

Digital Reactor Design

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LABORATORY



Rolls-Royce

wood.

VIRTUAL
ENGINEERING
CENTRE

edf ENERGY



NUCLEAR AMRC

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BEIS Nuclear Innovation Programme (NIP)



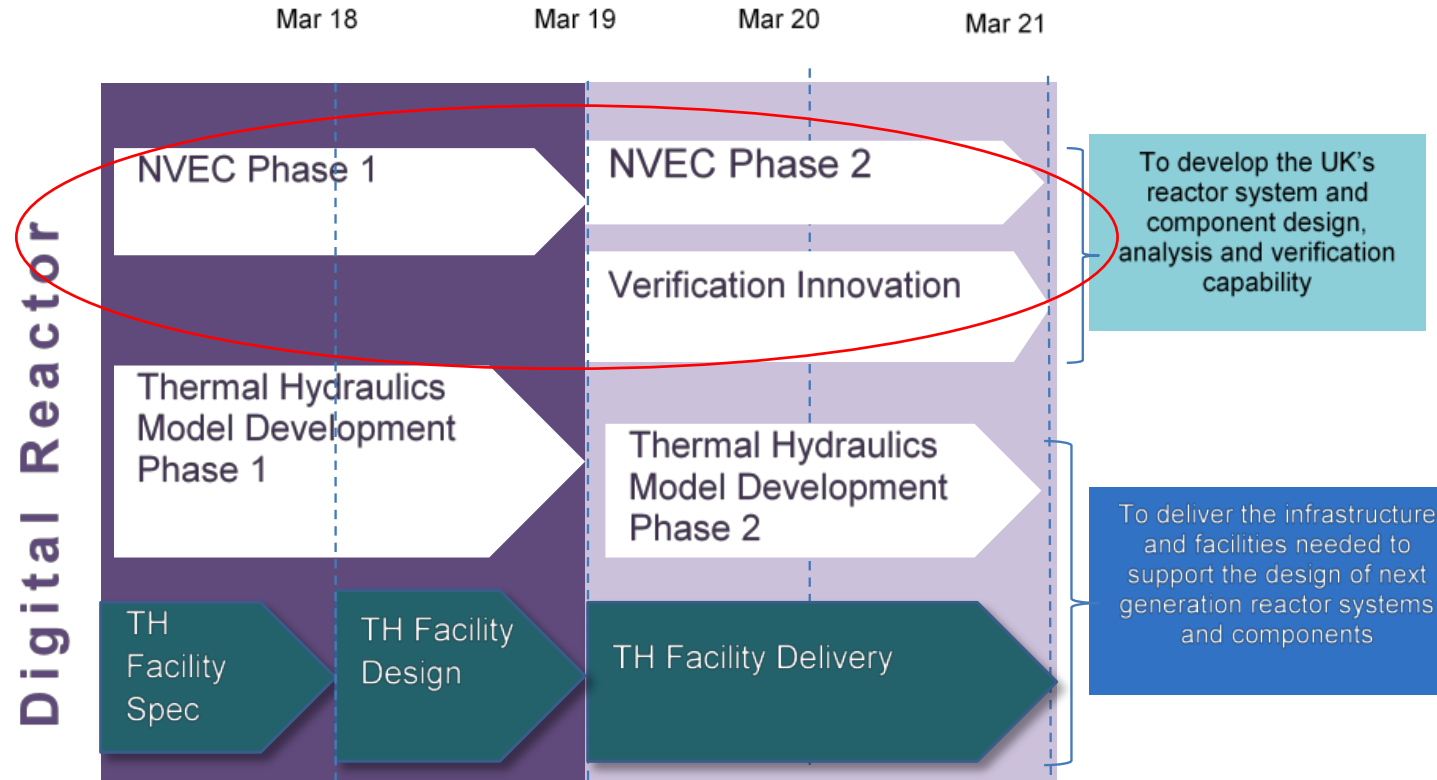
- Launched by Dept. of Business, Energy & Industrial Strategy (BEIS) in 2016



Department for
Business, Energy
& Industrial Strategy

- Five areas:
 - Strategic tool kit and facilities
 - Advanced Fuels
 - Advances Manufacturing & Materials
 - **Advanced Reactor Design**
 - Recycle and Reprocess
- Diagram illustrating the relationship between Advanced Reactor Design and its sub-areas:
- ```
graph LR; A[Advanced Reactor Design] --> B[Digital Reactor]; A --> C[Nuclear Safety and Security Engineering]
```

# Digital Reactor Design Programme



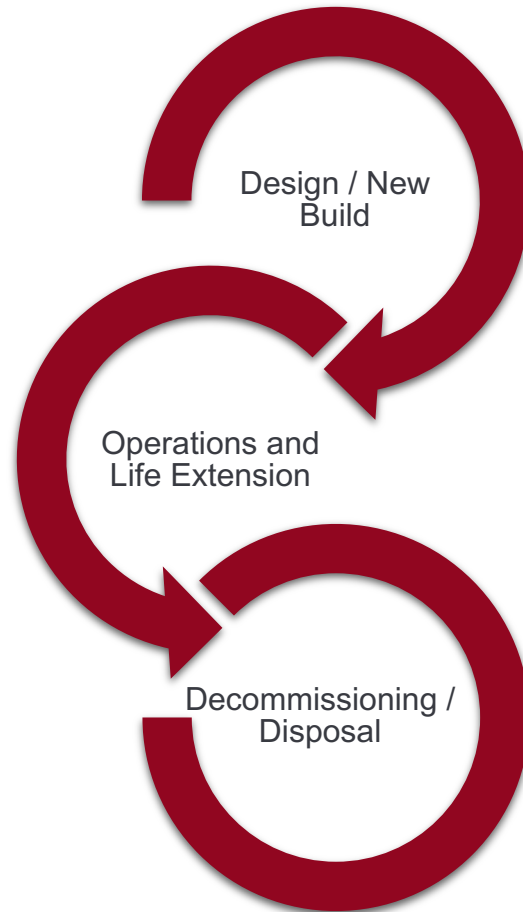
**NVEC = Nuclear Virtual Engineering Capability**

# NVEC Phases 1 & 2



- 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

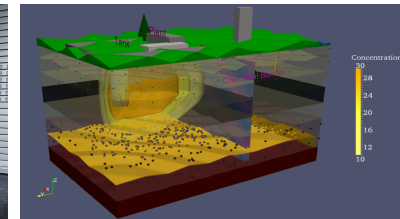
# Vision



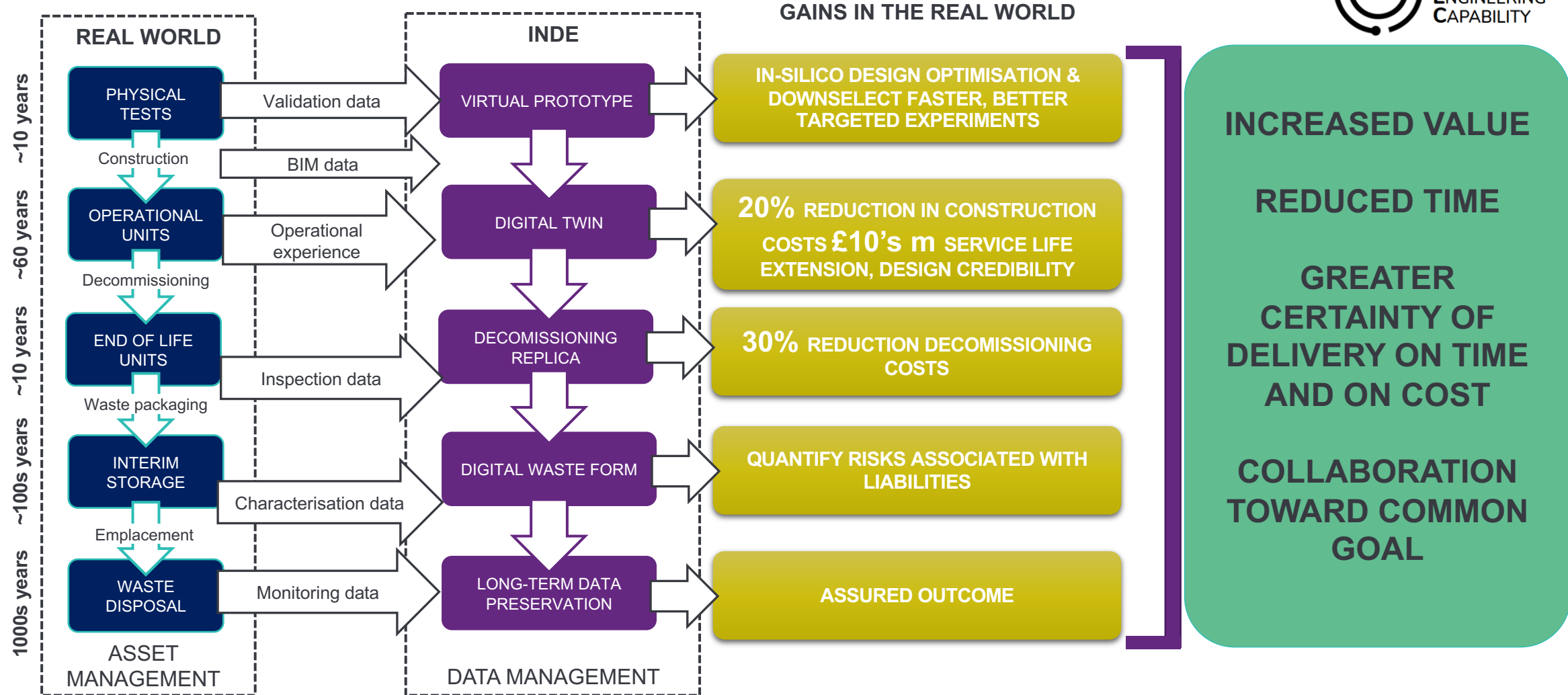
Nuclear engineering of the future, across the whole nuclear lifecycle:

- 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



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

# NVEC – What is it?

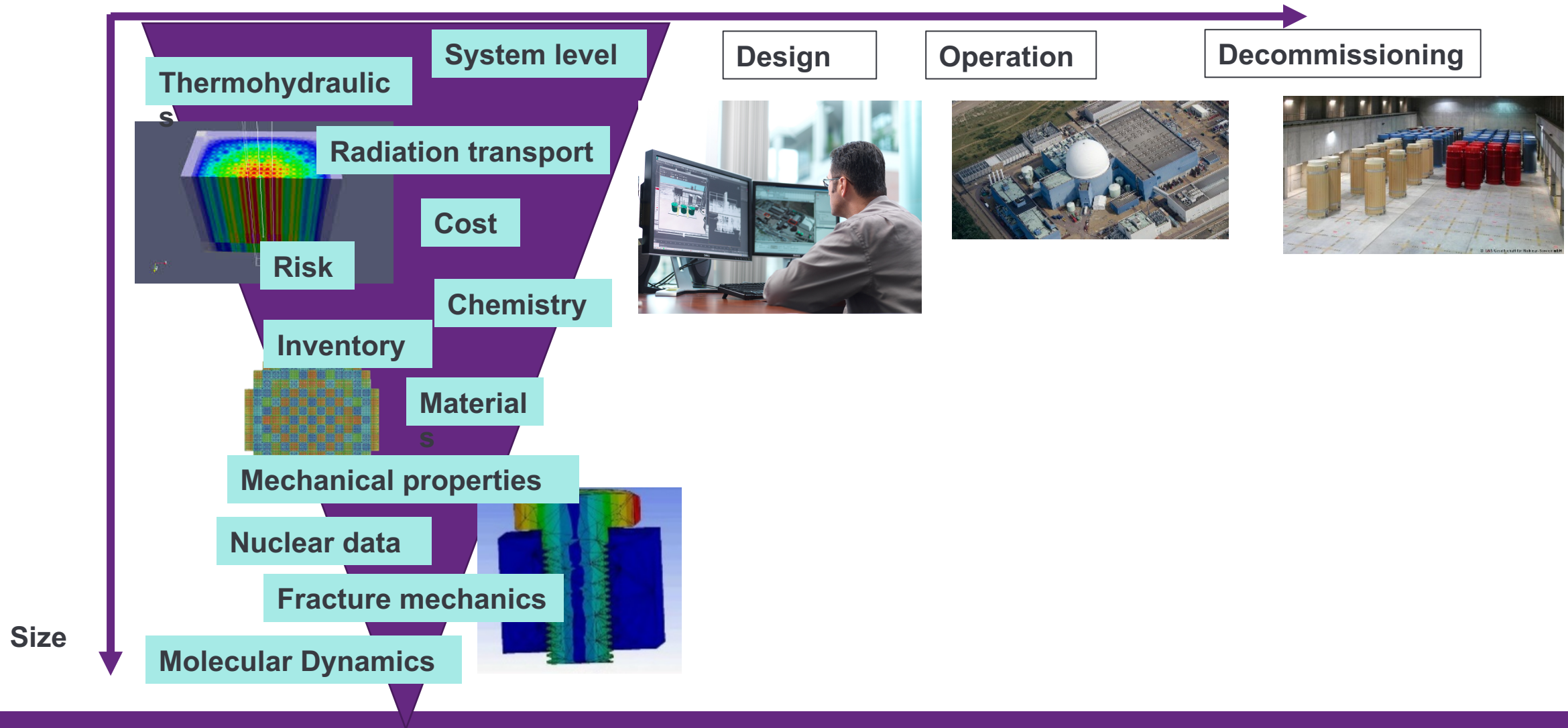
Integrated Collaborative Nuclear Design Environment  
with digital repository of tools and methods

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

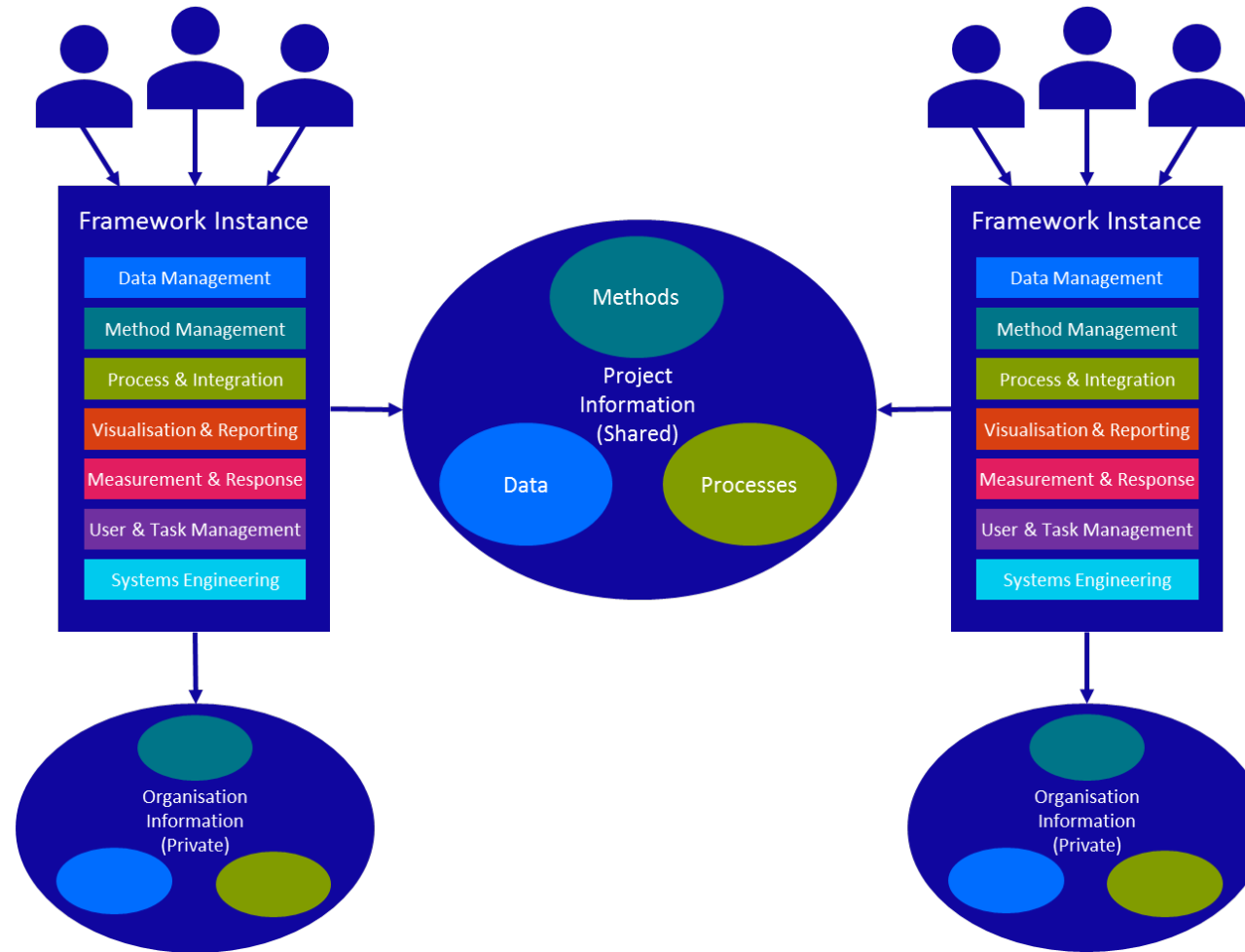
Securely  
**view/  
analyse/  
share** data

**Run analyses** and  
simulations on a  
common design from  
remote locations

# NVEC: Multi-discipline & multi-scale

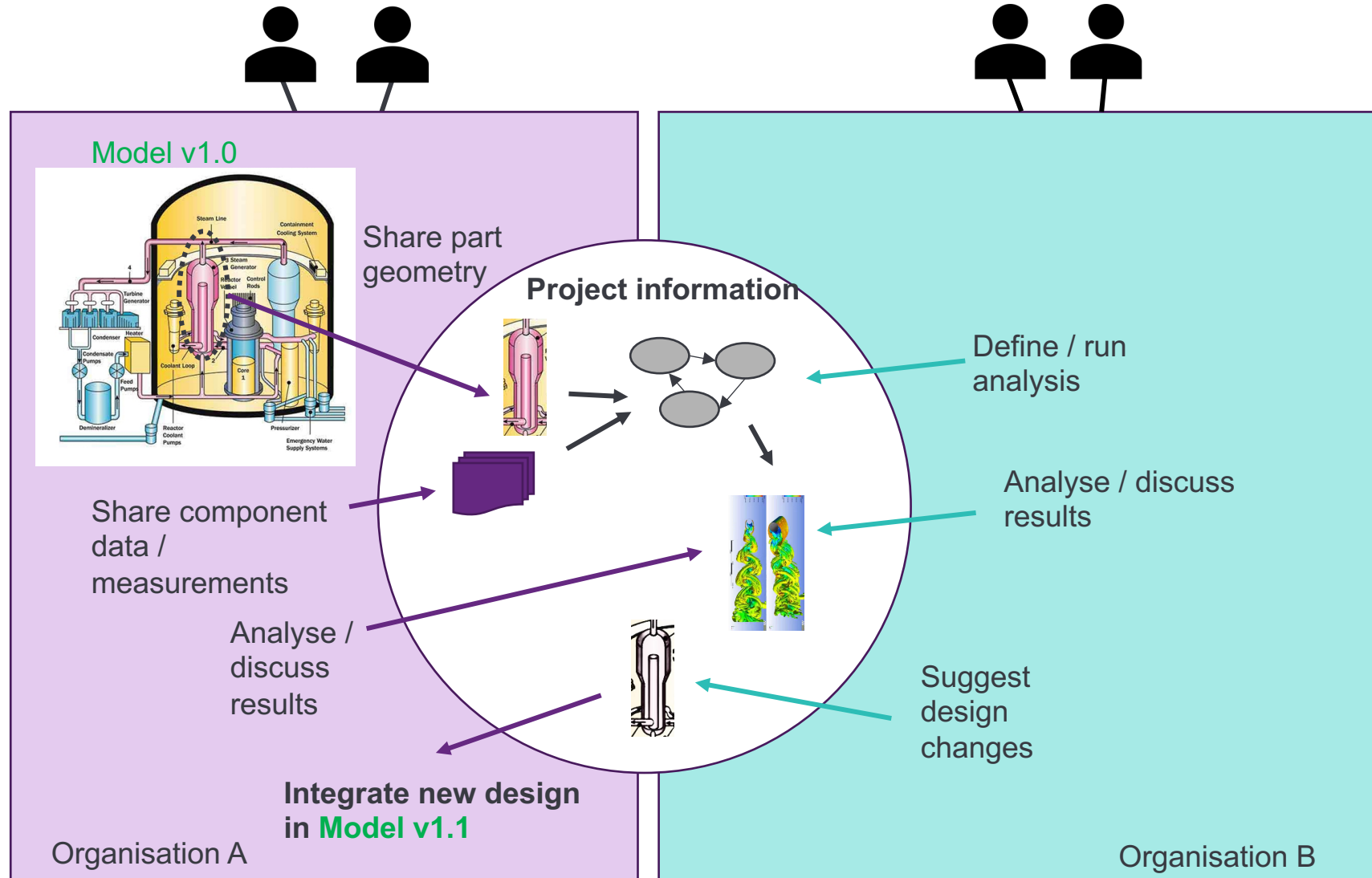


# NVEC software framework concept



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

# Example collaborative analysis

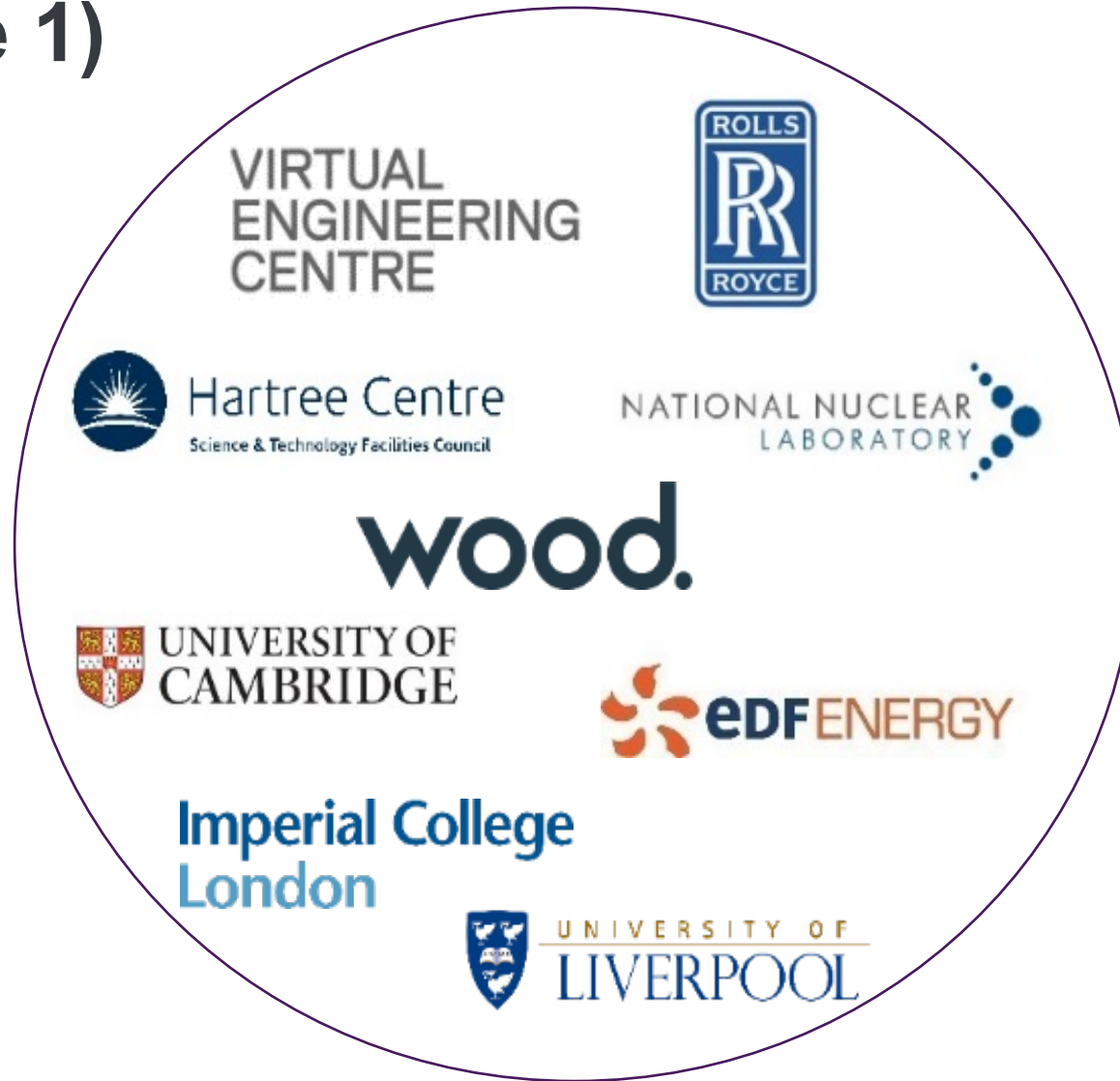


# Phase 1 – Highlights



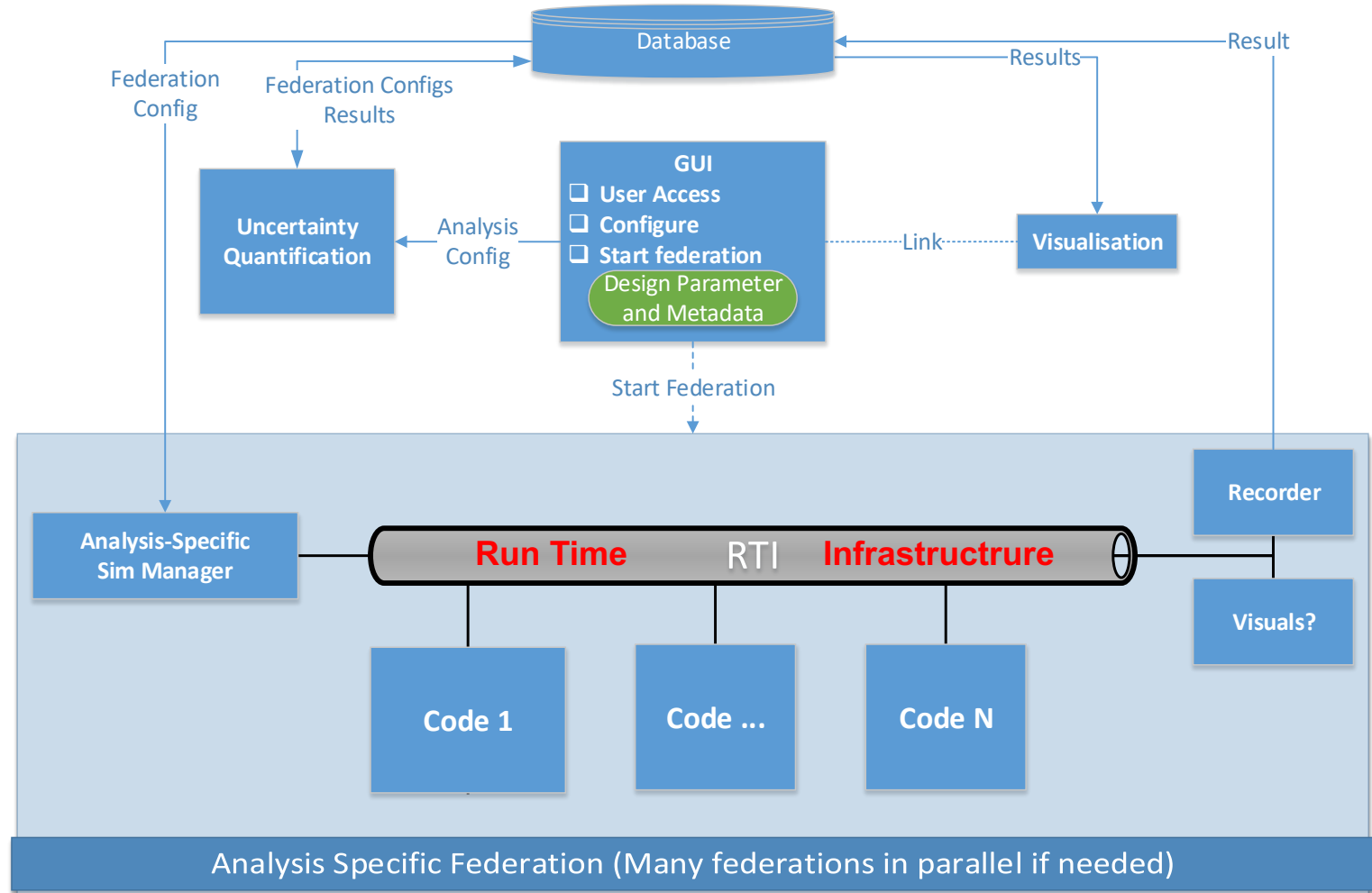
- Development of requirements for framework
- Development of prototype software framework for analyses using different codes together. Focussed on reactor.
- Development of 2 case studies (AGR graphite, PWR rod ejection)
- Visualisation, High Performance Computing and Virtual Reality
- Development of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

# Core partners (phase 1)

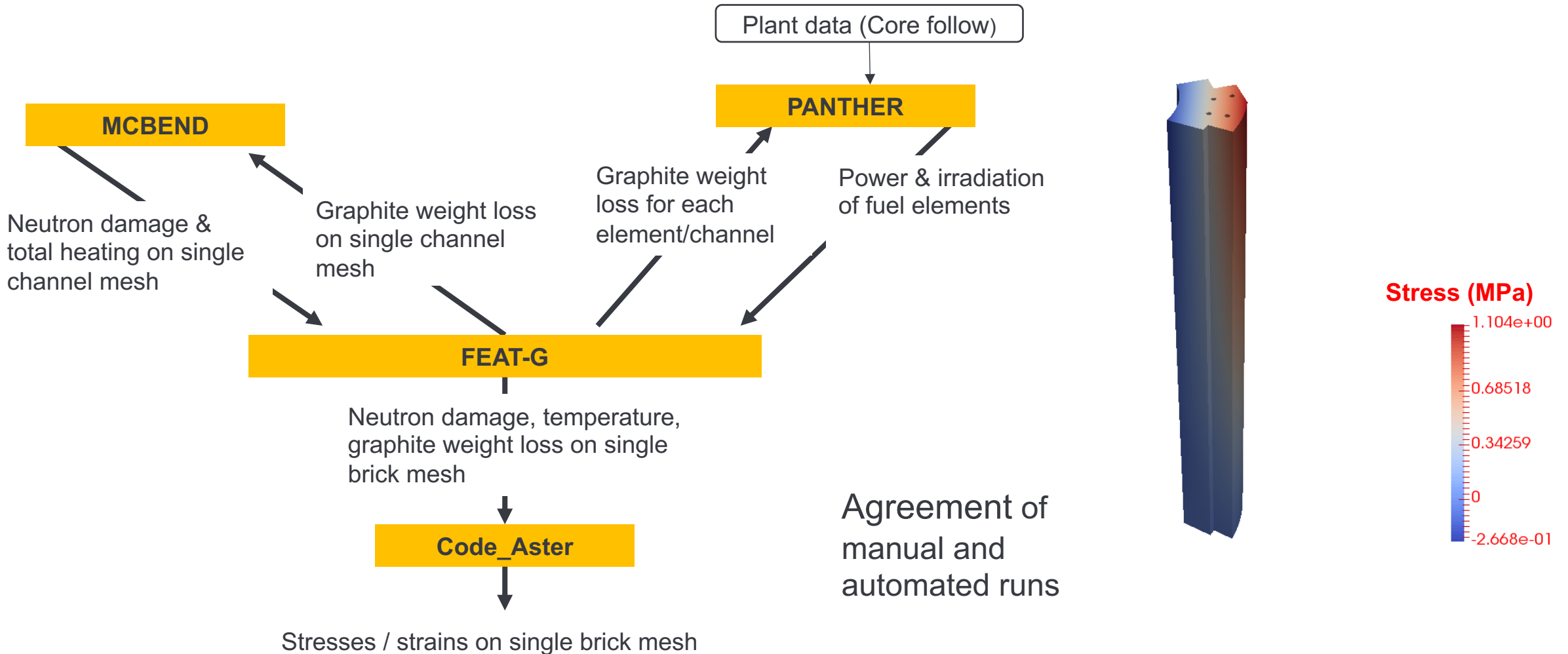


# Architecture (phase 1)

Based on High Level  
Architecture (HLA) concept

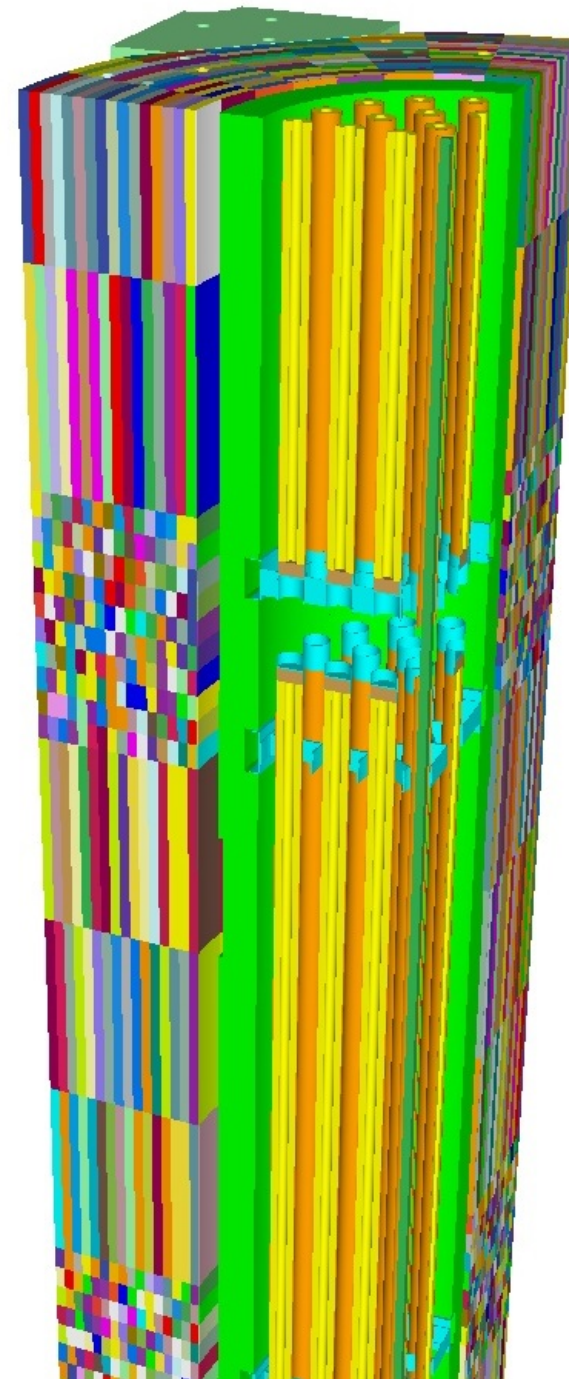


# AGR case study: Life time graphite damage

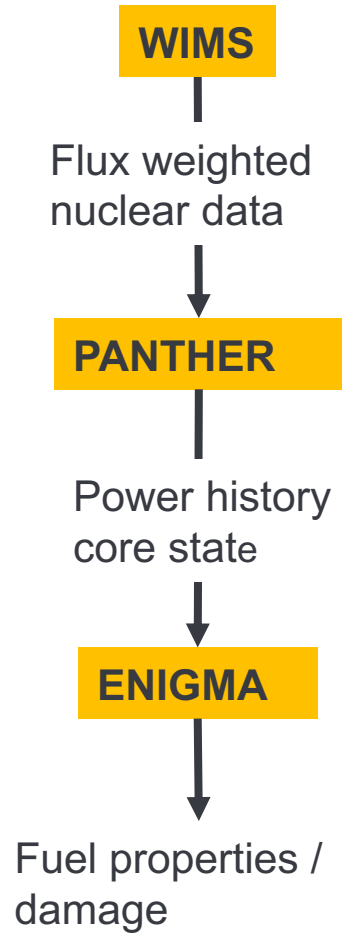


# MCBEND Model

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

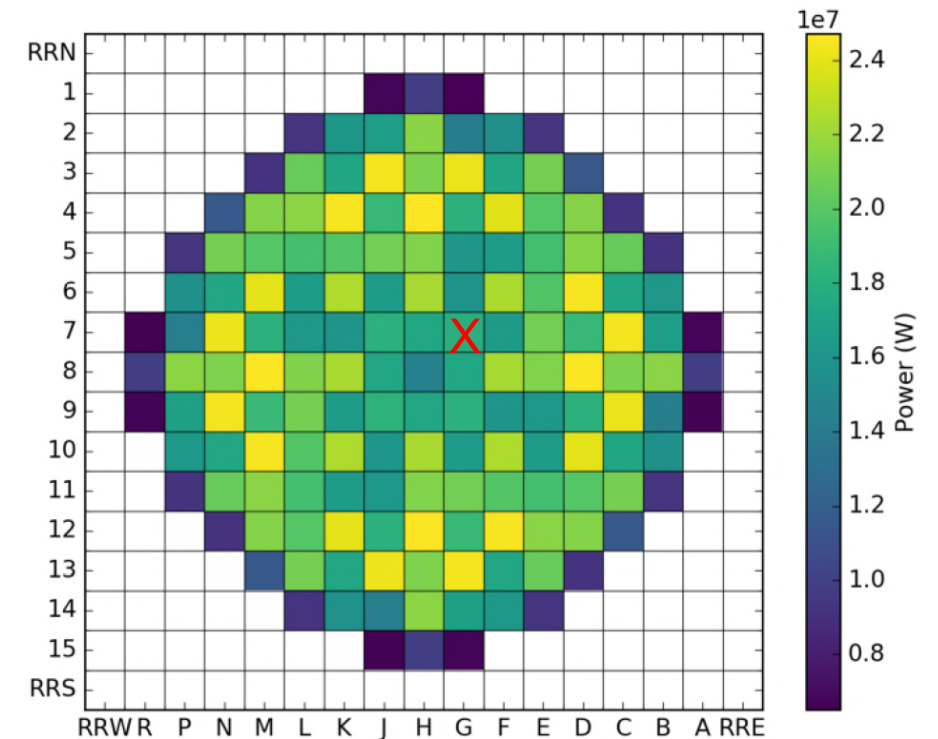


# PWR case study: rod ejection transient

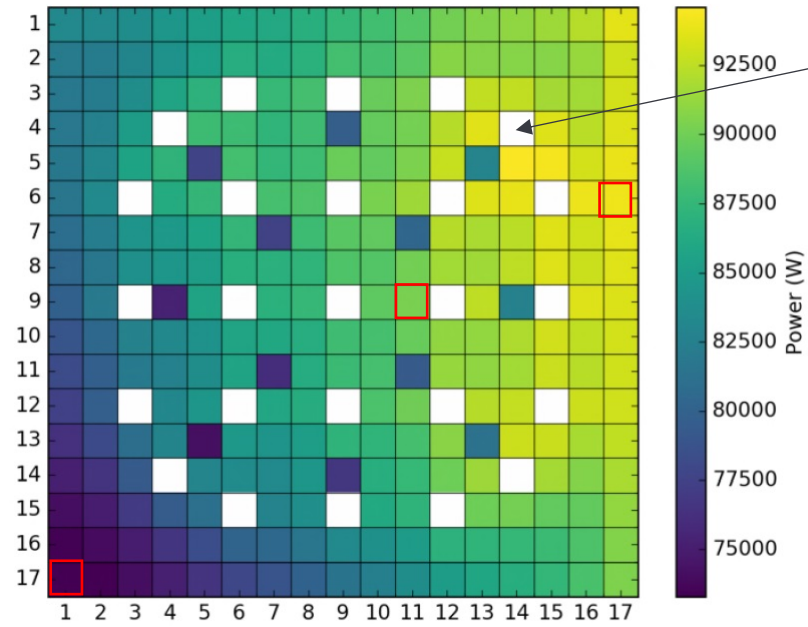


- After initial cycles, steady-state at full power
- Control rod (in G:7) inserted up to 75% insertion over 144s
- Then control rod ejected over 0.1s

Core power at start of rod insertion



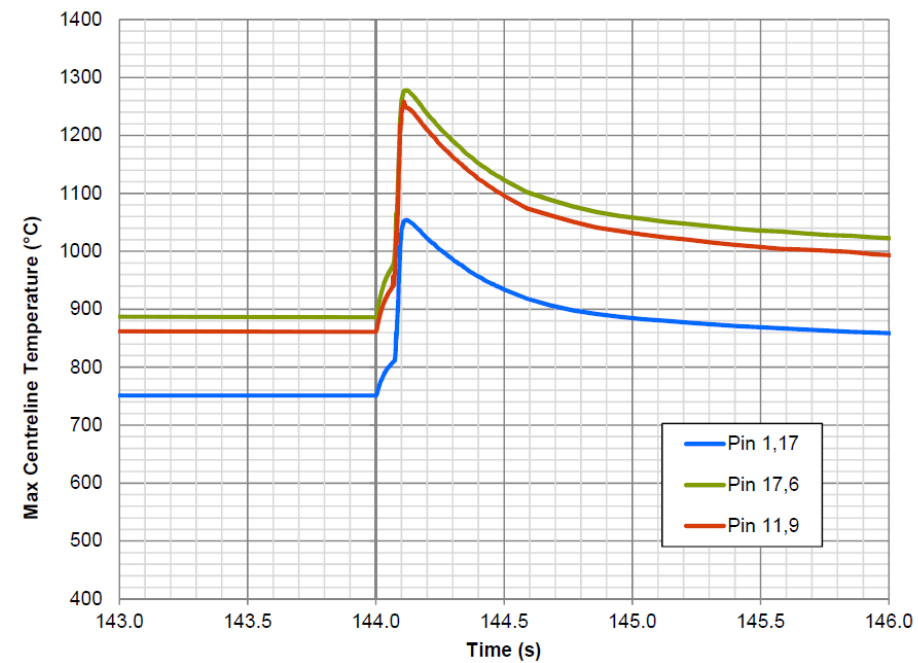
# Results



Power distribution in G:7  
after ejection

Control rod

Max centreline pin  
temperature (G:7)

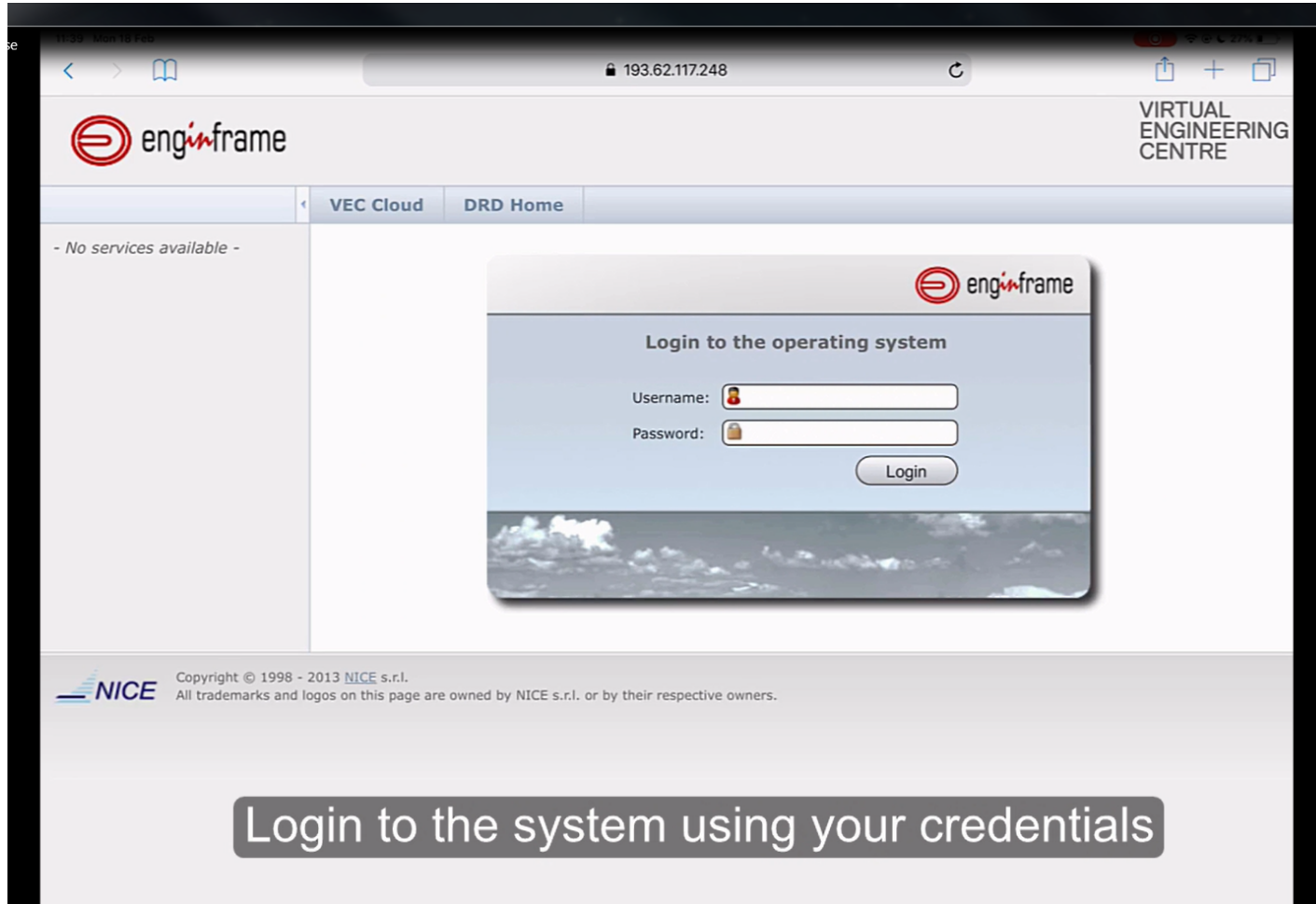


Agreement of manual and automated runs

# 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



The screenshot shows a web browser window with the address bar displaying "193.62.117.248". The page header includes the "enginframe" logo and the text "VIRTUAL ENGINEERING CENTRE". Below the header, there are tabs for "VEC Cloud" and "DRD Home". The main content area displays a login dialog box titled "Login to the operating system". The dialog box contains fields for "Username:" and "Password:", each with a corresponding icon (a person for username and a key for password). A "Login" button is positioned below the password field. The background of the dialog box features a cloudy sky image. At the bottom of the page, there is a footer with the "NICE" logo and copyright information: "Copyright © 1998 - 2013 NICE s.r.l. All trademarks and logos on this page are owned by NICE s.r.l. or by their respective owners."

enginframe

VIRTUAL ENGINEERING CENTRE

VEC Cloud DRD Home

- No services available -

enginframe

Login to the operating system

Username:

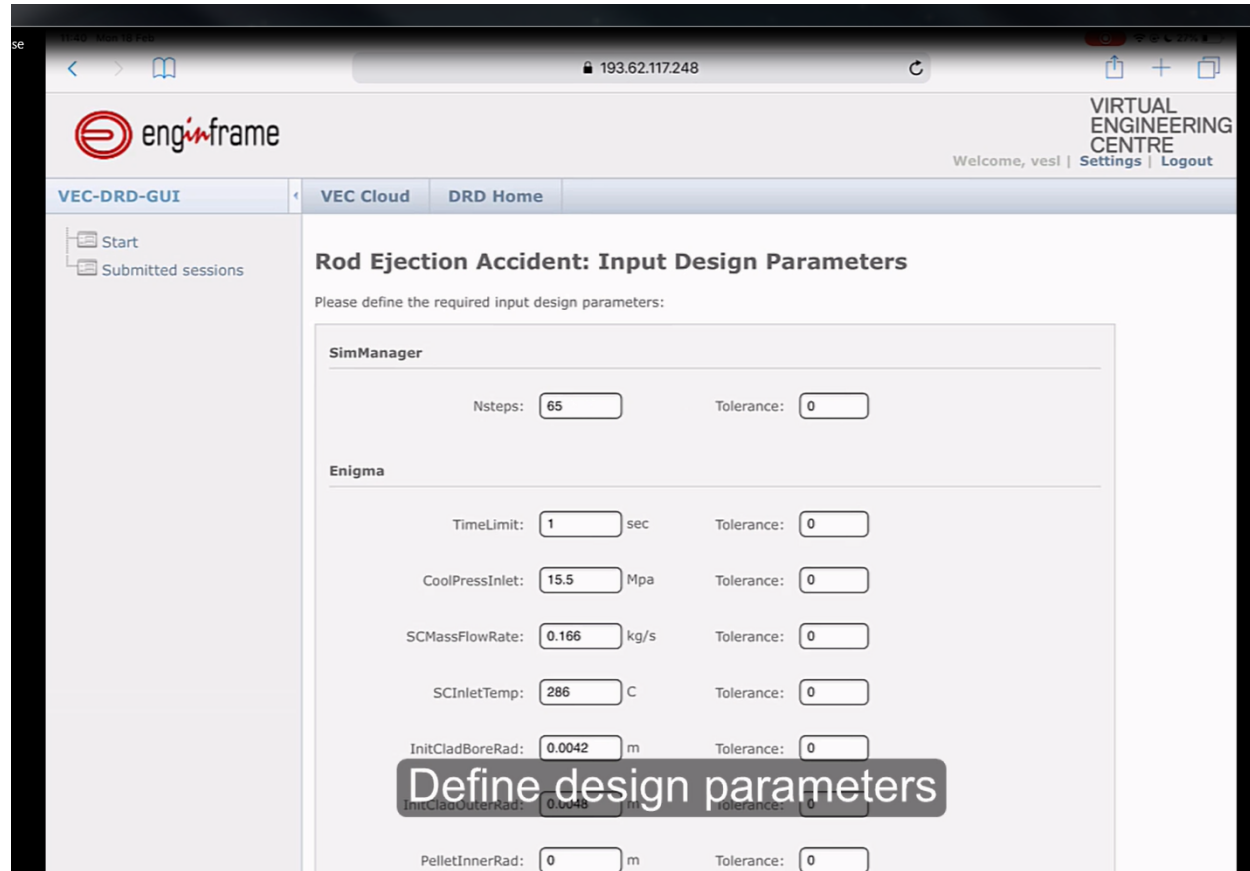
Password:

Login

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Login to the system using your credentials

# Web-interface - specification



The screenshot shows a web browser window displaying the 'enginframe' web interface. The browser's address bar shows the URL '193.62.117.248'. The page header includes the 'enginframe' logo and the text 'VIRTUAL ENGINEERING CENTRE' with links for 'Welcome, vesl', 'Settings', and 'Logout'. The main navigation bar has tabs for 'VEC-DRD-GUI', 'VEC Cloud', and 'DRD Home'. On the left side, there is a sidebar with 'Start' and 'Submitted sessions' options. The main content area is titled 'Rod Ejection Accident: Input Design Parameters' and contains a form for defining input design parameters. The form is divided into two sections: 'SimManager' and 'Enigma'. The 'SimManager' section has input fields for 'Nsteps' (65) and 'Tolerance' (0). The 'Enigma' section has input fields for 'TimeLimit' (1 sec), 'Tolerance' (0), 'CoolPressInlet' (15.5 Mpa), 'Tolerance' (0), 'SCMassFlowRate' (0.166 kg/s), 'Tolerance' (0), 'SCInletTemp' (286 C), 'Tolerance' (0), 'InitCladBoreRad' (0.0042 m), 'Tolerance' (0), 'InitCladOuterRad' (0.0048 m), 'Tolerance' (0), and 'PelletInnerRad' (0 m), 'Tolerance' (0). A semi-transparent text box with the text 'Define design parameters' is overlaid on the bottom part of the form.

enginframe

VIRTUAL ENGINEERING CENTRE

Welcome, vesl | Settings | Logout

VEC-DRD-GUI | VEC Cloud | DRD Home

Start  
Submitted sessions

### Rod Ejection Accident: Input Design Parameters

Please define the required input design parameters:

**SimManager**

Nsteps:  Tolerance:

**Enigma**

TimeLimit:  sec Tolerance:

CoolPressInlet:  Mpa Tolerance:

SCMassFlowRate:  kg/s Tolerance:

SCInletTemp:  C Tolerance:

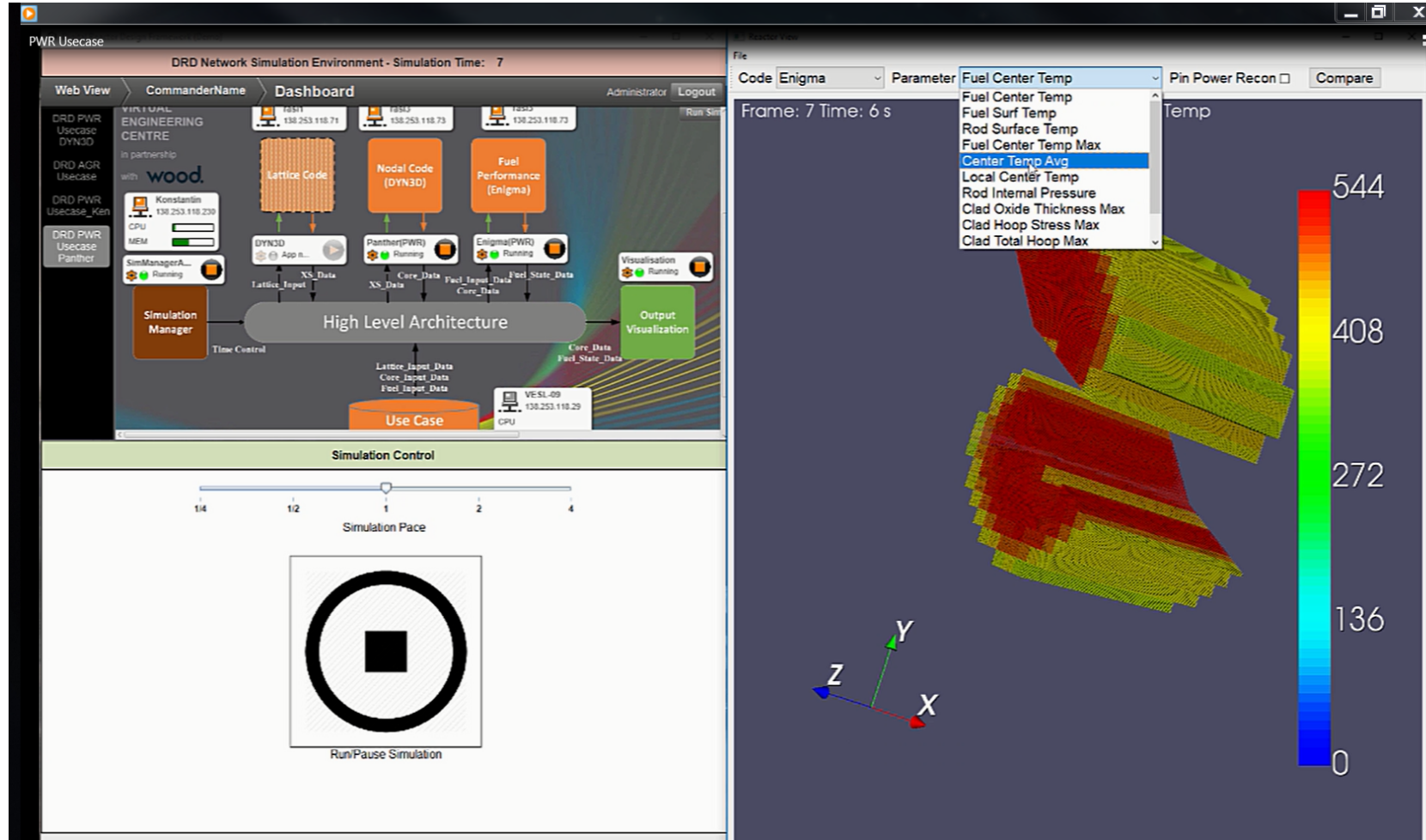
InitCladBoreRad:  m Tolerance:

InitCladOuterRad:  m Tolerance:

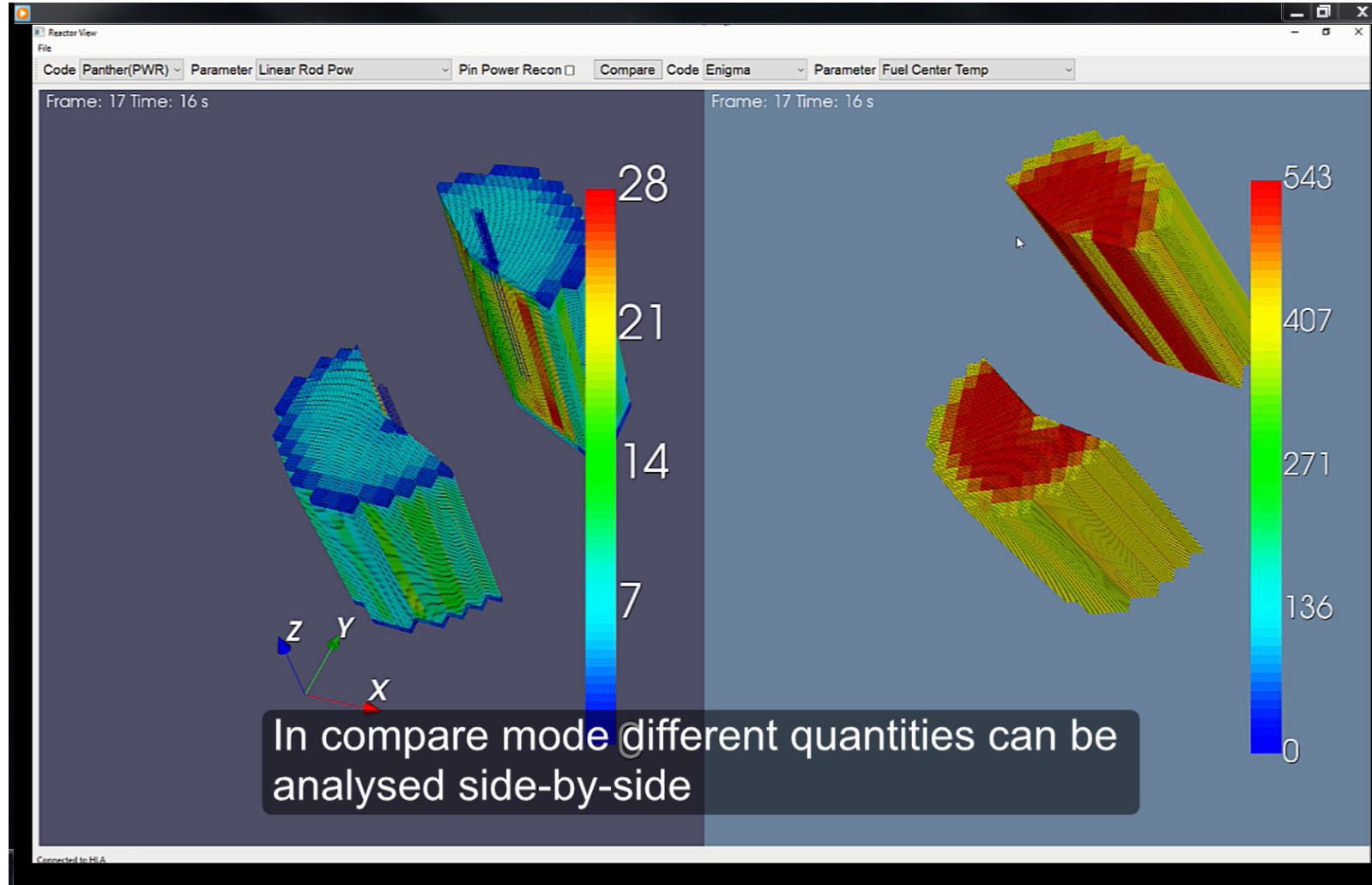
PelletInnerRad:  m Tolerance:

Define design parameters

# Web-interface: simulation control

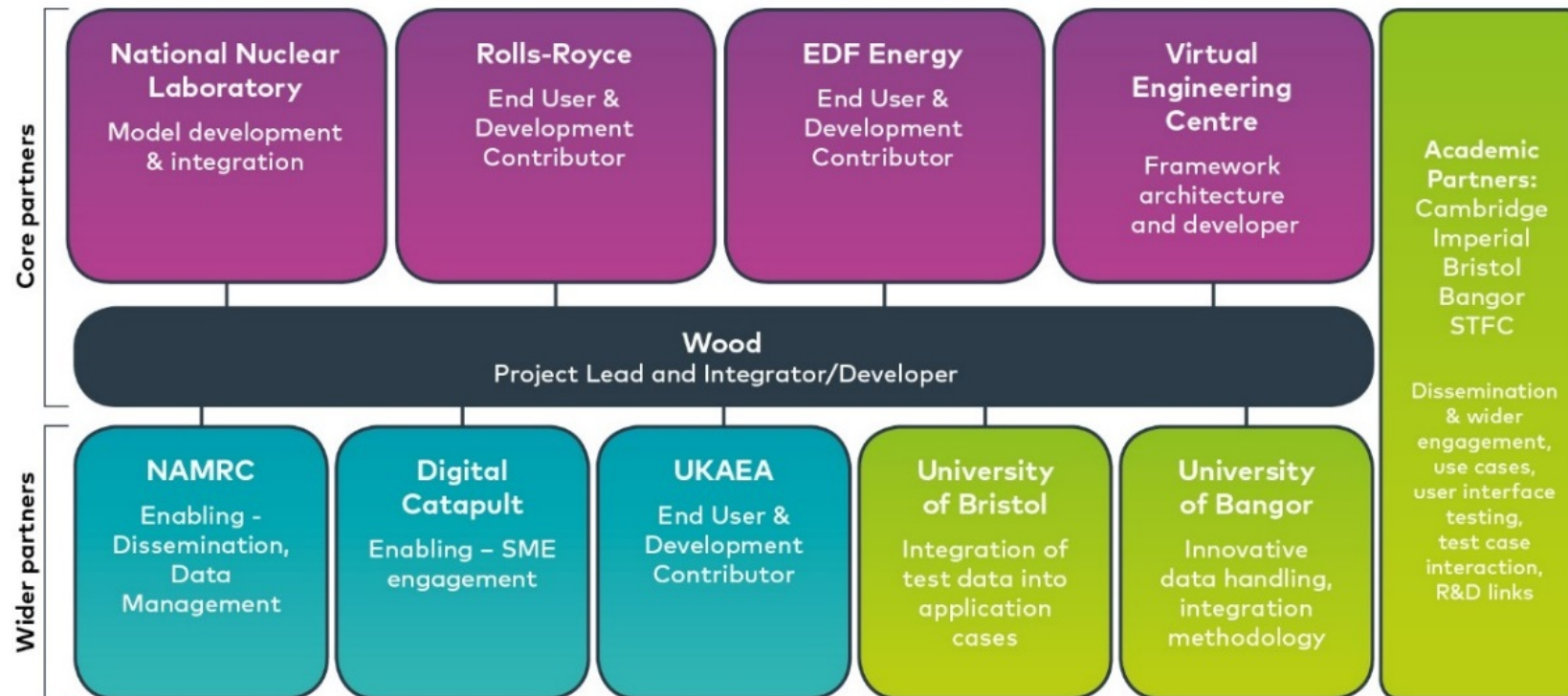


# Web-interface - visualisation



# NVEC Phase 2

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

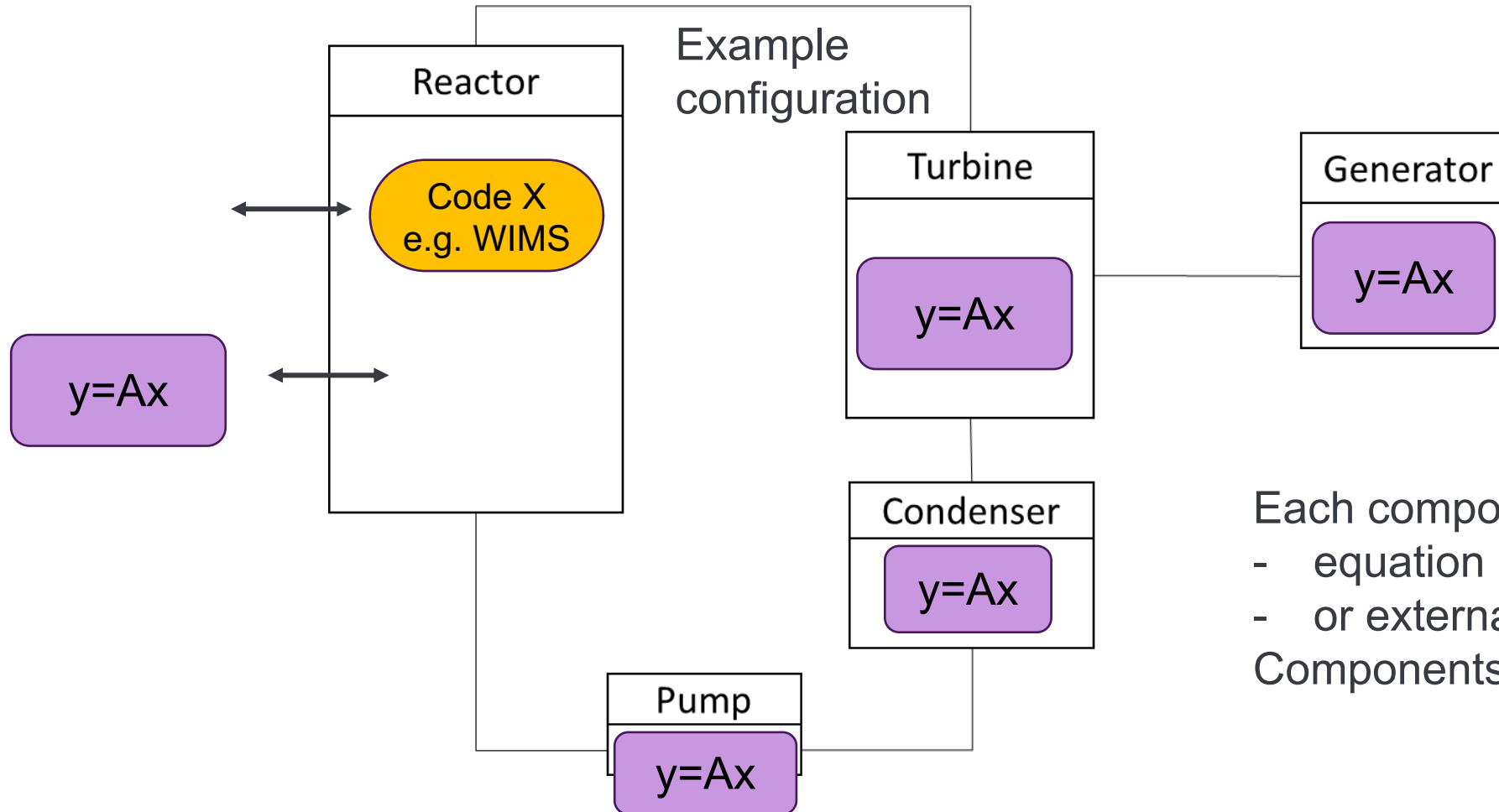


# Key aims phase 2



- 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



- Ahmed Aslam, Cathy Phelps (Wood)
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- Ionel Nistor, Jefri Draup (EDF-UK)