Digital Reactor Design

IOP Topical Research Meeting on Physics. Innovation. Nuclear
Manchester, 1-2 Nov 2017
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nirab
NUCLEAR INNOVATION AND
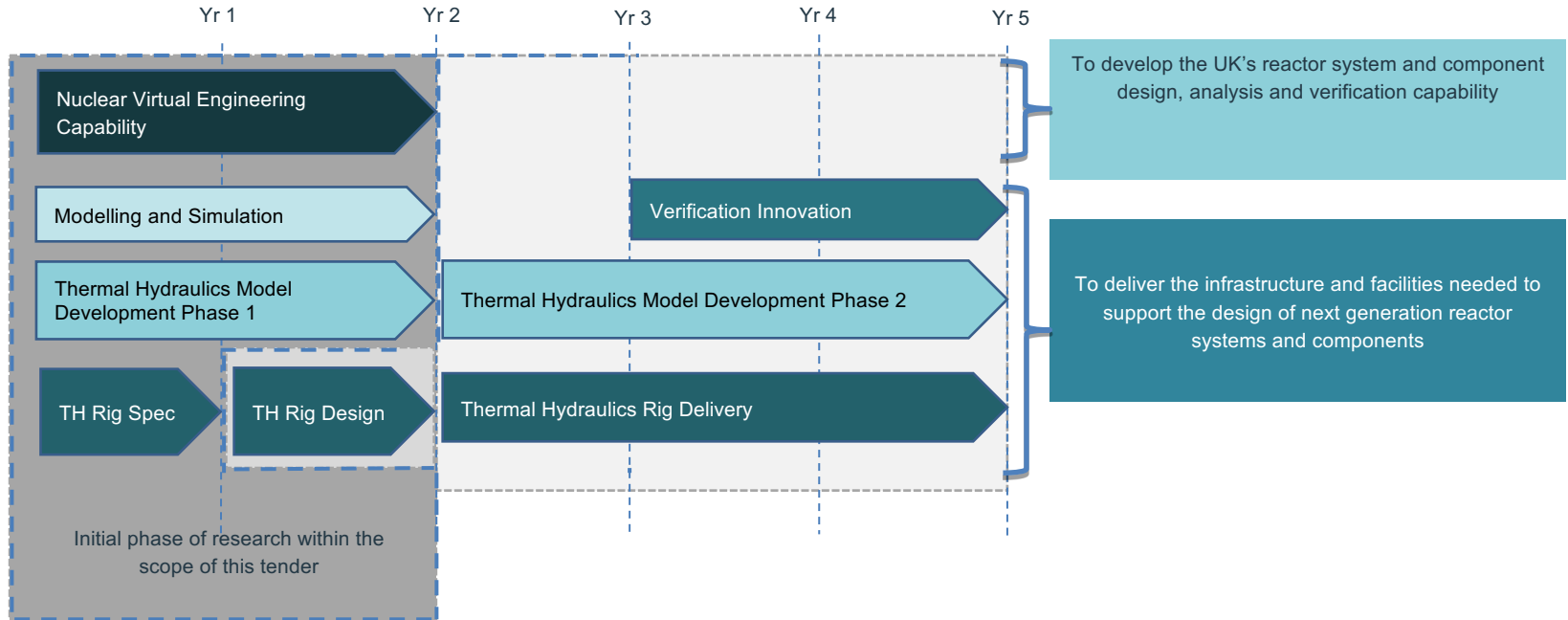RESEARCH ADVISORY BOARD

NIRAB Final Report

2014 to 2016

NIRAB-117-3

*"**Reactor Design:** Developing digital tools and fundamental scientific understanding needed to design and build future generations of reactors in an accelerated and cost effective way, with emphasis on ever increasing safety"*

Five Year Integrated R&D Programme

Yr 1   Yr 2   Yr 3   Yr 4   Yr 5

Nuclear Virtual Engineering Capability

Modelling and Simulation

Verification Innovation

Thermal Hydraulics Model Development Phase 1

Thermal Hydraulics Model Development Phase 2

TH Rig Spec

TH Rig Design

Thermal Hydraulics Rig Delivery

Initial phase of research within the scope of this tender

To develop the UK's reactor system and component design, analysis and verification capability

To deliver the infrastructure and facilities needed to support the design of next generation reactor systems and components

Programme Objectives

2020 — *"establish the UK as a partner engaged in collaborative design projects for new reactors (Generation IV and SMR), building on its existing and growing design expertise"*

2030 — *"maturing R&D results in deployment of new plant with significant UK design content and manufactured parts"*

2050 — *"R&D has facilitated UK industry to be a significant partner in the global deployment of Gen III+, Gen IV and SMR technologies"*

Source: BEIS

Programme Goals

- Step change in the way that nuclear design, development are delivered
- Increase uptake of modern digital engineering practices within UK nuclear industry
- Improved understanding and safety of through life performance of reactor components
- Enhanced predictive modelling capability
- Establish collaborative network of UK wide facilities for virtual engineering
- Innovative validated multi-scale and multi-physics models to predict through-life structural performance of key reactor components

Source BEIS

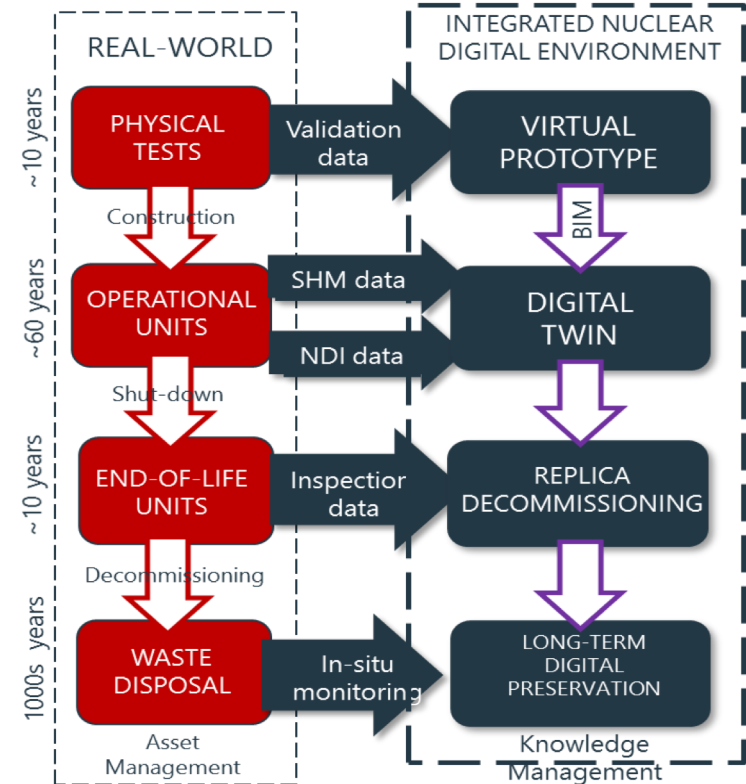*Bringing together industry, academia, national laboratories and scientific infrastructure*
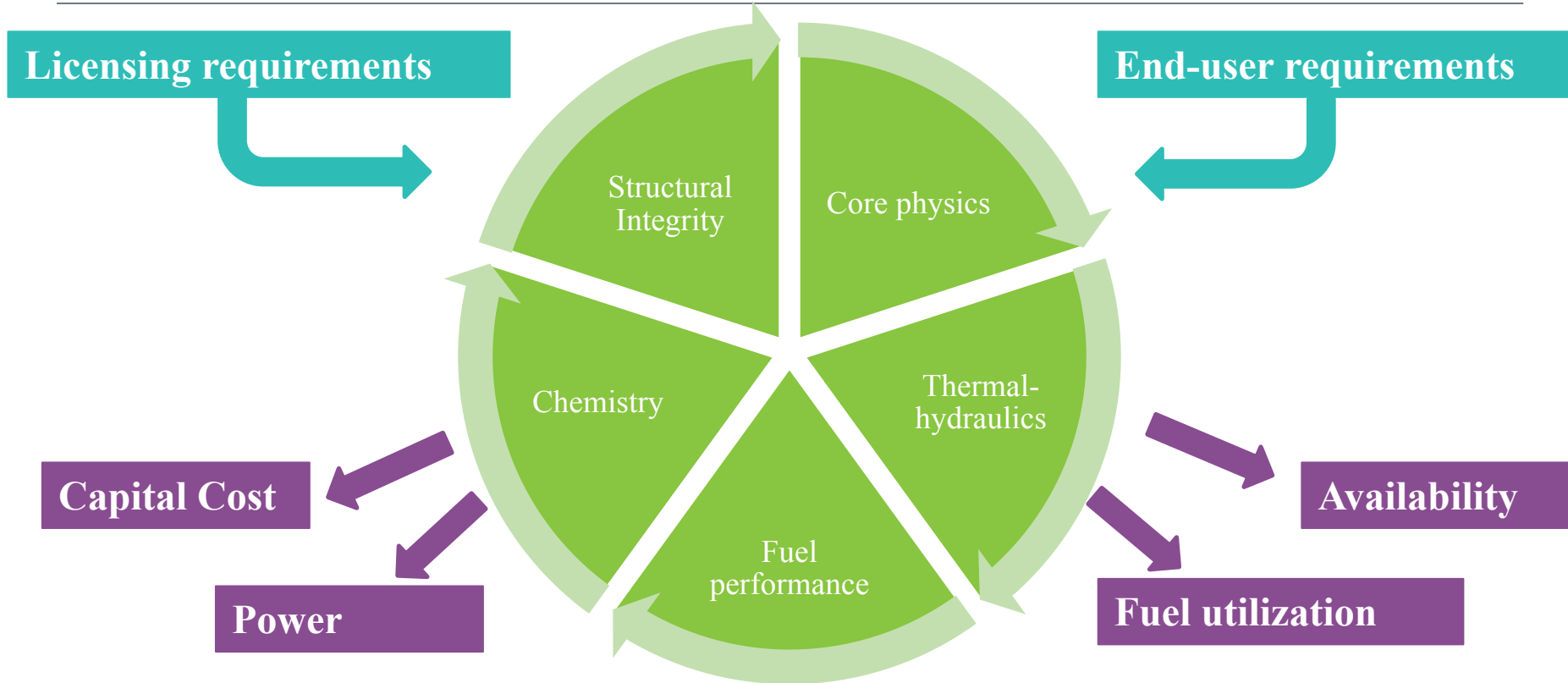
"UK plc"

Nuclear Innovation 2016-2018

Advanced Nuclear Fuels

Digital Reactor Design: Thermal-Hydraulics

Digital Reactor Design: Virtual Engineering and Multiphysics Modelling

Fuel Recycling

Nuclear Materials, Advanced Manufacturing and Modular Build

Source: BEIS
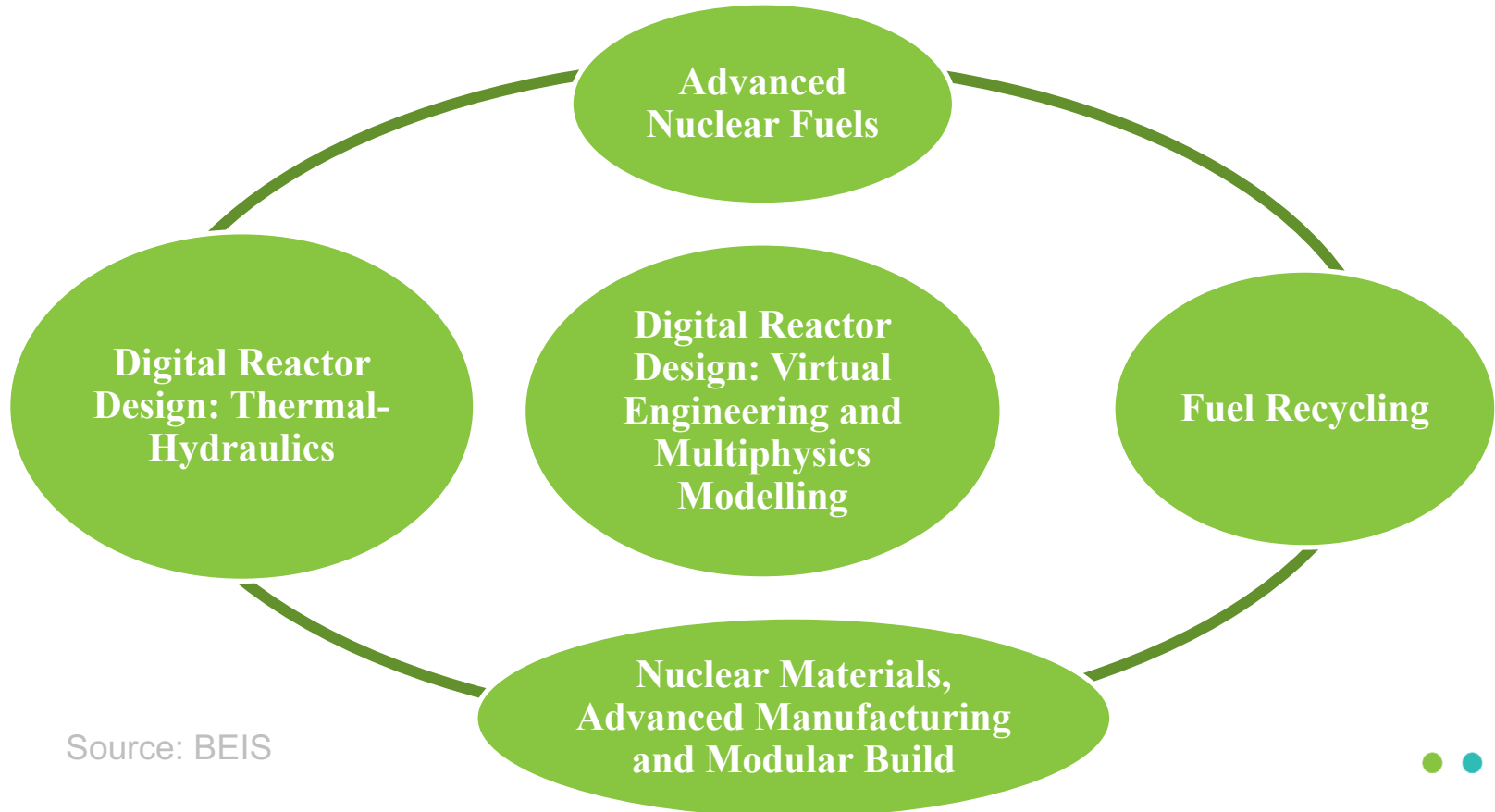
Integrated Nuclear Digital Environment

- Long term goal is to create an Integrated Nuclear Digital Environment (INDE)
- Introduce concepts used in other hi-tech industries
- Reduce development timescales and costs
- Increase safety and reliability
- Move towards small-scale mass production with inherent cost reduction
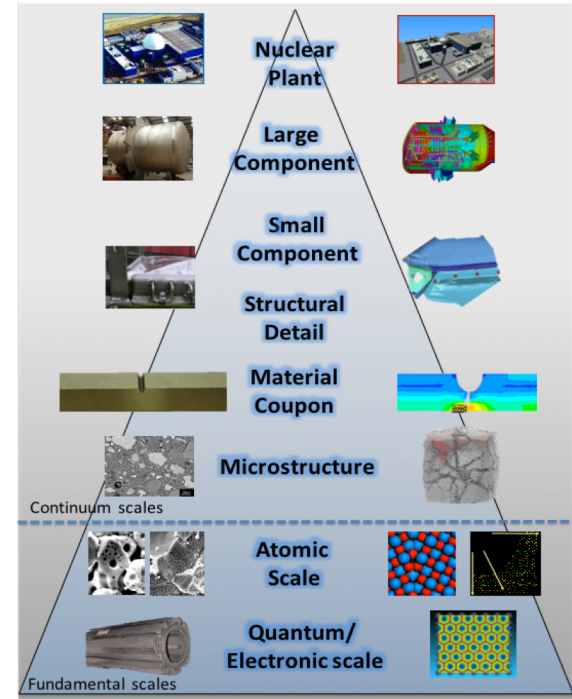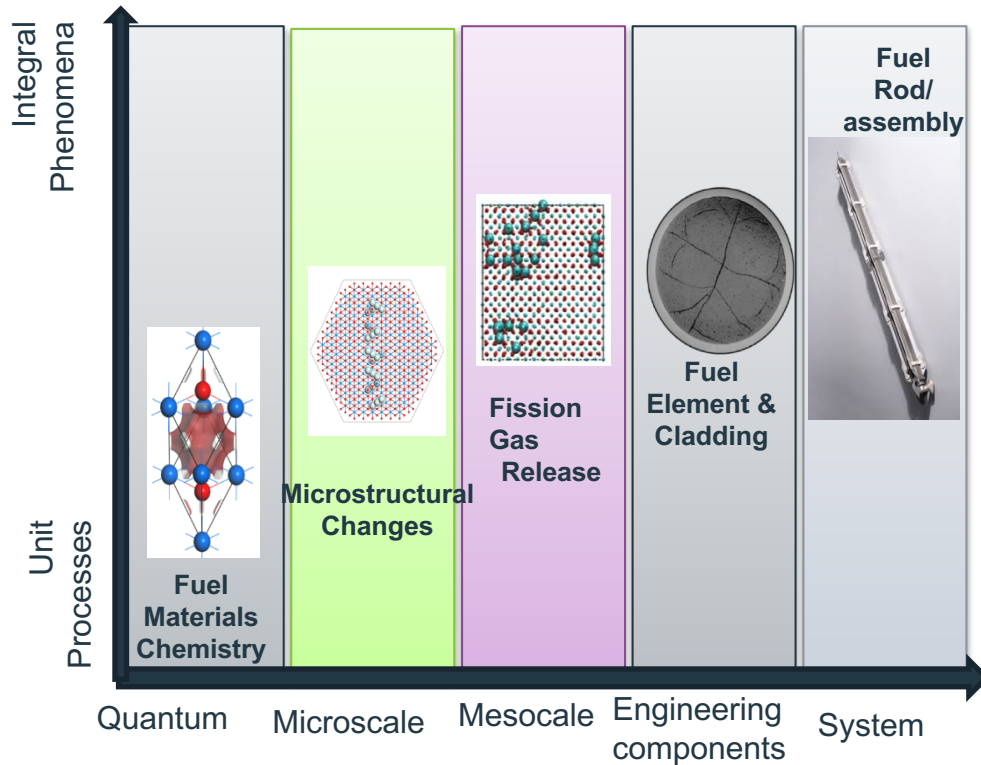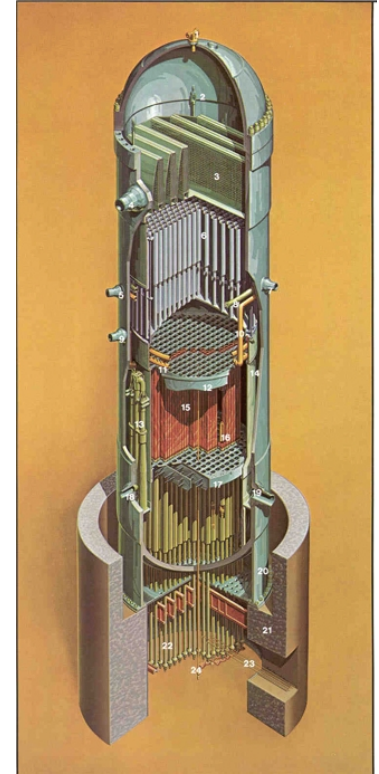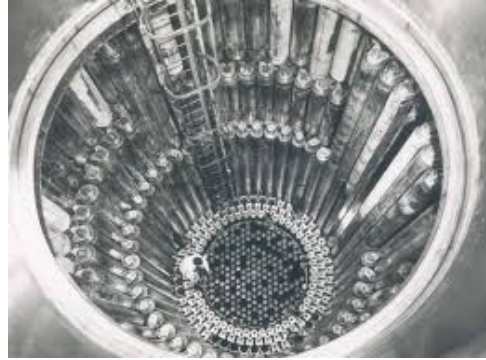

Source: Patterson, Taylor, Bankhead, Progress in Nuc. Eng 2016

Multiphysics in Nuclear Reactor Analysis

Licensing requirements

End-user requirements

Structural Integrity

Core physics

Chemistry

Thermal-hydraulics

Fuel performance

Capital Cost

Power

Availability

Fuel utilization

Multi-scale Modelling

Integral Phenomena

Unit Processes

Fuel Materials Chemistry — Quantum

Microstructural Changes — Microscale

Fission Gas Release — Mesocale

Fuel Element & Cladding — Engineering components

Fuel Rod/ assembly — System

Nuclear Plant
Large Component
Small Component
Structural Detail
Material Coupon
Microstructure
Continuum scales
Atomic Scale
Quantum/ Electronic scale
Fundamental scales

Source: Patterson, Taylor, Bankhead, Progress in Nuc. Eng 2016; M Bankhead, 2017

There are many different types of reactor

Source: nuclear-power.net, bbc, nuclearstreet.com, world nuclear news, twitter
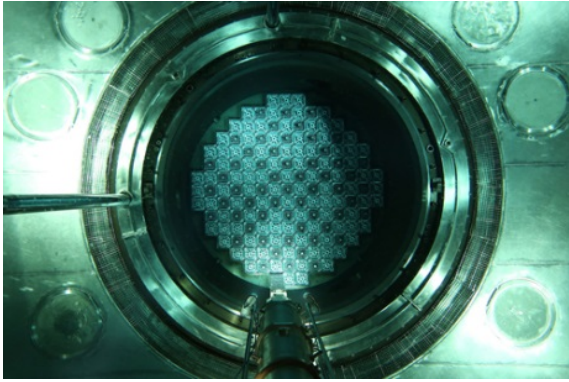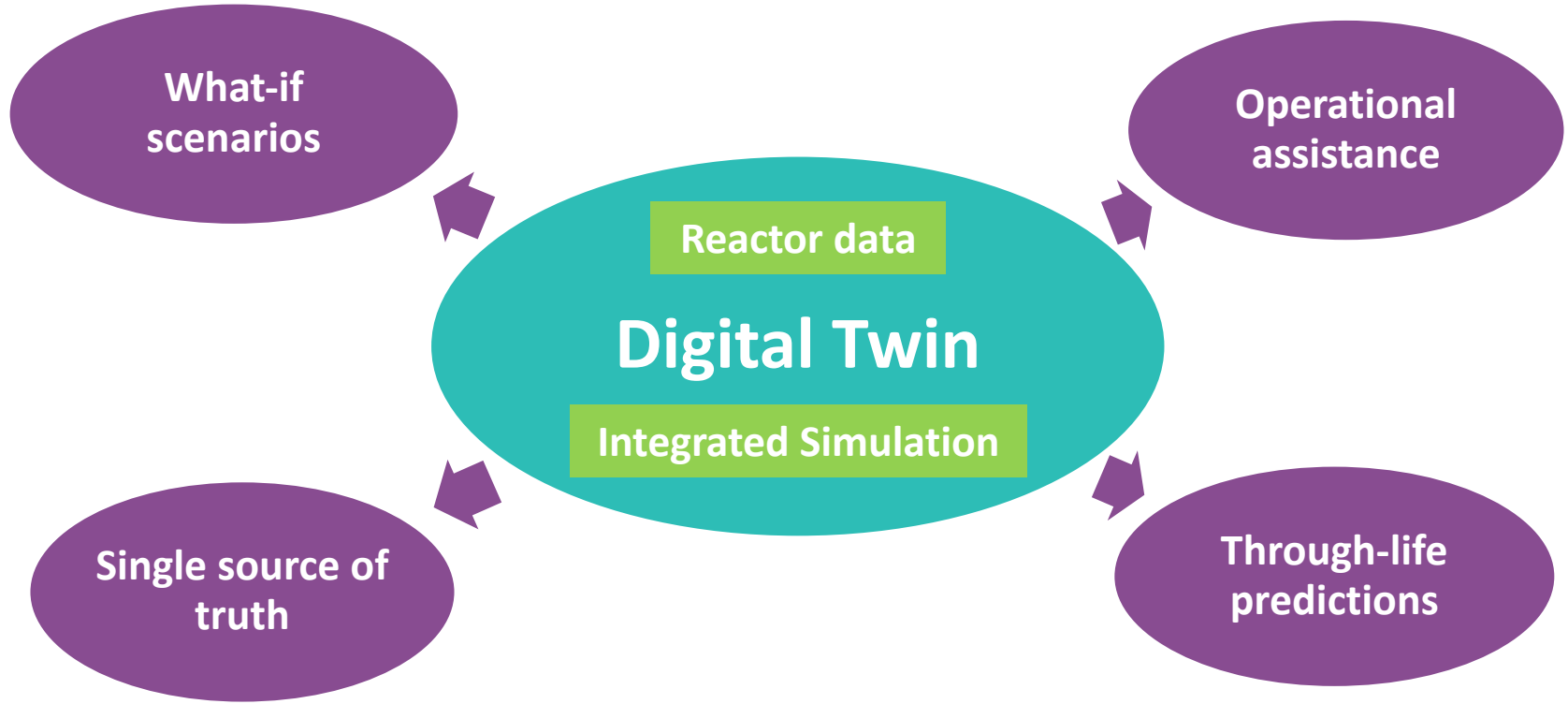
Enabling Reactor Design

- Integrate CAD with physics models
- Perform rapid iteration cycles
- Understand constraints and trade-offs
- Perform design optimization
- Consistent treatment of uncertainties
- Improved QA

Source: Barker et al., 2008
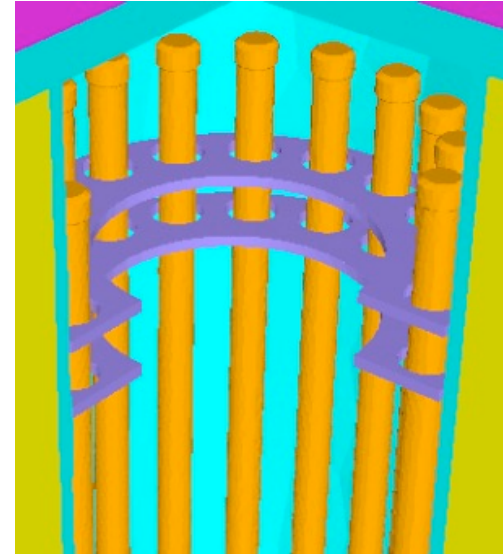
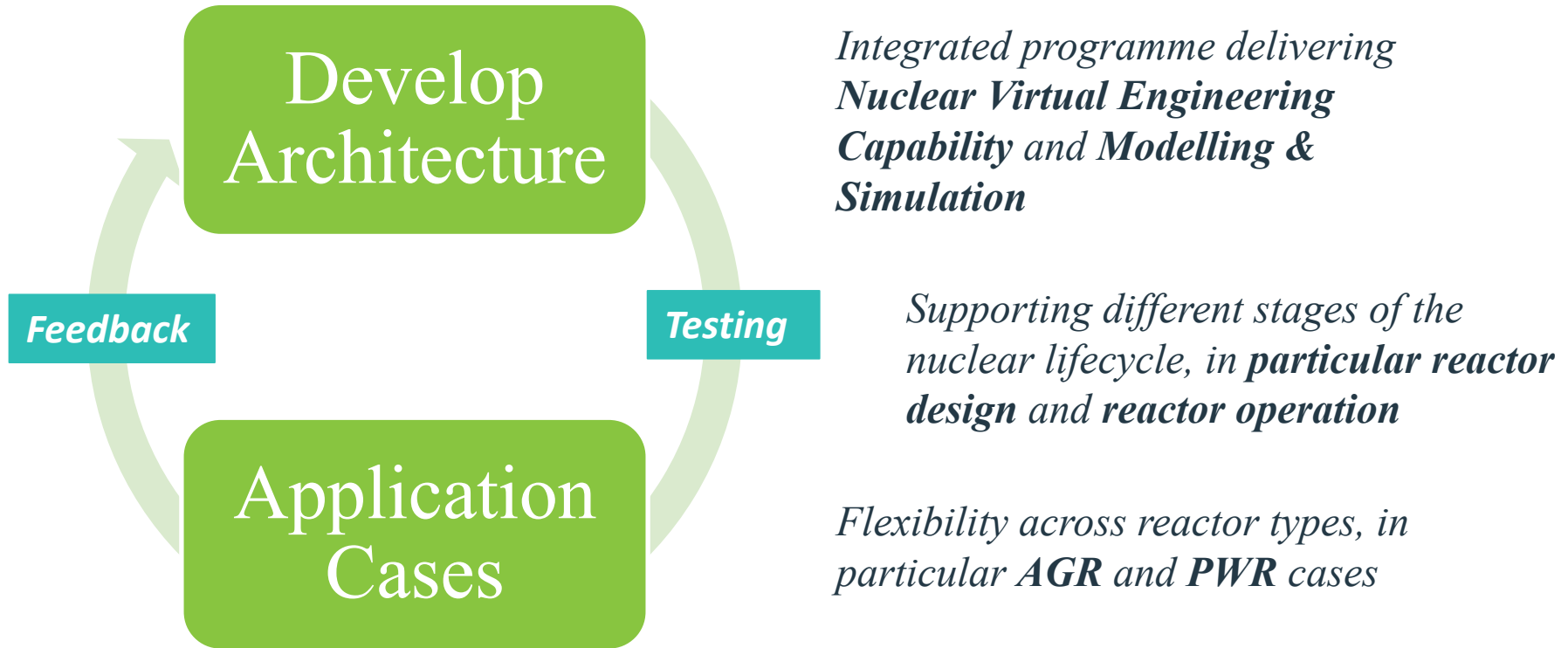# Enhancing Reactor Operations

Engagement across the nuclear industry

- Hosting of requirements capture workshops
- Develop requirements to guide future activities
- Establish international links
- Leverage existing UK capabilities
- Link industry, academia and national facilities
- Develop a Security Strategy and Safety Assurance Roadmap

Development of INDE Framework

Develop Architecture

Feedback

Testing

Application Cases

Integrated programme delivering **Nuclear Virtual Engineering Capability** *and* **Modelling & Simulation**

Supporting different stages of the nuclear lifecycle, in **particular reactor design** *and* **reactor operation**

Flexibility across reactor types, in particular **AGR** *and* **PWR** *cases*

Modelling and Simulation: AGRs

Driver
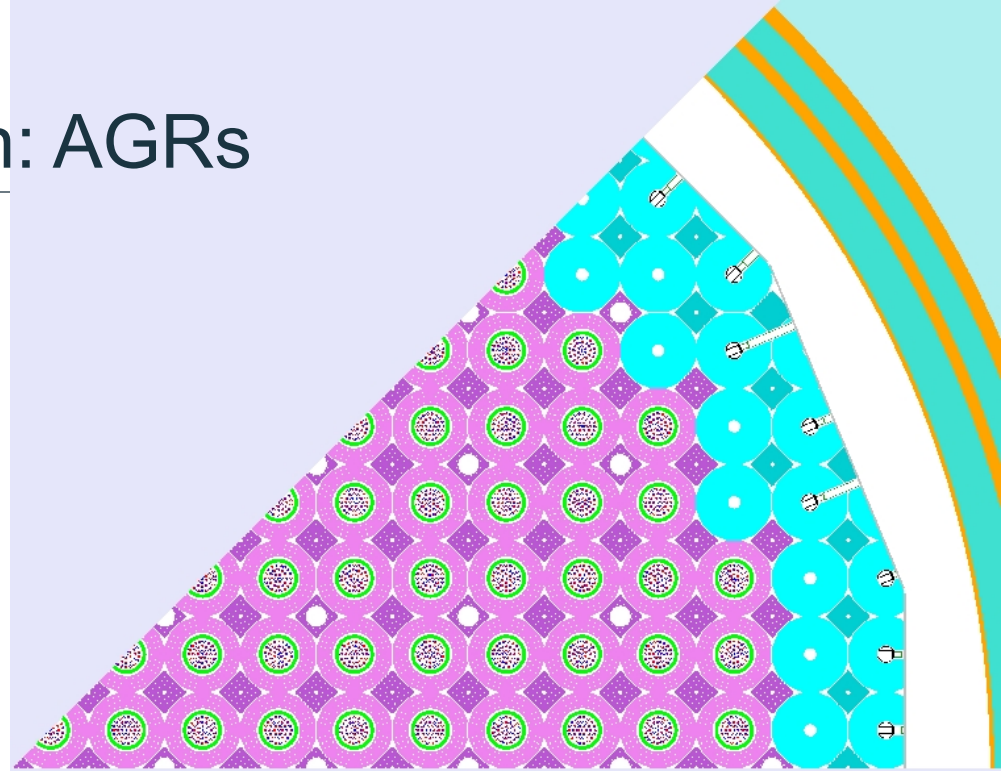AGRs comprise all but one of the UK's current nuclear generating fleet
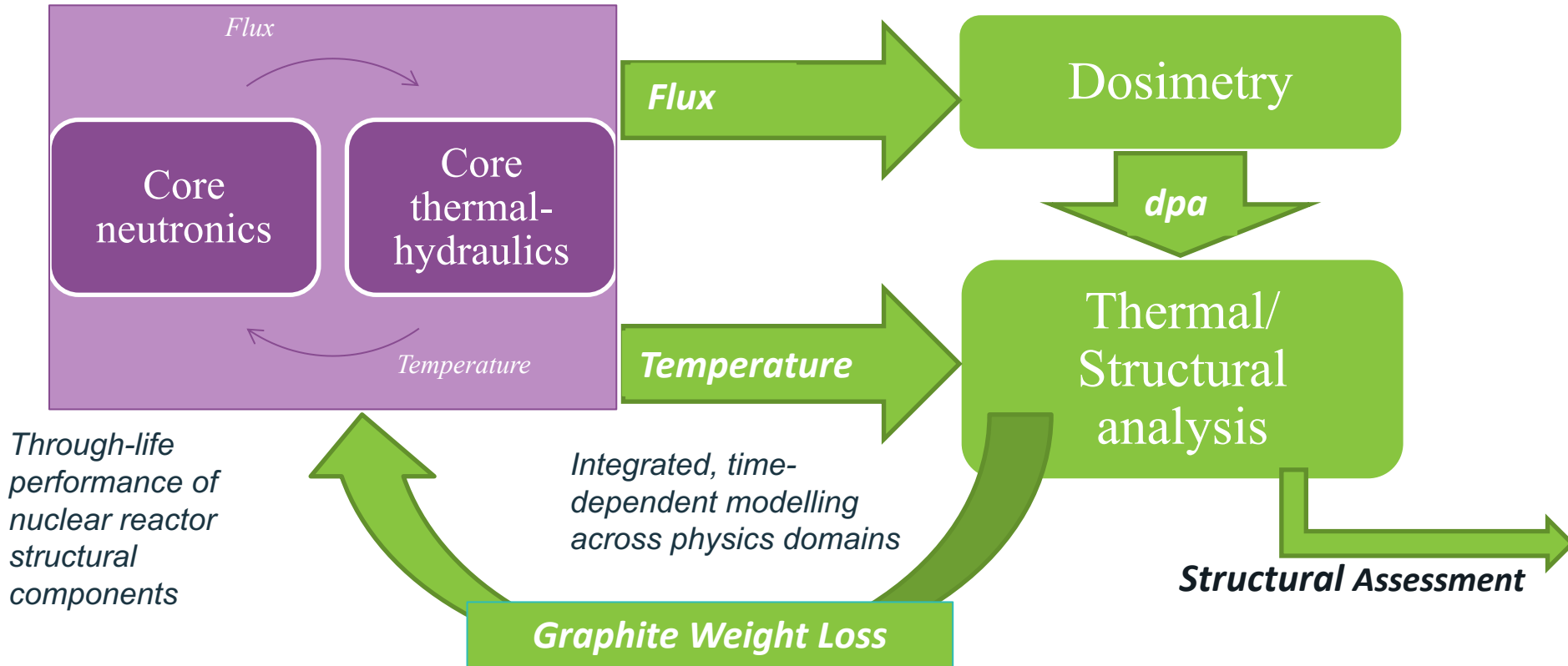
Challenge
AGRs moving towards end of life

Application
Structural performance of graphite bricks is potentially life-limiting.

AGR Integrated Modelling

Flux

Core neutronics

Core thermal-hydraulics

Temperature

Flux → Dosimetry

dpa

Temperature → Thermal/ Structural analysis

Through-life performance of nuclear reactor structural components

Integrated, time-dependent modelling across physics domains

Graphite Weight Loss

Structural Assessment

Application of INDE

High Level Architecture

Core simulation

Dosimetry

Structural Analysis

Through-life simulation

Integrated simulation with feedback
Unified problem description

Modelling and Simulation: PWRs

Driver
Operating PWR in UK
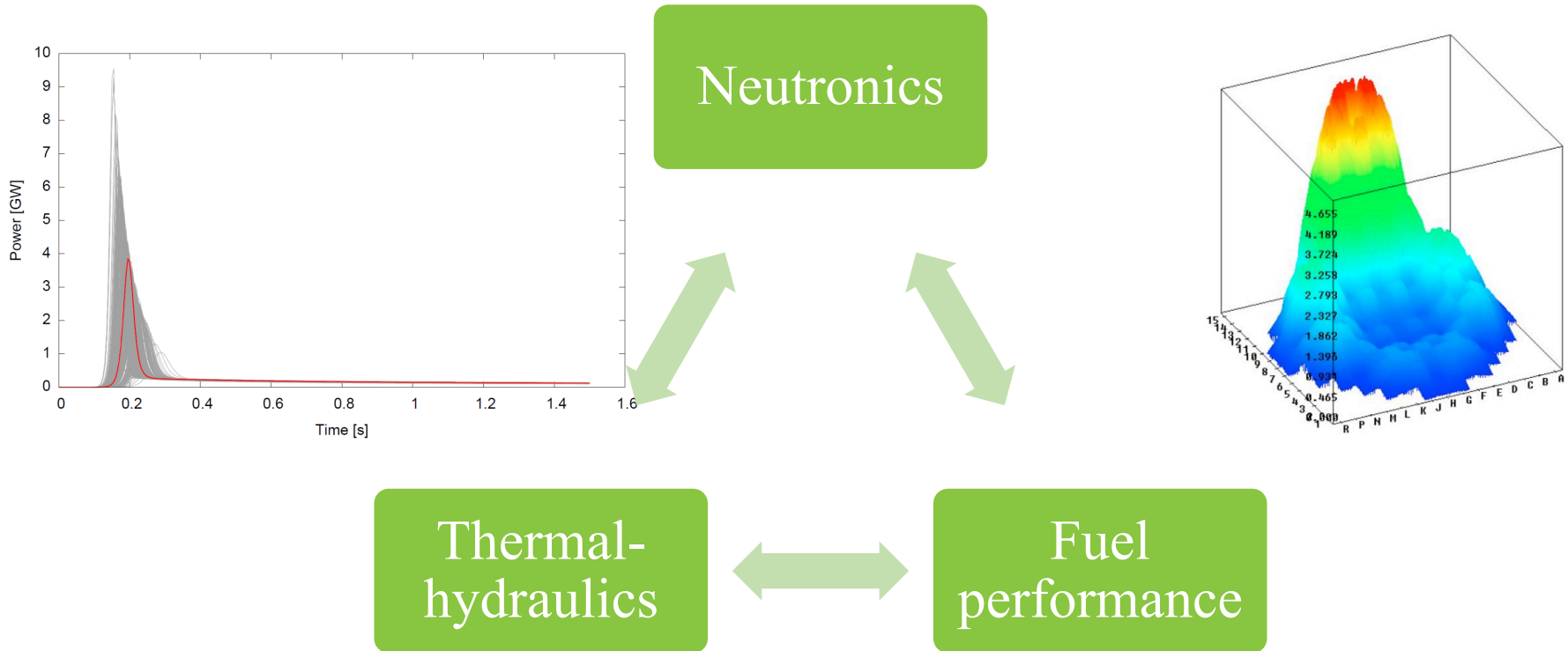Plans for PWR new build
SMR prospects in the UK

Challenge
Integrated modelling of reactor core
higher fidelity modelling, reduced
uncertainties, improved performance

**Application**
Modelling of a rod
ejection accident scenario

Source: EDF Energy, Telegraph, uknuclearsmr.org

PWR Integrated Modelling

Neutronics

Thermal-hydraulics

Fuel performance

Source: C Schneidesch, May 2014

Enabling New Technology

- Revolutionary reactor designs may offer unique cost and fuel cycle advantages
- Licensing is a challenge given lack of operational experience
- Digital prototyping has the potential to act as an enabling technology
- Potential to support UK and international efforts across the nuclear industry

Source: u-battery.com, Wikipedia.org (Stable Salt Reactor)
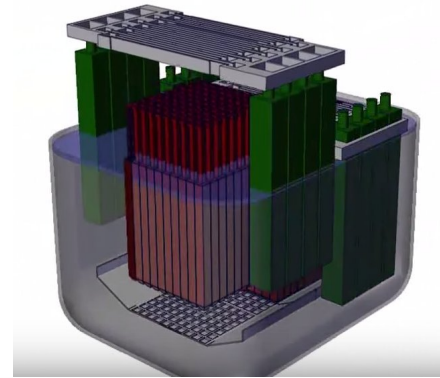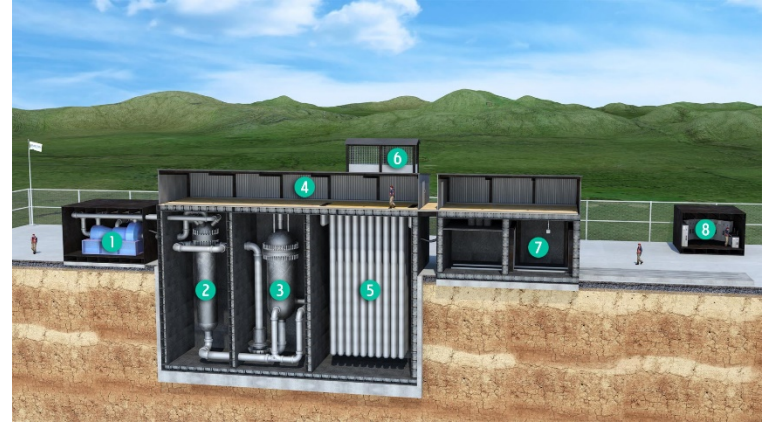
Conclusions

- Development of a **nuclear virtual engineering capability**
- Integration with a programme of **multiphysics modelling**
- Proposed solution is the development of an **Integrated Nuclear Digital Environment**
- This project is the **first step** towards this goal
- We are working to ensure the end product is **useful across the nuclear industry**.
- **Your suggestions and feedback are greatly valued**

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Thank You…

Questions?

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