NUCLEAR VIRTUAL ENGINEERING CAPABILITY

Digital Reactor Design

October 2019

Dr Albrecht Kyrieleis
NVEC Technical Lead
Wood

Contents

NUCLEAR
VIRTUAL
ENGINEERING
CAPABILITY

BEIS Nuclear Innovation Programme (NIP)

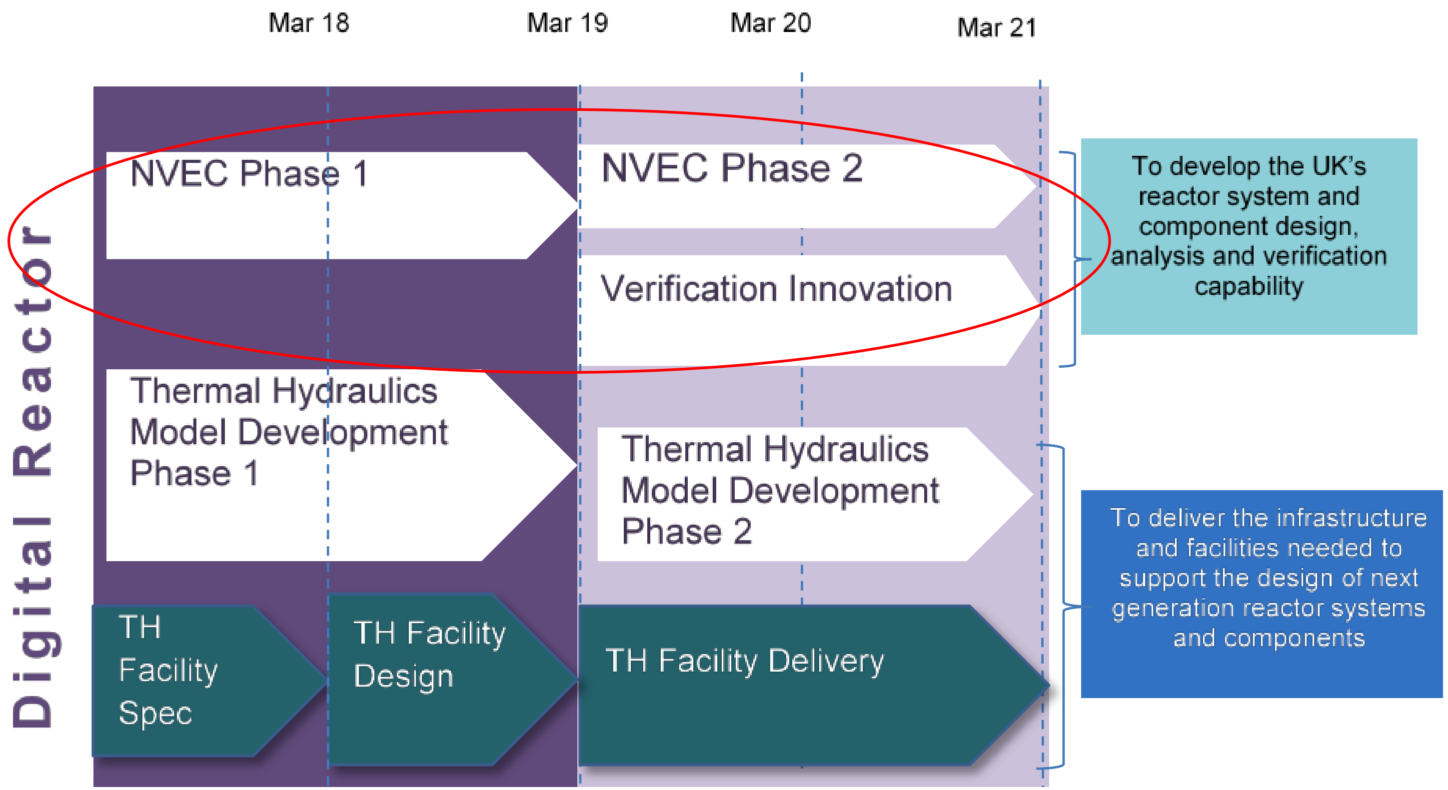
NUCLEAR VIRTUAL ENGINEERING CAPABILITY

- Launched by Dept. of Business, Energy & Industrial Strategy (BEIS) in 2016

Department for Business, Energy & Industrial Strategy

- Five areas:
  - Strategic tool kit and facilities
  - Advanced Fuels
  - Advances Manufacturing & Materials
  - **Advanced Reactor Design** → **Digital Reactor**; Nuclear Safety and Security Engineering
  - Recycle and Reprocess

Digital Reactor Design Programme



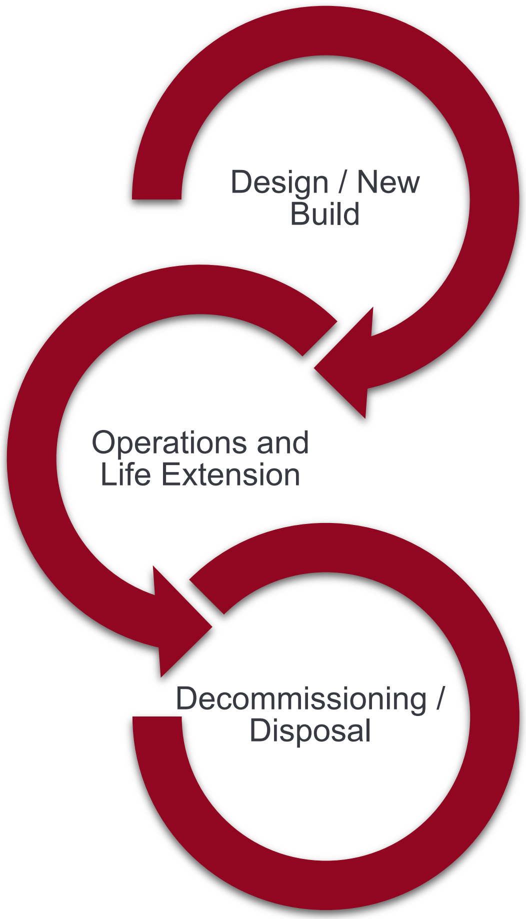
NVEC = Nuclear Virtual Engineering Capability

NVEC Phases 1 & 2

NUCLEAR VIRTUAL ENGINEERING CAPABILITY

- NVEC phase 1:
  - Partnership of 9 organisations (Wood as lead) was formed and finalised work on phase 1 in 2019
  - A vision for a UK Nuclear Virtual Engineering Capability (NVEC) was developed.
  - A proof-of-concept software framework and user portal was developed and operated
- NVEC phase 2:
  - Recently secured by Wood leading a partnership similar to phase 1

Nuclear lifecycle



Multitude of activities and workflows

Bespoke and standard software tools, for example:

- CAD for design, record keeping
- BIM (Building information management) tools during design and construction
- Neutronics and shielding software tools
- Reactor core physics, radiation shielding, dosimetry, nuclear criticality (e.g. using Wood's ANSWERS software suite)
- CFD for thermohydraulic flow and heat transfer calculations
- FE analysis for design calculations, structural analysis and to address ongoing operational performance

Wide range of data to be handled, e.g.:

- Design / as-build data
- Plant measurements
- Inspection results
- Analysis results / reports

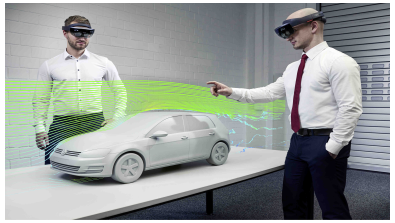
Vision

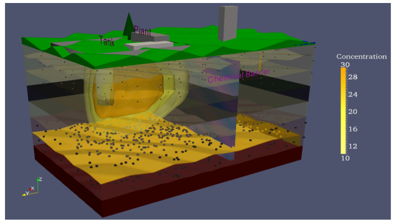
Nuclear Virtual Engineering Capability

Nuclear engineering of the future, across the whole nuclear lifecycle:

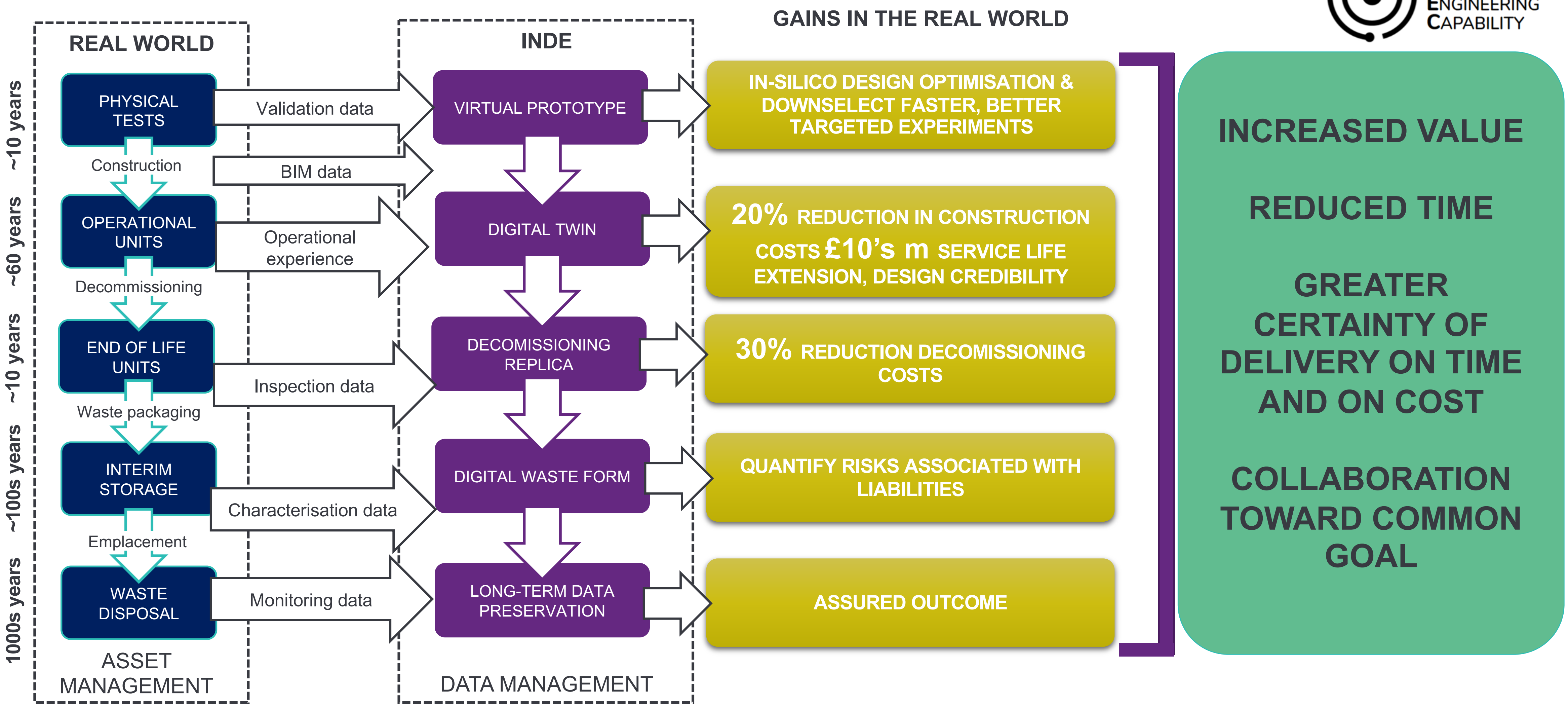
- Integrated simulation
- Trusted in-silico simulation
- Faster / (lower cost) increased value
- Easily auditable decisions
- Appropriate application of VR and AR
- Integrated smart systems
- Real-time monitoring and diagnosis

End-to-end integration for the design licensing of future nuclear plant





Vision – Integrated Nuclear Digital Environment



NUCLEAR VIRTUAL ENGINEERING CAPABILITY

Patterson EA, Taylor RJ & Bankhead M, A framework for an integrated nuclear digital environment, *Progress in Nuclear Energy*, 87:97-103, 2016

8

NVEC – What is it?

Nuclear Virtual Engineering Capability

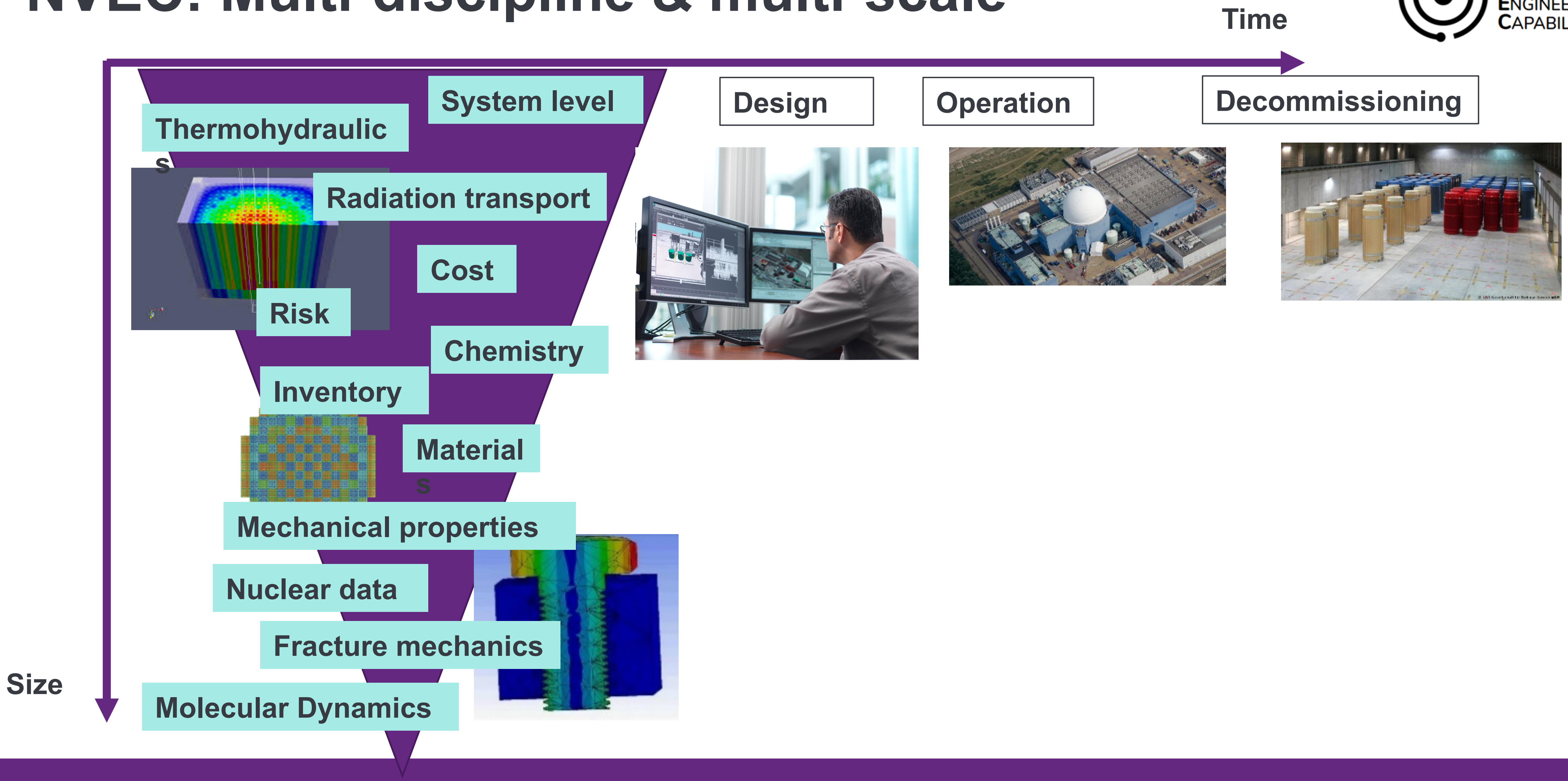
Integrated Collaborative Nuclear Design Environment with digital repository of tools and methods

Maintain a digital model of the plant, component or facility together with related design data

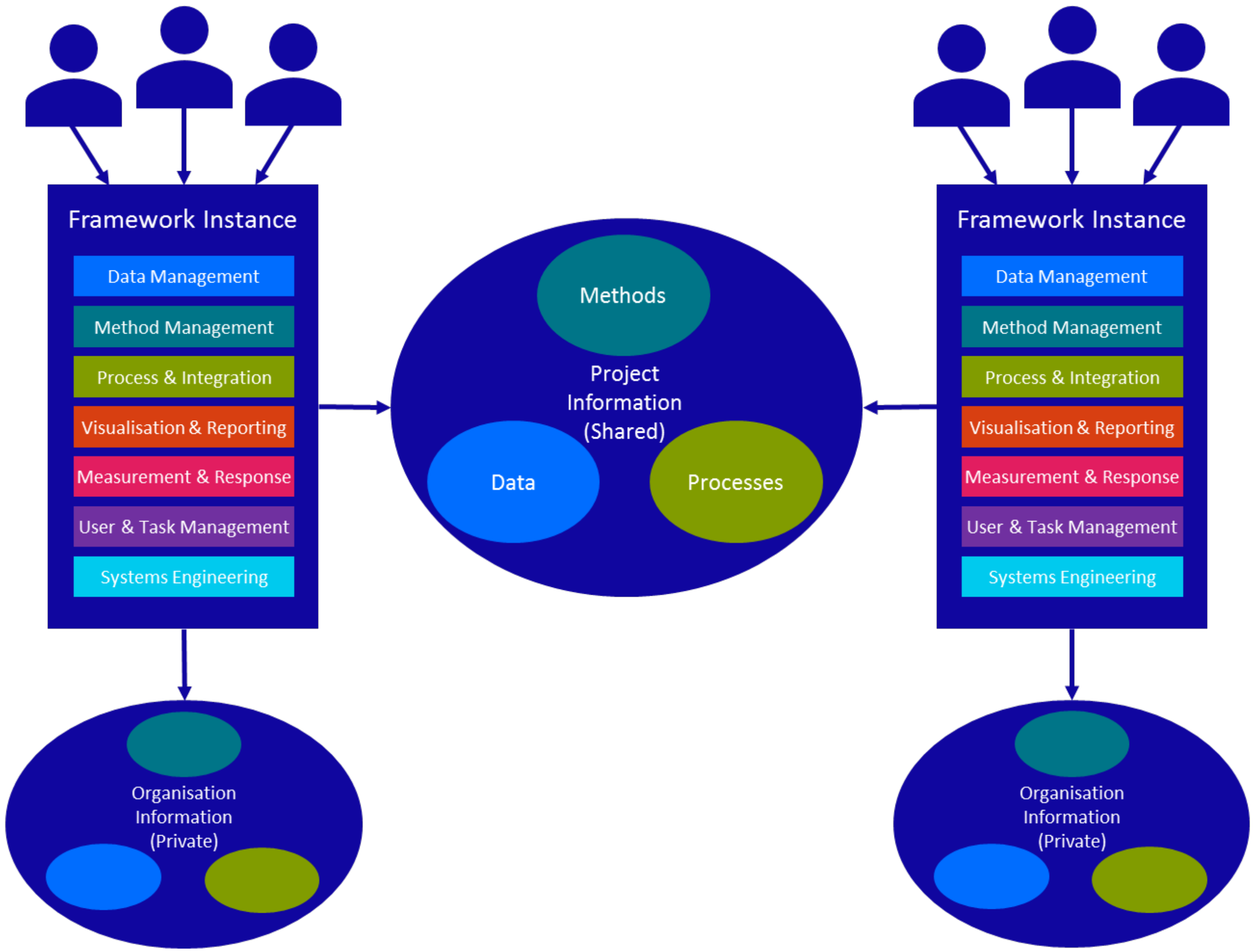
Securely view/ analyse/ share data

Run analyses and simulations on a common design from remote locations

NVEC: Multi-discipline & multi-scale

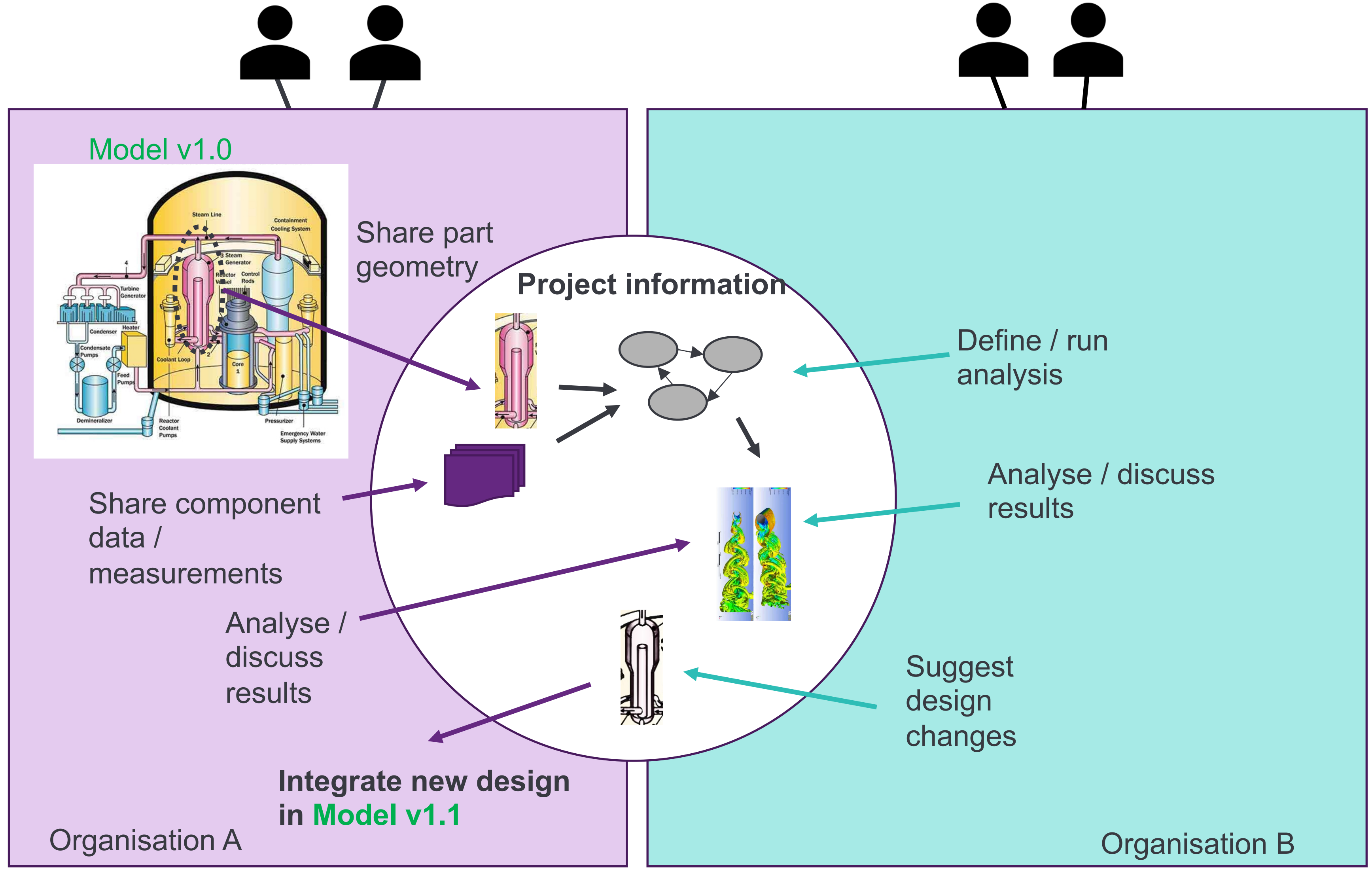


NVEC software framework concept



Method = operation on data (e.g. physics simulation code)

Example collaborative analysis



Phase 1 – Highlights

- Development of requirements for framework
- Development of prototype software framework for analyses using different codes together. Focussed on reactor.
- Development of 2 case studies (AGR graphite, PWR rod ejection)
- Visualisation, High Performance Computing and Virtual Reality
- Development of Safety and Security roadmap
- Engagement with broader UK nuclear sector and internationally

Core partners (phase 1)

NUCLEAR VIRTUAL ENGINEERING CAPABILITY

VIRTUAL ENGINEERING CENTRE

ROLLS ROYCE

Hartree Centre
Science & Technology Facilities Council

NATIONAL NUCLEAR LABORATORY

wood.

UNIVERSITY OF CAMBRIDGE

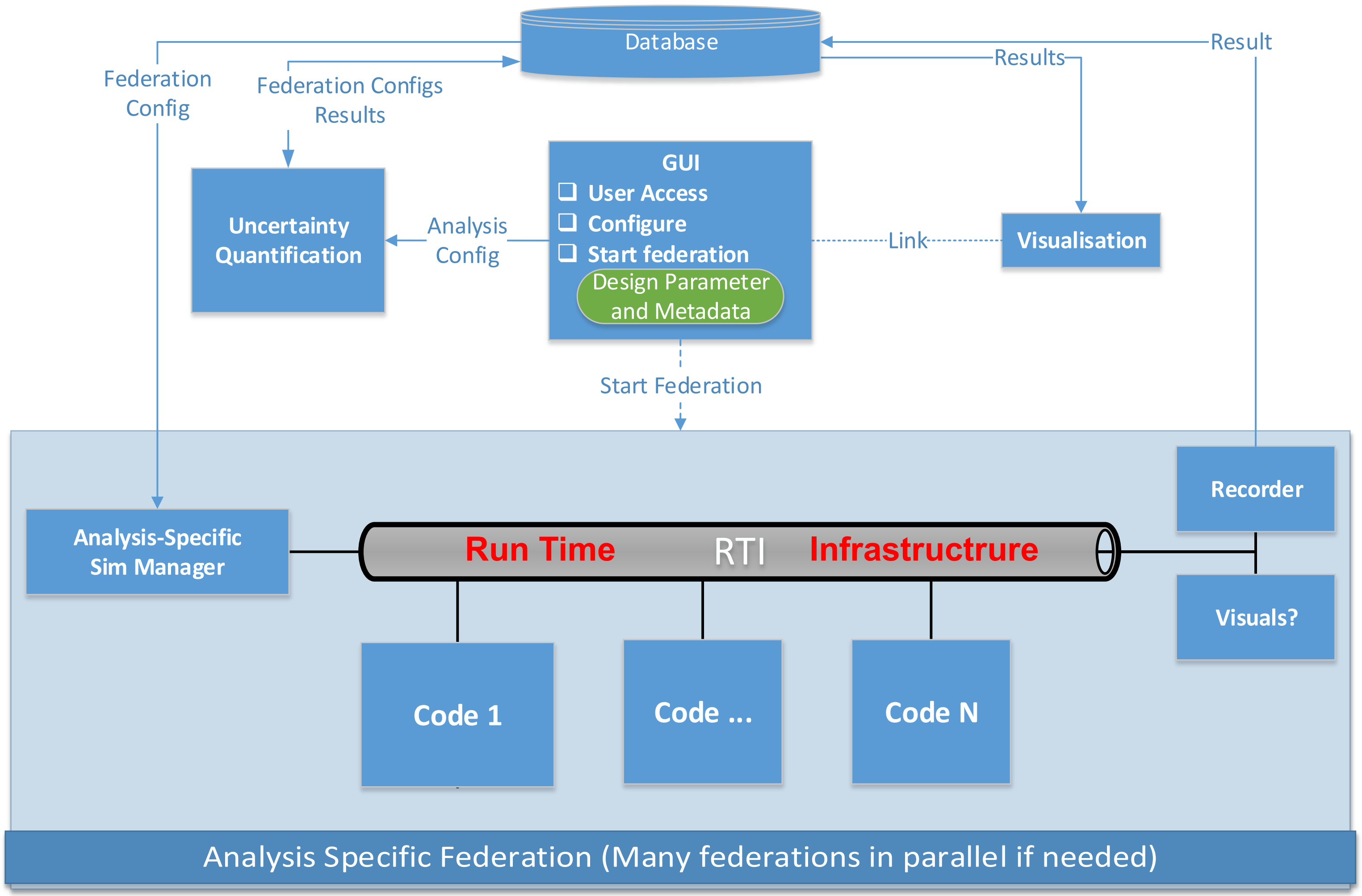
EDF ENERGY

Imperial College London

UNIVERSITY OF LIVERPOOL

Architecture (phase 1)

Based on High Level Architecture (HLA) concept



AGR case study: Life time graphite damage

NUCLEAR VIRTUAL ENGINEERING CAPABILITY

Plant data (Core follow)

PANTHER

MCBEND

Neutron damage & total heating on single channel mesh

Graphite weight loss on single channel mesh

Graphite weight loss for each element/channel

Power & irradiation of fuel elements

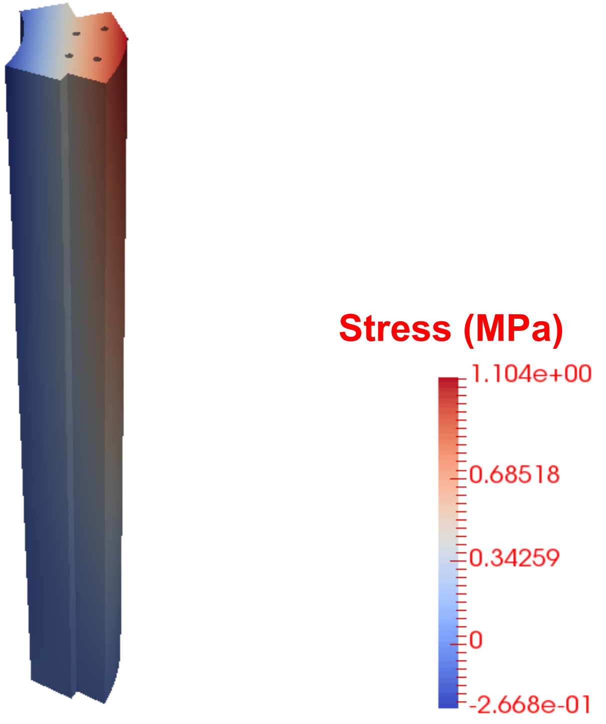
FEAT-G

Neutron damage, temperature, graphite weight loss on single brick mesh

Code_Aster

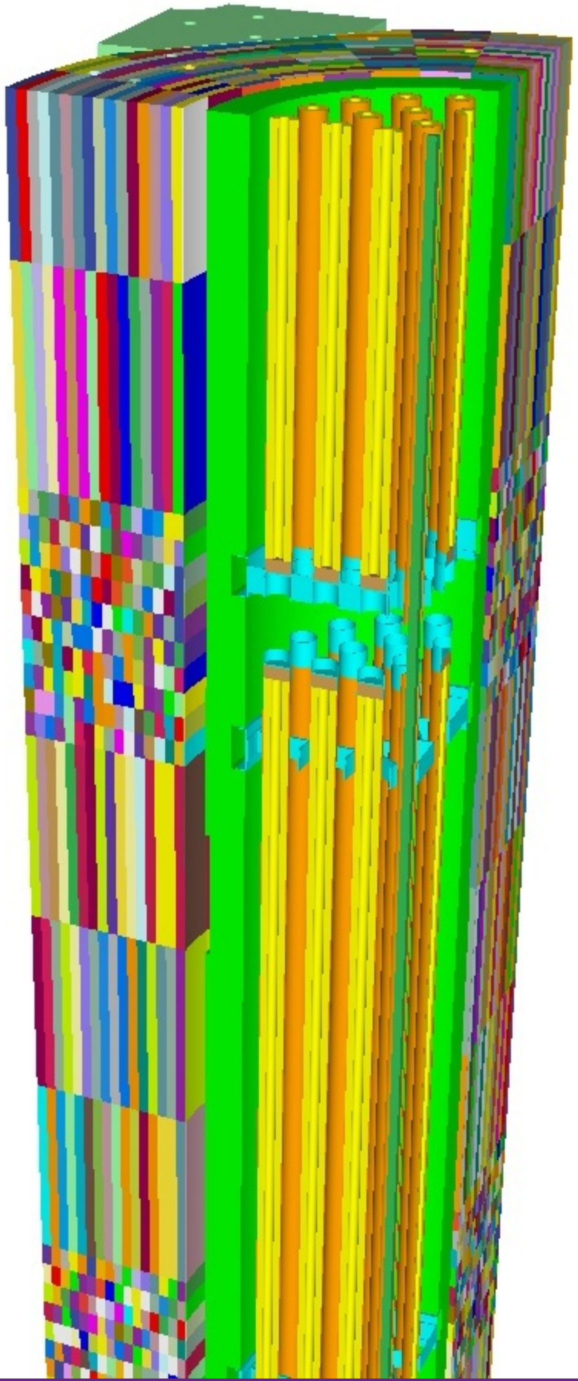
Stresses / strains on single brick mesh

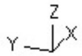
Agreement of manual and automated runs



MCBEND Model

- Full channel 3d (quarter channel)
  - Shown by <u>material</u>
- 3d distribution of graphite density
  - Graphite density discretised
  - Each graphite density is a different material
- Score (on mesh)
  - Neutron damage & heating
  - Primary γ-ray heating
  - No secondary γ-rays





PWR case study: rod ejection transient

NUCLEAR VIRTUAL ENGINEERING CAPABILITY

WIMS

Flux weighted nuclear data

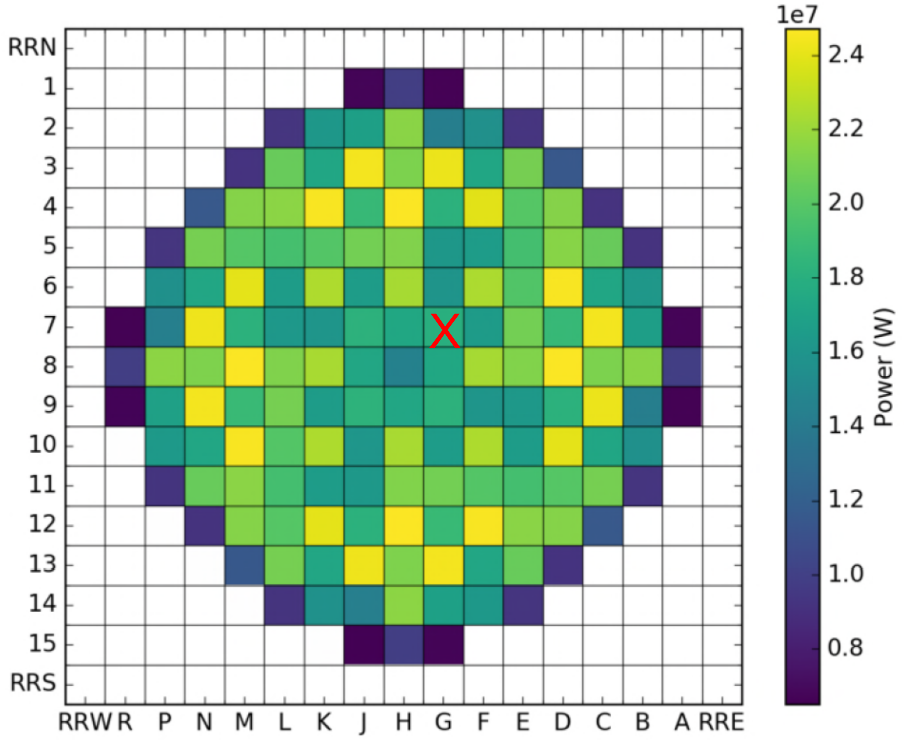
PANTHER

Power history core state

ENIGMA

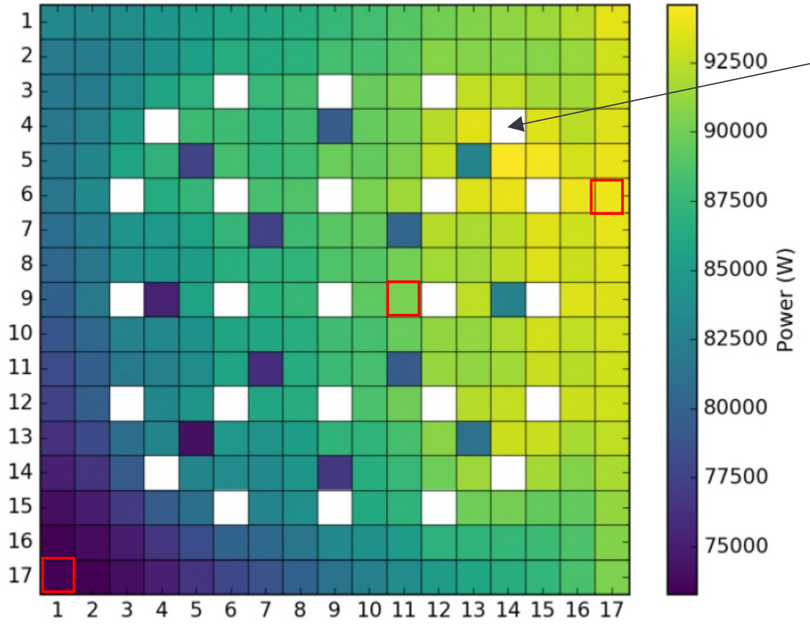
Fuel properties / damage

- After initial cycles, steady-state at full power
- Control rod (in G:7) inserted up to 75% insertion over 144s
- Then control rod ejected over 0.1s



Core power at start of rod insertion

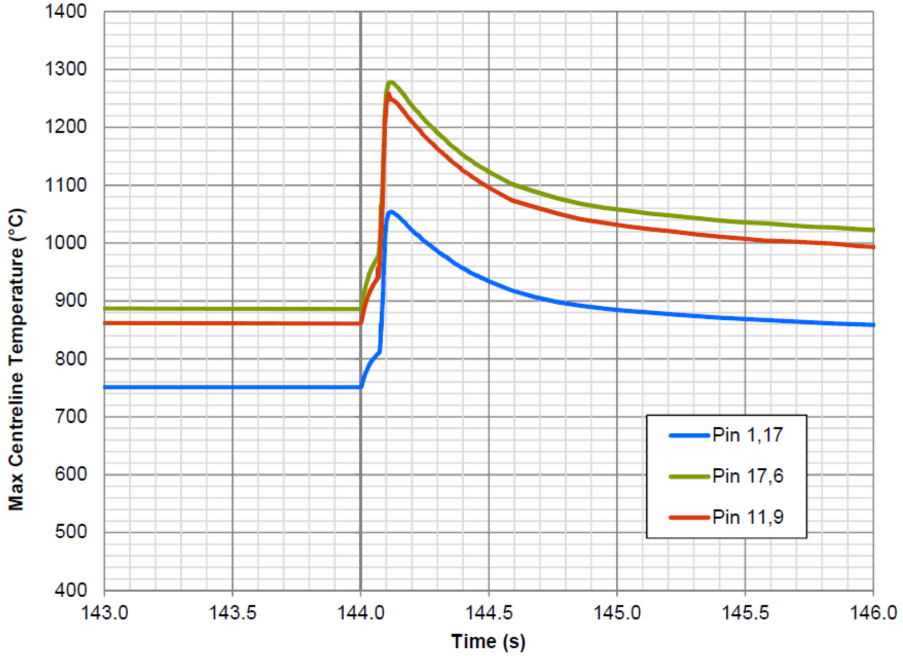
Results



Control rod

Power distribution in G:7 after ejection

Max centreline pin temperature (G:7)



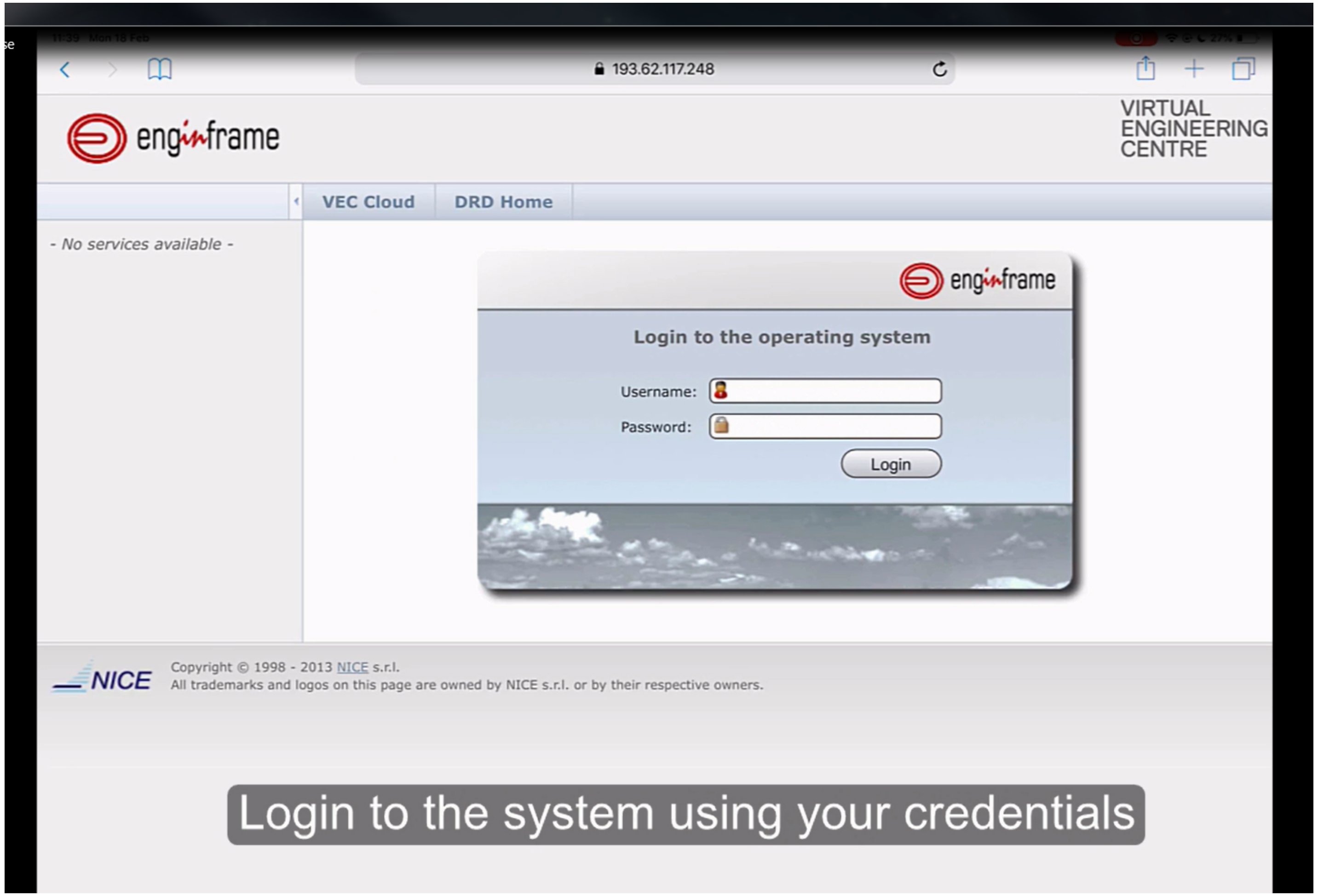
Agreement of manual and automated runs

Web-interface of the framework

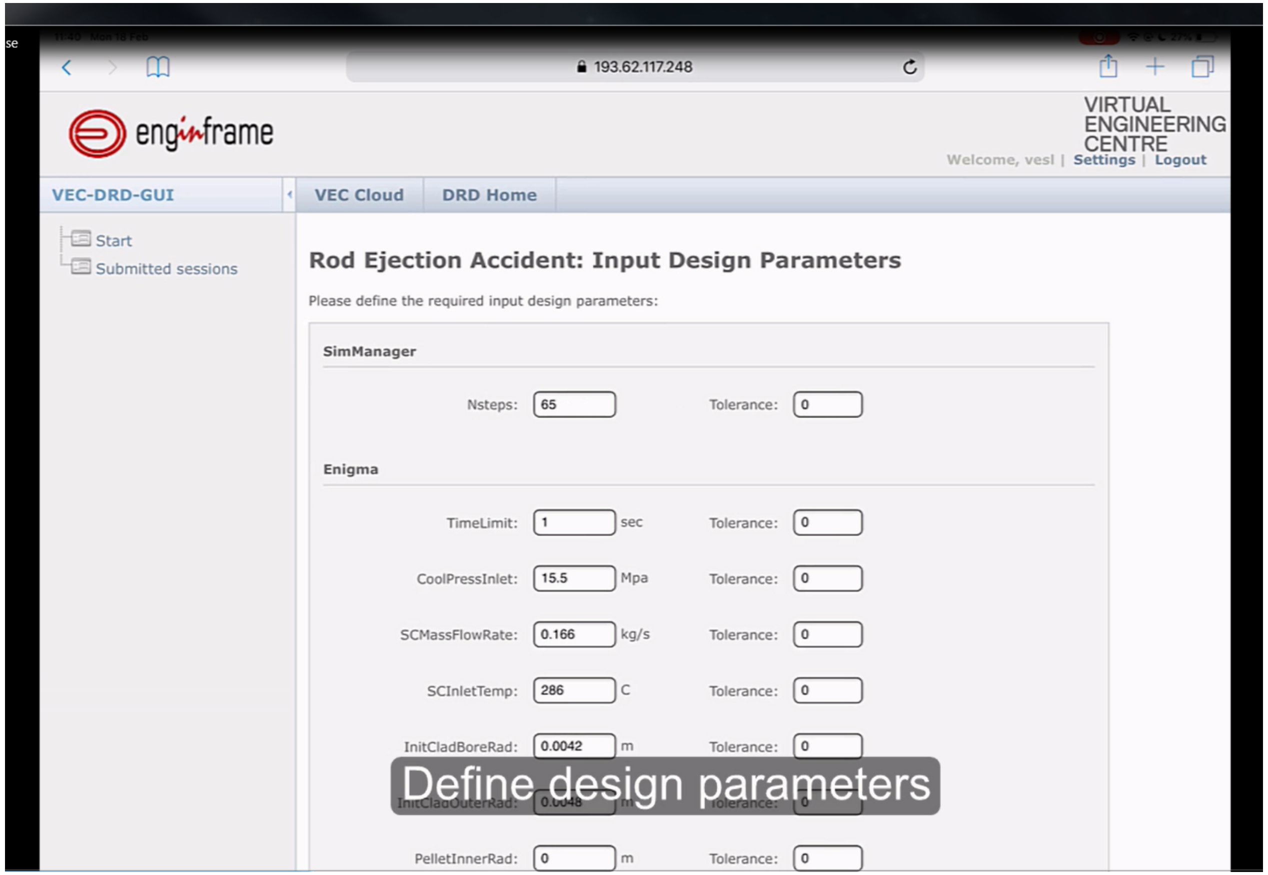
- Prototype web-based access and visualisation portal developed
  - Log in to framework
  - Define / run calculation
  - Extract/visualise results

- Combined remote real time PWR rod ejection calculation with Virtual Reality setup

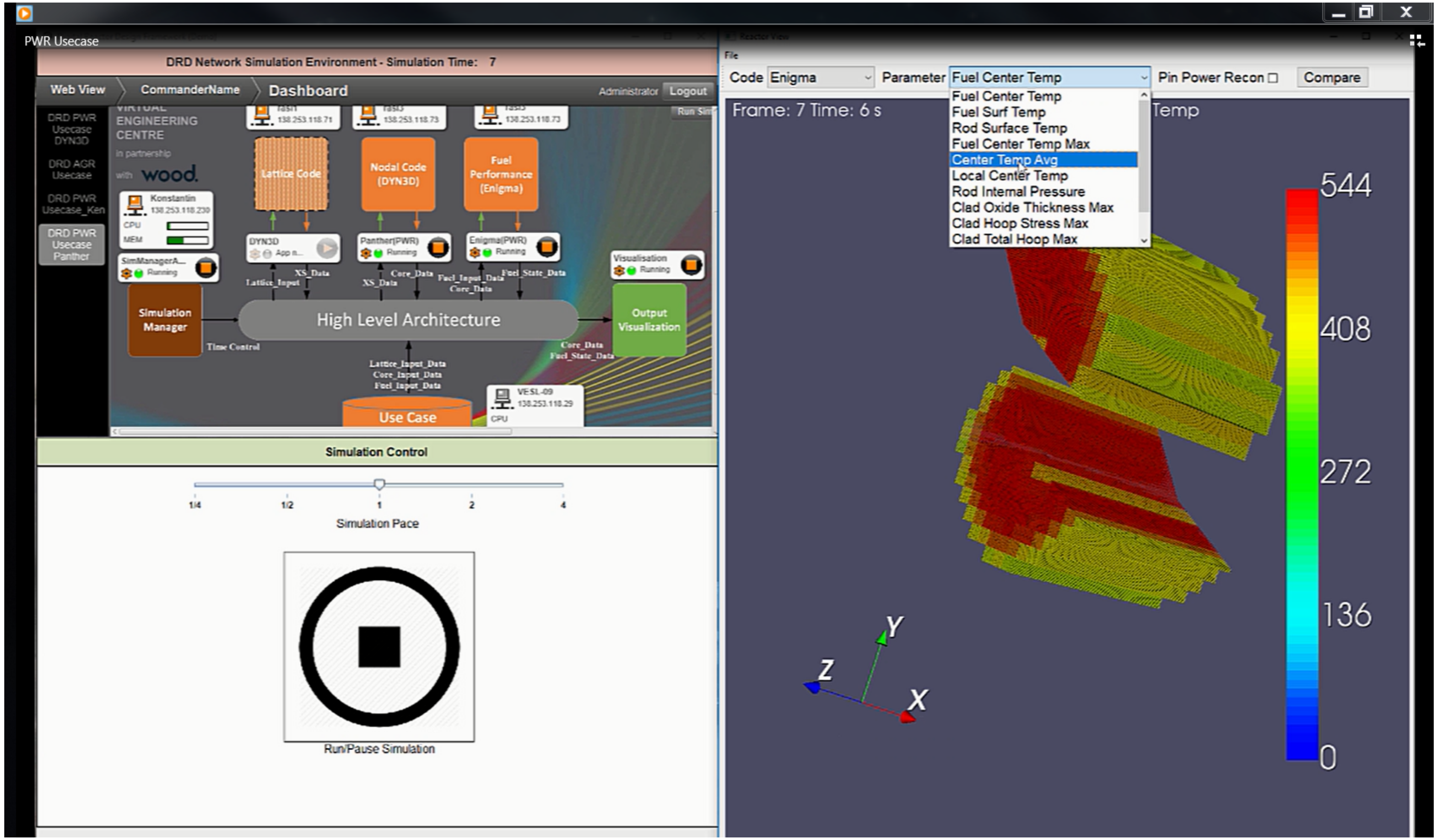
Web-interface - login



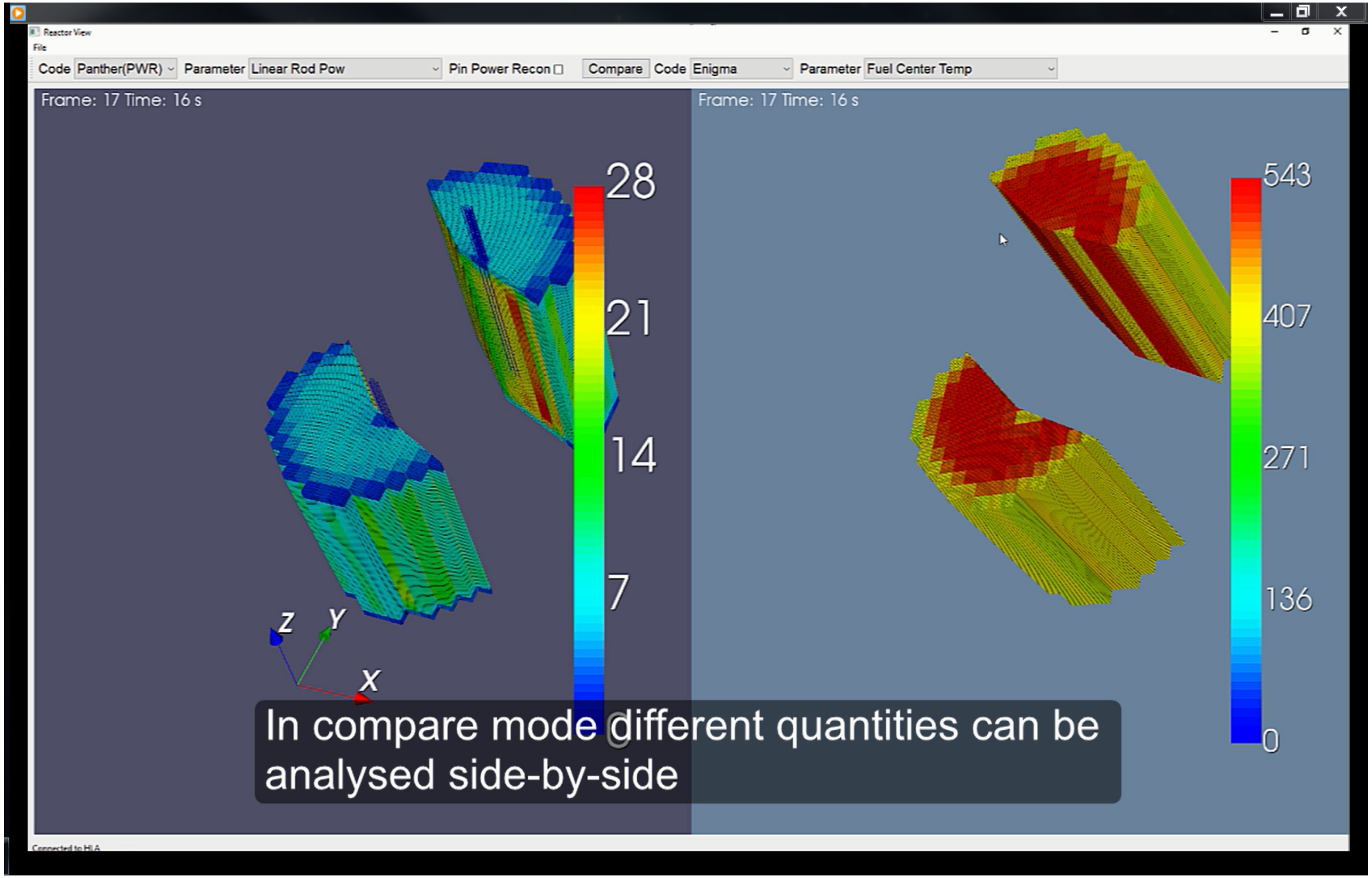
Web-interface - specification



Web-interface: simulation control

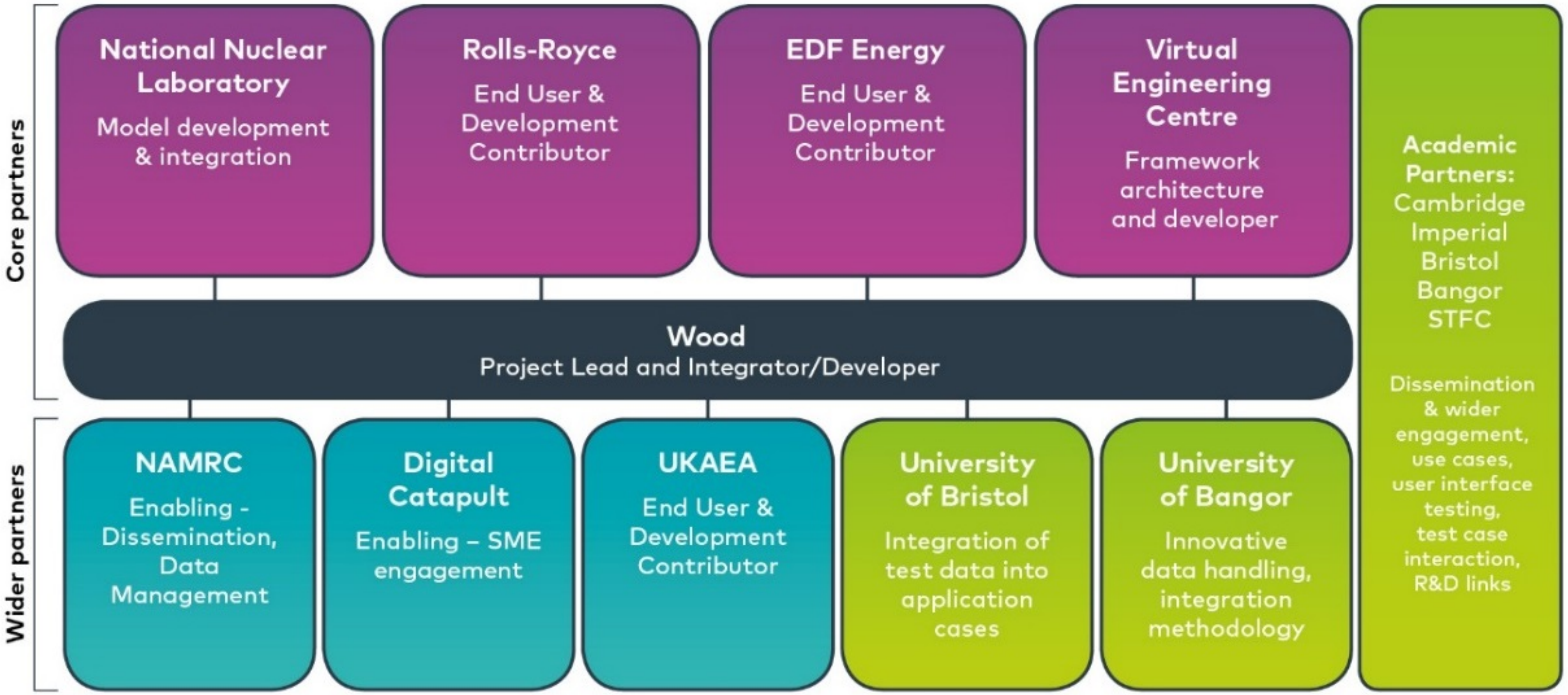


Web-interface - visualisation



NVEC Phase 2

- Wood have recently secured BEIS NVEC Phase 2 contract
- Duration: 2 years

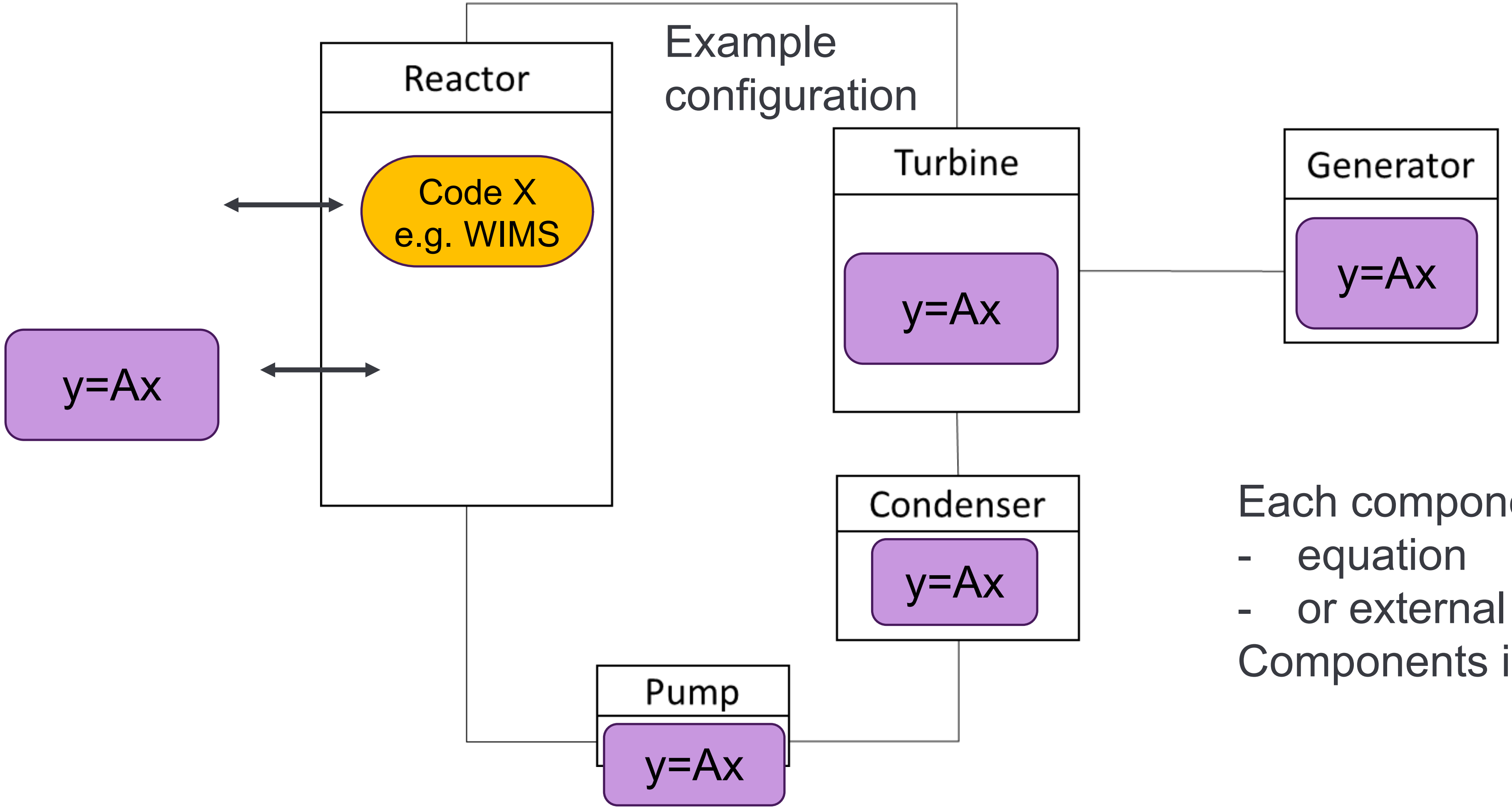


Key aims phase 2

NUCLEAR VIRTUAL ENGINEERING CAPABILITY

- Further develop open framework architecture building on phase 1 to establish NVEC in UK
  - Development beyond proof-of-concept
  - Demonstrate benefits through case studies: cost efficiency, reliability, accuracy
- Develop operating model planning transition into sustainable industry funding
- Link with other BEIS R&D programmes and dissemination activities

Extended equation based modelling



Each component either:
- equation
- or external code

Components interacting via HLA

Case studies

To demonstrate developed features and benefits:

- Nuclear plant system level model
- AGR graphite analysis
- Geometry management / change control
- Whole-life-cycle modelling
- Internal coupling
- Decommissioning
- Component digital twin / data import

Conclusion

- Long term aim: develop Nuclear Virtual Engineering Capability
  - lower costs across the whole nuclear lifecycle (incl regulation)
  - support increased innovation and facilitate cultural change
- Phase 1 of BEIS funded project successfully finished
  - Establish requirements of UK industry
  - Develop prototype software framework, implement 2 case studies (PWR and AGR)
- Recently secured Phase 2
  - Develop software framework beyond proof-of-concept
  - Demonstrate benefits of framework
  - Develop operating model for sustainable funding

Acknowledgements

NUCLEAR
VIRTUAL
ENGINEERING
CAPABILITY

- Ahmed Aslam, Cathy Phelps (Wood)
- Mark Bankhead (NNL)
- Dave Bowman, Konstantin Vikhorev, Lynn Dwyer (UoL-VEC)
- Bruno Merk (Liv-NNL)
- Chris Jackson (Rolls Royce)
- Ionel Nistor, Jefri Draup (EDF-UK)