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A member of the Russell Group

LIFE CHANGING | World Shaping

‘You may say I'm a dreamer
But I'm not the only one
I hope someday you'll join us
And the world will be as one’
John Lennon

Taking the Risk of Disruption – a Slightly New Look into P&T

Prof. Dr. Bruno Merk

NNL/RAEng Research Chair in Computational Modelling for Nuclear Engineering

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Risk Seminar 2018

P&T where we are today

Separation of Pu

Industrial level
AREVA NC, Sellafield

Reprocessing of Am bearing fuel

started

Completing the cycle for Pu

Pre-Industrial level?

Separation of MA

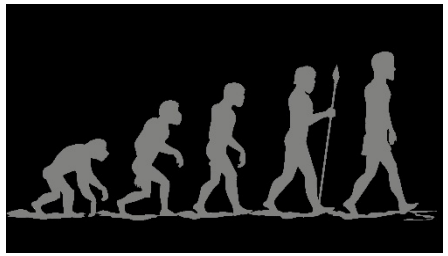
Lab scale
several processes

Transmutation

Lab scale
e. g. PHENIX

Production of Transmutation fuel

Lab scale
e. g. ITU



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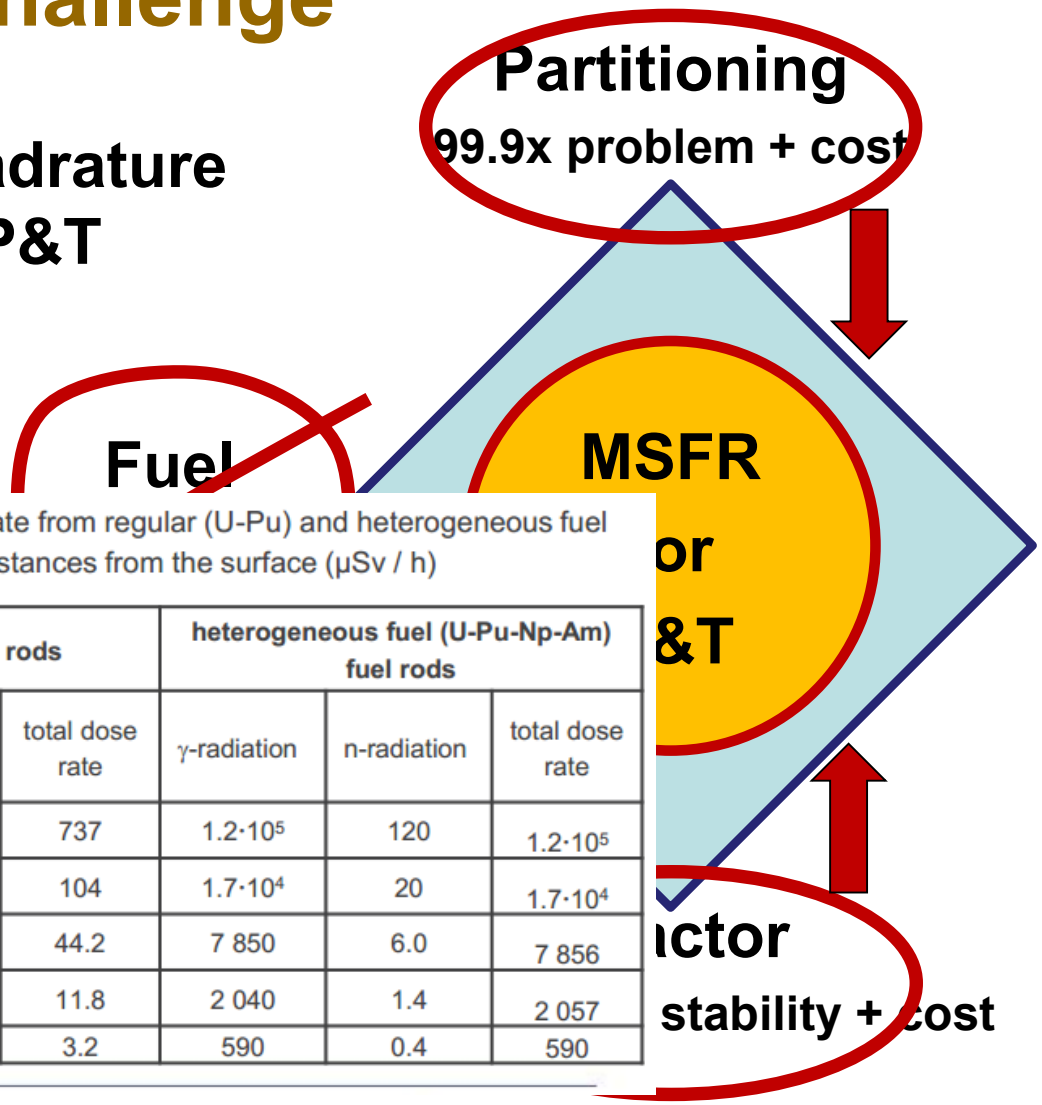
P&T the Challenge

The reverse quadrature of the circle or P&T between today and tomorrow



Gamma and neutron radiation dose rate from regular (U-Pu) and heterogeneous fuel (U-Pu-Np-Am) fuel rods at different distances from the surface (μSv / h)

Distance (cm)	regular (U-Pu) fuel rods			heterogeneous fuel (U-Pu-Np-Am) fuel rods		
	γ-radiation	n-radiation	total dose rate	γ-radiation	n-radiation	total dose rate
1	674	63	737	$1.2 \cdot 10^5$	120	$1.2 \cdot 10^5$
10	96	8.0	104	$1.7 \cdot 10^4$	20	$1.7 \cdot 10^4$
20	41	3.2	44.2	7 850	6.0	7 856
50	11	0.76	11.8	2 040	1.4	2 057
100	3	0.21	3.2	590	0.4	590

…but we could follow the things down to the last consequence…

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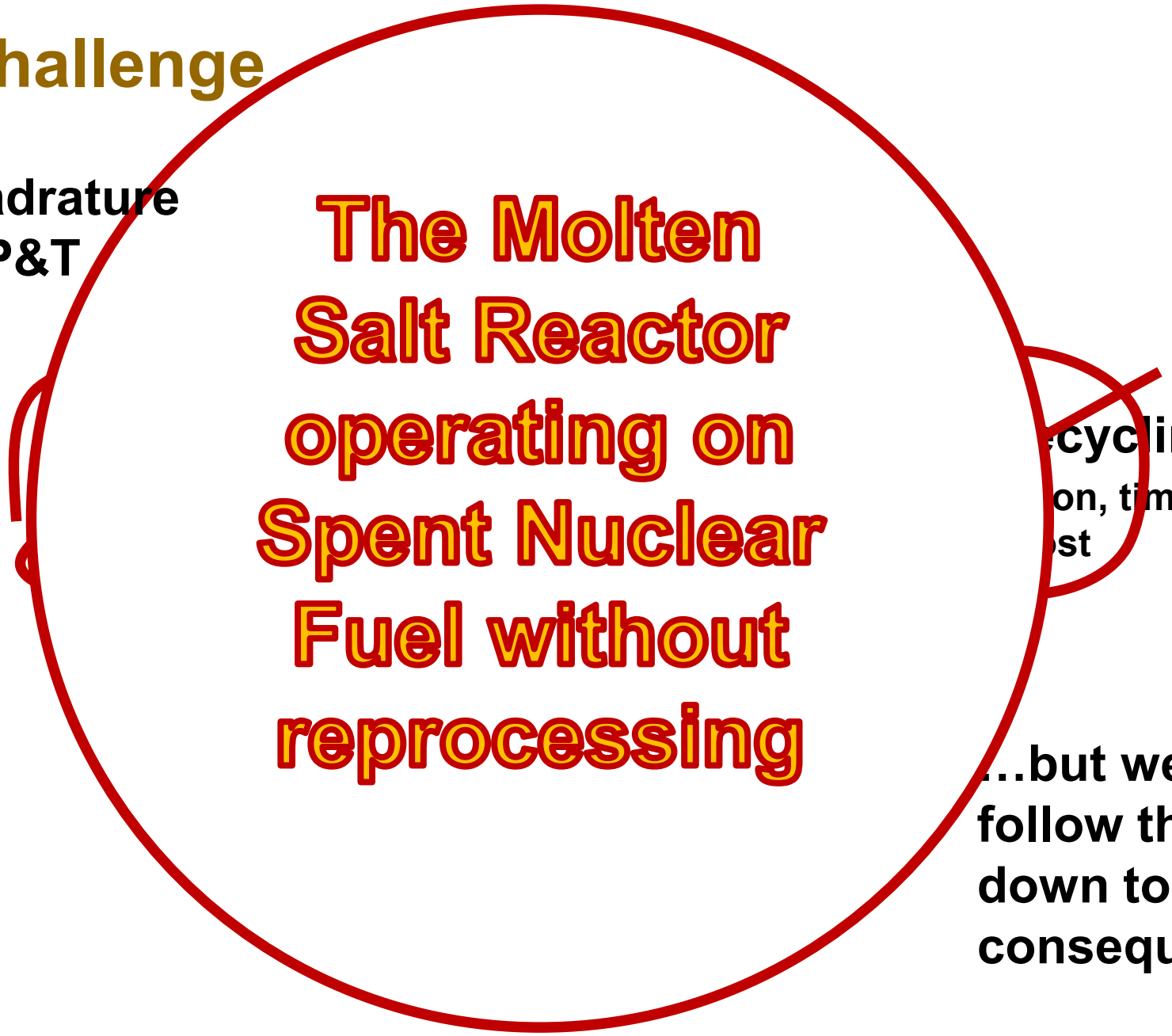
P&T the Challenge

The reverse quadrature of the circle or P&T between today and tomorrow



…but we could follow the things down to the last consequence…

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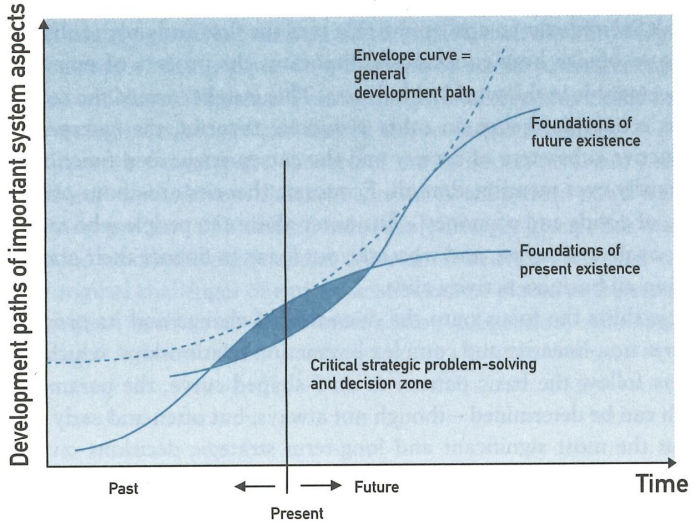
Management Literature: Strategic Development



"Symphony of S-curves: Seeing the Future"

Fredmund Malik in his book |Strategy| Navigating the Complexity of the New World

He tries to motivate the people to **leave the track of purely evolutionary development** when it is indicated by **changed boundary conditions**. He argues that **evolutionary development slows down significantly when the market is saturated**. The **development speed can only be kept** in this phase when a **disruption in development appears** which creates a **new technology entering in to a new phase of rapid development**. In this case strategic development enters into a **new s-curve**.

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iMAGINE – A Highly Innovative Nuclear Energy System Operating Directly on Spent Nuclear Fuel

Prof. Dr. Bruno Merk, D. Litskevich, M. Bankhead, R J. Taylor, A. R. Mount

NNL/RAEng Research Chair in Computational Modelling for Nuclear Engineering

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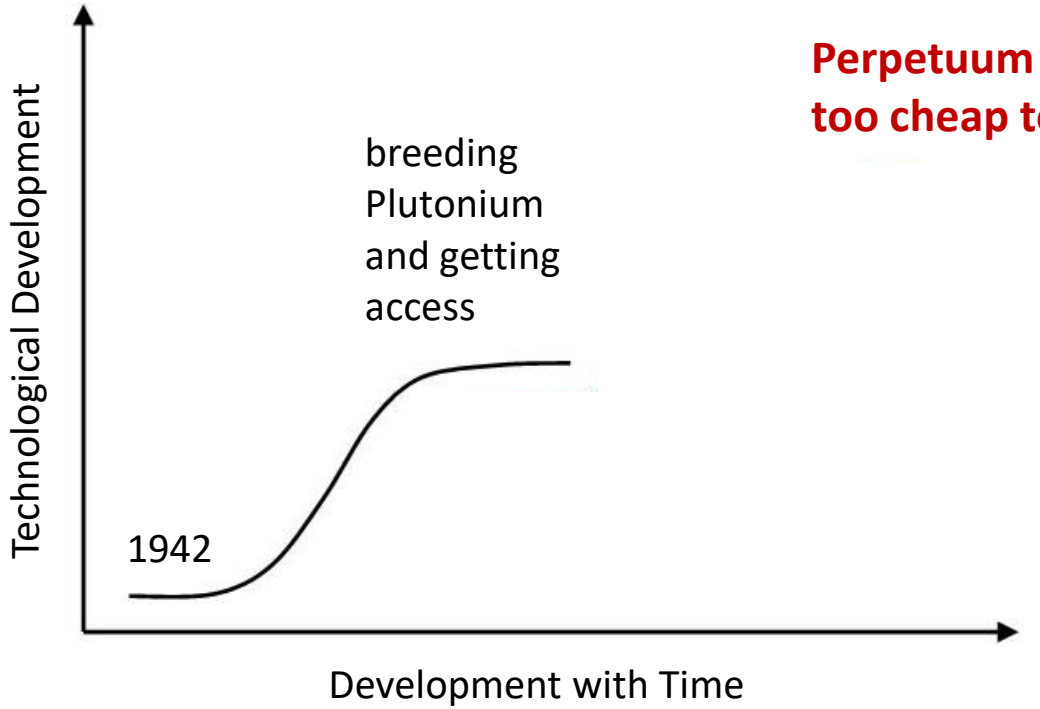
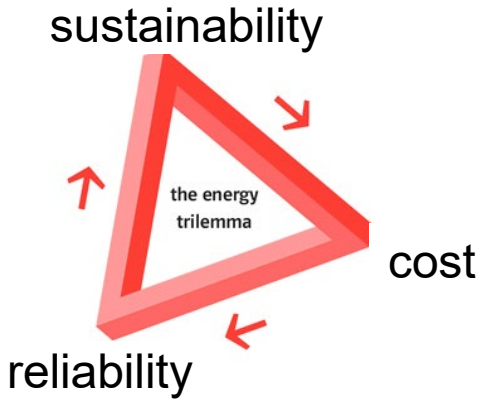
Risk Seminar 2018

Strategic Development for Electricity Production

- continuing chain reaction and potential application
- material for military purposes
- energy generation from the chain reaction



Perpetuum mobile –
too cheap to meter



- **No resources requested**
- **No waste produced**
- **Highly economic**
- **Highly reliable and secure**
- **Safe**

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B. Merk, D. Litskevich, K. R. Whittle, M. Bankhead, R. J. Taylor, D. Mathers: "On a Long Term Strategy for the Success of Nuclear Power", Energies 2017, 10(7), 867; doi:10.3390/en10070867

Strategic Objectives

- **Being economically viable** – depending on the geographic region and the public
- **Being safe to operate** – depending on the expectations of the local public
- **Being innovative** – solving the problems of the future, ideally not with the methods of the past
- **Creating believe in Nuclear**– getting the local public support to build
- **Being sustainable** – avoiding large problems for the future and solving the ones from the past
- **Being Secure** - avoiding proliferation issues in the reactor as well as in the fuel cycle

→ Partitioning & Transmutation could become a side effect of a new energy system

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iMAGINE

a reactor which operates on spent nuclear fuel without prior reprocessing

Improved economic performance due to:

- **avoiding reprocessing** as a prior step into a closed fuel cycle
- replacing traditional reprocessing with **a strong demand driven salt clean-up**
- **applying low pressure technology** in the primary and secondary power generation systems
- **avoiding solid fuel production,** a major cost of the fast reactor fuel cycle
- **avoiding massive amounts of fuel** staying in the fuel cycle

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iMAGINE

a reactor which operates on spent nuclear fuel without prior reprocessing

- **avoiding:**
  - **mining as the major source of eco toxicity and carbon emissions**
  - **enrichment as the major energy consumption and proliferation risk**
  - **solid fuel production as the major cost driver in the closed fuel cycle**
- **reducing waste production by the reuse of spent fuel of existing and future thermal reactors**
- **eliminating the established aqueous reprocessing**
- **eliminating the highly radiotoxic transuranium from SNF reducing the waste storage challenge**
- **producing a factor of 20 more energy out of the given material**

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iMAGINE – The Reactor Element

Prof. Dr. Bruno Merk, D. Litskevich,
M. Bankhead, R J. Taylor, A. R. Mount

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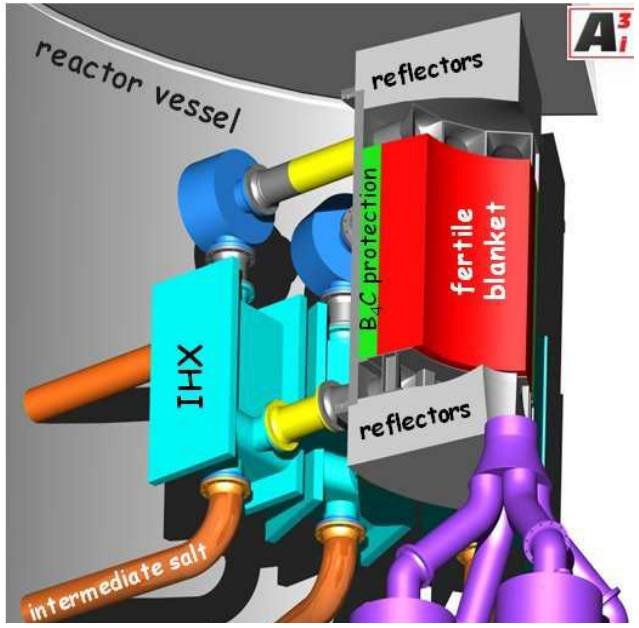
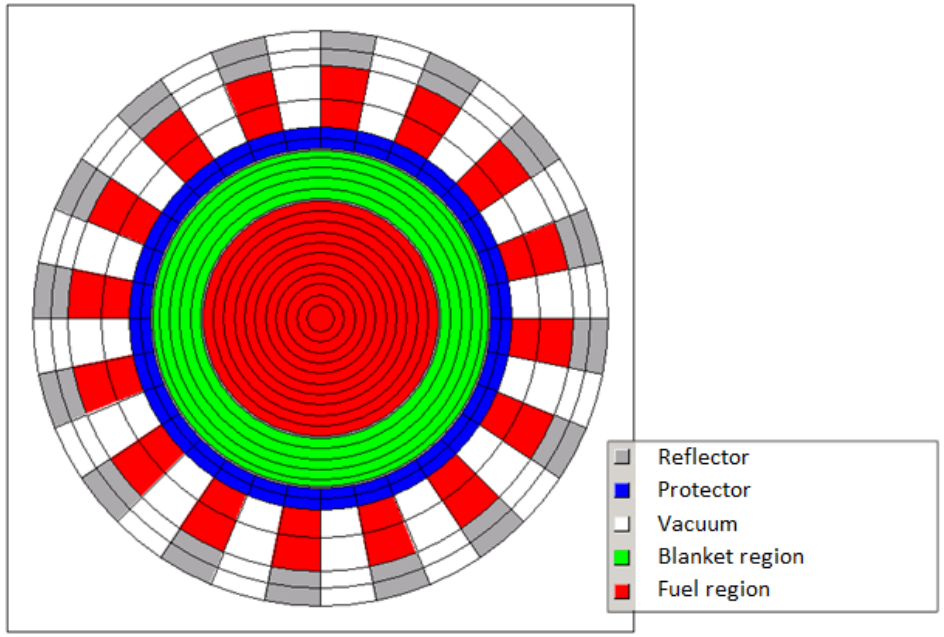
Fifteenth NEA Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation, Manchester UK

iMAGINE – possible system

- **Molten Salt Fast Reactor**





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iMAGINE - safety

- continuous feeding – lower fissile content and no excess reactivity
- homogeneous system – no critical surface cooling
- continuous salt cleaning – lower fission product content

→ low source term in accident conditions, but distributed sources

- strong negative feedback – inherently stable system
- significantly reduced fuel cycle – no critical hand overs
- no solid fuel production – reduced radiation exposure to people

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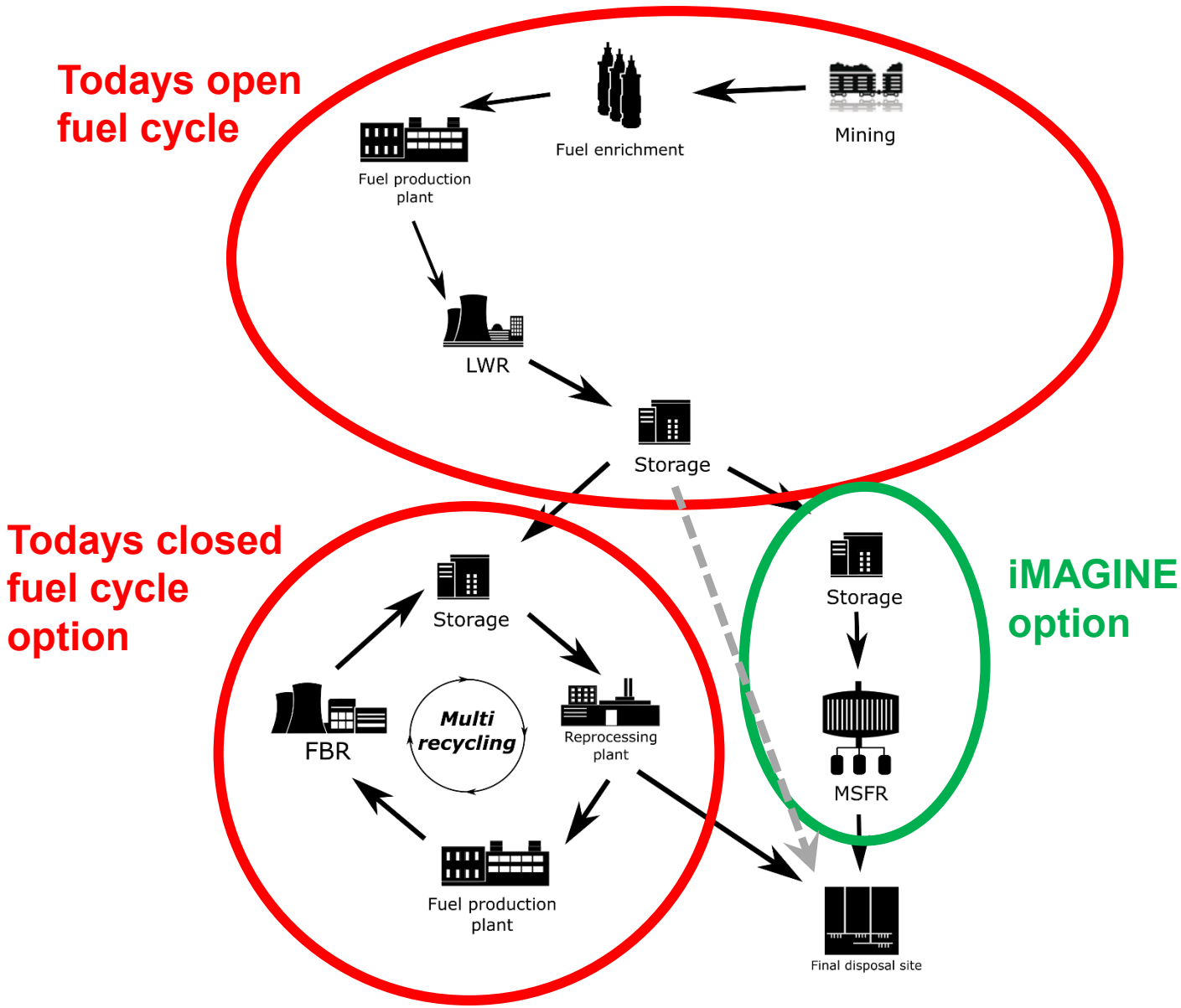
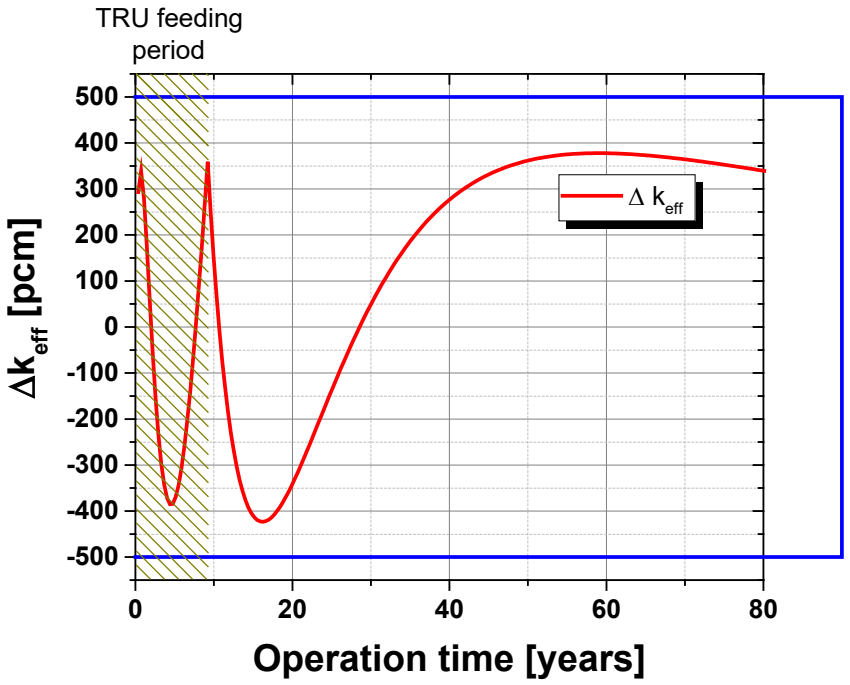
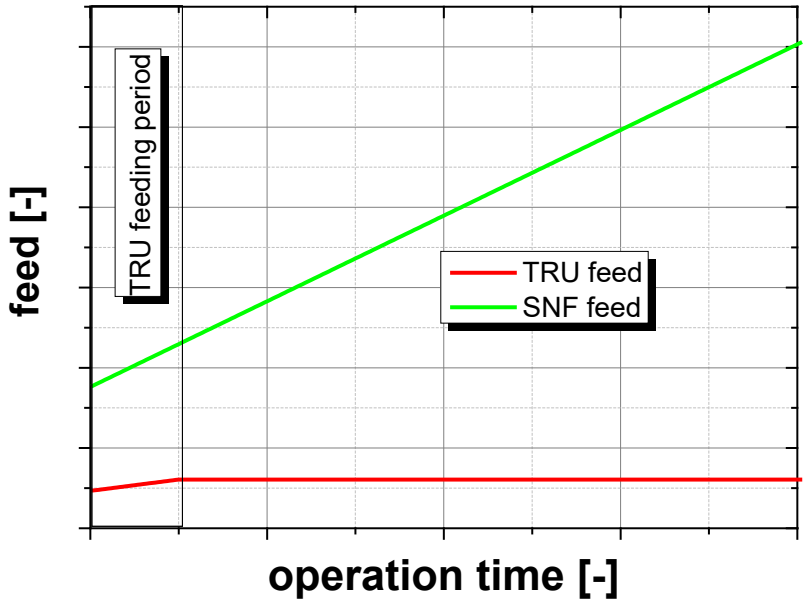
iMAGINE – the bigger picture



iMAGINE – Could it work?

- Δk_{eff} over operational time and feed





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iMAGINE - Challenges

Engineering:

- System simulation for SNF burning – demonstration, optimization & validation problem
- Reactor design optimization – better than EVOL
  - Fluid dynamic under normal operational and accidental conditions
  - Components for molten salt system
- Structural material under multiple stresses – high temperature, high damage, corrosive environment

iMAGINE - Challenges

Chemistry:

- **Design of the salt clean-up system – fission product separation from the liquid phase**
- **Design of the off gas cleaning system – capturing and immobilization of volatile fission products**
- **Fuel preparation – dissolving the LWR oxide fuel**
- **Chemical thermodynamics & kinetics, molten salt with high actinide loads and with e.g. solubility limits**

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iMAGINE - Challenges

Safety:

- **Safety approach for a liquid fuelled system – Gen-V reactor!**
- **Safety of a co-located site – reactor and reprocessing**

Other:

- **Economic viability – development and operational cost of a completely new reactor**
- **Public acceptance – we can't claim anymore, nothing is coming out of the chimney**
- **request for a completely new technology**

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iMAGINE - Challenges

- request for a first reactor physics experiment to re-create the skills basis in
  - designing
  - licensing
  - building
  - commissioning
  - operating

  a new nuclear reactor system

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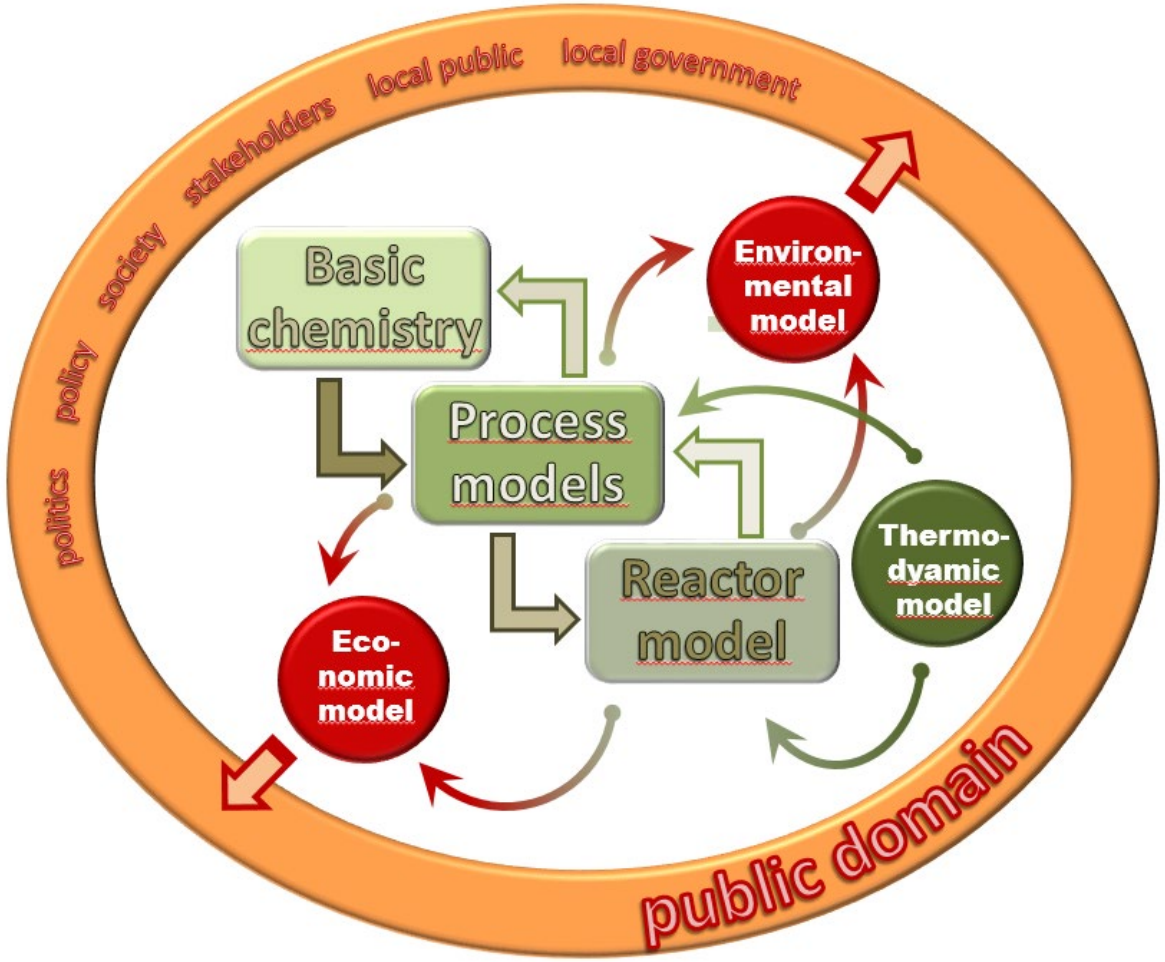
iMAGINE – Approaching the Challenges



Modelling & Simulation

- modelling of the integral nuclear system
- integrating of sustainability and social environment

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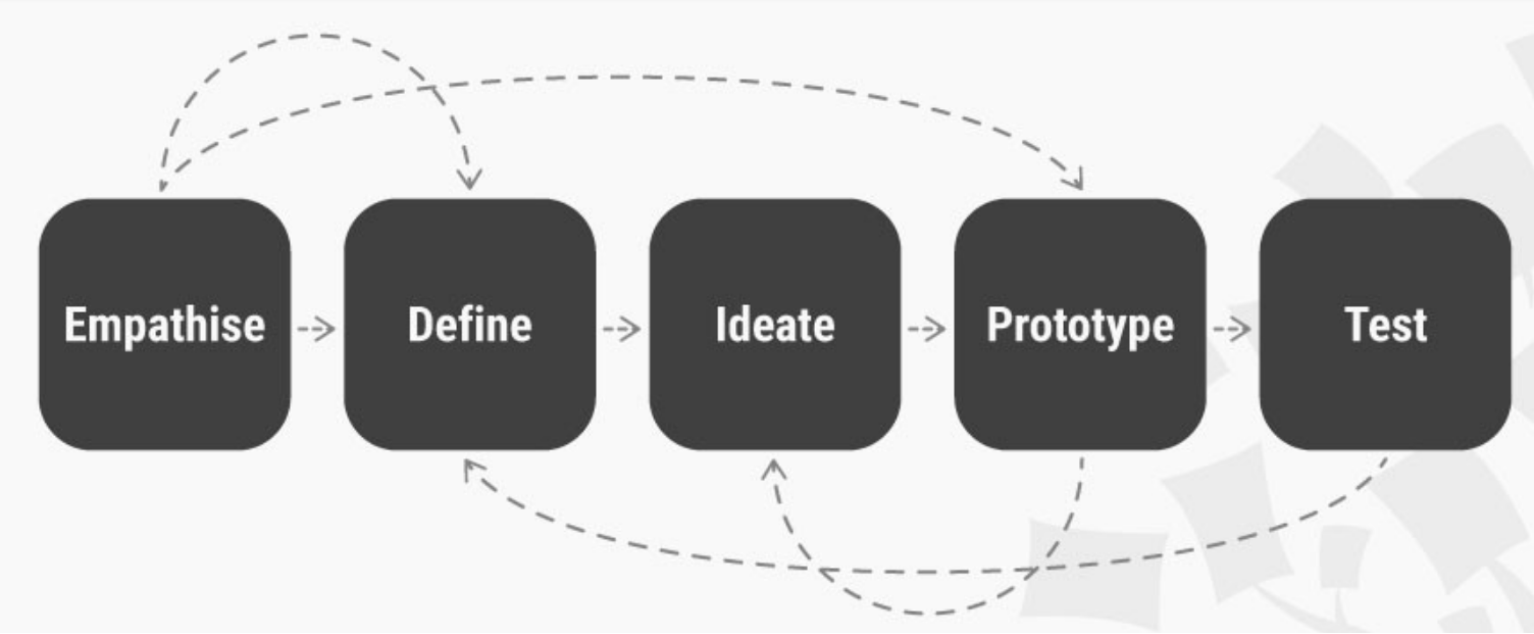
iMAGINE – How to come there

- **Design Thinking Approach - The 5 Stages**



https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process

Design Thinking supported by massive Modelling & Simulation for digital prototyping

iMAGINE - Challenges

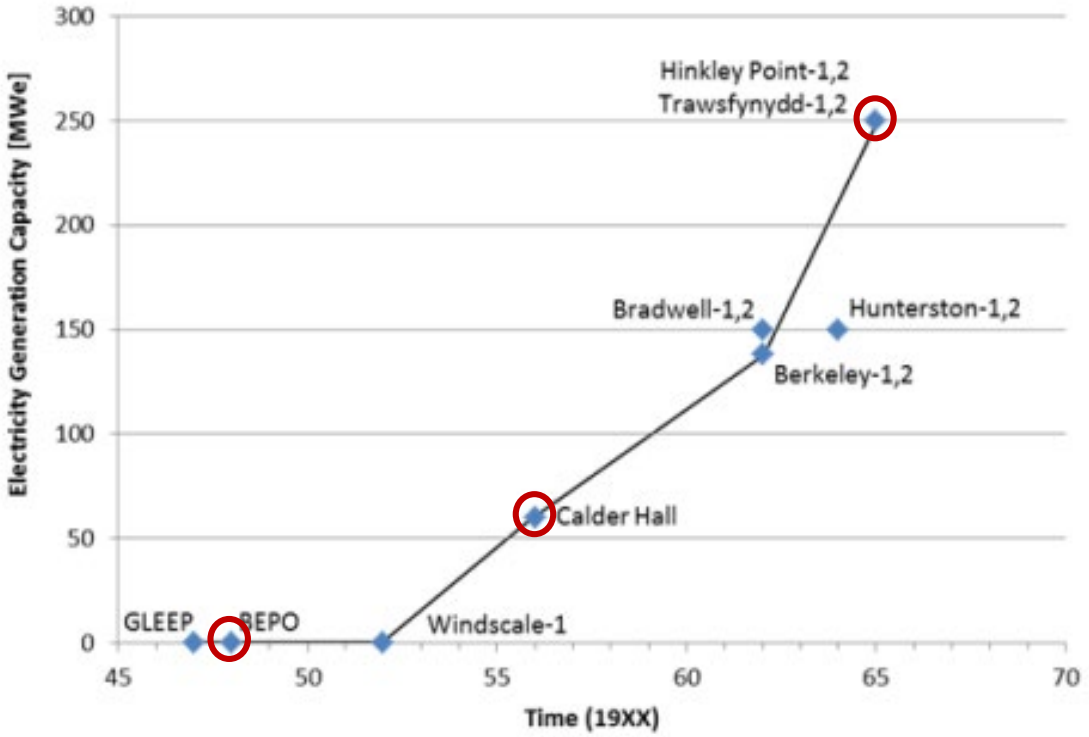


Figure A-4
GCR (Magnox) development timeline

- **what do we gain from new technologies?**
  - **modelling and simulation**
  - **design thinking**
  - **digital prototyping**

- **doing the right experiments instead of doing no experiments**

Program on Technology Innovation: Government and Industry Roles in the Research, Development, Demonstration, and Deployment of Commercial Nuclear Reactors: Historical Review and Analysis. EPRI, Palo Alto, CA: 2017. 3002010478 (https://www.epri.com/#/pages/product/3002010478/?lang=en)

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iMAGINE – Conclusions

- long term sustainable nuclear can be made possible
- the requests of P&T would be solved as side effect
- reduced challenges for the closed fuel cycle
  - no reprocessing, no separation of actinides
  - significantly reduced proliferation risk
  - no multi-recycling
  - no solid fuel production
- opportunity for reliable carbon free, sustainable electric energy production

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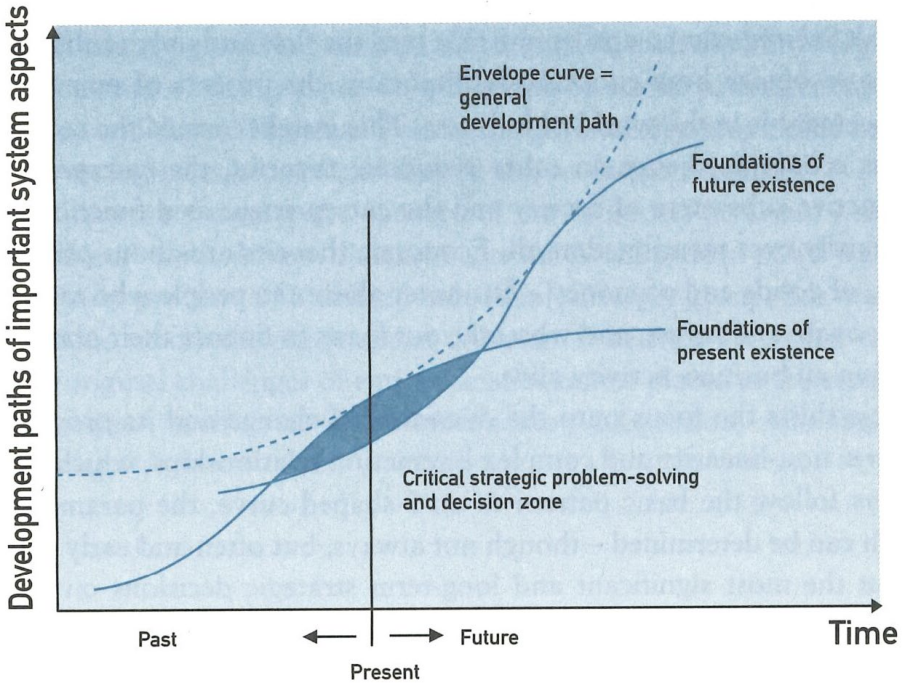
iMAGINE – Conclusions



What we need:

- disruptive innovation
- fresh thinking and re-thinking the decisions of the past
- joining the forces
- strong interdisciplinary working style
- as much international collaboration as possible

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