap

The Roadmap is the skills and technology trajectory analysis for the UK nuclear industry.

Follows the principle of keeping technology options open.

Many scenarios considered, but all their needs fall within the bounds of 3 scenarios, representing limits of likelihood. These are those that the Roadmap considers:

- No new nuclear plant (not even those currently proposed).
- Up to 75 GW open cycle around mid-21st Century.
- Up to 75 GW closed cycle around mid-21st Century.

Fuel cycle modelling and ORION

Feasible futures require feasible fuel cycles!

All scenarios use NNL's ORION for fuel cycle modelling.

Allows complete mining-to-disposal modelling of fuel cycle scenarios by predicting the evolution of fuels and wastes as they progress through nuclear facilities (e.g. fuel manufactories, reactors, reprocessing, cooling, etc.)

- Ensures a feasible fuel cycle.
- Modelling occurs out to either shut down of fuel cycle or an equilibrium in late 22nd Century.
- Descriptions of many variants of individual facilities in the model.
- Must have a description of the neutronics of any reactors being used.

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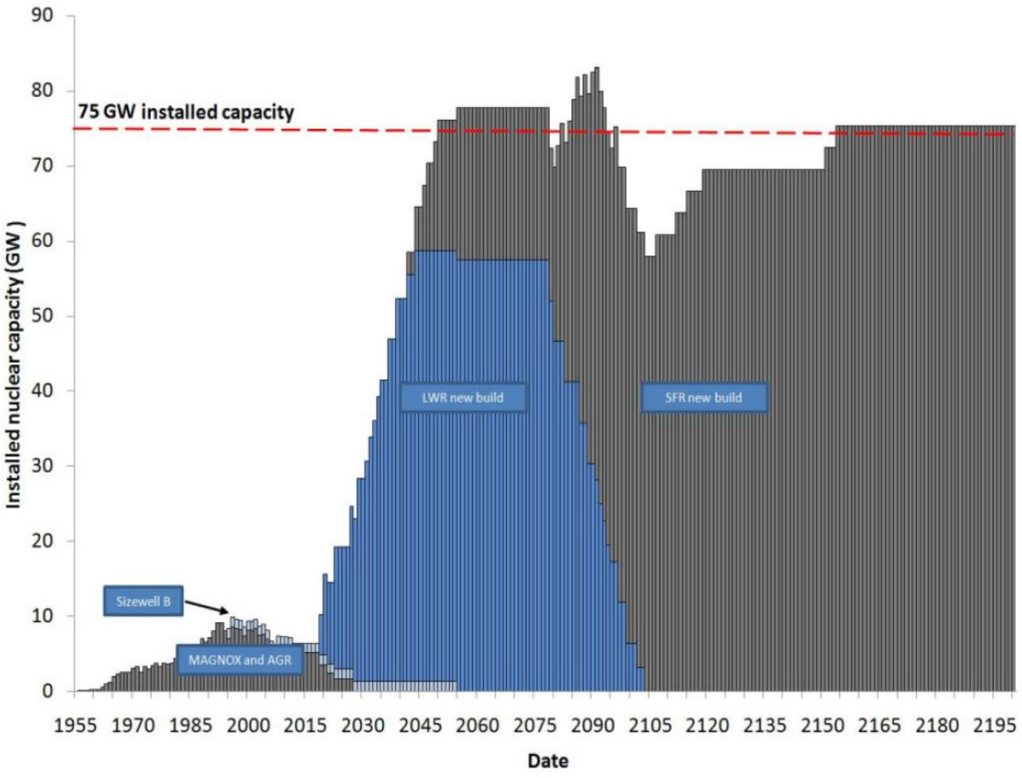
ORION Scenarios

ORION models generated for 16, 40 & 75 GW_e scenarios, with many variants.

Typical output includes: Decay heat key factor (governing repository capacity); radiotoxicity; volumes of waste.

An example 75 GW(e) variant assumes New Build LWR fleet followed by a sodium fast reactor fleet to provide long term sustainability.

Thermal fleet is required to generate sufficient Pu to fuel the FR fleet.



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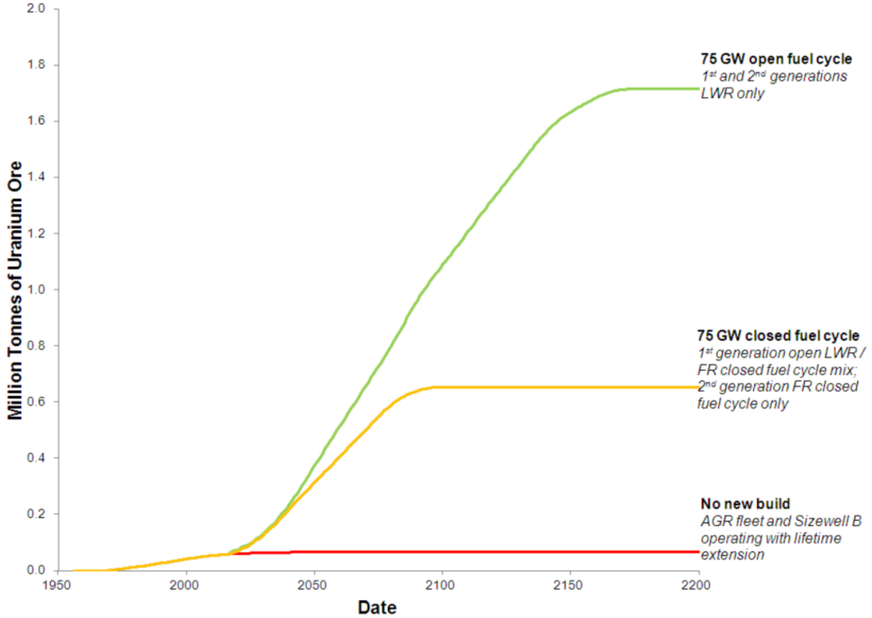
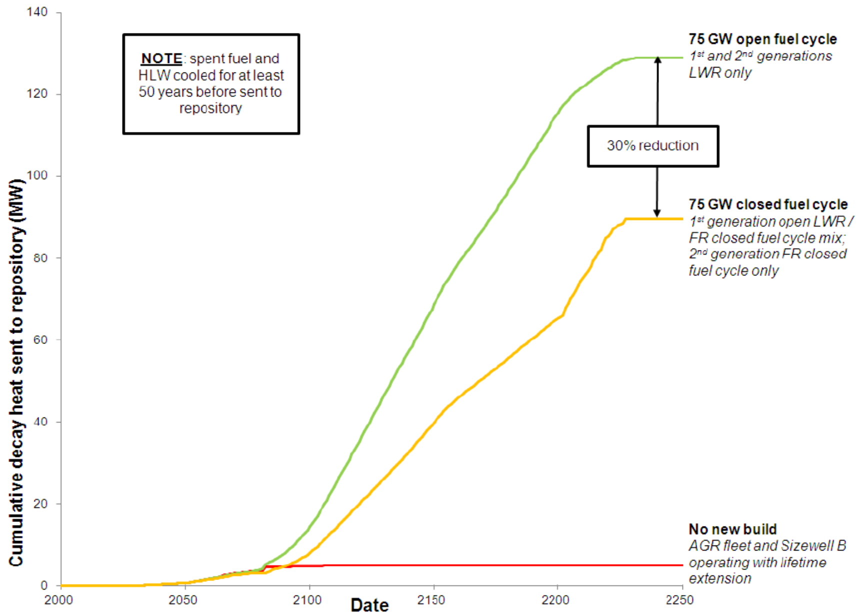
Roadmap findings include…

A closed fuel cycle, recycling fuel into fast reactors, has significantly lower demands on fuel and final repository thermal management than an open one.





Roadmap findings include…

Most technologies and skills are needed in all scenarios.

Compared against current capabilities for gap analysis.

	Next Generation Reactors/Fuels	Reprocessing/Recycle	Advanced Thermal Reactors/Fuels	Current Thermal Reactors/Fuels	Materials and Components	Construction and Installation	Operations	Spent Fuel and Nuclear Material	Decommissioning and Clean-up	Waste Management	Geological Disposal	Fusion Reactors/Fuels
CLOSED FUEL CYCLE PATHWAY	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OPEN FUEL CYCLE PATHWAY			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
BASELINE PATHWAY				✓	✓	✓	✓	✓	✓	✓	✓	✓

Roadmap findings include…

… on thorium.

- Assessing thorium-fuelled reactors and understanding the implications for the attainable rates of expansion of nuclear capacity will be important for understanding the potential role of thorium in a UK fuel cycle.
- Further analysis and fuel cycle modelling will be necessary to understand the implications on waste management and disposal of using thorium fuels.

In the wider UK context, decisions on which fuel to use are down to the developer (and the regulator!)

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Modelling of a fast spectrum thorium molten salt reactor

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Modelling of a fast thorium MSR

Th-fuelled MSFRs were included early on in NNL's fuel cycle modelling because:

A model was available – neutronic description developed by Dr. E. Merle-Lucotte and used as part of the EVOL project.

Fewer key constraints than conventional fast reactors:

- No cooling-off period for spent fuel – immediate recycle reduces cycling time for fuel .
- Highest degree of recycling for fast reactors potentially possible.
- Mechanical structure of solid fuels and associated neutron loss is avoided.

What rates of roll-out does this result in from breeding alone?

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Modelling of a fast thorium MSR

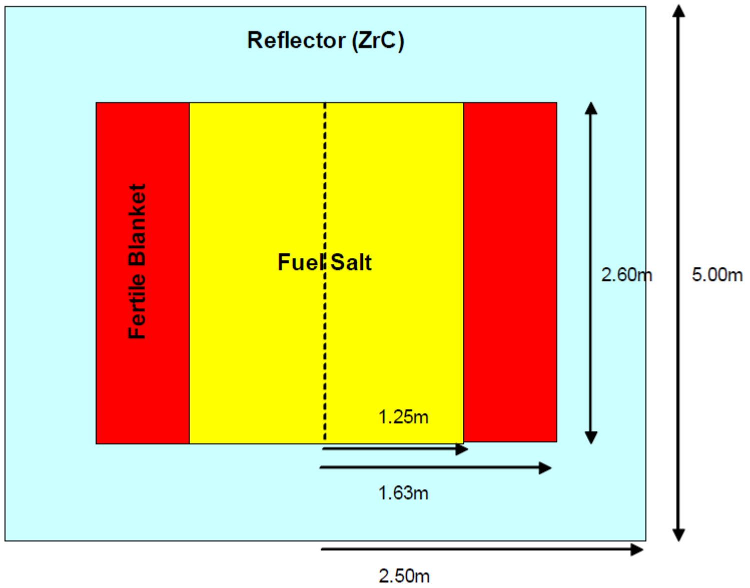
Design parameters for the core were the same as used by Merle-Lucotte *et. al.* [1]

Same two start up scenarios for the initial fissile load: U-233 and Pu + minor actinides (PuMA) – both with about 17.5% mol heavy nuclide concentration.

NNL study used a different neutronic modelling code:

- Merle-Lucotte *et. al.* used MCNP [2]
- NNL [3] used ERANOS [4]

MSFR Core Schematic



1. "Introduction to the Physics of Molten Salt Reactors", E. Merle-Lucotte et. al., Materials Issues for Generation IV Systems - NATO Science for Peace and Security Series B: Physics and Biophysics 2008, pp 501-5212.
2. "MCNP4B-A General Monte Carlo N Particle Transport Code", Briesmeister J.F., Los Alamos Lab. report LA-12625-M (1997)
3. "Fast Spectrum Molten Salt Core Calculations Incorporating the Thorium Fuel Cycle", NNL 2013
4. "The ERANOS code and data system for fast reactor neutronic analyses", G Rimpault et al, Proc. Int. Conf. on Physics of Reactors, Seoul, Korea, 2002

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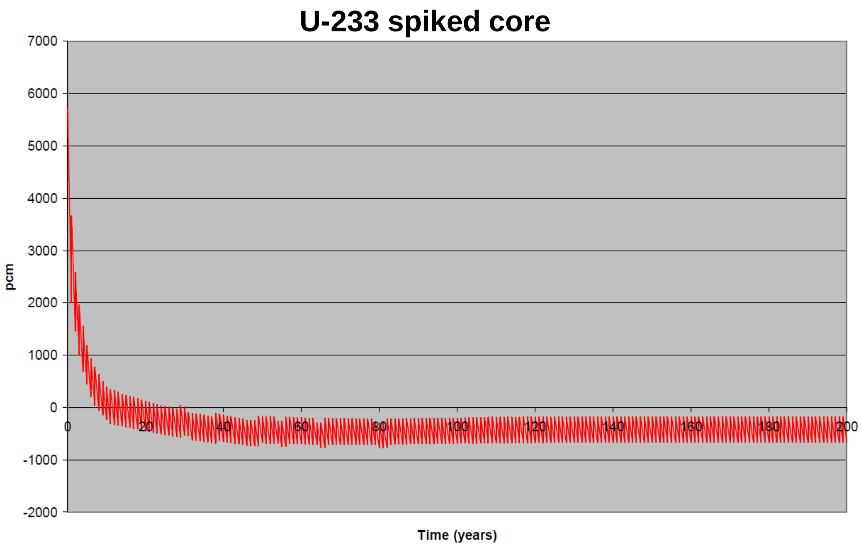
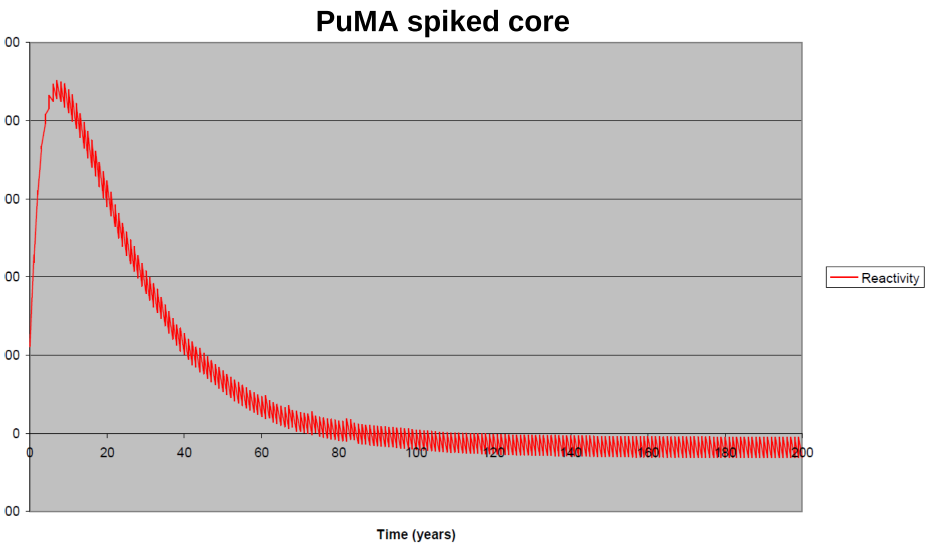
Modelling of a fast thorium MSR

Modelling assumed that U-233 is extracted on recycle:





Excessive reactivity in the core started with PuMA leads to greater U-233 production (and extraction to manage the core) and a shorter doubling-time for the fissile inventory.

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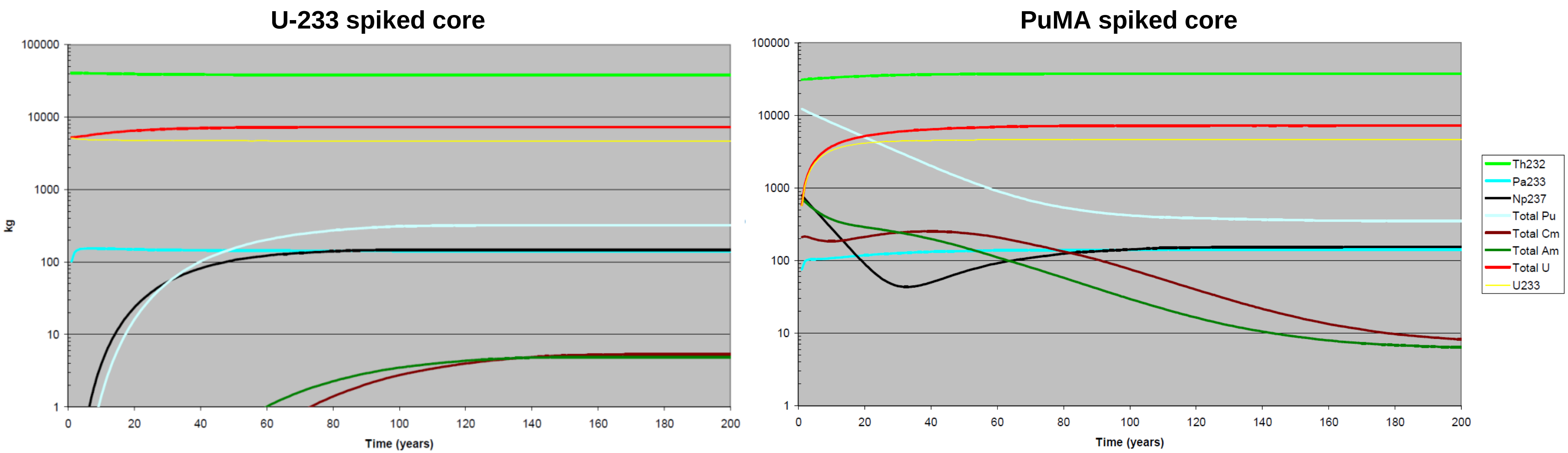
Modelling of a fast thorium MSR

However, the U-233 core has a much lower inventory of transuranic elements (and hence lower very long term radiotoxicity) early on in the fuel cycle.



Eventually, heavy nuclide inventories from the two start-up scenarios do converge.

Modelling of a fast thorium MSR

Fissile inventory doubling times for core startup scenarios:

U-233 : approx 53 years PuMA : approx 38 years

NNL's results yield similar values to those found by Merle-Lucotte *et al.*

Thus:

If relying on fuel breeding only for the roll-out of MSFRs (if they are developed), the speed of roll out is likely to be improved by the use of plutonium and minor actinides as the initial fissile charge over U-233. However this entails a higher long term radiotoxicity of the core inventory for at least the first 100 years of the fuel cycle.

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Thank you for your attention

http://www.gov.uk/decc
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DECC 2050 Pathways Analysis Tool:
https://www.gov.uk/2050-pathways-analysis

UK Nuclear R&D Roadmap and related documents:
https://www.gov.uk/government/collections/nuclear-industrial-strategy