UNIVERSITY OF CAMBRIDGE

Research in Nuclear Energy Group
Cambridge University Department of Engineering

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Engineering - Energy, Fluid dynamics and Turbo-machinery

Nuclear Energy Group

Main research topics:

- Advanced Reactor Design
- Core Layout Optimisation
- Reactor Physics Modelling Methods
- Small Modular Reactors

Academic staff:

- Dr Geoff Parks
- Dr Eugene Shwageraus
- Tony Raulstone
- Dr Miles Stopher

16 Doctoral Students

1 year MPhil in Nuclear Energy Course:

- 14 -20 students each year

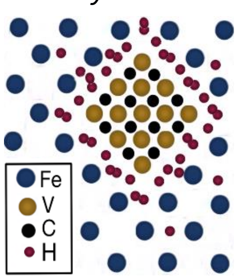
Miles Stopher -Nuclear alloy design

Nuclear alloy design for improved life – From DFT, thermodynamics and kinetics to microstructural characterisation, thermal desorption analysis and mechanical testing.

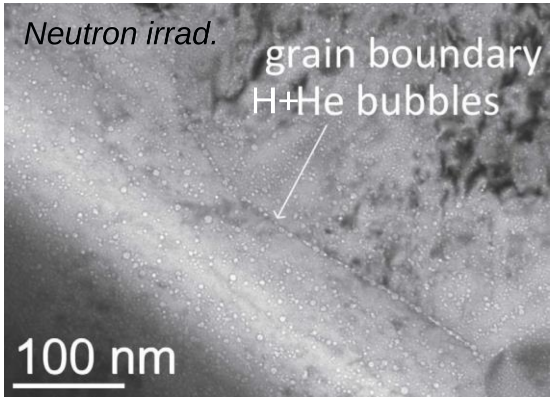
Commercial alloys are improved to resist the extreme environments of nuclear reactors e.g. corrosive, transmutation products and irradiation hardening via compositional and thermomechanical variations.

Sample	wppm trapped hydrogen
1- 10 nm carbides	3.74
2 - commercial grade (GB carbides)	3.01
3 - Solutionised (dislocations & GBs)	2.2
4 - 20 nm carbides	1.34

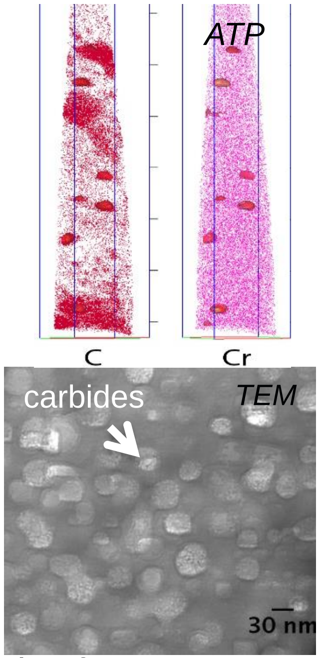
Less H on GB = reduced embrittlement



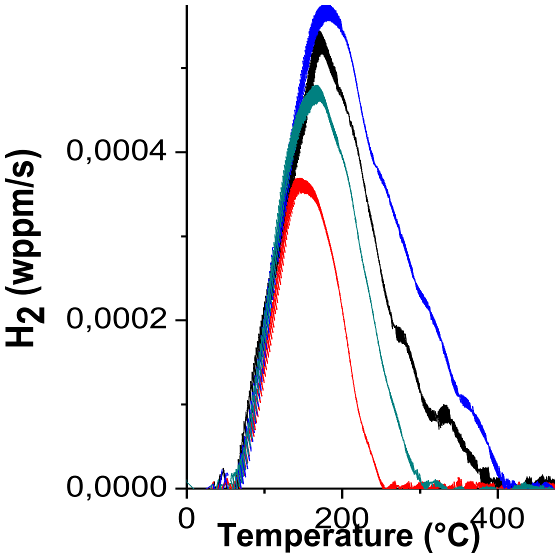
Modelling



Irradiation of commercial alloy



Optimise for H + He trapping (carbide traps)

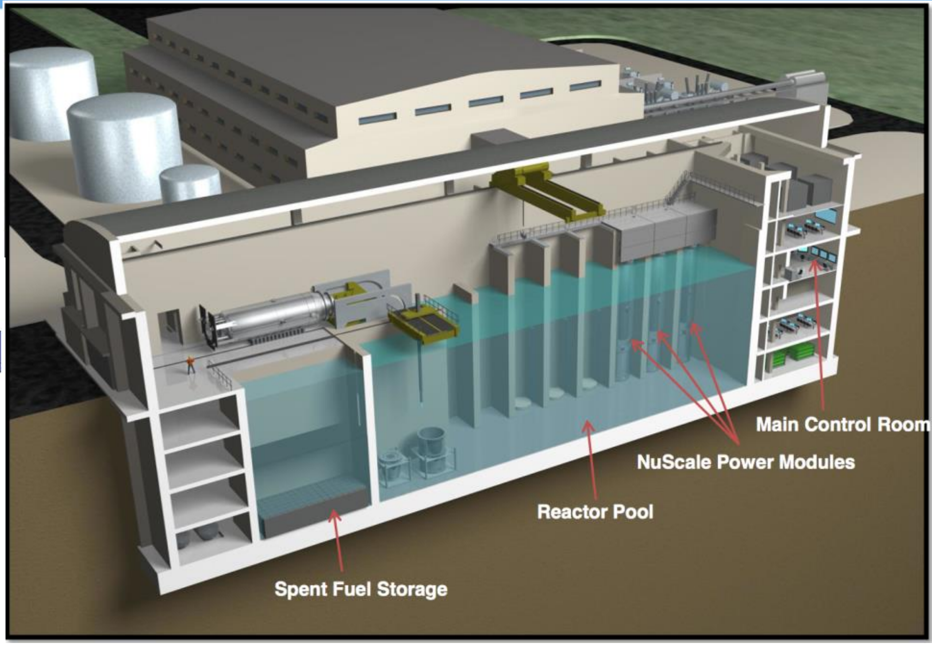


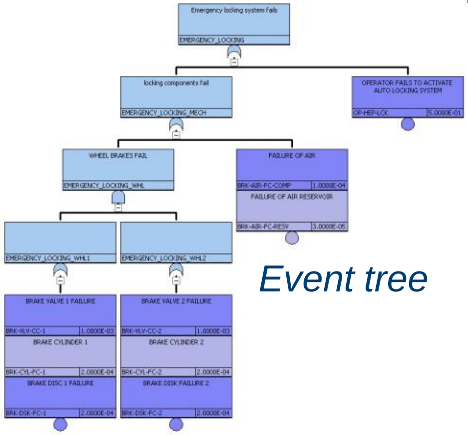
TDA to test H retention

Miles Stopher - Probabilistic risk assessment

Provide an independent analysis of SMR core damage frequency claims of the NuScale SMR system using open-sourced data and modern probabilistic methods.

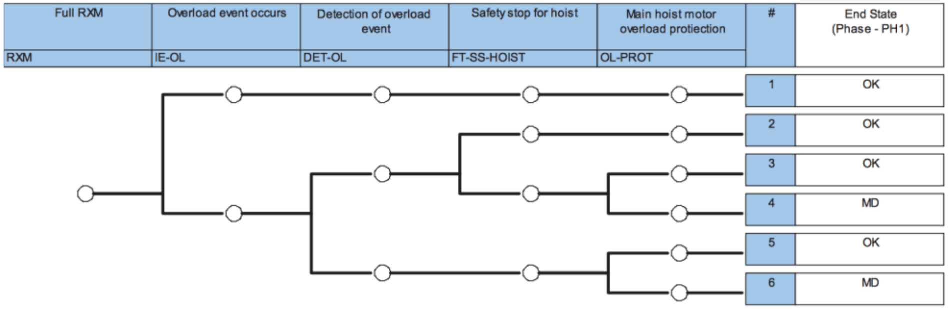
e.g. NuScale Module drops during refueling process.



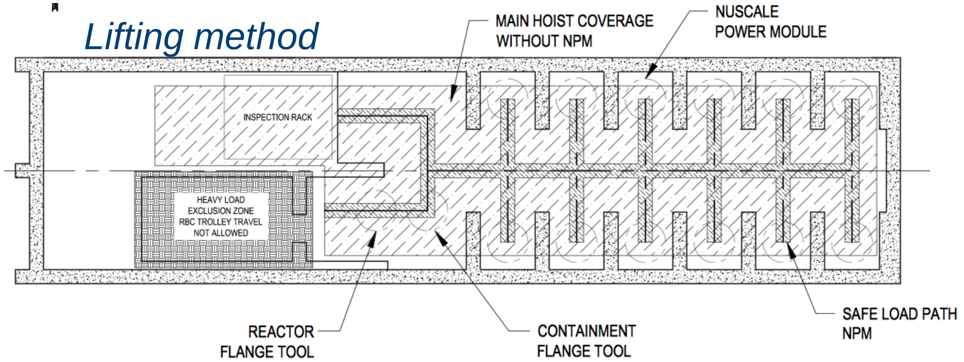


Event tree

Fault tree



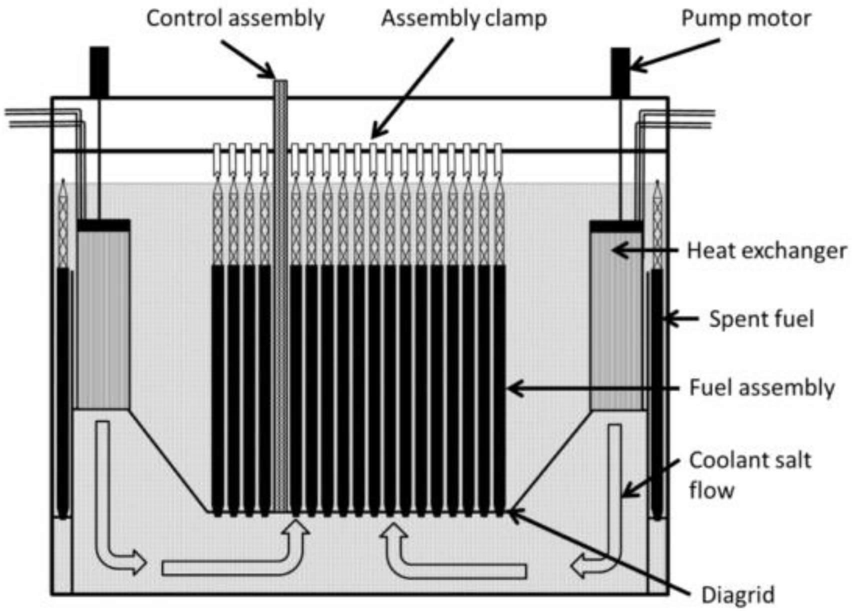
Lifting method



Alisha Kasam- Bread & Burn MSR

- **Dual-salt:** Separate fuel & coolant salts (based on Moltex)
  - Corrosion & irradiation damage limited to cladding (replaceable)
  - Fuel thermal expansion → passively safe fast reactor

- **Breed & burn:** LEU feed fuel → breeds Pu in fast spectrum → high burnup → direct disposal



I. Scott, et al., "Stable Salt Reactor Design Concept," in Proceedings of the Thorium Energy Conference, (Mumbai, India), 2015.

Alisha Kasam- Bread & Burn MSR

Dual-salt

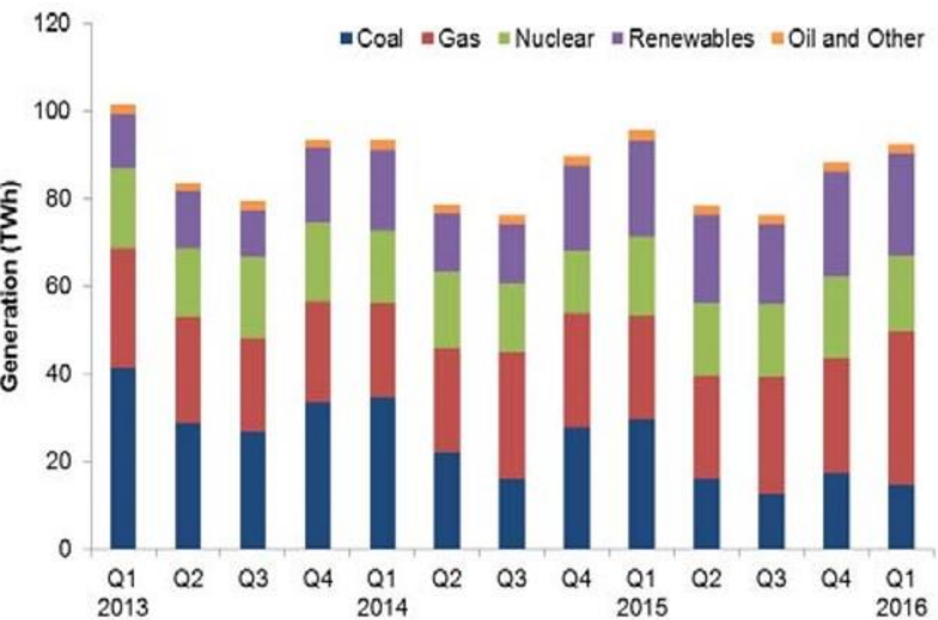
- **Premise:** natural convection of fuel salt in tube → enhances heat transfer → allows larger fuel diameter
- **Thermal-hydraulic feasibility:** how much natural convection, heat transfer from fuel to coolant?

Breed & burn

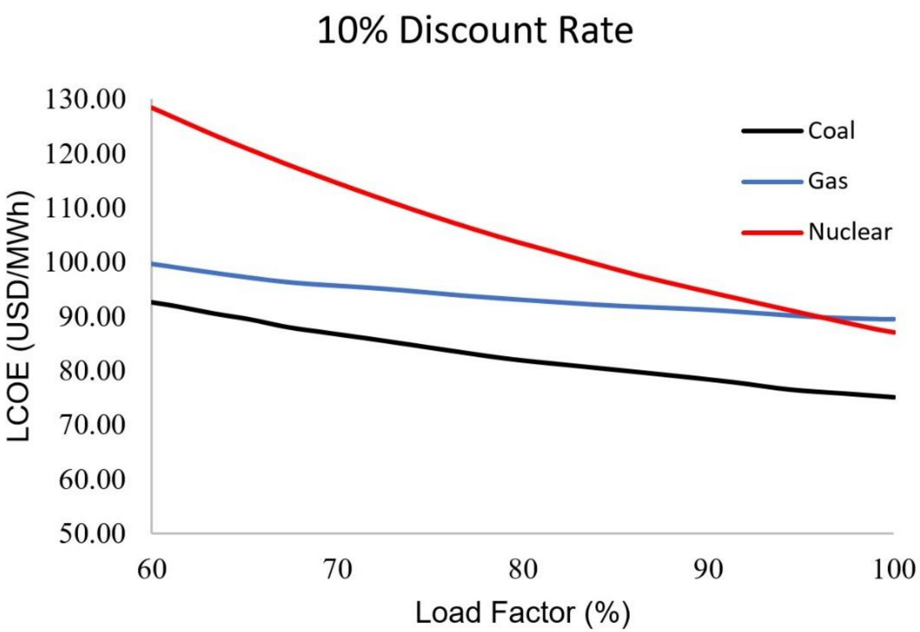
- **Premise:** Fresh (k<<1) fertile fuel breeds enough Pu to become driver (k>>1) fuel
- **Neutronic feasibility:** can fuel tube configuration sustain B&B mode?
  - Requires large fuel diameter, tight lattice, hard spectrum

Andhika Feri Wibisono – Hybrid Small Modular BWR with External Superheater

UK energy statistics (2015)



NEA study (2011)



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Andhika Feri Wibisono – Hybrid Small Modular BWR with External Superheater

Parameter	AP1000		ESBWR	
	No Superheater	With Superheater	No Superheater	With Superheater
HP turbine inlet temp. (°C)	271	600	284	600
Nuclear Power generated (MWe)	1,031.3	2,045.0	1,593.3	2,838.0
Fossil Heat Required (MWt)	-	2,318.0	-	2,906.0
Reactor Thermal Power/Nuclear Heat (MWt)	3,416.6	3,416.6	4,503.9	4,503.9
Increment of Power (%)	-	98.00	-	78.12
Fossil Fuel Cycle Efficiency (%)	-	43.66	-	42.83
Total Cycle Efficiency (%)	30.23	35.66	35.38	38.30

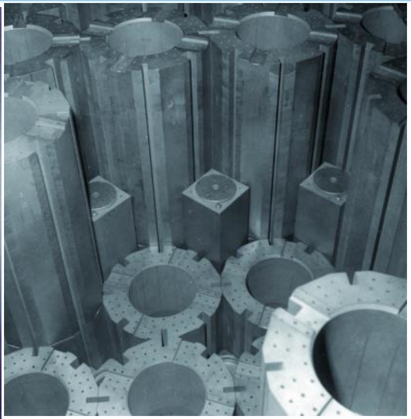
Benefits of coupling NPP with external superheater:

- Improvement in cycle thermal efficiency;
- Load can be reduced down to 65-70% by adjusting the superheater heat, while maintaining the reactor to operate at 100% of its full-rated power.

Possible extra effects:

- Vessel size reduction
- Further increase of cycle thermal efficiency by increasing system pressure

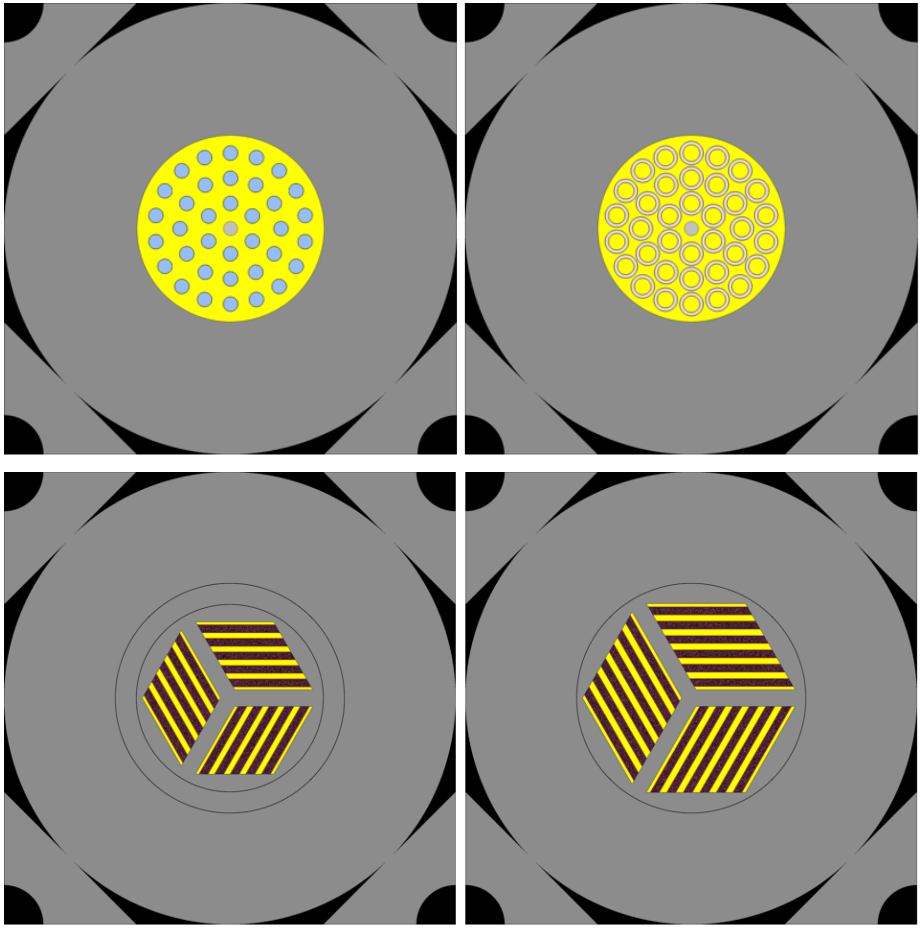
Zhiyao Xing– Alternative FHR Design Leveraging AGR Technology



- What is an FHR?
  - Solid high-temperature fuel
  - Molten salt coolant (700 °C)
  - High temperature moderator (graphite)
- Advantages?
  - Salt with high boiling point → reduced concerns about coolant boiling
  - Operation at atmospheric pressure
  - High solubility of most fission products in liquid Fluoride salts

Zhiyao Xing– Alternative FHR Design Leveraging AGR Technology

- Fuel options explored:
  - solid pin annular pellet
  - plate type fuel
- Fuel materials explored:
  - UO_2 UC
  - FCM
- Fuel materials explored:
  - FLiBe
  - FLiNaK
  - $NaF\text{-}ZrF_4$



Una Davis – Computational benchmarking of SFRs for safety analysis

- ESFR-SMART project aims to enhance safety of Gen-IV SFRs
- Improving public acceptance by proving new reactors are significantly safer than previous designs
- Work Package 2.1: calibration and validation of computational tools used for safety assessments
- SFRs have more complicated reactivity feedbacks than LWRs – how do we model this? Are our current methods sufficient?
- Superphénix (1981-1998) data used for benchmark for computational models

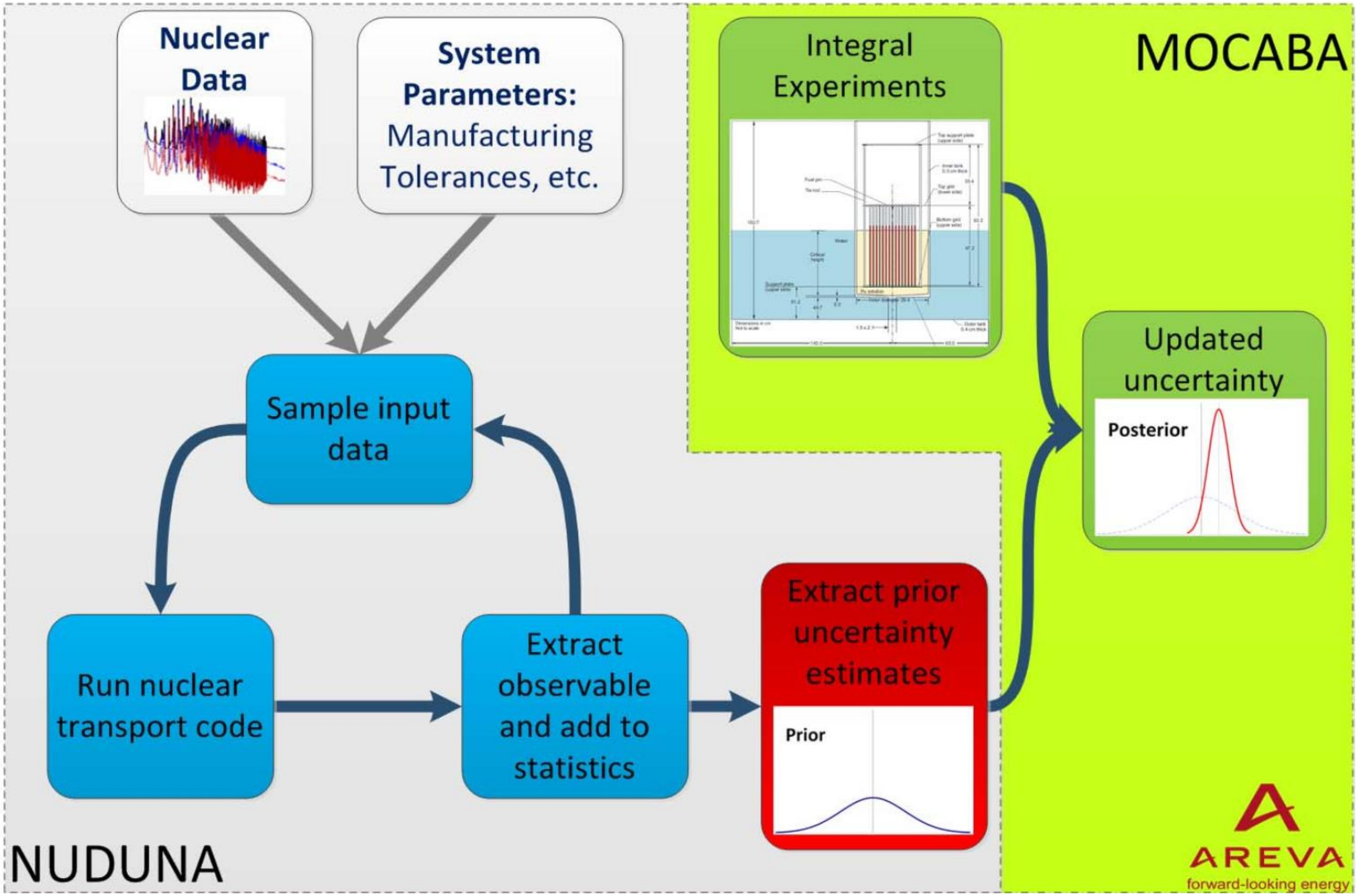
Jonathan Dixon – Propagating uncertainties of graphite weight loss in AGR

- Nuclear industry very conservative. Uncertainty quantification is still a young concept to the industry as a whole.
- Computational project using reactor physics codes to quantify impact on reactor performance and safety parameters as graphite weight loss increases combined with other sensitivity studies.
- Interests in determining variation reduction techniques.

Motivations

- Developing new techniques for industry which can assist in future code releases.
- UQ has a growing regulatory interest and could have a role in life extensions.

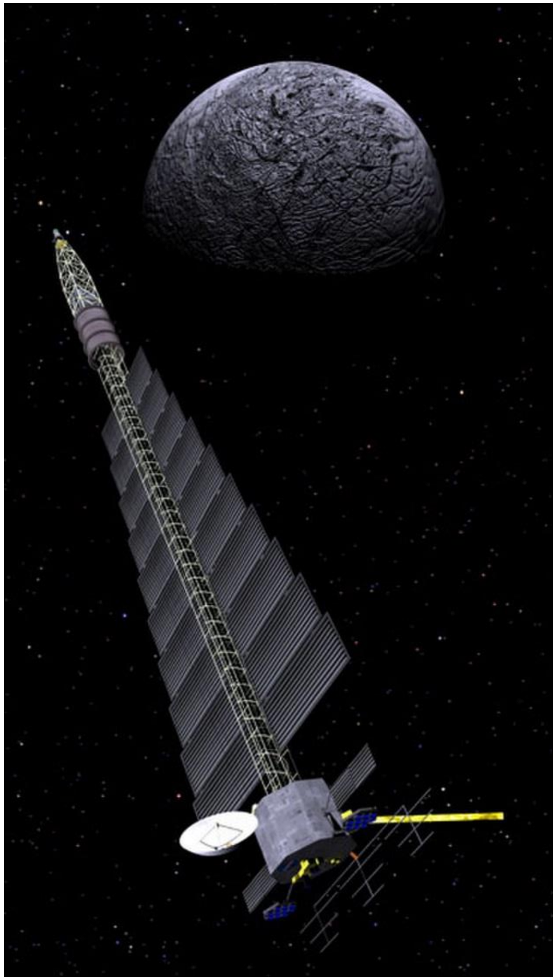
Jonathan Dixon – Propagating uncertainties of graphite weight loss in AGR



Nathan Read– Nuclear Electric Propulsion with Low Enriched Uranium

Why nuclear in space?

- Need power for propulsion and instrumentation
- RTGs and solar PV are not easily scalable to megawatt power levels
- Need to turn to fission reactors
- Cancelled *Prometheus* project was intended to utilise nuclear electric propulsion

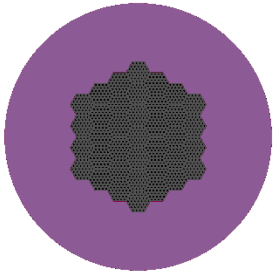


Nathan Read– Nuclear Electric Propulsion with Low Enriched Uranium

Ideal fuel from technical viewpoint is U-235

BUT:

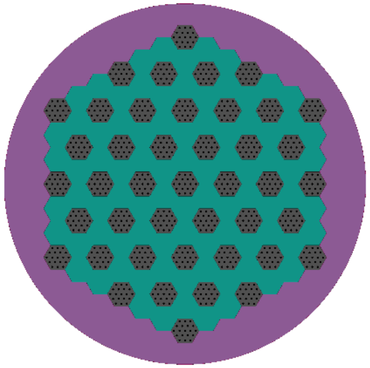
- Proliferation concerns
- Want civilian space exploration
- Security costs
- Can't collaborate easily with industry and academia
- Fine for USA but not workable in Europe



HEU

Project aims:

- Quantify impact of using LEU rather than HEU:
- Core mass
- Core volume
- Total system mass
- Materials compatibility
- Crash safety



LEU

Other topics:

- Genetic algorithms & TABU Search –core and assembly optimisation
- Collision history based sensitivities in burn-up calculations
- SMR cost analysis
- SMR supply chain analysis
- LEU nuclear power reactor for spacecraft applications
- Fuel behaviour model for OpenFOAM (GeN-FOAM)