UNIVERSITY OF CAMBRIDGE

Nuclear Energy Research in Cambridge

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Department of Engineering

SERPENT / Multi-physics Workshop, LPSC Grenoble **26-27 February 2015**

Nuclear Energy Education in Cambridge

- **Undergraduate**
  - Introduction to NE, Nuclear Materials, Reactor Engineering, Advanced Systems/Fusion, Medical Physics
  - Over 150 students took NE introductory module last year
  - 10 – 20 fourth-year Engineering Projects were offered
- **Graduate**
  - NE MPhil – one year full time masters course
  - 15 PhD students in Engineering/Physics, Waste/Materials and Business/Policy
  - Centre for Doctoral Training (CDT) – jointly with OU and ICL

Nuclear Energy Research Community in Cambridge

- Cambridge Nuclear Energy Centre
- Coordinates cross-discipline collaboration
- About 15 academics are actively engaged in NE related research
  - Department of Engineering: Physics and design of advanced systems
  - Department of Earth Sciences and Department of Materials Science & Metallurgy: Waste and decommissioning, high temperature reactor materials, fuel reprocessing, fracture mechanics and steels
  - Judge Business School: Economics, technology policy

MPhil in Nuclear Energy - Overview

- Taught 1 year MPhil in Nuclear Energy (runs October – August each year)
  - 20 -25 top students from around the world each year
  - 5 core nuclear engineering modules
  - Nuclear policy module
  - Elective modules from Engineering, Materials Science, Chemical Engineering, Physics and Judge Business School
  - 4 months project on either:
    - Cambridge University or
    - Industry partner research topic

Nuclear Energy MPhil - Core Scope

Core Topic	Scope
Reactor Physics	Core physics & shielding – steady state power & shapes, depletion control elements & use of poisons, core kinetics & system control.
Reactor Engineering & Heat Transfer	Coolant types, thermal cycles, heat transfer, thermal limits – reactor systems, their optimisation and operating characteristics including normal operation & how to address main types of fault condition.
Fuel Cycle, Waste & Decommissioning	Whole fuel cycle: mining to waste & how waste is managed, decommissioning principles.
Fuel & Reactor Materials	Fuel and reactor materials – including selection, safety and life issues – radiation behaviour & damage, structural integrity & fracture mechanics, EAC.
Safety & Advanced Systems	Safety philosophies, impact on design, justification approaches, control & reliability, advanced systems including Gen IV, Thorium & Fusion
Nuclear Technology Policy	Energy studies & climate change, economics of energy, nuclear politics, proliferation & physical security.

MPhil – Breadth & Depth of NE Education

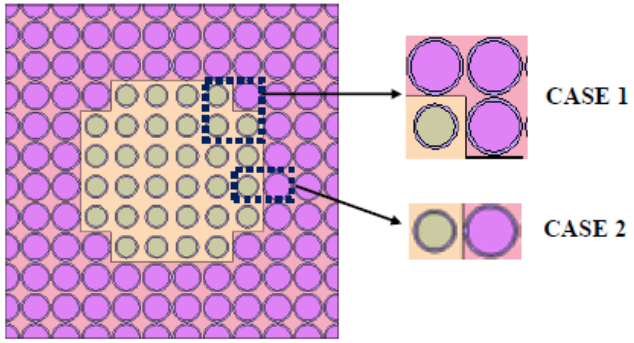
- **Breadth:**
  - Teaching a wide range of nuclear engineering and policy topics
  - Visits & experiments: Sizewell B, Culham Fusion R&D lab, Research Reactor
  - External lectures by leading figures from the nuclear industry
- **Depth:**
  - Choice of optional/elective courses
  - Long research project and dissertation
  - Projects from industry – on a real issue with supervision by industry

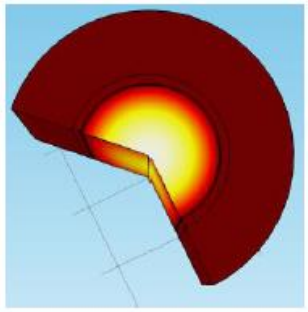
Examples of MPhil Projects

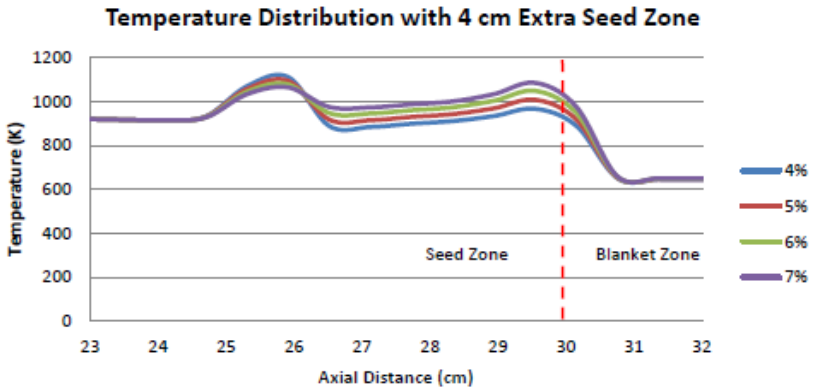
Title	Student
WIMS/ PANTHER model for a start-up EPR Core	Jinfeng LI
Economics of SMRs – design options	Inkar Yertayeva
Managing power peaking at fissile-fertile interface in HC LWRs	Cuicai Dong
Ethical Principles & Values in Nuclear Safety	Annie Bonaccorso
Accelerator Production of medical isotopes	Tianyi Wang
Commercial Nuclear Marine Core Design	Hao Sun
Electron Beam welds in nuclear pressure-vessels	Chris Duffy
Waste glass dissolution modelling	Rui Guo
Modelling of Fast Reactor transients	Xinyu Zhao
Energy group structure optimisation for fusion reactor applications	Michael Fleming

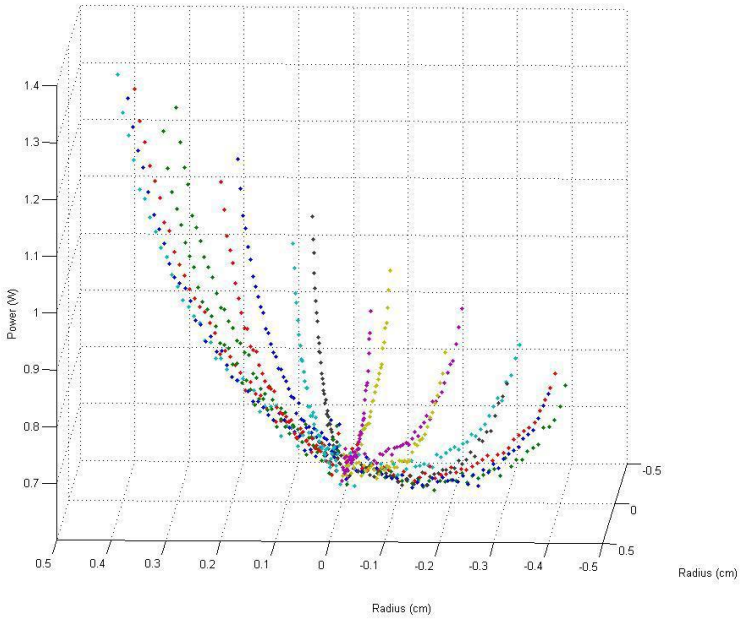
Examples of using Serpent

- **Seed-blanket interface multi-physics modelling**



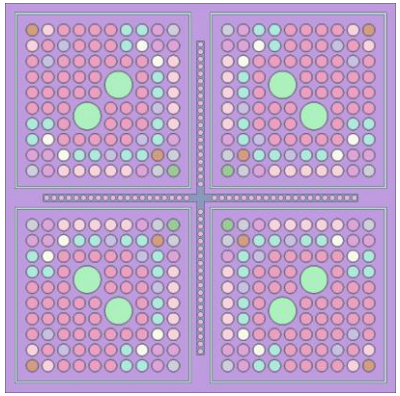


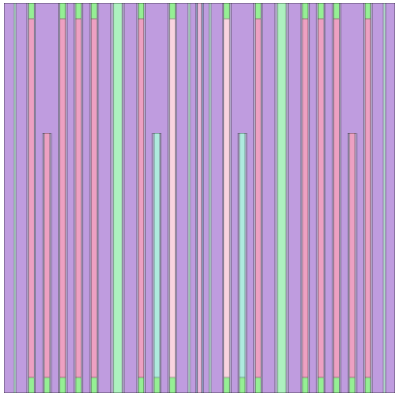


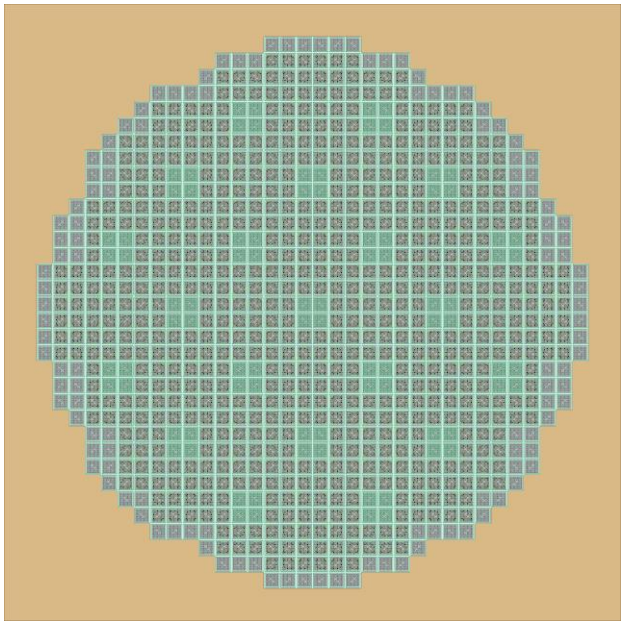


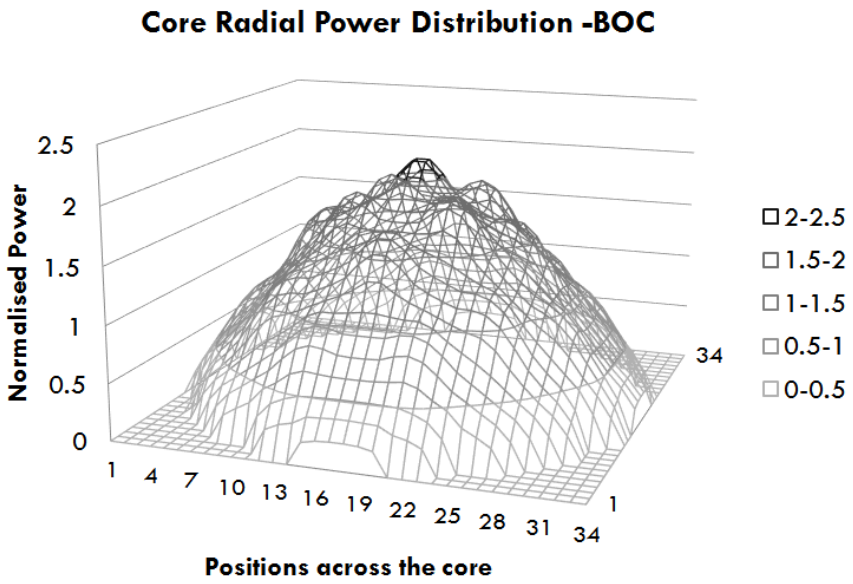
Examples of using Serpent

- **ABWR modelling**
  - **Serpent XS + PANTHER**
  - **Thermal feedbacks included**





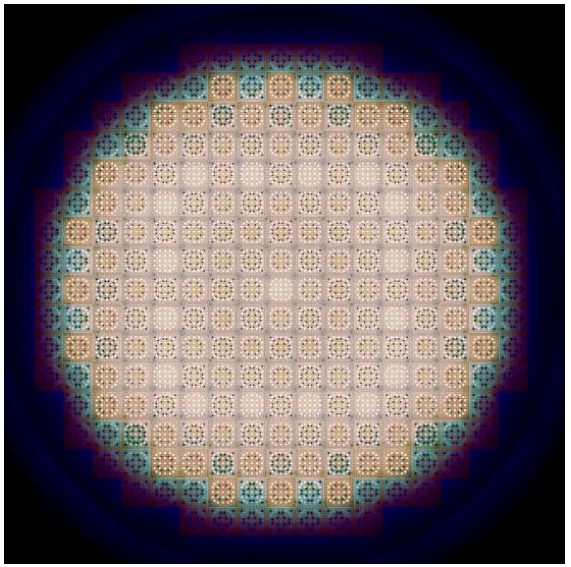




Examples of using Serpent

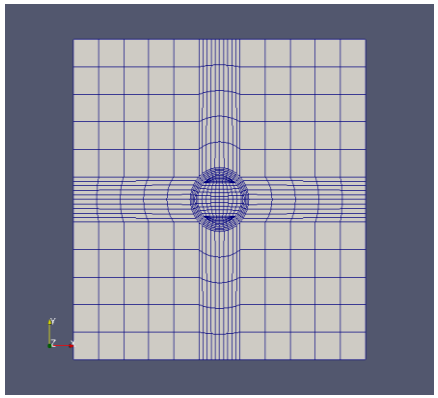
- **EPR startup core modelling**
  - **WIMS/Serpent XS + PANTHER**
  - **Thermal feedbacks included**

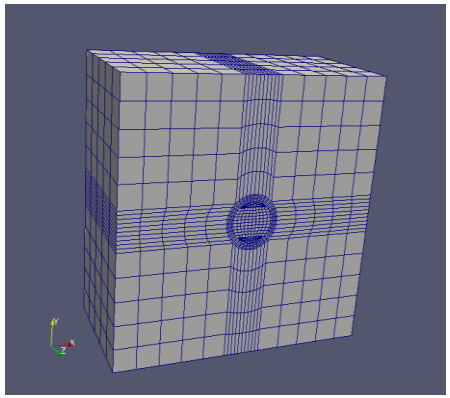
		This work	ONR report	Difference
Critical Boron Concentration (ppm)		1029	1026	0.3 %
Total Heat Flux Hot Channel Factor		2.69	2.82	-4.8 %
Hot Channel Factor		1.63	1.61	1.2 %
Doppler Coefficient (pcm/K)	BOC	-2.90	-2.93	1.0 %
	EOC	-3.17	-3.21	1.2 %
MTC (pcm/K)	BOC	-13.7	-13.0	5.4 %
	EOC	-64.2	-60.6	5.9 %
Boron Worth (pcm/ppm)	BOC	-9.1	-9.3	2.2 %
	EOC	-9.4	-9.7	3.1 %

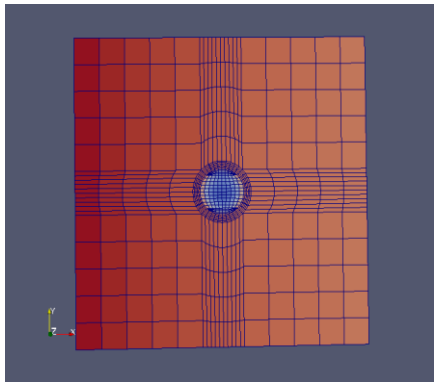


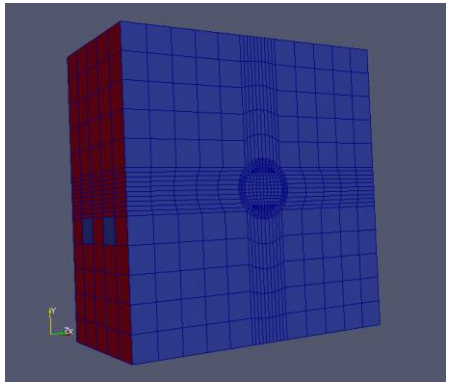
Examples of using Serpent

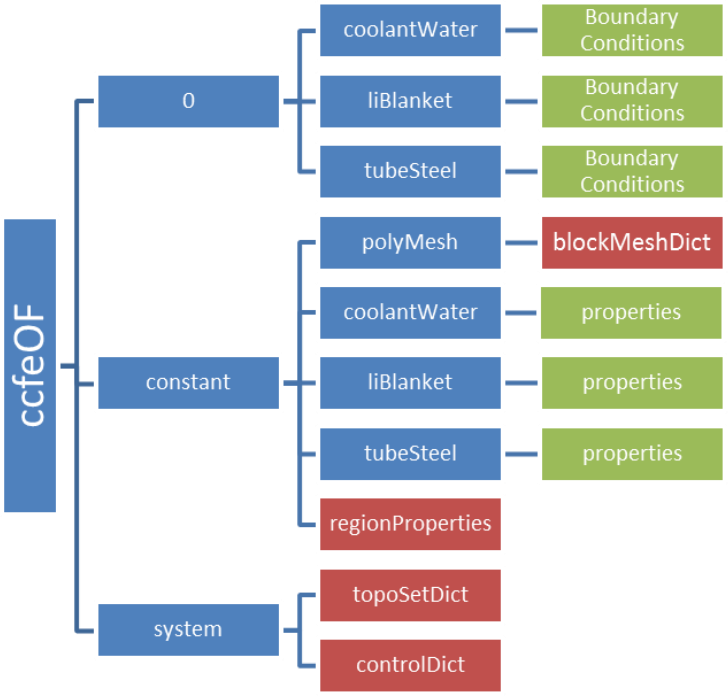
- **Multi-physics modelling of fusion breeding blankets**





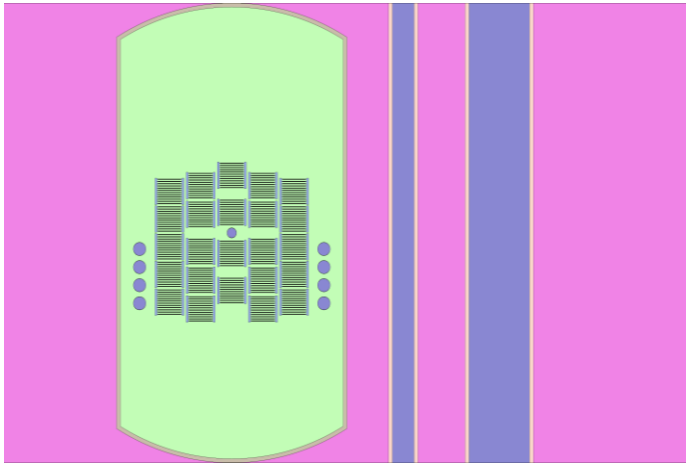


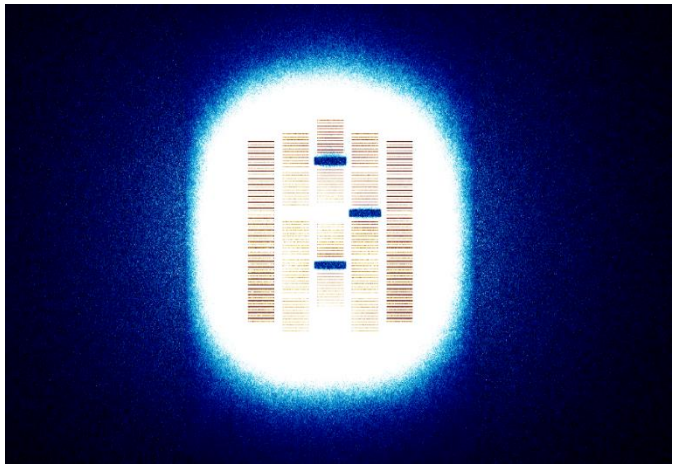


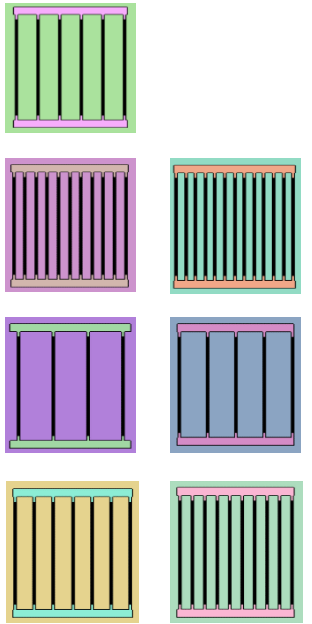


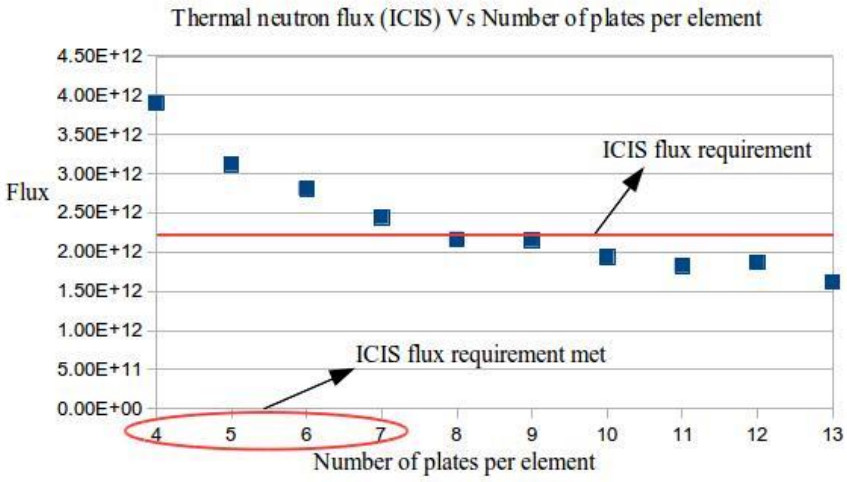
Examples of using Serpent

- **HEU to LEU fuel conversion of CONSORT reactor**









High Conversion LWRs Modelling

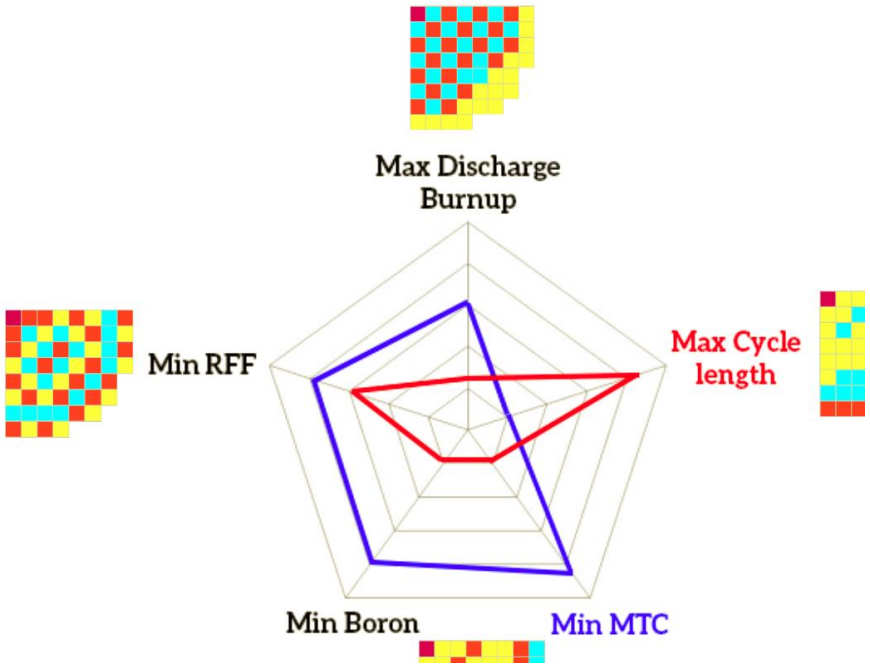
- Highly heterogeneous cores
- Analysis methods
  - Monte Carlo XS + nodal diffusion codes for transients
  - Coupled Monte Carlo – multi-physics
    - Accelerated convergence and numerical stability
  - SP3 option in DYN3D
  - 3D MoC – WIMS/CACTUS
- Dynamic modelling of fuel cycle systems

Molten Salt (and Molten Salt-Cooled) Reactors

- Real potential to compete with LWRs economically
  - High temperatures for non-power applications
  - Hybrid systems to complement fossil fuels and renewables
- Design space remains largely unexplored
- Fast/thermal, Pebbles/blocks, SMR/large
- Ongoing collaboration with MIT-UCB-UW
- Joint NEUP proposal submitted

LWR Core Design

- Stochastic fuel loading optimisation algorithms
- Advanced PWR/BWRs with exotic fuels
  - I2S-PWR project
  - Accident tolerant fuels
  - Thorium/Pu/MA
- Transients and steady state
- WIMS/PANTHER/DYN3D
- PARCS-TRACE



Fast Reactors

- Once-through Fast Reactors (no reprocessing)
  - A.K.A Traveling-Wave, Breed & Burn, USFR etc.
- Passive safety (DHR and reactivity control)
  - High leakage “Pancake” shape is no longer needed
  - Cheaper, more neutronically efficient core
- Core disruptive accidents
  - Tightly coupled problems - OpenFOAM ?
- Thorium fuel cycle for Fast Reactors
  - EPSRC UK – India Civil Nuclear Collaboration Proposal submitted

Thank you