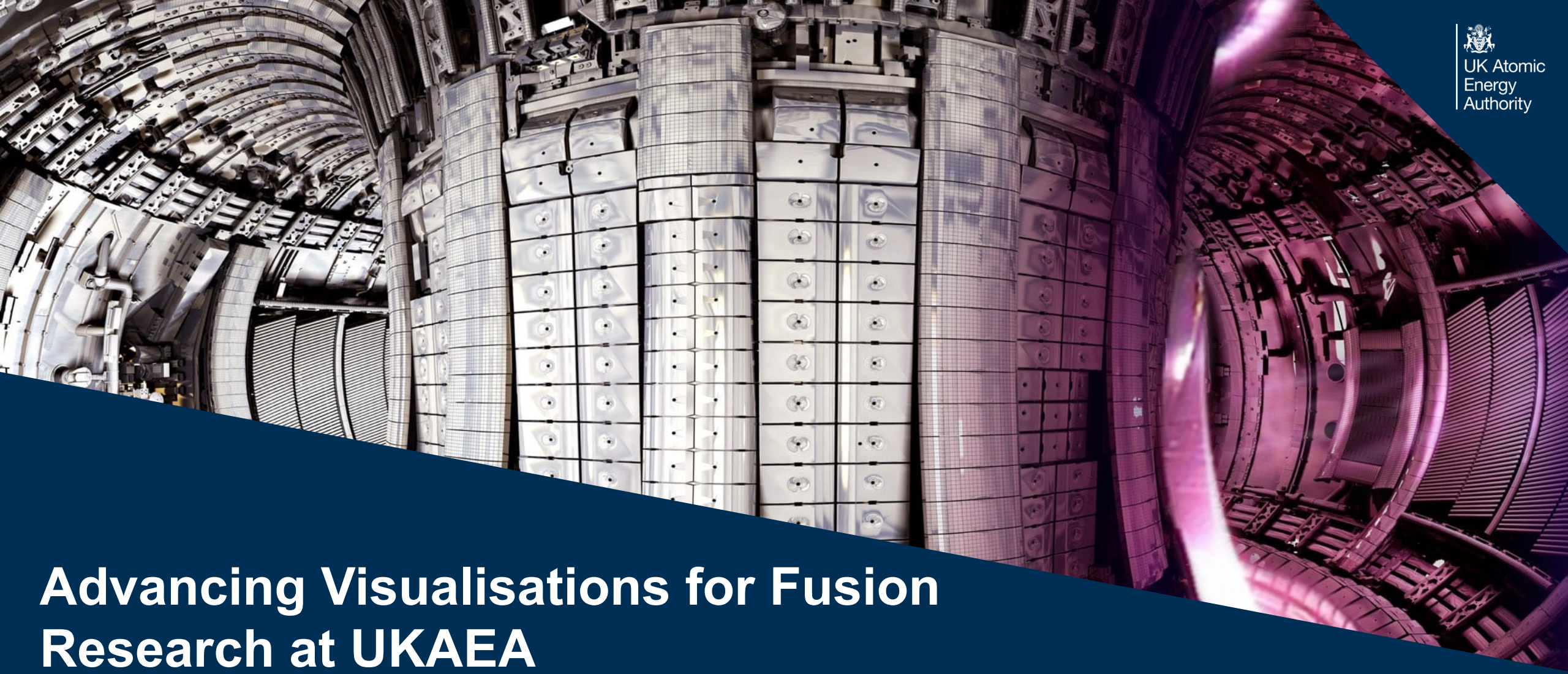


UK Atomic Energy Authority

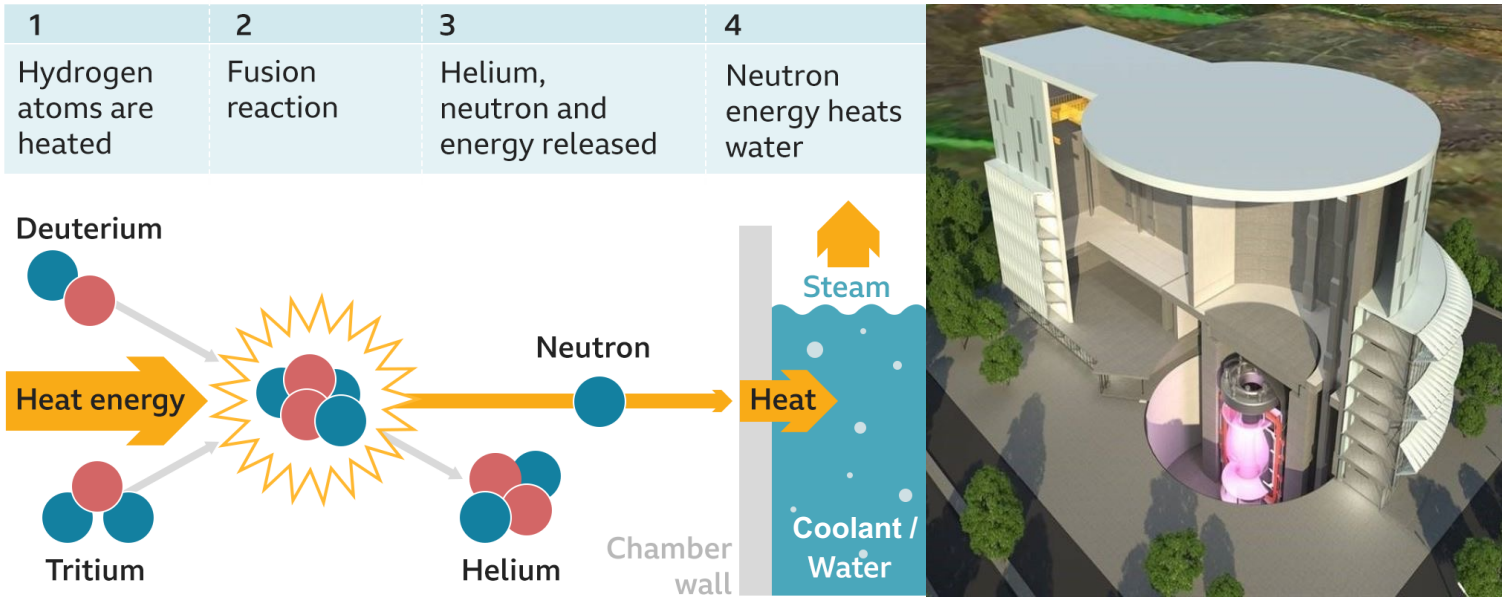
Advancing Visualisations for Fusion Research at UKAEA

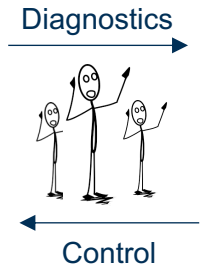
Visualizing large dataset workshop, Princeton, June 2024

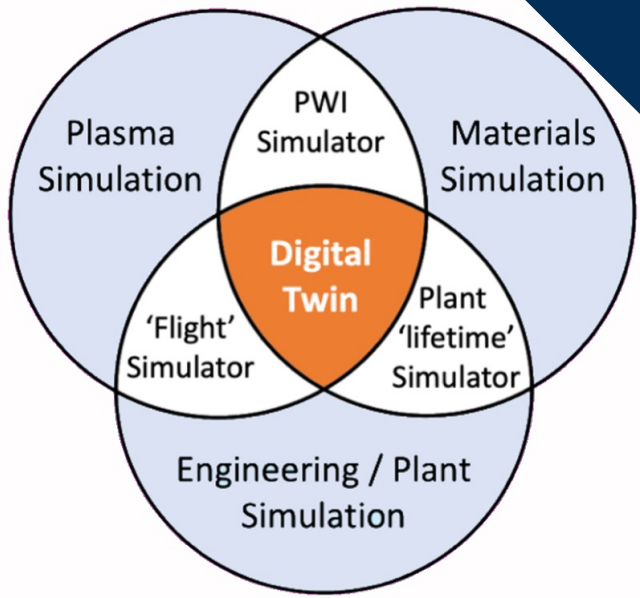
Nitesh Bhatia, Lead Data Visualisation, Computing Division, UKAEA

Stanislas Pamela, Robert Akers, Lee Margetts, Andrew Davis, Daniel Mason, Max Boleininger, Alex Blair, Luca Reali, Stephen Dixon, Samuel Jackson, Nathan Cummings, Ed Threlfall, William Hornsby, Vignesh Gopakumar, Lorenzo Zanisi

Introduction







Fusion Power Plant

Simulated Digital Twin

Data from Diagnostic Sensors

- ~2PB for 40 years of JET. ~1PB/day on ITER
- 1D, 1.5D, 2D, Signals from Probes: Reflectometry, Thomson Scattering, Bolometry, Soft Xray, Divertor Camera, IR

Data from Simulations

- TBs - PBs, Complex, Multi-physics, Multi-scale
- Unstructured grids, large meshes, CAD
- Slab Simulations, JOREK MHD, BOUT++, MOOSE (Exascale)

Advanced Visualisation at UKAEA

UK Atomic Energy Authority

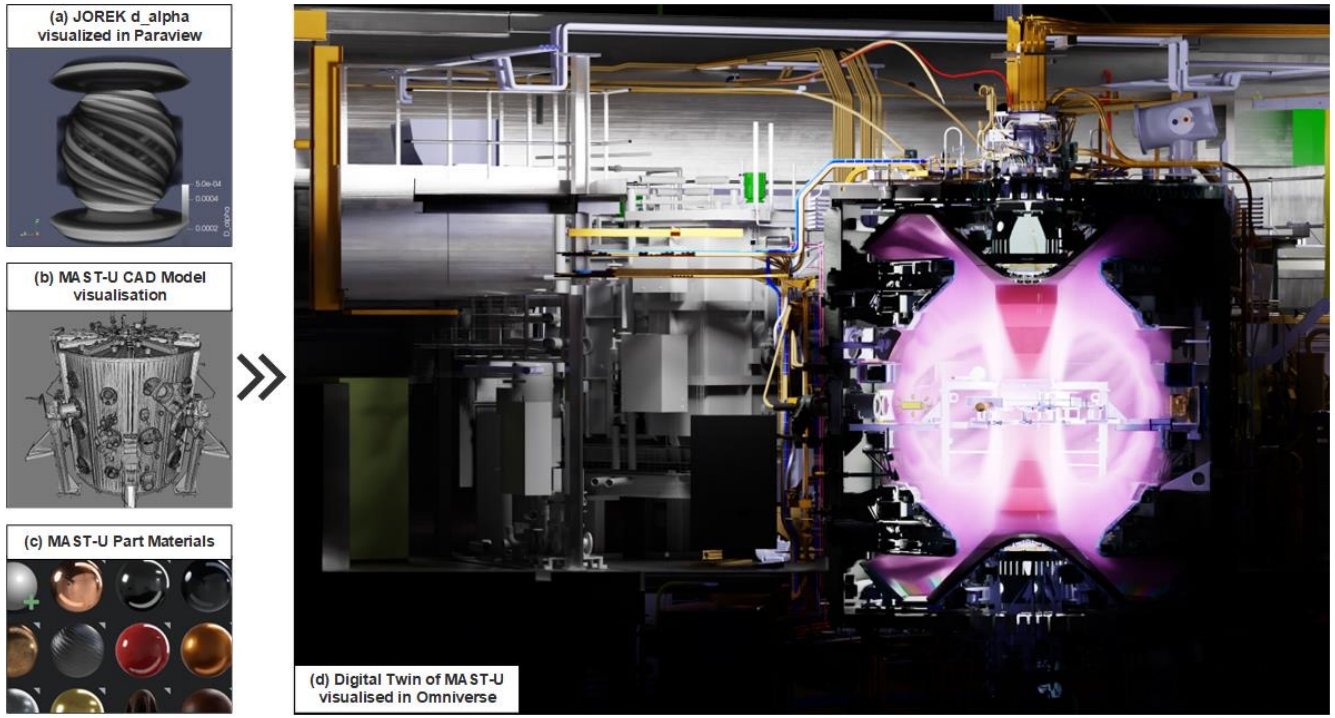
Advanced visualisation plays a crucial role in:

- Analysing predictive simulations
- Understanding complex data
- Communicating results effectively
- Validating simulation accuracy
- Improving outcomes in tokamak design and operation

ML and Data Science:

- Accelerate compute-intensive machine learning (ML) modeling and inferencing jobs

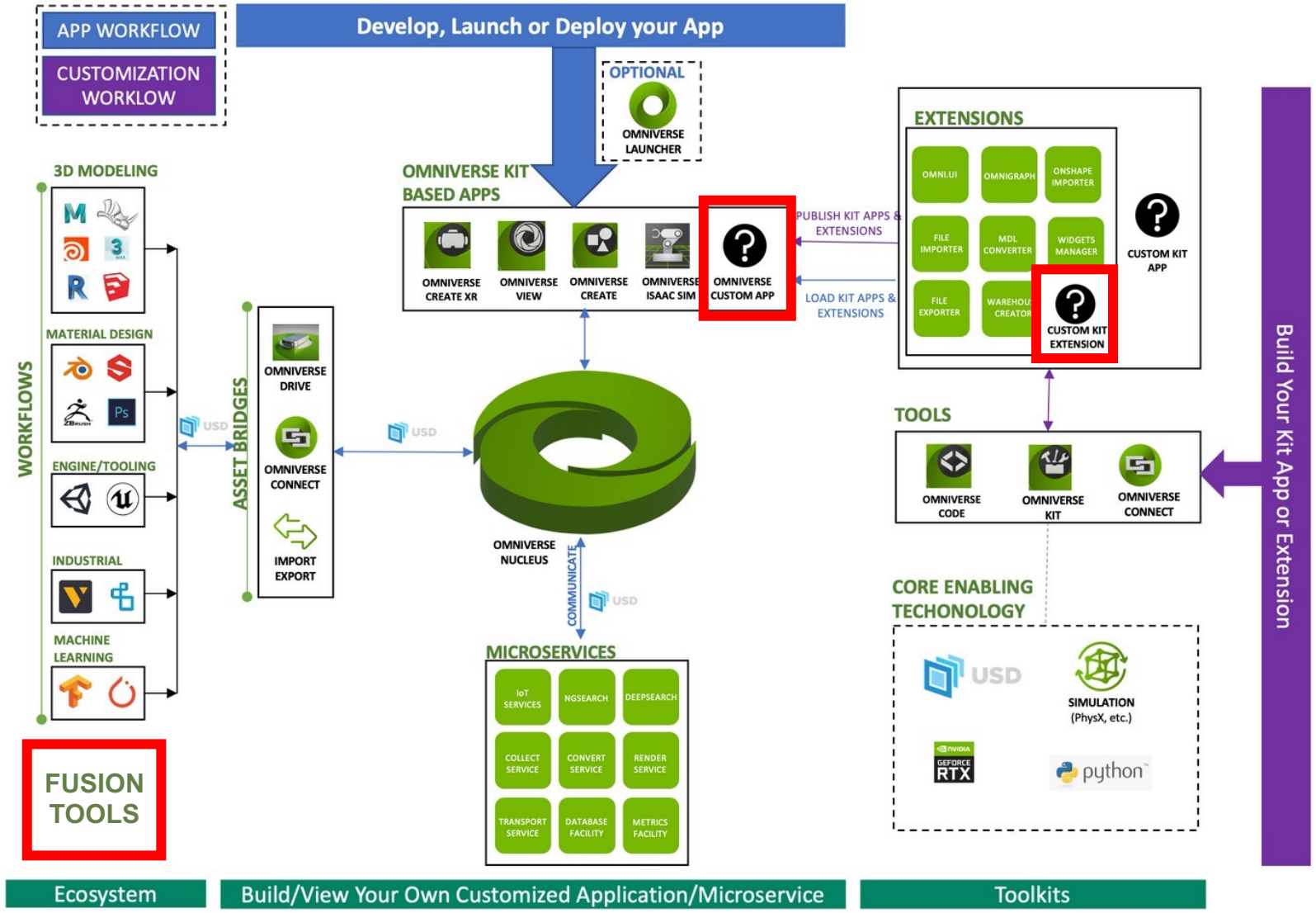
Macro-scale Visualisation (System Level)



MAST-U CAD & JOREK MHD visualised using Omniverse at UKAEA

- Use visualisation platforms such as NVIDIA Omniverse to integrate
  - Detailed CAD models - the physical structure of fusion reactor facilities
  - Material models - parametric materials
  - Simulation data - the operational and functional aspects
- Interactive exploration and analysis
- Safe and cost-effective experimentation, enabling the testing of new research without risk to the actual system
- Cambridge HPC (CSD3)

Nvidia Omniverse



Source: MCFELab, Manchester

Omniverse is a platform for 3D design collaboration and simulation

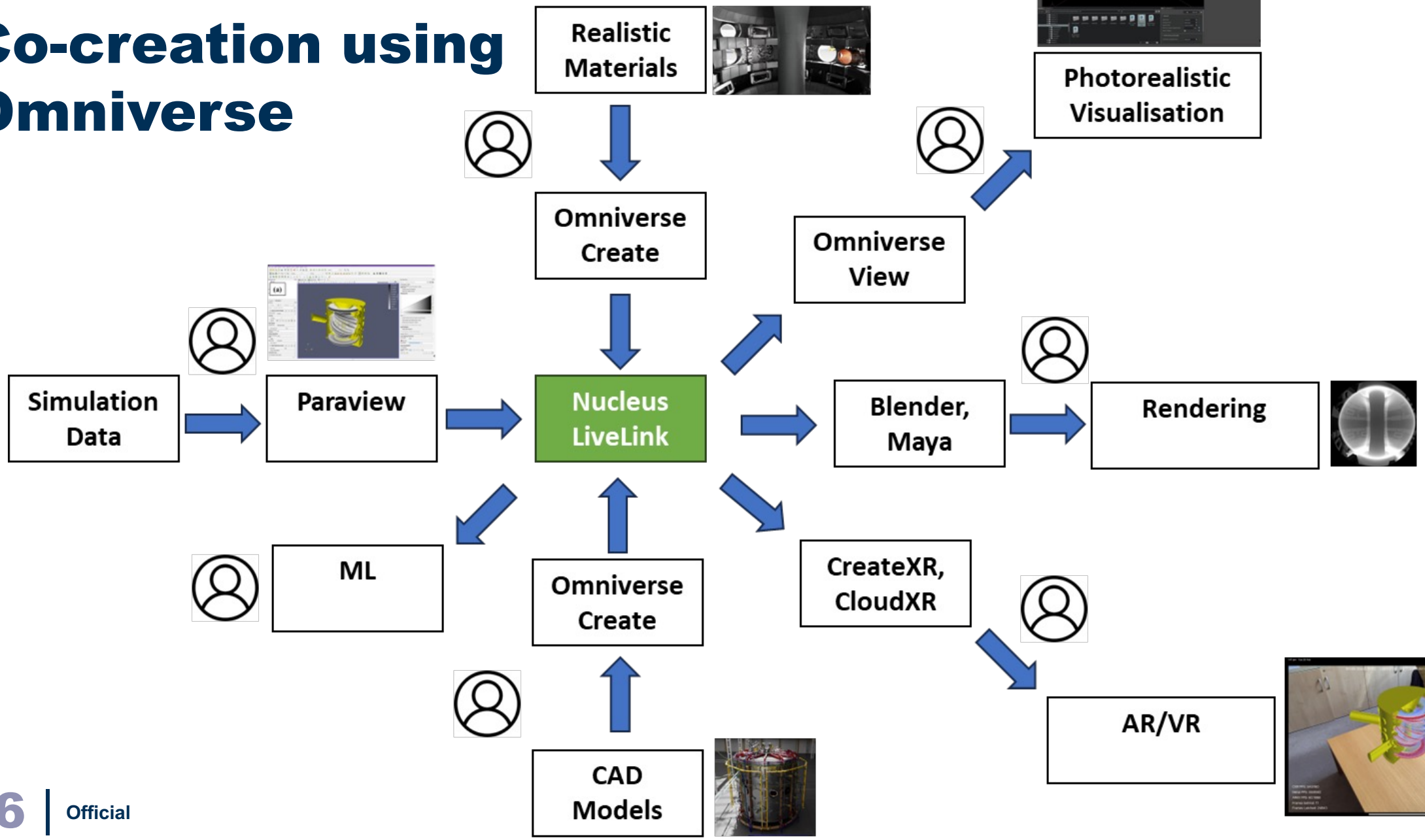
Key Features:

- Real-time collaboration
- High-fidelity visualisation
- Integration with various tools and datasets

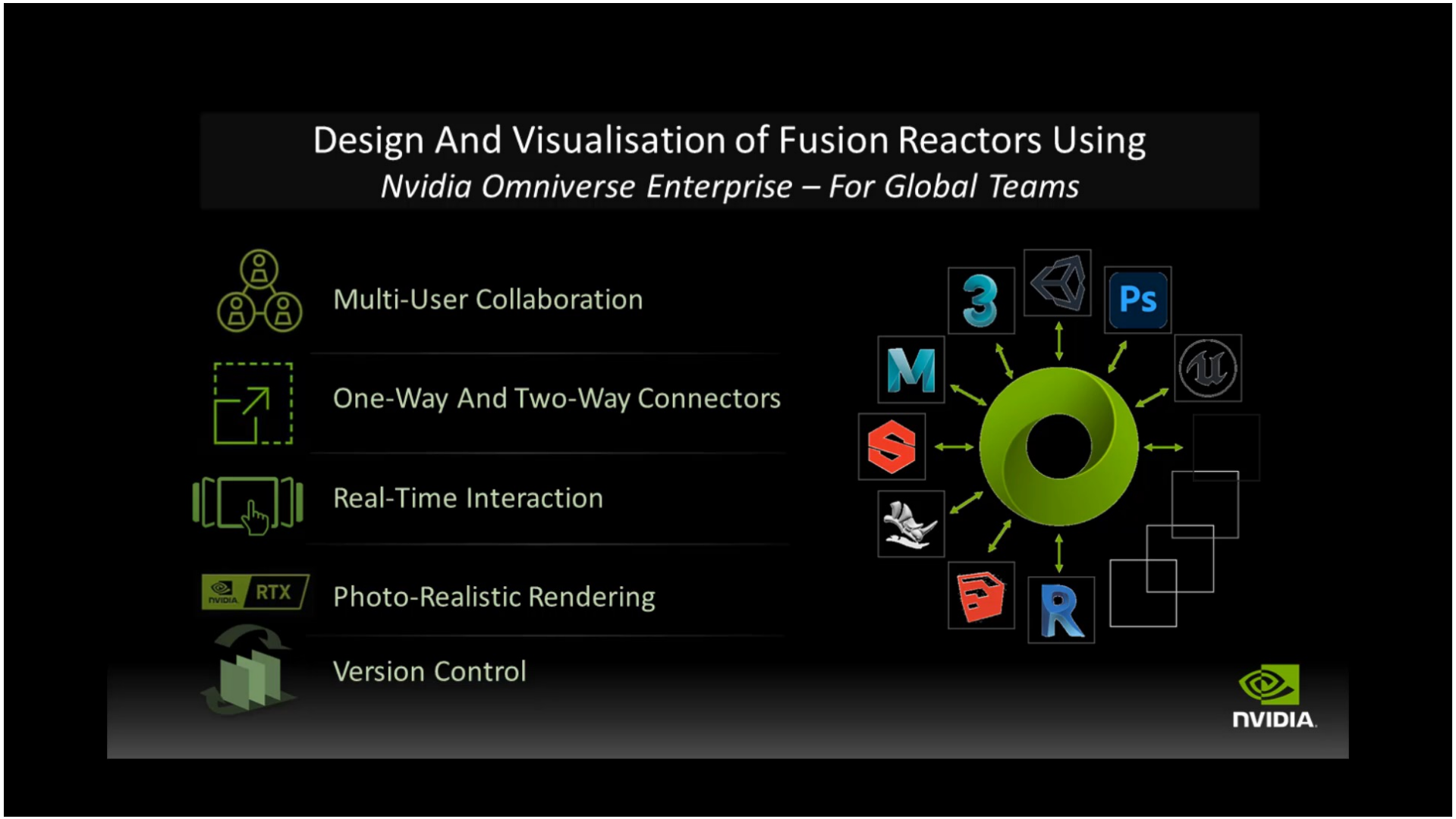
Components:

- Omniverse USD Composer
- Omniverse Kit for ***custom apps***
- Omniverse Nucleus file server
- Connectors for Paraview, Autodesk, Adobe, etc

Collaboration & Co-creation using Omniverse

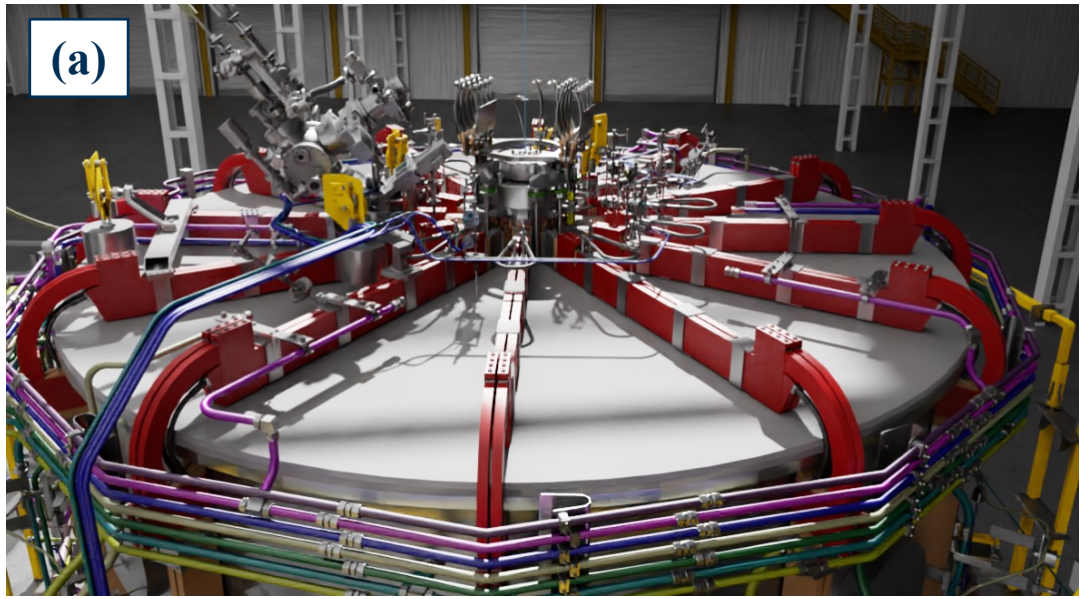


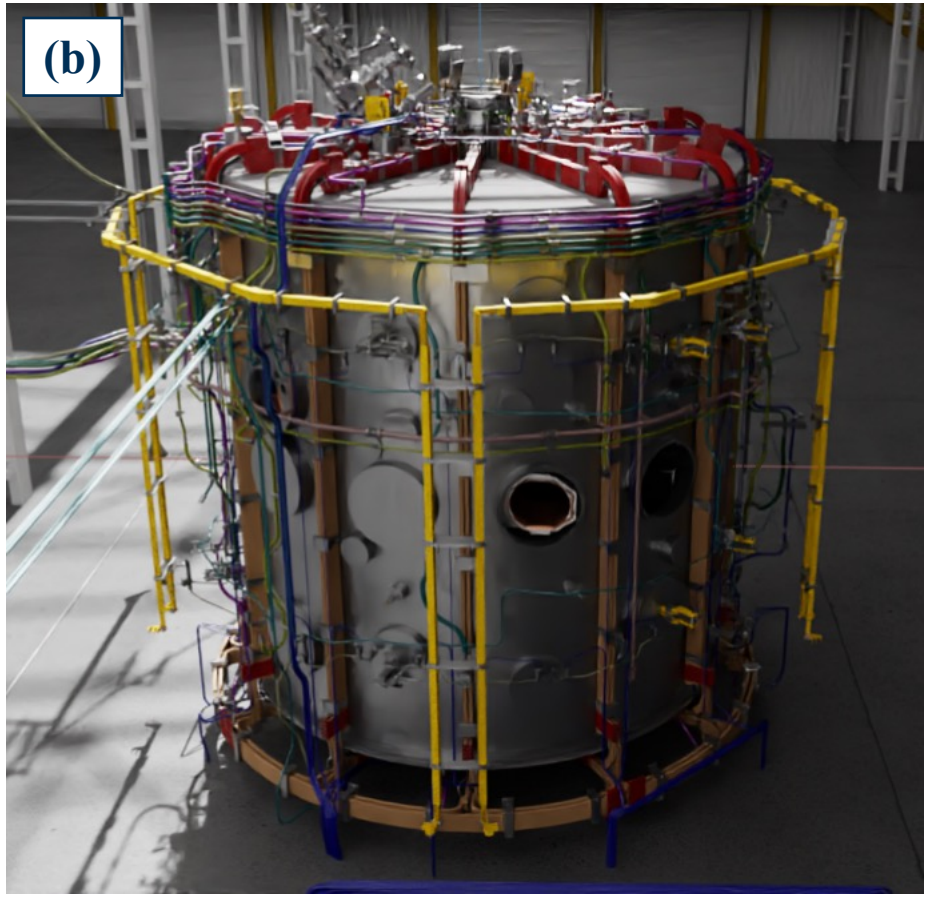
Use-Case: Collaboration & Co-creation using Omniverse

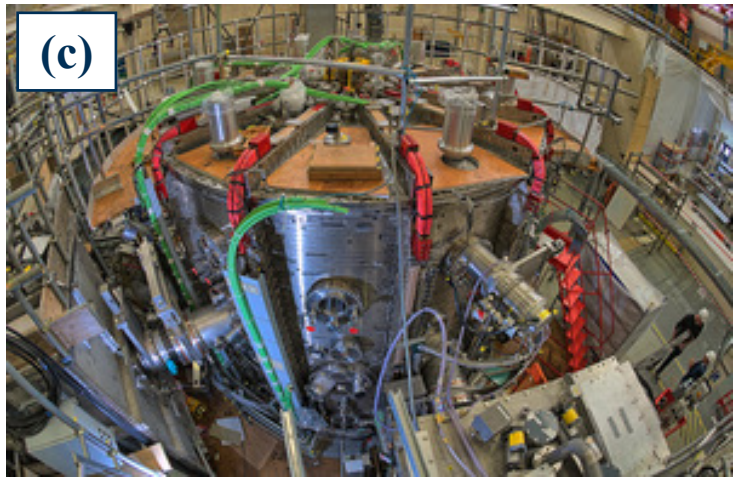


Material Mapping and Engineering Models

UK Atomic Energy Authority







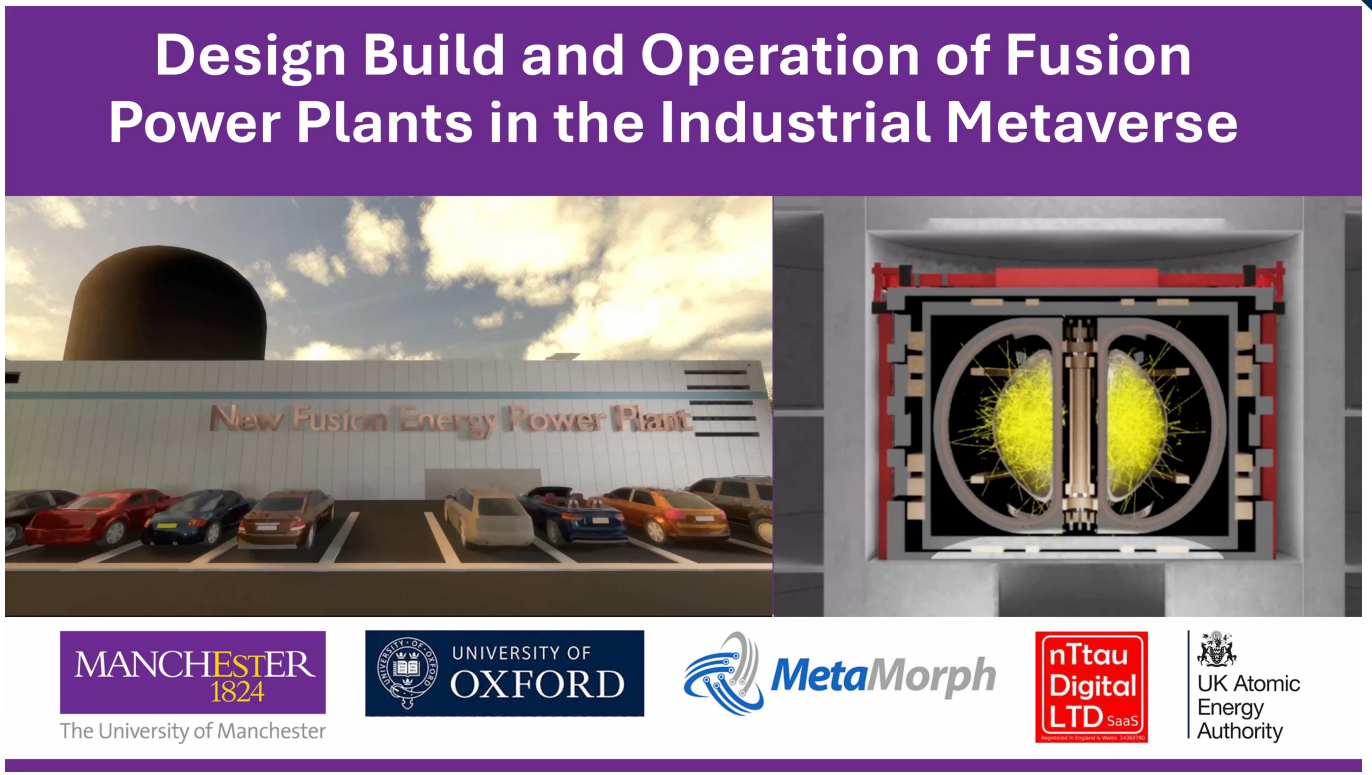
(a,b) Photorealistic rendering of MAST-U CAD Model using Nvidia Omniverse. (c) Real MAST-U.

Source: MCFELab, Manchester

Use-case: MCFELab Omniverse App

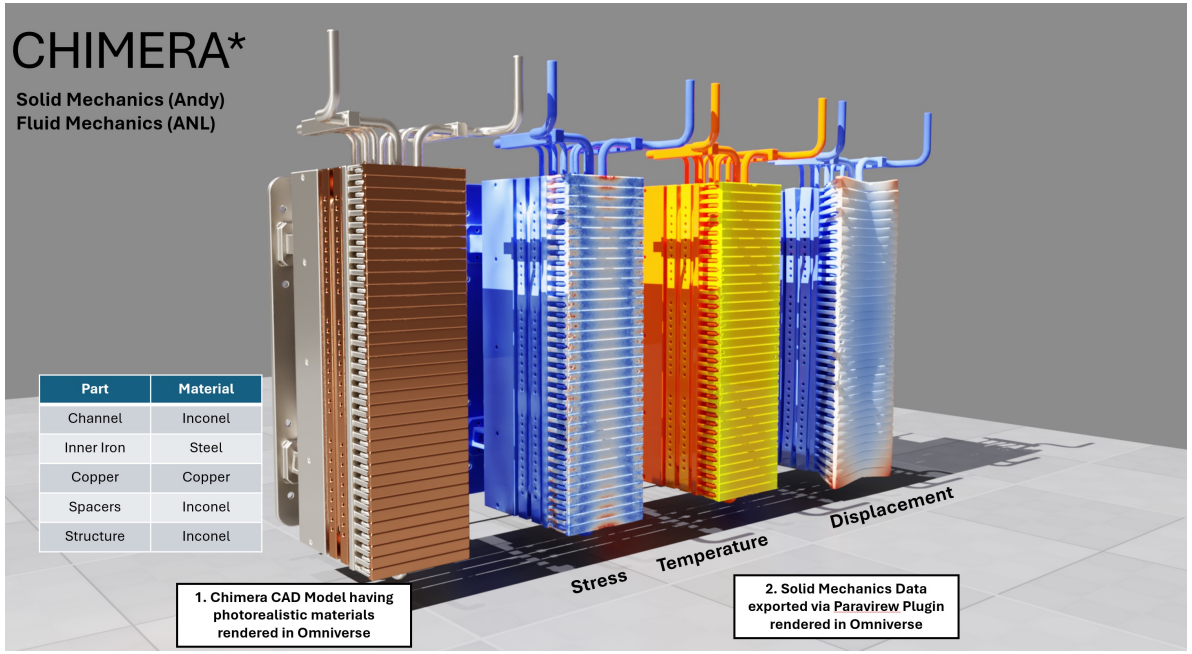
UK Atomic Energy Authority

- **Parameterised Simulations**: Run using AI/ML to select optimal geometries for high-performance computing (HPC).
- **Omniverse Workflows**: Utilize model-based systems engineering and FAIR automated workflows.
- **Provenance Data**: Captured from all tool interactions, building a comprehensive design knowledge base.
- **Fusion Power Plant Generation**: Parameters from simulations generate the entire plant, including all key structures and areas.
- **Automated Costing**: BIM models provide detailed cost estimates.



Source: MCFELab, Manchester

Macro & Micro scale Visualisation (Component Level)



CHIMERA Thermal Commissioning Sample Under Test (CSUT) showing Thermo-Mechanical behaviour

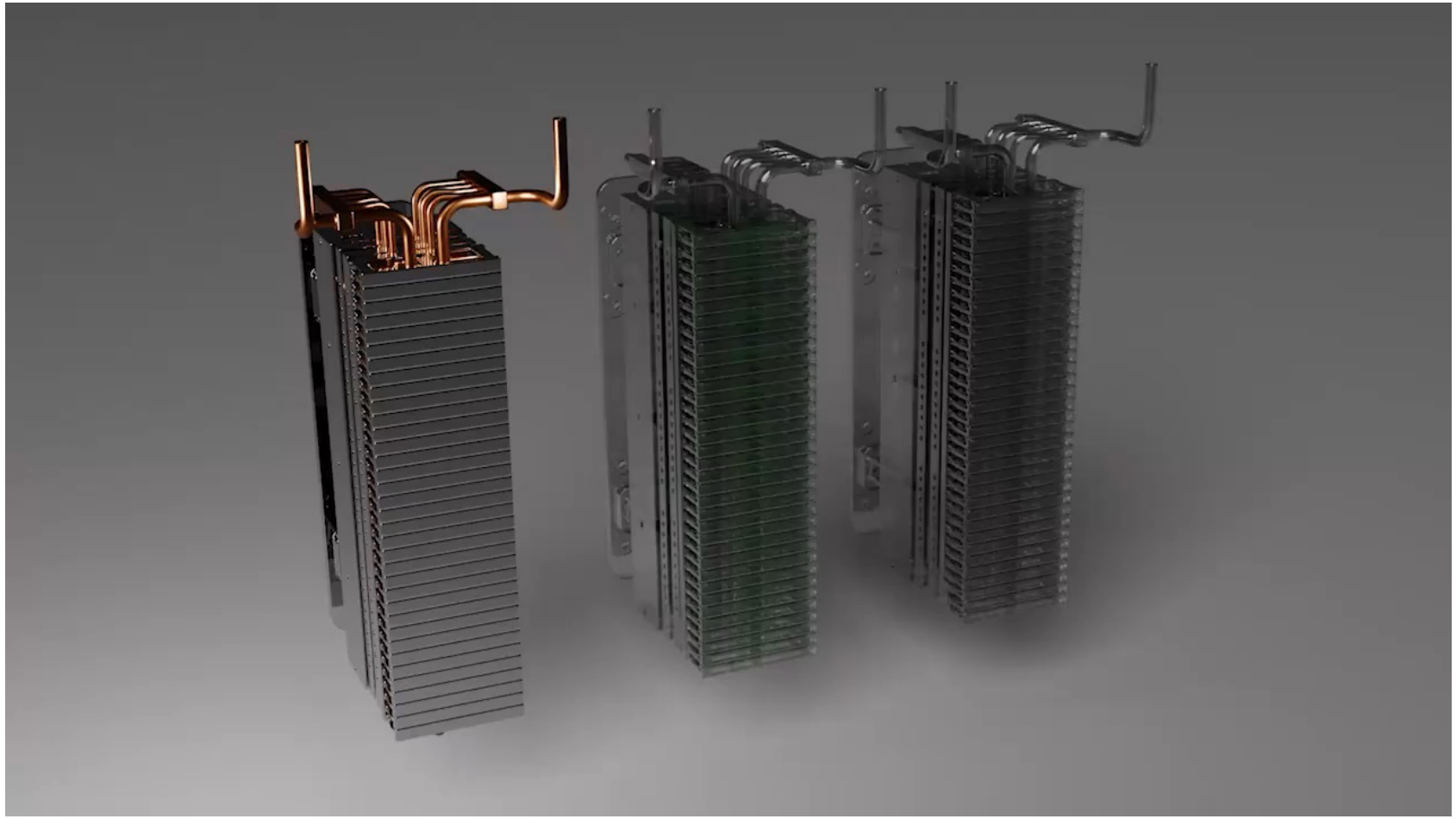
Visual Tools for Cross-Disciplinary Collaboration

- **Common Visual Language:** Enhances collaboration among experts in material science, physics, and engineering.

Understanding Material Properties:

- **Thermal Conductivity:** Simulations reveal heat transfer properties, essential for reactor integrity.
- **Radiation Damage:** Predicts material degradation under neutron radiation, aiding in the development of durable materials.
- **Mechanical Strength:** Evaluates material resilience to mechanical stresses in reactors.

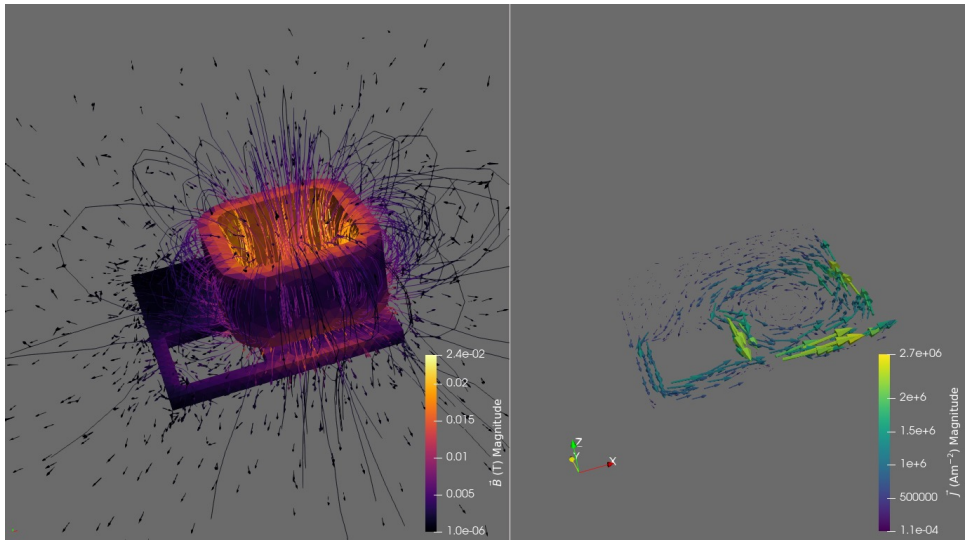
Use-Case: CHIMERA Thermal Commissioning Sample Under Test (CSUT) showing Thermo-Mechanical behaviour



Macro & Micro scale Visualisation (Component Level)

UK Atomic Energy Authority

Use-Cases based on type of Data



TEAM Problem 7 Benchmark: Magnetic field around a racetrack coil carrying a time-harmonic source current of 2742Amp turns oscillating at 200 Hz, above an asymmetric conducting plate of conductivity 3.526 x 10^7 S/m.
Note: TEAM is an acronym for Testing Electromagnetic Analysis Method

(Data from Alex Blair Simulations)

Vector Visualisation:

- **Purpose**: Represents directional data
- **Applications**: Current flow, Magnetic fields, Fluid flow
- **Methods:** Streamlines, Path-lines, Vector fields

Scalar Visualisation:

- **Purpose:** Depicts magnitude-based data
- **Applications:** Temperature, radiation intensity
- **Methods:** Volume Rendering, ISO-Surfaces, Clipped Planes

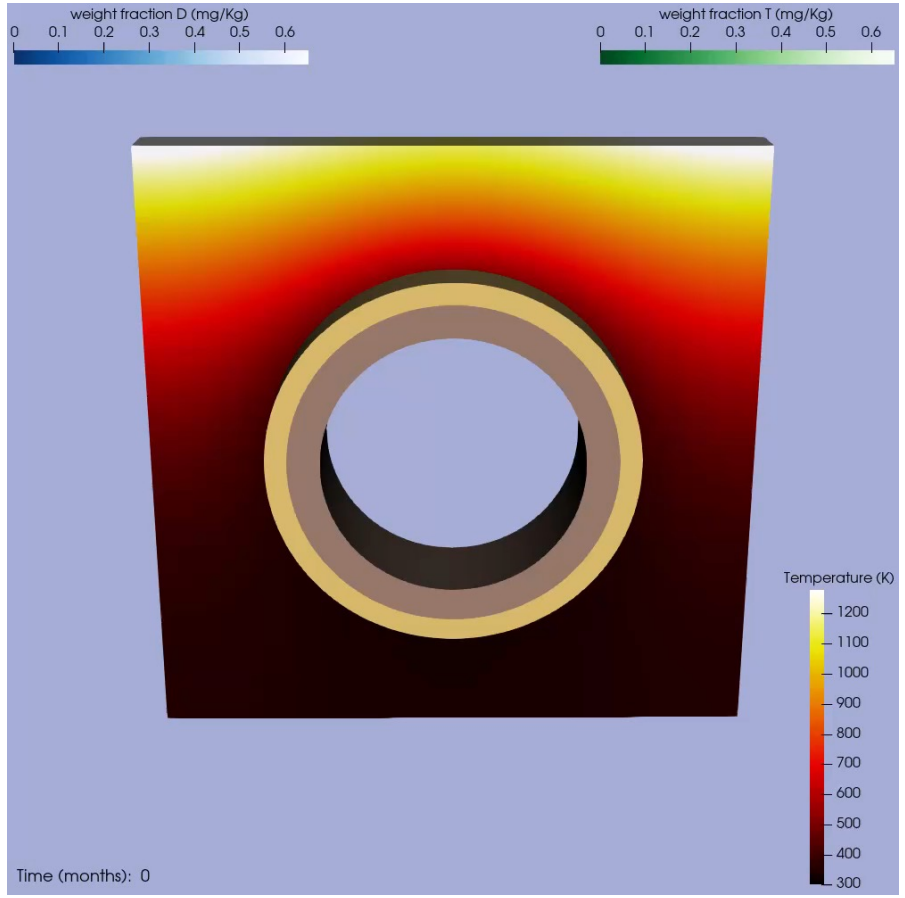
Surface Visualisation:

- **Purpose:** Illustrates surfaces under stress, heat or displacement.
- **Applications:** Material interfaces, stress analysis
- **Methods:** Surface Rendering, Material-Mapped Photorealistic Rendering

Macro & Micro scale Visualisation (Component Level)

UK Atomic Energy Authority

Use-Cases based on type of Data



Deuterium & Tritium retention in divertor block
(Data from Daniel Mason, Stephen Dixon simulations)

Vector Visualisation:

- **Purpose**: Represents directional data
- **Applications**: Heat flow, Magnetic and Electric fields, Fluid flow
- **Methods:** Streamlines, Path-lines, Vector fields

Scalar Visualisation:

- **Purpose:** Depicts magnitude-based data
- **Applications:** Temperature, radiation intensity
- **Methods:** Volume Rendering, ISO-Surfaces, Clipped Planes

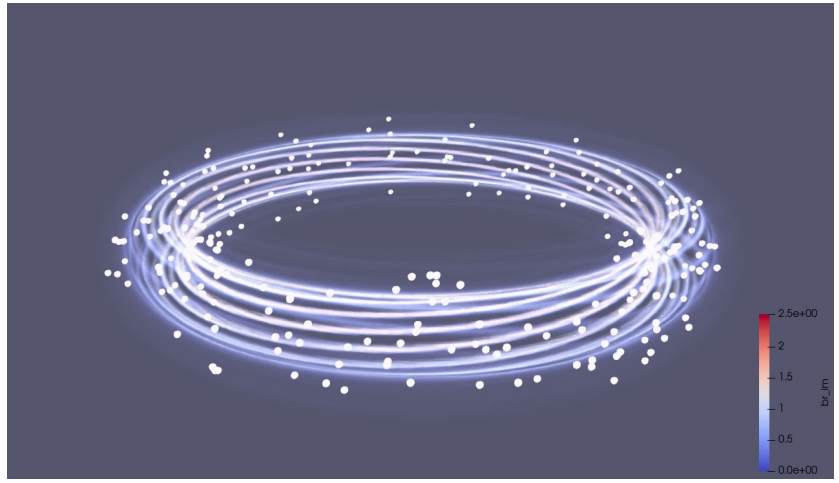
Surface Visualisation:

- **Purpose:** Illustrates surfaces under stress, heat or displacement.
- **Applications:** Material interfaces, stress analysis, molecular
- **Methods:** Surface Rendering, Material-Mapped Photorealistic Rendering

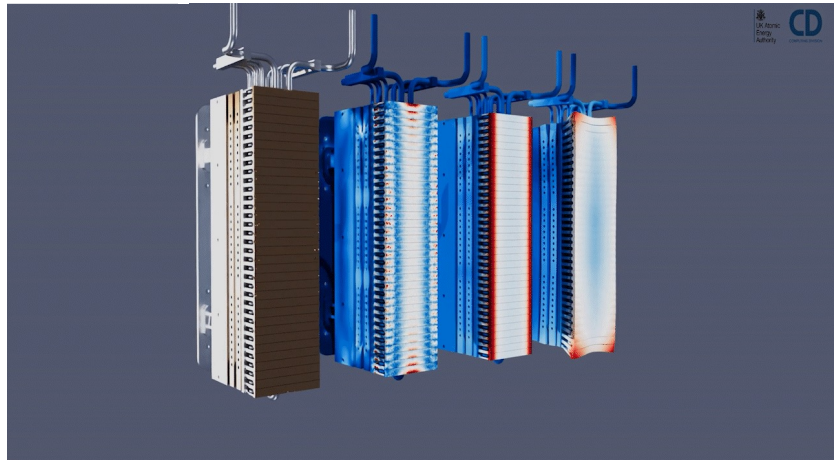
Macro & Micro scale Visualisation (Component Level)

UK Atomic Energy Authority

Use-Cases based on type of Data



Energetic ion trajectories in a global mode using new fast particle modelling tools (Data from William Hornsby simulations)



Thermo-mechanical results on CHIMERA Thermal CSUT (Data from Andy Davis simulations)

Vector Visualisation:

- **Purpose**: Represents directional data
- **Applications**: Heat flow, Magnetic and Electric fields, Fluid flow
- **Methods:** Streamlines, Path-lines, Vector fields

Scalar Visualisation:

- **Purpose:** Depicts magnitude-based data
- **Applications:** Temperature, radiation intensity
- **Methods:** Volume Rendering, ISO-Surfaces, Clipped Planes

Surface Visualisation:

- **Purpose:** Illustrates surfaces under stress, heat or displacement.
- **Applications:** Material interfaces, stress analysis, molecular
- **Methods:** Surface Rendering, Material-Mapped Photorealistic Rendering

Use-case: First Wall Armour Materials

UK Atomic Energy Authority

Advanced Visualisation

Overview:

- The irradiation damage process in metals is simulated with massively parallel Molecular Dynamics simulations using LAMMPS.
- Stresses develop around lattice defects leading to plastic deformation and swelling.
- The defects can be directly observed in the transmission electron microscope.

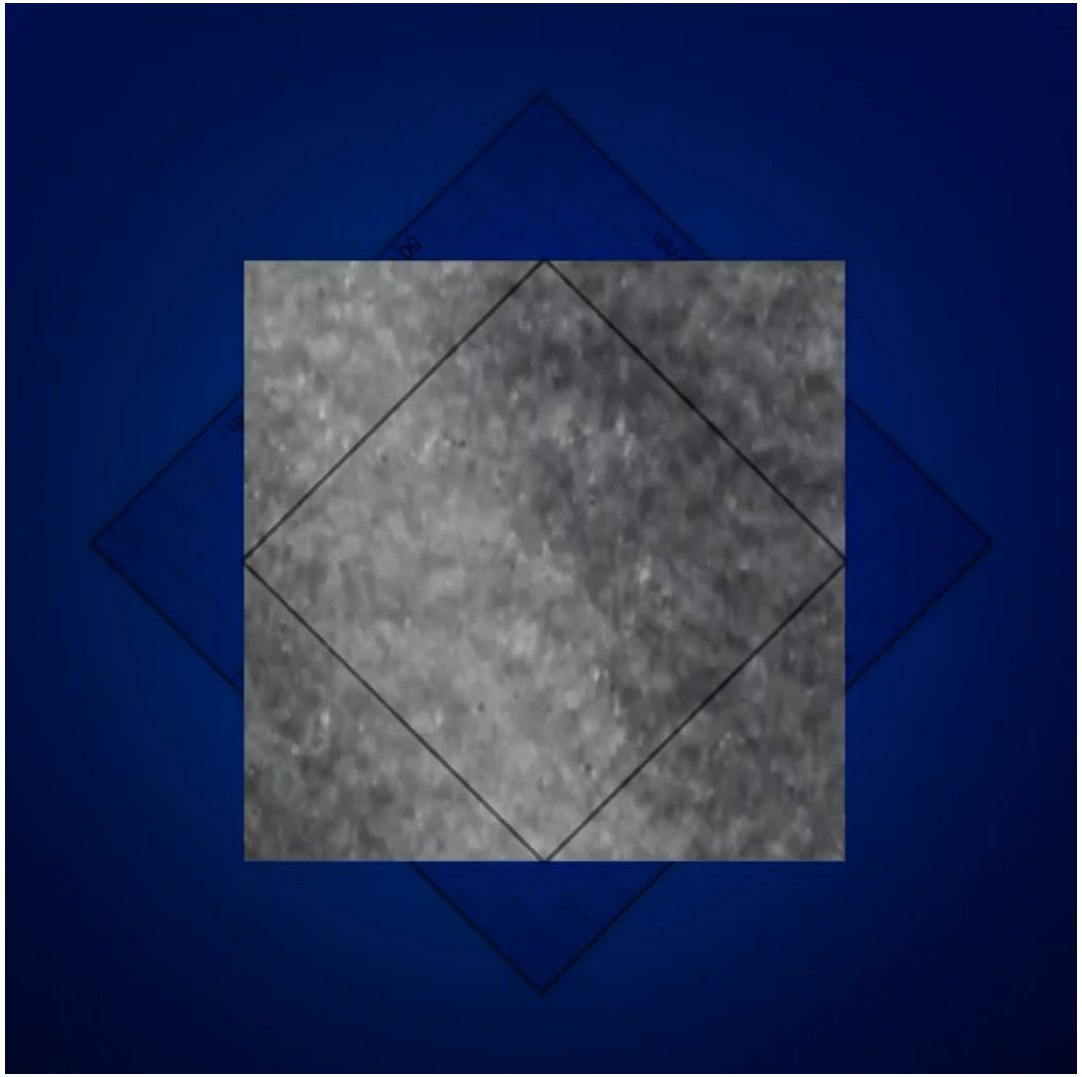
Visualisation:

A box of 21M tungsten atoms

- At 1 dpa (displacements per atom) simulated irradiation
- 3D Emissive Volume Render: Data of the accumulating von Mises stress
- 2D Image on top: Simulated weak-beam dark-field Transmission Electron Microscopy (TEM) data

Tools:

- Paraview 5.11, Blender 3.5 on Cambridge HPC (CSD3)



(Data from Daniel Mason, Max Boleininger simulations)

Mason et al (2024) arXiv:2401.14781
Mason et al (2021) Phys Rev Mater 5:095403
Boleininger et al (2022) Phys Rev Mater 6:063601

Leveraging GPUs & SLURM Jobs

UK Atomic Energy Authority

Utilising of GPUs for rendering large-scale visualisations using HPC

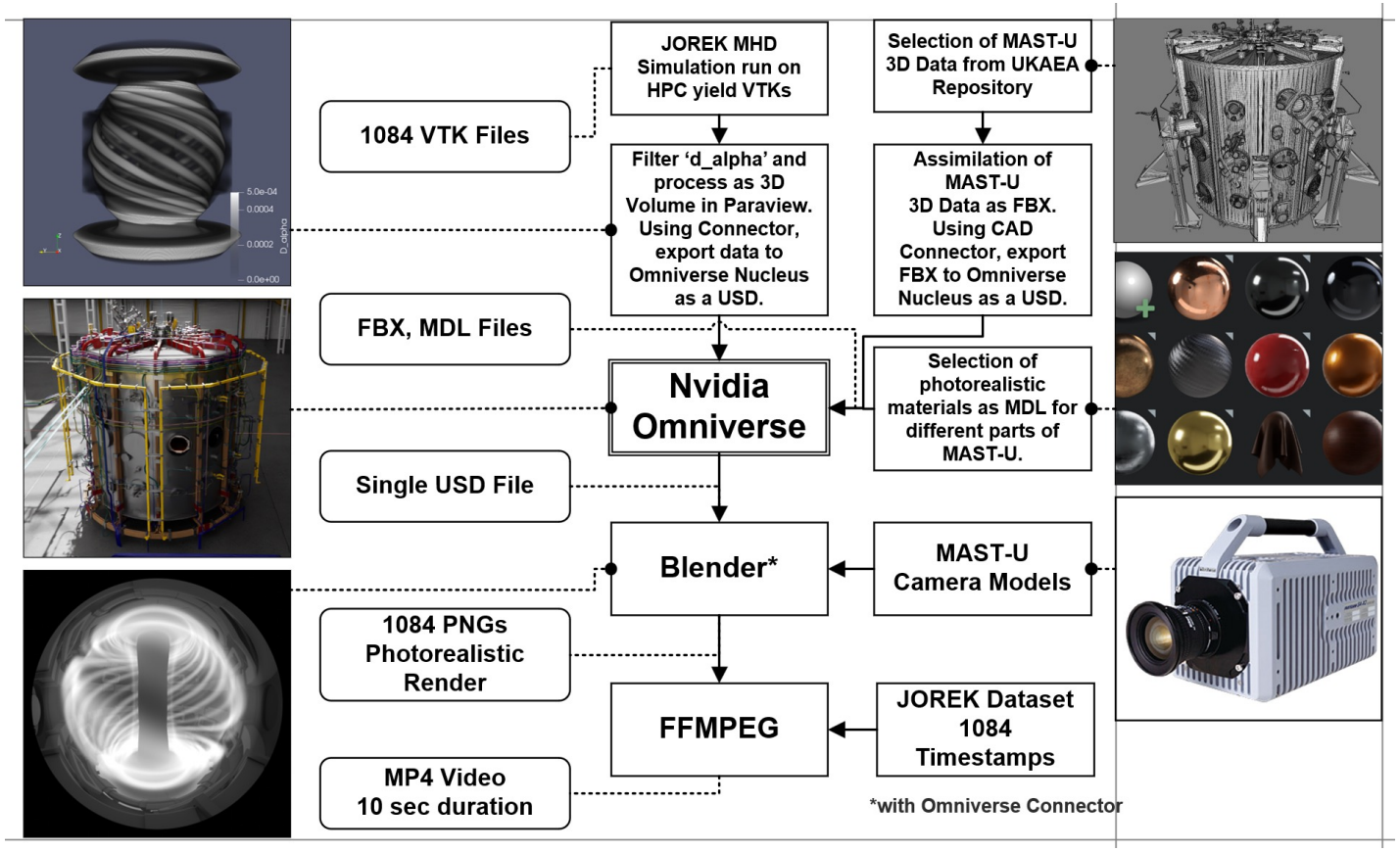
Running visualisations using SLURM jobs

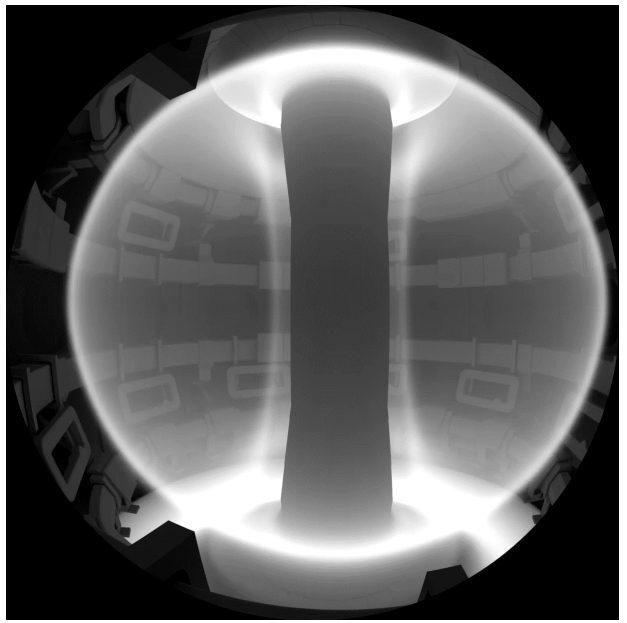
Use Case: Camera correct visualisation of simulated Plasma in Fusion Reactor

SLURM JOB 01

SLURM JOB 02

SLURM JOB 03





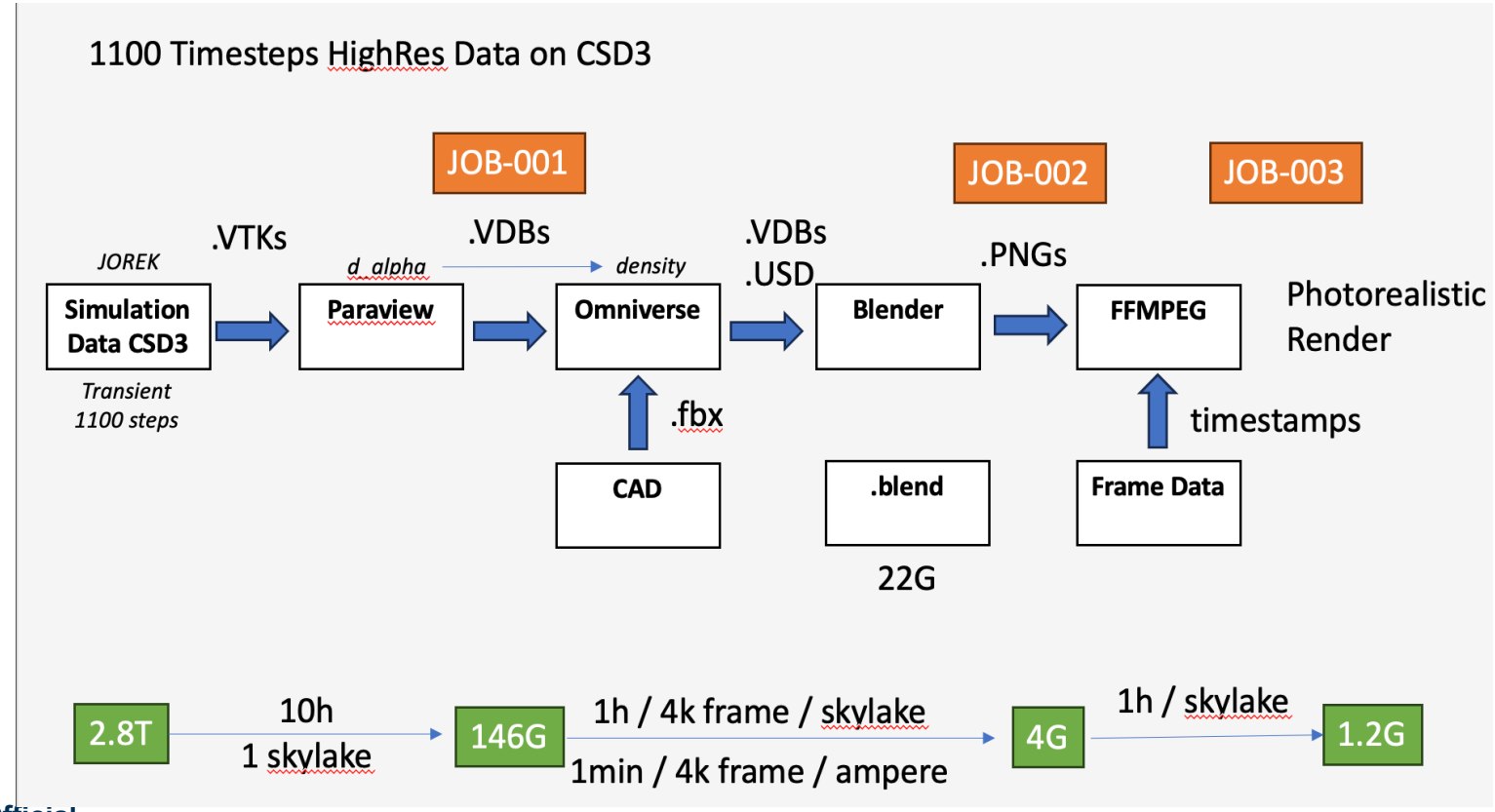
Leveraging GPUs & SLURM Jobs

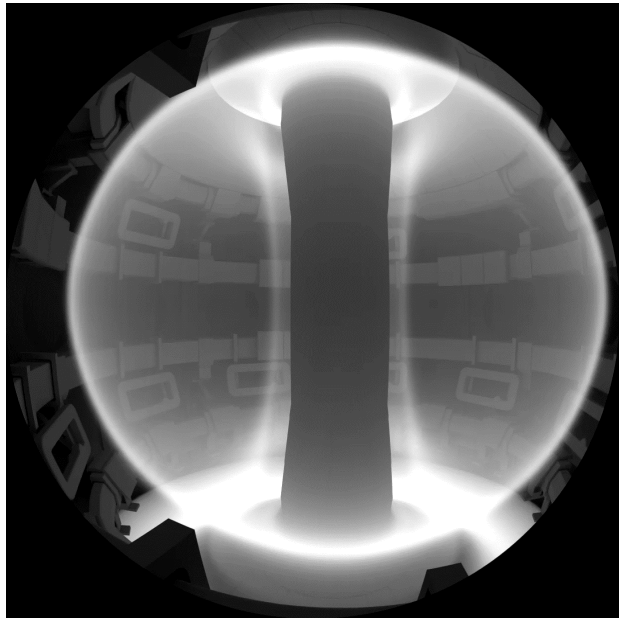
UK Atomic Energy Authority

Utilising of GPUs for rendering large-scale visualisations using HPC

Running visualisations using SLURM jobs

Use Case: Camera correct visualisation of simulated Plasma in Fusion Reactor





Visualising Fusion Data using AR/VR

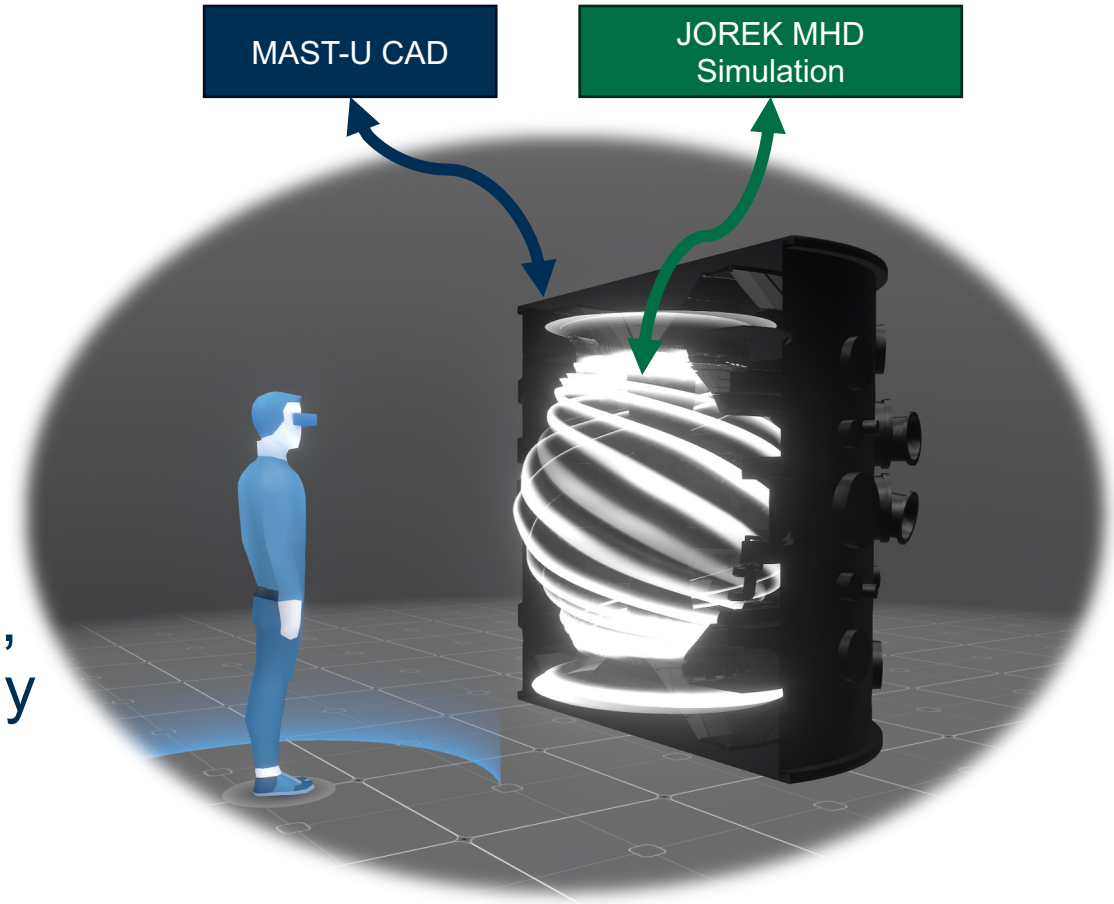
UK Atomic Energy Authority

Simplified, visually appealing representations of complex data and processes

Engineering Design Exploration & Collaboration

Enhance public understanding of fusion energy, fostering greater support for funding and development

Promote community involvement and awareness, emphasizing the societal benefits of fusion energy research



AR / VR Data Exploration App

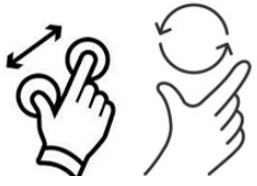
Use-Case AR App

- WebXR for AR and VR
- Users can interact with 3D model of MAST-U fusion reactor, exploring components and processes in a hands-on manner.
- Web based apps can reach a wide audience, providing an accessible means to explore fusion research.
- AR/VR content can be updated in real-time, reflecting the latest advancements and discoveries in fusion research.

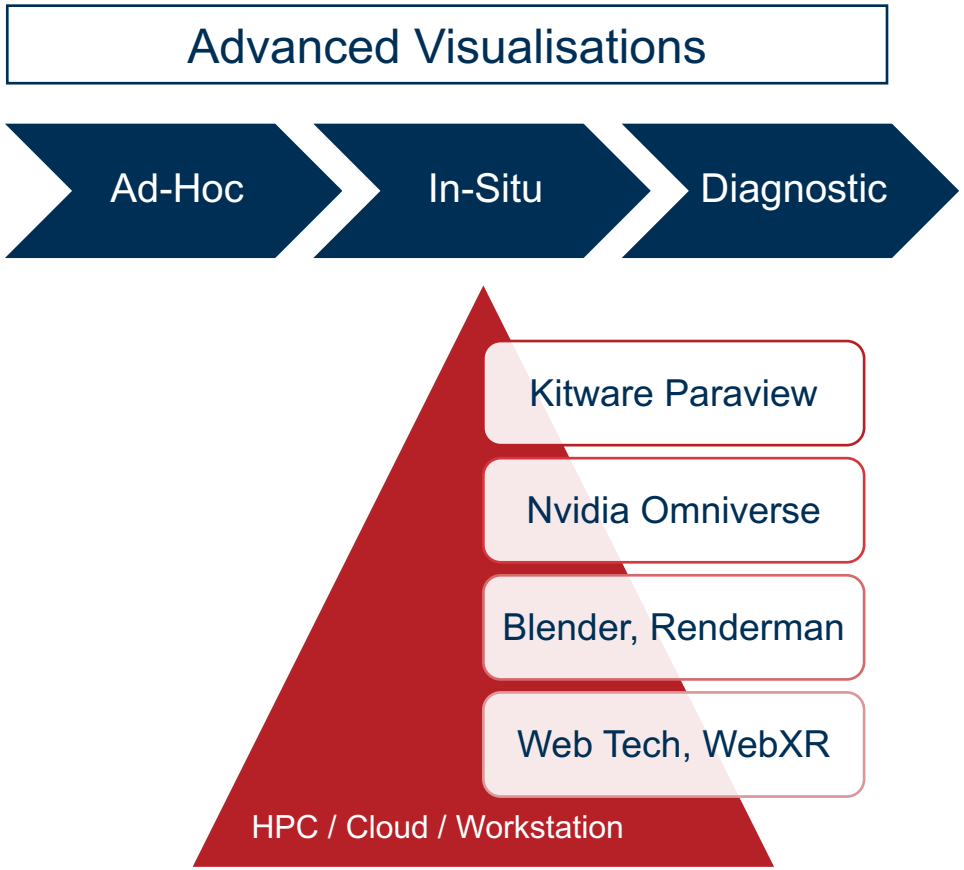
https://niteshbhatia008.github.io/ukaea

2. Press View in AR button.

3. Scan any flat surface like a floor. The model will automatically load in AR.
Touch the screen with Two-fingers pinch to change the size and turn to rotate the model.



Conclusions



- Predictive Simulations
- Complex Data Explorations
- Communication
- Validations
- Improving outcomes in engineering design & operation
- ML Modeling & Inferencing

Thank you - Q&A

UK Atomic Energy Authority

Nitesh.Bhatia@ukaea.uk

/niteshbhatia

/niteshbhatia