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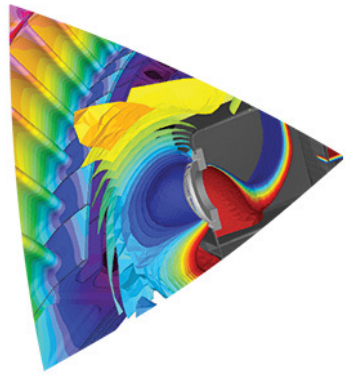

DIGITAL TWINS IN THE NUCLEAR INDUSTRY: IMPLEMENTATION AND KEY LESSONS

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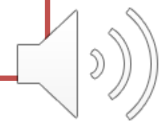
Content

- What is Digital Twin, Framework and Simulation
- How to integrate
- Integrated Nuclear Digital Environment
- Digital Framework for Civil Nuclear Industry
- Key Lessons



Digital Frameworks and Twins

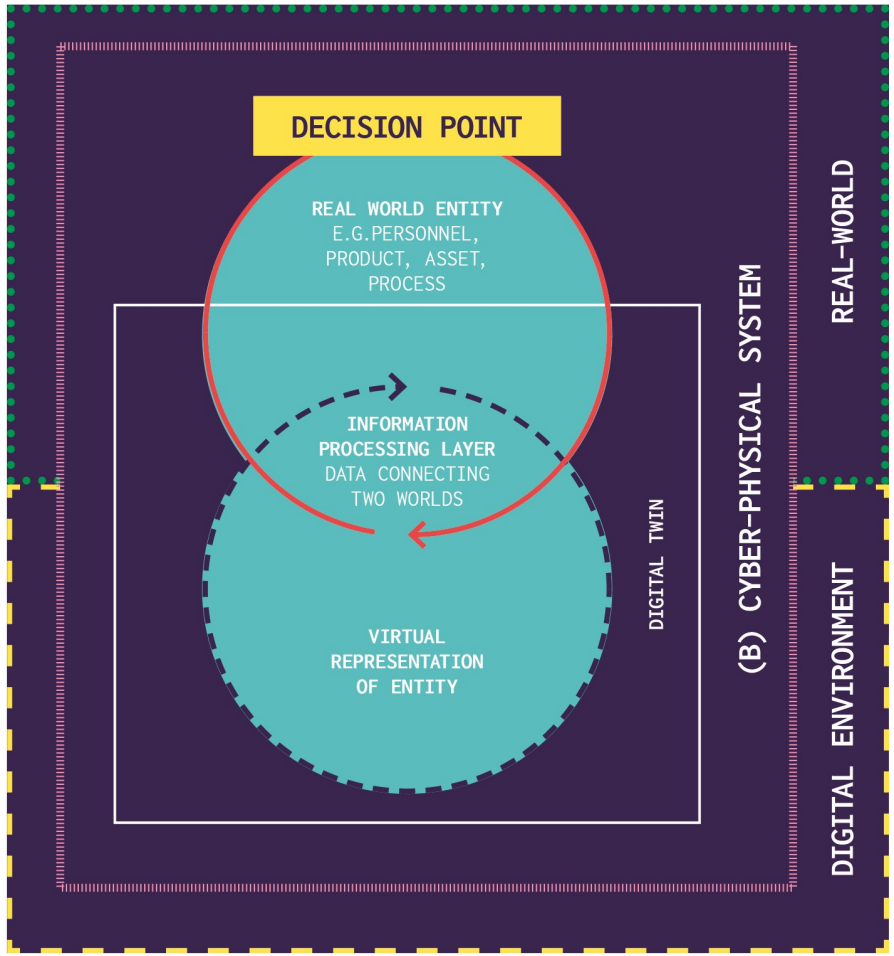
- No actual definition
- Some think we already have them
- Some think we need them
- Once implemented:
  - enable virtual verification,
  - failure mode prediction,
  - analysis
  - providing a capability to explore what-if scenarios
  - change perception of the risk

What are integrated digital frameworks?

- An **integrated digital framework** is the architecture needed to unite and integrate all hardware, software, user and organisational interfaces to allow seamless operability for an application.

- It *must* include the protocols and procedures needed to define this common way of working, in addition to the technology elements.

Digital Twin Definition



Digital twins are a combination of

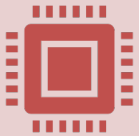
1) a real-world entity (e.g. a product, process or service)
2) a digital representation of that real-world entity, and
3) a data connection and information processing layer that joins the two worlds

When both digital and physical twins are combined, they become a cyber-physical system

Digital Twin Requirements

a specified purpose or scenario that it is established to replicate

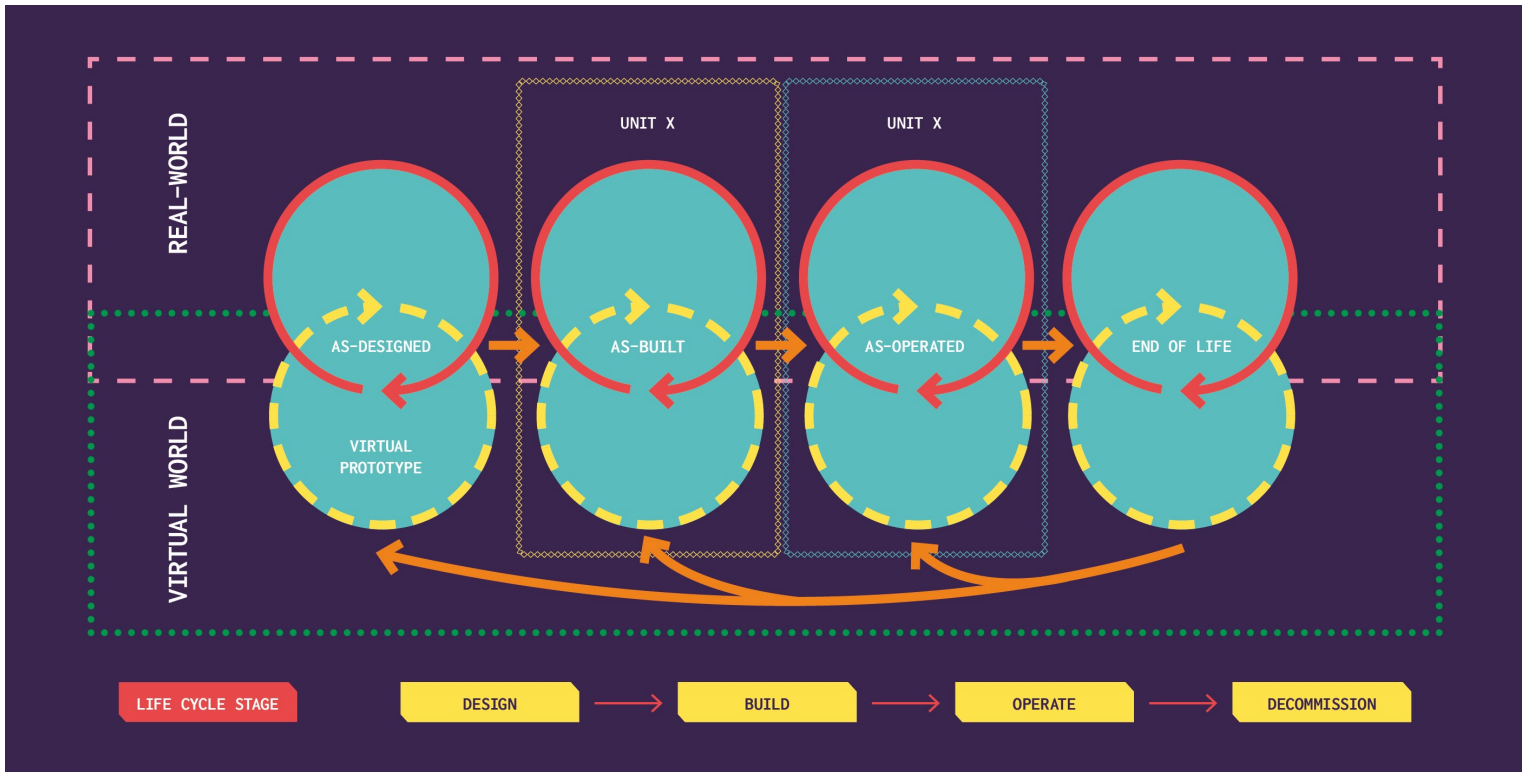
validation versus its real-world equivalent and resultant accuracy found to be within the limits required by the purpose defined and



continual updating and optimisation based on the input of ‘real-world’ data from its physical counterpart, as required to continue delivering the purpose defined.

Digital Thread

The digital thread is the communication framework that empowers a connected data flows and integrated view of the asset's data throughout its lifecycle and delivers "the right information to the right place at the right time".



Digital Simulation

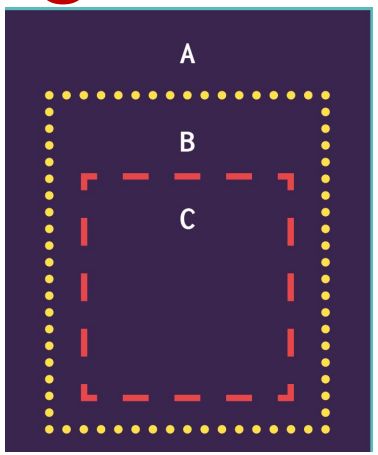
These are models used to understand *what could* happen in the real-world

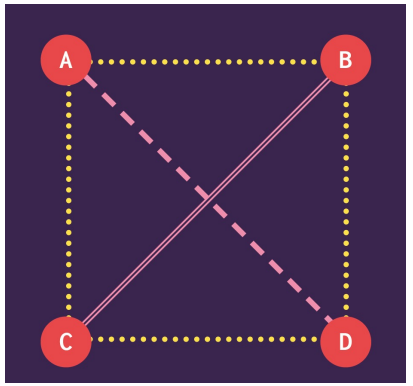
A digital twin can be used as a platform for simulation with appropriate validation and interconnectivity to a real-world asset

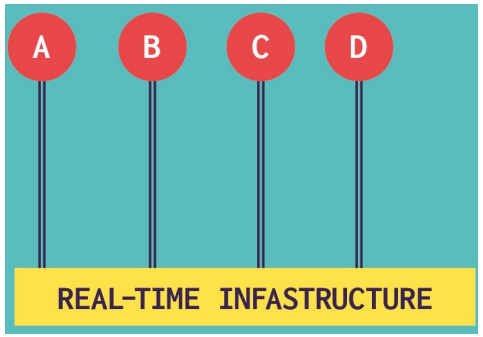
Simulations can be either qualitative or quantitative

Methods of Integration

- Vertical Integration
  - Cheaper and faster in short term
  - Cost of ownership is high
  - “Modular Monolith”
  - Limited reuse and flexibility
- Star Integration a.k.a. Spaghetti Integration
  - Pair-wise integration
  - Time and cost of integration increase exponentially
  - Mixed standards, very flexible
  - Integration and configuration management and IP nightmare
- Horizontal Integration (Enterprise Service Bus)
  - Runtime Infrastructure Component
  - Reduced number of connections
  - Flexible and Scalable
  - Service oriented

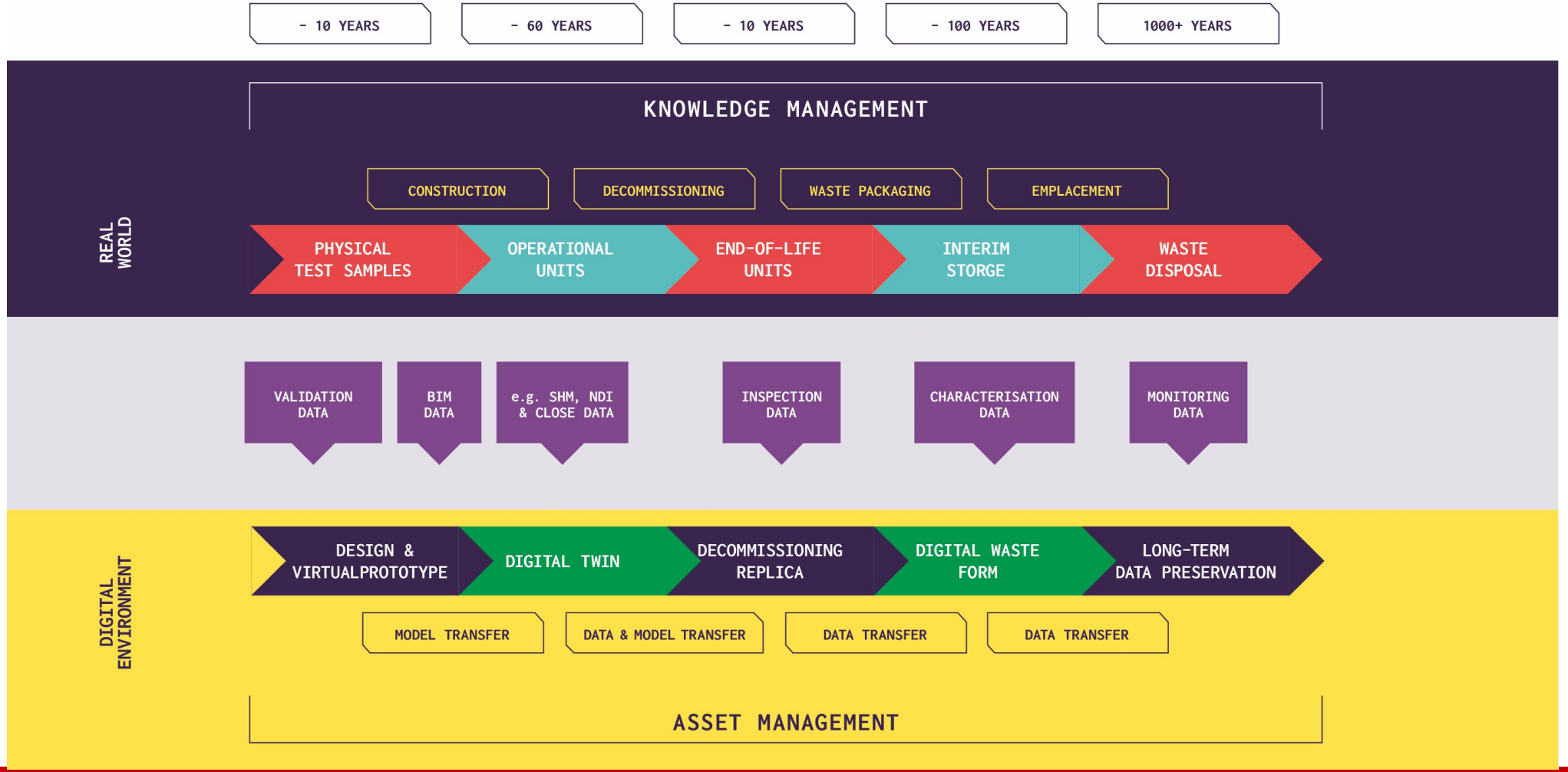






Integrated Nuclear Digital Environment

- Integrated Nuclear Digital Environment (INDE) - digital frameworks to the nuclear sector has been proposed by *Patterson EA, et. al (2016) A framework for an integrated nuclear digital environment. Prog. Nucl. Energy.* ***87****: 97–103*



Digital Reactor Design Programme

- Phase 1 Completed; Phase 2 On going
- Drivers:
  - Provide UK Civil nuclear sector with a competitive advantage
  - Support development of new generation of power plants, e.g SMR,
  - Provide techniques that encourage new ways of working between the supply chain
  - Enable easier access for non-nuclear community – stakeholders and new supply chain

Digital Reactor Design Programme (NVEC)

Aim:

- To develop a digital integrated framework to support operation of a current ‘fleet’ as well as future nuclear reactor build – design through to decommissioning
- To develop capability to produce, use and manage digital twins – virtual prototypes with real data linkage, multi-level, mixed fidelity

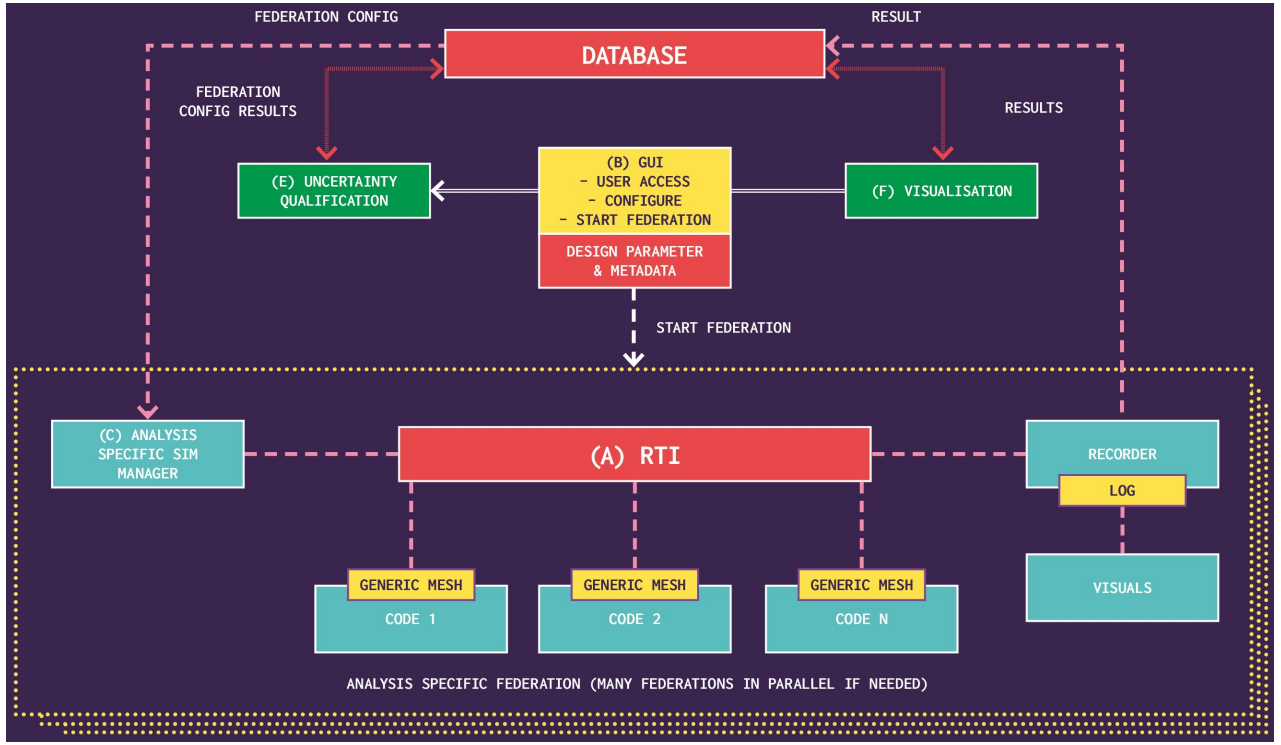
Digital Framework for the Civil Nuclear Industry

- Open Framework
- Enable collaboration across the nuclear lifecycle
- Top-down' approach philosophy
- It is 'plug and play', i.e. codes can be substituted if needed
- It is developed in accordance with IEEE 1516-2010 and IEEE 1730-2010

Digital Framework for the Civil Nuclear Industry

Includes:

a) Run-time infrastructure (RTI)
b) Graphical user interface (GUI)
c) Sim Manager (SM)
d) Database (DB)
e) Uncertainty Quantification (UQ)
f) Visualisation of outputs
g) Logger
h) Set of Codes (i.e software apps)

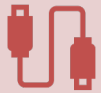


Application: AGR Reactor

- Through-life assessment of cracking of graphite fuel bricks
- Integrated simulation provided a seamless linkage of analysis capability from 3 organisations
- Compare results in real-time
- Processing time for analysis was reduced from 4 days to approximately 4 hours

Application: PWR Reactor

Rod ejection accident, part of safety case



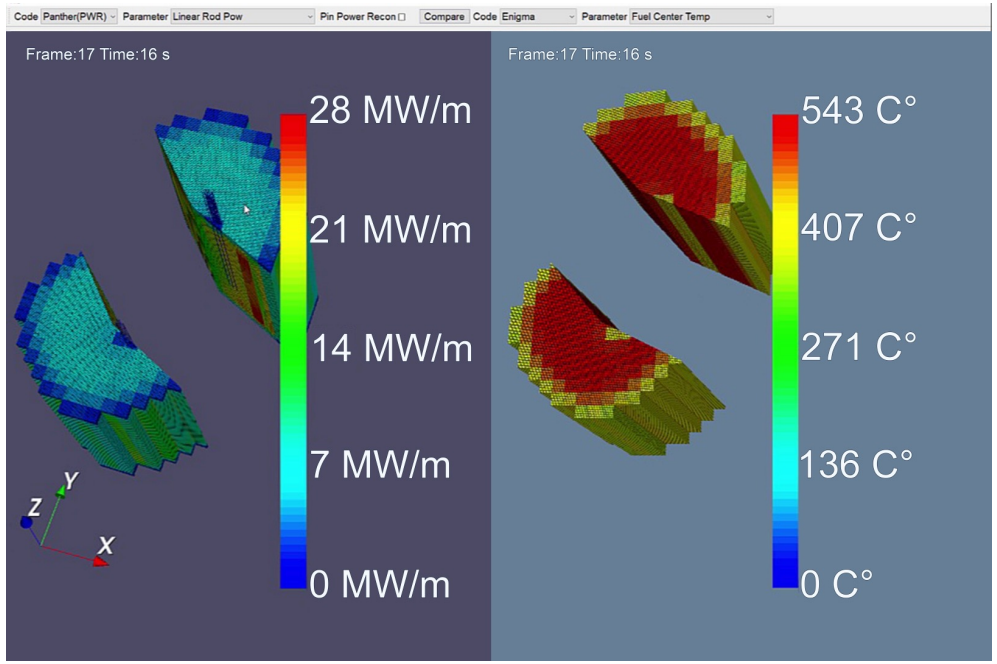
Plug and Play with substituting codes

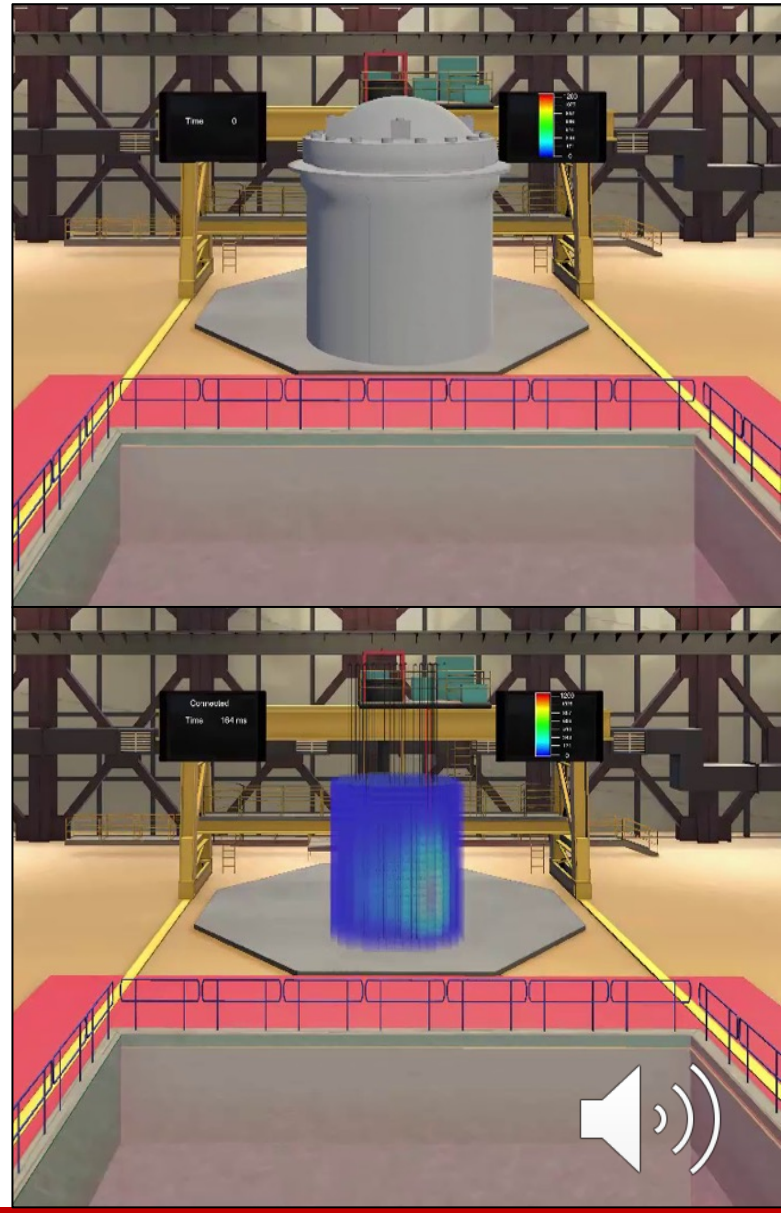
Rapid analysis of differing scenarios with no loss of accuracy

Analysis time was reduced from approximately 8 days to 12 hours

Visualisation of Results

- 2D graphics, 3D visualisation, and immersive, full-scale virtual reality (VR)
- Open-source and commercial packages, e.g. VTK, Unity, etc





Key Lessons: Use of Digital Framework

- Increases efficiency
- Removes a large number of manual interventions
- Delivers the flexibility and scalability
- Protects Intellectual Property
- Empower Collaboration

Key Lessons

- Adoption of new way of working and discipline of utilising standardise approach is required
- Implementation of digital framework and twin without the foundational elements of a digital prototype can be prohibitively expensive
- The focus should be on developing a for future assets
- Scepticism about the ability to achieve effective integration
- Reluctance to modify existing software and change operational procedure

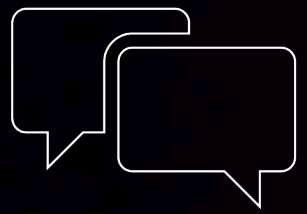
Key Lessons

Adaptive visualisations and a ‘single version of the truth’ was found to improve communication between partners

Single ‘version of the truth’ eliminated issues of version control and reduced the burden of configuration management

Training, deployment and the cultural change programmes required for widescale adoption

Need for decision-maker or establish a clear governance structure



Thank You