R&D on Digital Nuclear Reactor Design
Virtual Engineering, Modelling and Simulation

John Lillington, Chief Technologist
Modelling in Nuclear Science and Engineering (MiNSE)
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Virtual Engineering in Nuclear Reactor Applications

- Virtual engineering provides multi-faceted links between collaborating engineering teams through the development of computer models and other tools within a multi-disciplinary environment.

- It is becoming ever more practical through the increasing availability of High Performance Computers (HPCs) and also strides in effective ‘big data’ management.

- It is already extensively used in some industries e.g. aerospace, automotive, etc.; its use is now growing within the nuclear industry, the subject of this presentation.

Digital Reactor Design Project

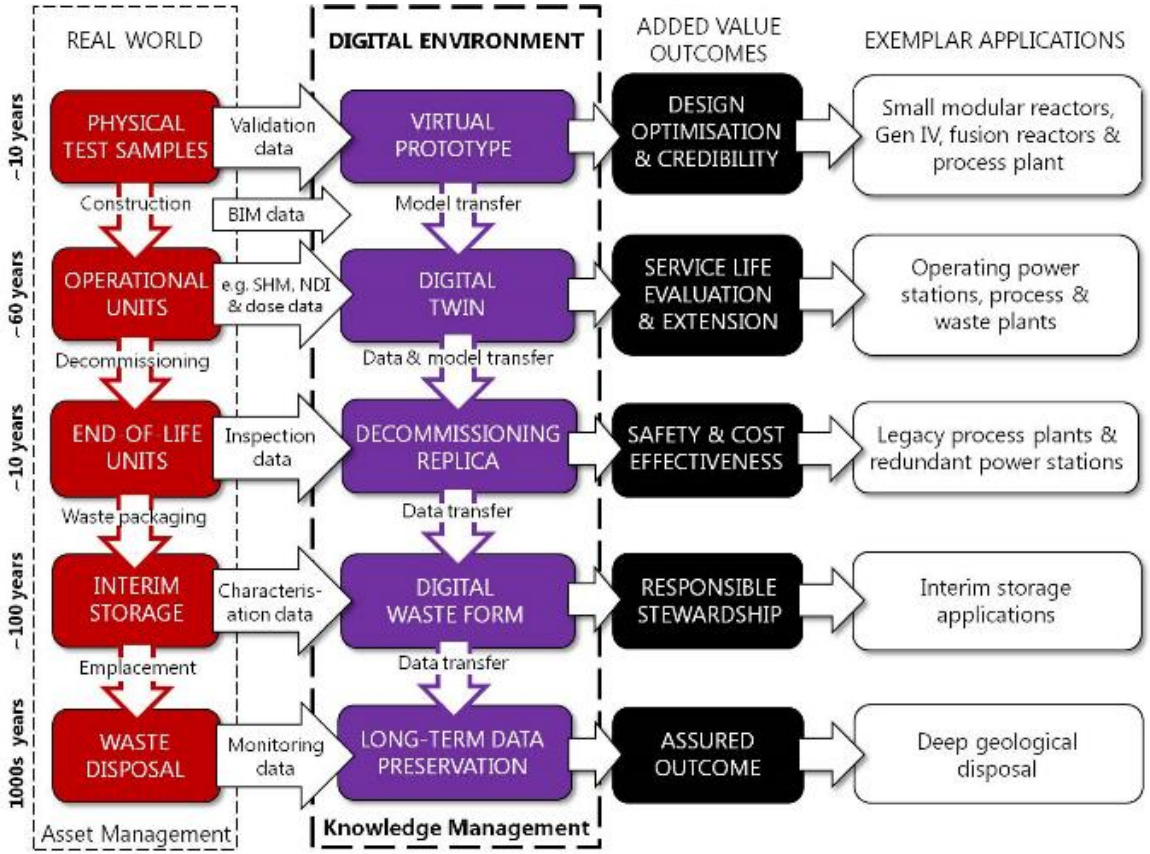
- The presentation will provide some examples of developments in progress from experience gained from the UK BEIS supported nuclear virtual engineering project, which covers integration of different design steps / data transfer, code coupling, multi-physics etc.
- Short summary of some of the material presented to an Engagement & Review Workshop on the BEIS Integrated Digital Nuclear Design Programme, Thursday 3rd May 2018.
- In the context of a representative UK nuclear industry study, the methodology can be applied to design development but also for normal operational support and fault studies analysis in risk assessments.
- The presentation will cover the overall simulation framework, how the integrated nuclear digital environment works and the benefits it can provide.
- This will be by reference to several different applications. The presentation will also refer briefly to some international activities in this field.

Partners in Digital Reactor Design Project

Website www.digitalnucleardesign.com

Courtesy: Lynn Dwyer, Virtual Engineering Centre

A Simulation Framework: INDE

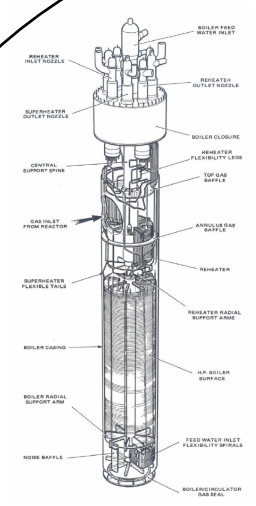


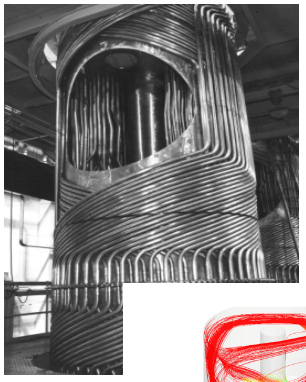
Courtesy: Eann A Patterson, A. A. Griffith Chair of Structural Materials & Mechanics, University of Liverpool, &
Senior Visiting Fellow, National Nuclear Laboratory

Ref: Patterson EA, Taylor RJ, Bankhead M, A framework for an Integrated Nuclear Digital Environment, Progress in Nuclear Energy, 87, 97 – 103, 2016

AGR Pod Boiler Spine Digital Twin (EDF Energy)

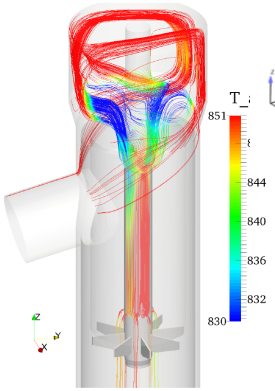
Complex Geometry
- *10m structure*
- *>700 pipes*

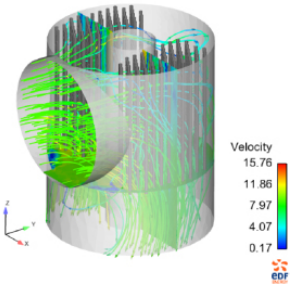




Multi-tools
- *Legacy engineering tool (1D)*
- *Advanced CFD tool*
- *Thermal tool*

Multi-scale
e.g. manufacturing imperfections, turbulent boundary layer flow around tubes



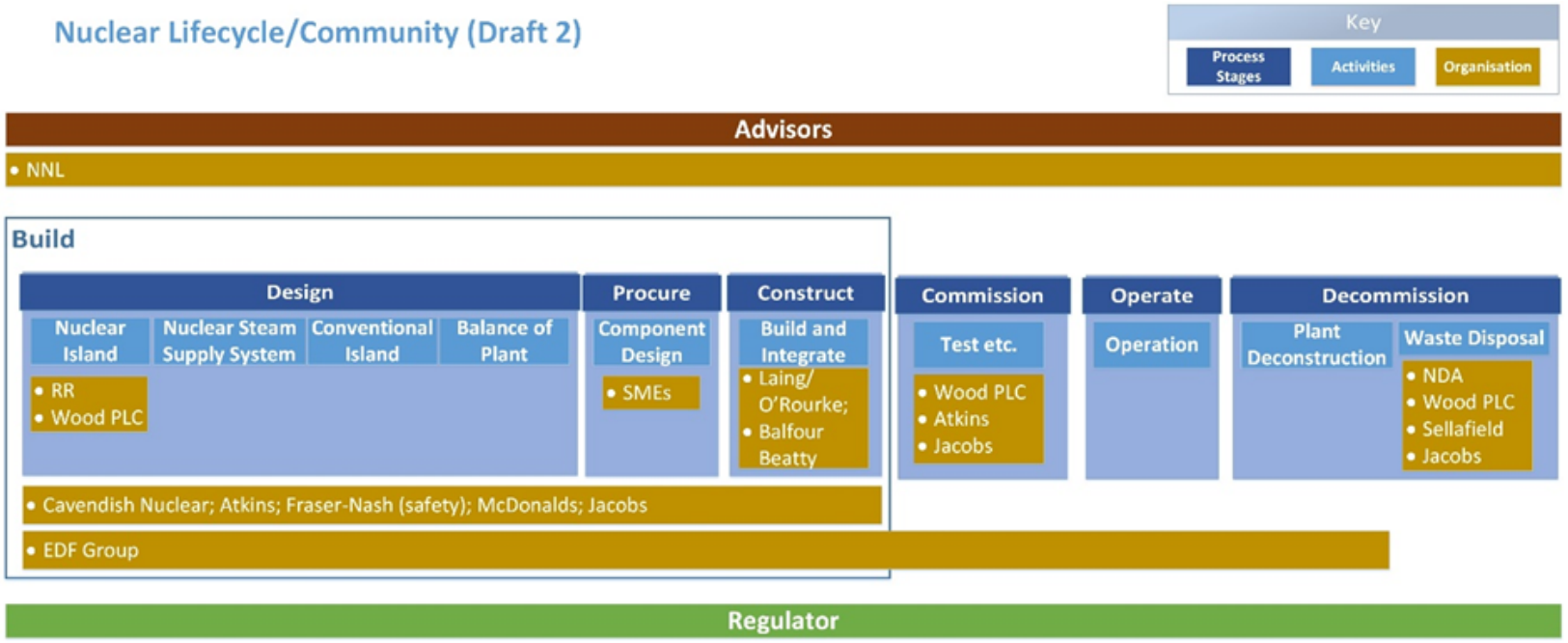


Multi-Physics
- *Primary Gas flow*
- *Secondary steam flow*
- *Heat transfer with structures*

Different parameters of interest
Temperature at welds (creep, stress corrosion cracking)
Impact of carbon deposition
Impact of tube blanking

Courtesy: Erwan Galenne – Head of R&D Nuclear, EDF Energy R&D UK Centre

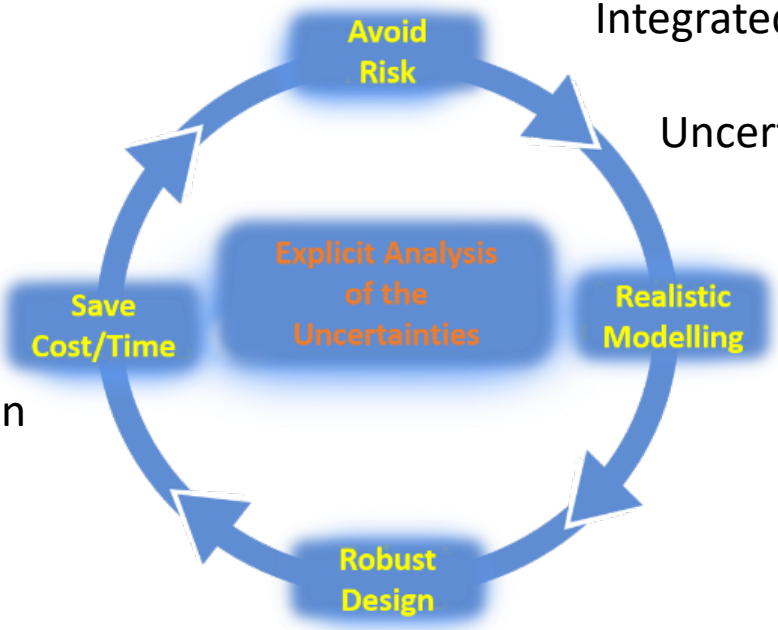
Stakeholders



Courtesy: Dave Bowman – Technical Lead, Virtual Engineering Centre, Engineering Centre

Uncertainty Quantification Tools

- Better understanding of the system
  - How much robust is it?
  - Can we enhance it (in the most efficient way)?
- Increase model credibility
  - What accuracy can I have in output given what I know?
- Fully risk-informed decision making
  - How much can I trust the response?
  - How uncertain is it?



Integrated UQ cutting-edge tool

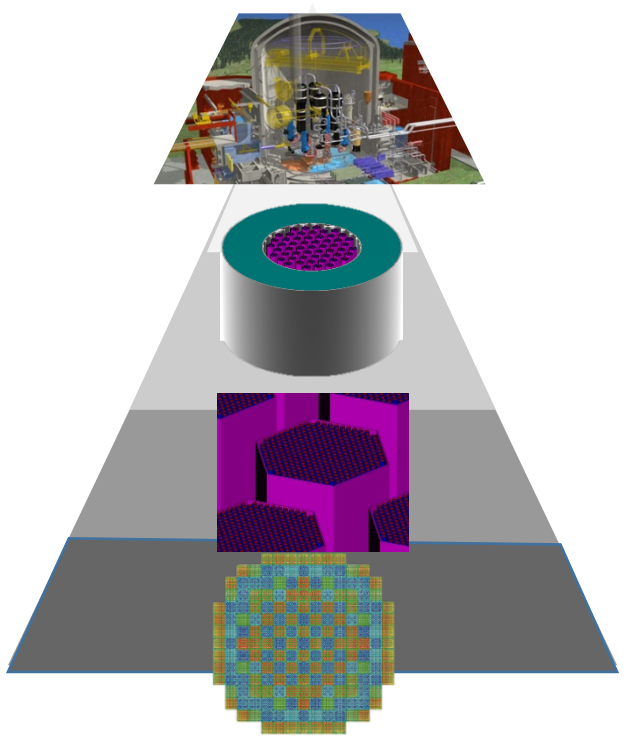
Uncertainty Characterization

Sensitivity Analysis
Reliability Analysis
Surrogate Model Implementation
Model Validation

Courtesy: Silvia Tolo – University of Liverpool

Integrated Nuclear Digital Environment (INDE)

- Multi-scale, multi-physics computational models
- Distributed simulation network
- Integration of HPC, Virtual Reality, simulation codes
- Visualization of simulation results (local and remote)
- Real-time collaboration between participants



Courtesy: Ahmed Aslam – Wood, Mark Bankhead - NNL

Ongoing activities: Development and Testing

- Demonstration of integration of diverse computer codes (including Wood ANSWERS and EDF codes) and data transfer between modules:
  - On-going development on the framework to implement requirements
  - AGR Use case completed
  - PWR Use case close to completion

- Demonstration of current visualisation capabilities at a recent Nuclear Digital Environment Engagement Event , University of Liverpool, Thursday 27th September 2018

AGR Use Case: Whole life cycle graphite weight loss and structural analysis

- A verified model from Torness is providing the base data
- Through-life modelling of individual AGR graphite bricks to assess damage and corrosion through the life of the plant and how this impact upon their structural performance.
- This case requires links between several codes (PANTHER, MCBEND, FEAT-GRAPHITE macros & CODE-ASTER).
- FETCH2 has also been installed and running to demonstrate HPC capability.

PWR Use Case: Reactor system response to the ejection of a control rod

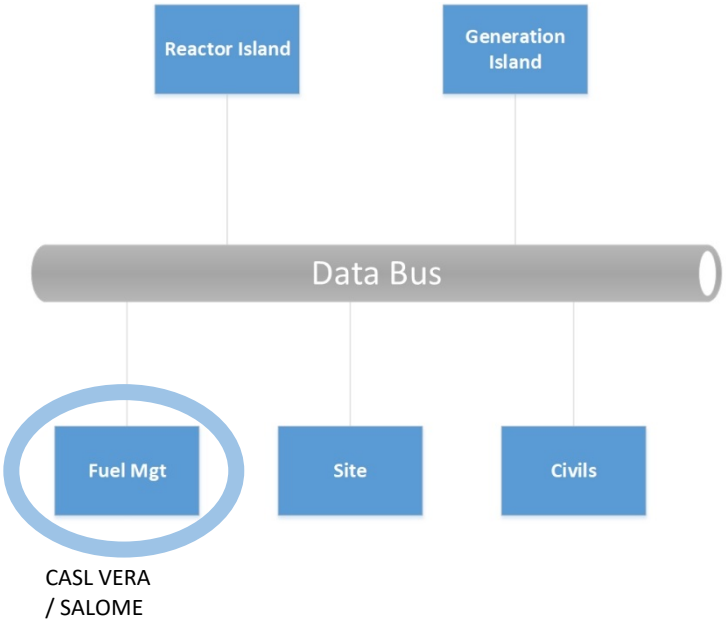
- The use case is focussed around a control rod ejection accident (REA). A REA generates a reactivity insertion, causing the temperature of the fuel and cladding to increase potentially leading to damage. Design assessments must justify that in this event the reactor remains safe.

- Three codes are used to complete these assessments for the purposes of the use case: WIMS, PANTHER and ENIGMA. These are integrated into the INDE being developed by the project. The analyses will be completed in several stages to look at:
  - Steady-state cycle behaviour
  - Response to a rod ejection accident.

- By comparison of technical results and the ease of generating them, the key outcome of the work will be to verify the functionality of the INDE and feedback on its use.

Ongoing Activities: International Collaboration

- International collaboration is an important aspect of the programme
  - LFE to accelerate development of UK codes
  - Opportunity to exploit UK IP in international markets
- Collaboration with CASL through ORNL
  - Workshop planned for September 2018 to discuss collaboration themes
- Engagement with EDF on SALOME platform



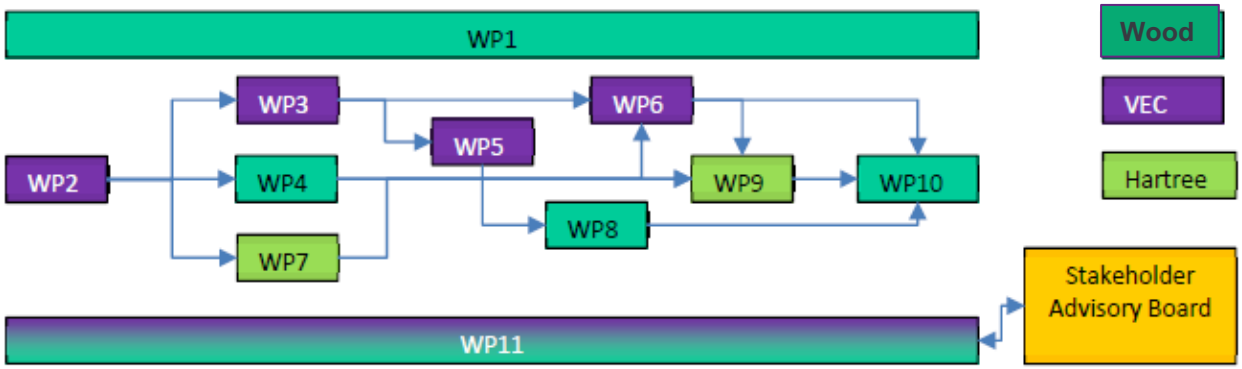
BEIS Requirements

- **World-leadership!** VE, HPC, 'big data' management & eScience needed to promote UK nuclear science & technology in the UK and globally; UK to become a world-leader?
- **Energy Security.** To support UK infrastructure, framework and tools to support industry in providing UK future energy supply security.
- **Joined-up industry.** To enable the whole of UK nuclear industry, including supply chain & SMEs to have easy access to innovation, expertise, facilities and capabilities, including access to HPC, data and computer visualisation facilities i.e. an Integrated Nuclear Digital Environment (INDE).
- **Cross-discipline benefits.** To bring together expertise from industry and academia to combine the latest digital techniques with advanced multi-scale, multi-physics modelling and simulation expertise.
- **Informed decision making.** Develop VE and associated technologies to inform, underpin and assist Government policy as well as to support informed decision making by all stakeholders.

Industry Requirements

- **Keeping pace with other Industries.** VE & associated technologies are widespread and developed across other high technology industries. There is a requirement to bring these into the nuclear sector to enhance similarly design and development throughout the nuclear lifecycle.
- **Managing operational risks.** Modelling and simulation using VE and associated technologies are crucial to understanding technical risks, therefore lowering costs, reducing the probability of delays, overspends etc.
- **Improved connectivity.** An INDE will allow digital twins to be generated for individual nuclear plants. This will enable connectivity and seamless data transfer between design authorities and CAD models, manufacturers, operators, decommissioning authorities and regulators over the life cycle of the nuclear system.
- **Improved operation and safety.** The advantages of an INDE specifically include reduced development timescales and costs, higher standards of safety, reliability and operability.

Project Organisation



- WP1 Project Management
- WP2 Requirement Capture & Management
- WP3 Capability Mapping
- WP4 Defining Pilot Projects/Use Cases
- WP5 Architecture Design
- WP6 Integration of VE Capabilities
- WP7 Integration/Access to HPC
- WP8 Development of Radiation Simulation Models
- WP9 Security Strategy & Safety Assurance Roadmap
- WP10 Multi-physics, Multi-scale Use Cases
- WP11 Dissemination & Supply Chain/User Engagement