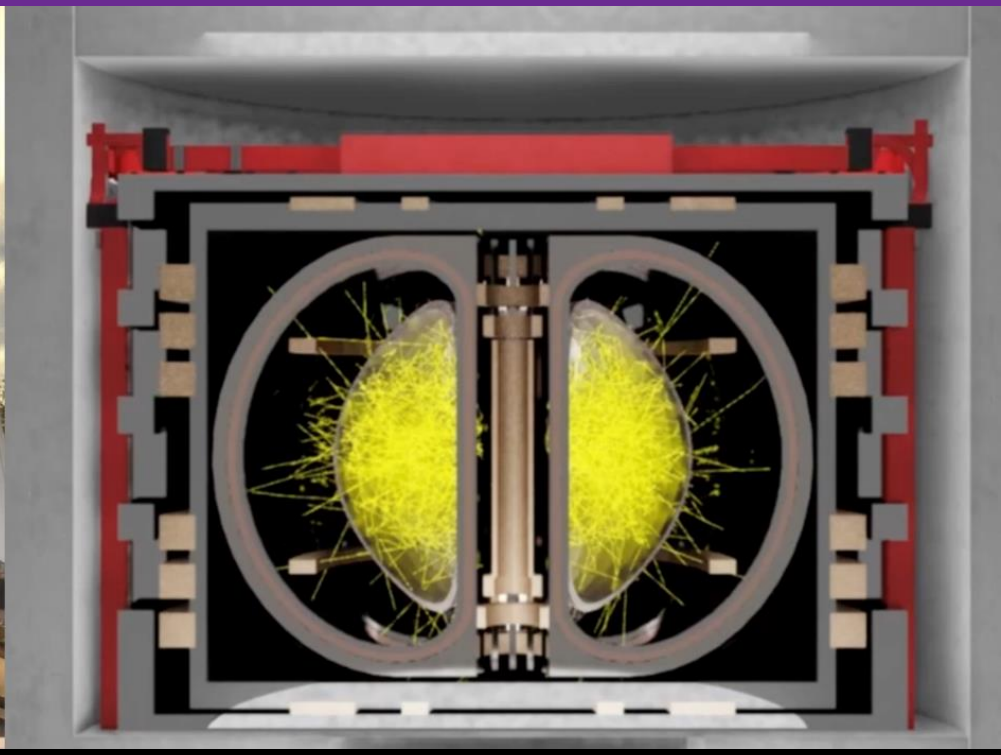
Re-engineering Engineering

Transforming a Digitally Enabled Craft Industry With AI/ML



Lee Margetts[1,2], Rob Akers[2], Ted Bapty[4], Adam Barker[1], Helder Castro[2], Fazal Choudry[2], Philip Edmondson[1], Yat Leung[1], Jinjiang Li[1], Dominic Longhorn[3], Douglas Lowe[1], Zeyuan Miao[1], Muhammad Omer[3], Matthew Roy[1,6], Sophie Sharpe[3], William Smith[1], Raska Soemantoro[1], Paul Watry[5], Tom Wilson[1], Simon Woodruff[3], Oliver Woolland[1] and Hujun Yin[1]

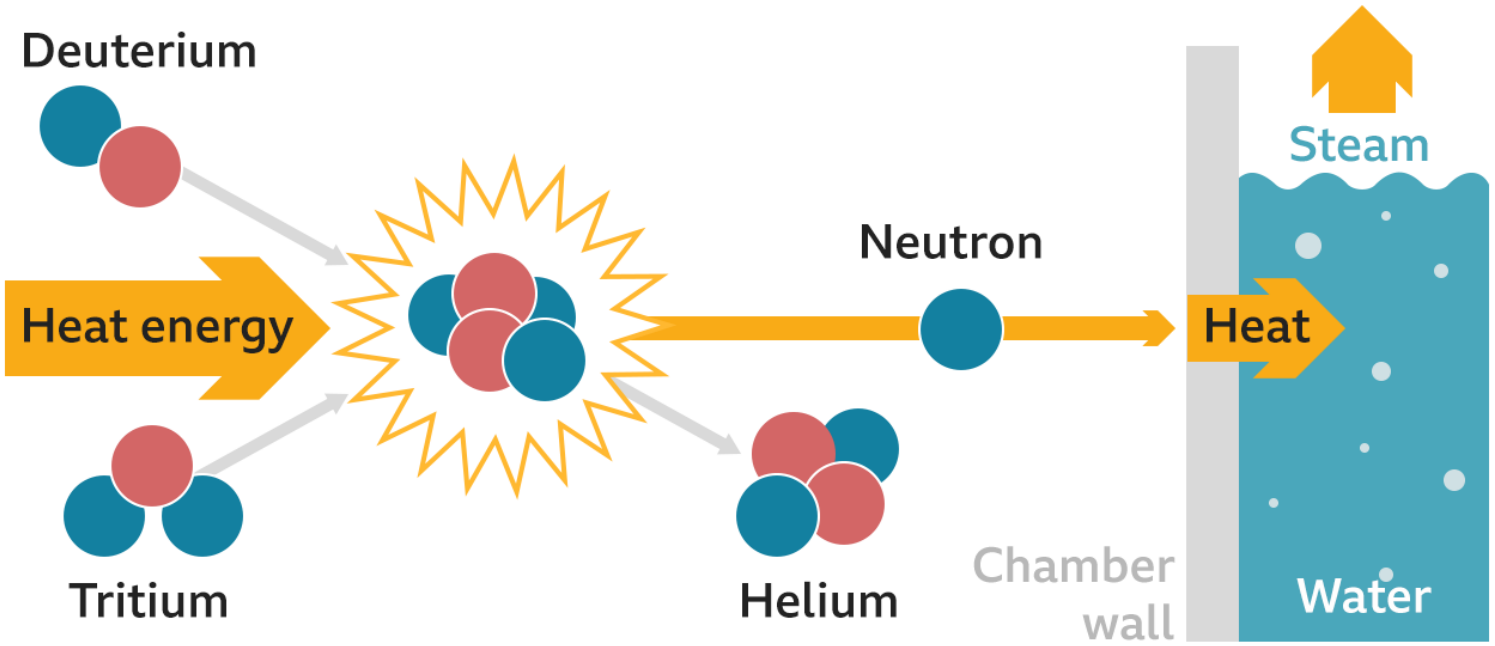
[1]University of Manchester, [2]UKAEA, [3]nTtau Digital Ltd, [4]Metamorph Inc, [5]University of Oxford, [6]Henry Royce Institute

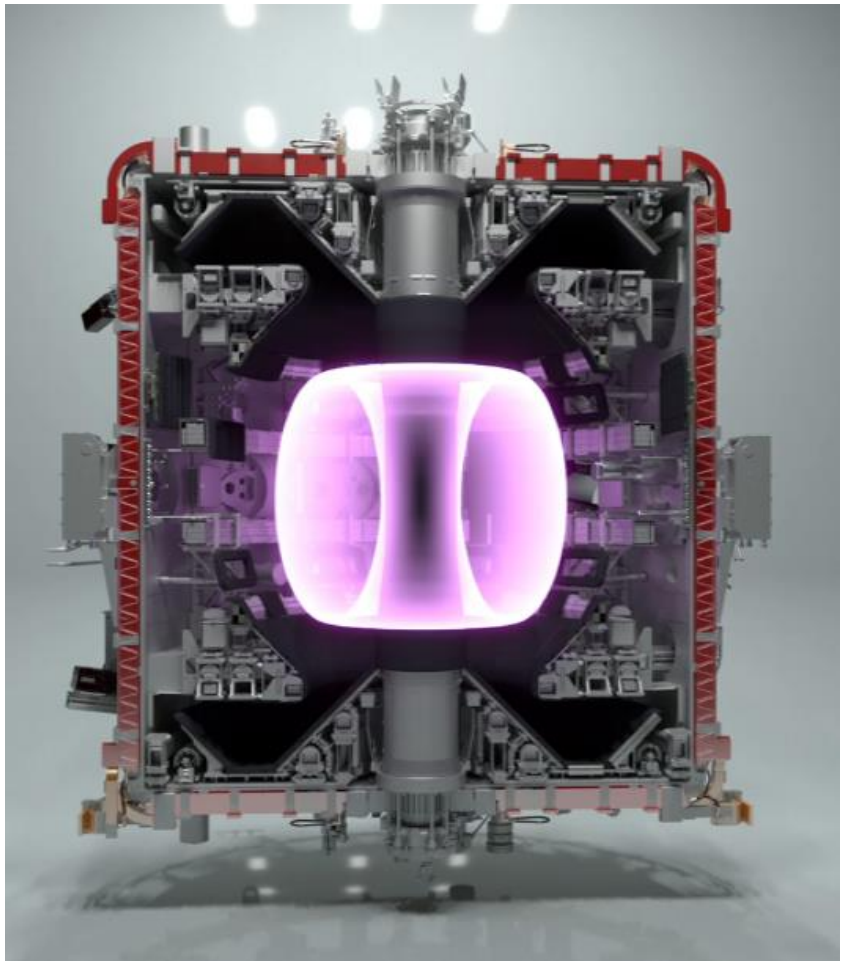
Presentation Overview

- Fusion in a bottle
- Engineering as a digitally enabled craft industry that inhibits automation AI/ML outside of silos
- UKAEA SBRI Fusion Industry Programme competition requirements
- UKAEA funding and project delivery team from April 2023 to March 2024
- Building an integrated engineering software framework that enables high performance AI/ML
- Summary demonstration with automated power plant construction

How Fusion Works

1	2	3	4
Hydrogen atoms are heated	Fusion reaction	Helium, neutron and energy released	Neutron energy heats water





Engineering Pioneers

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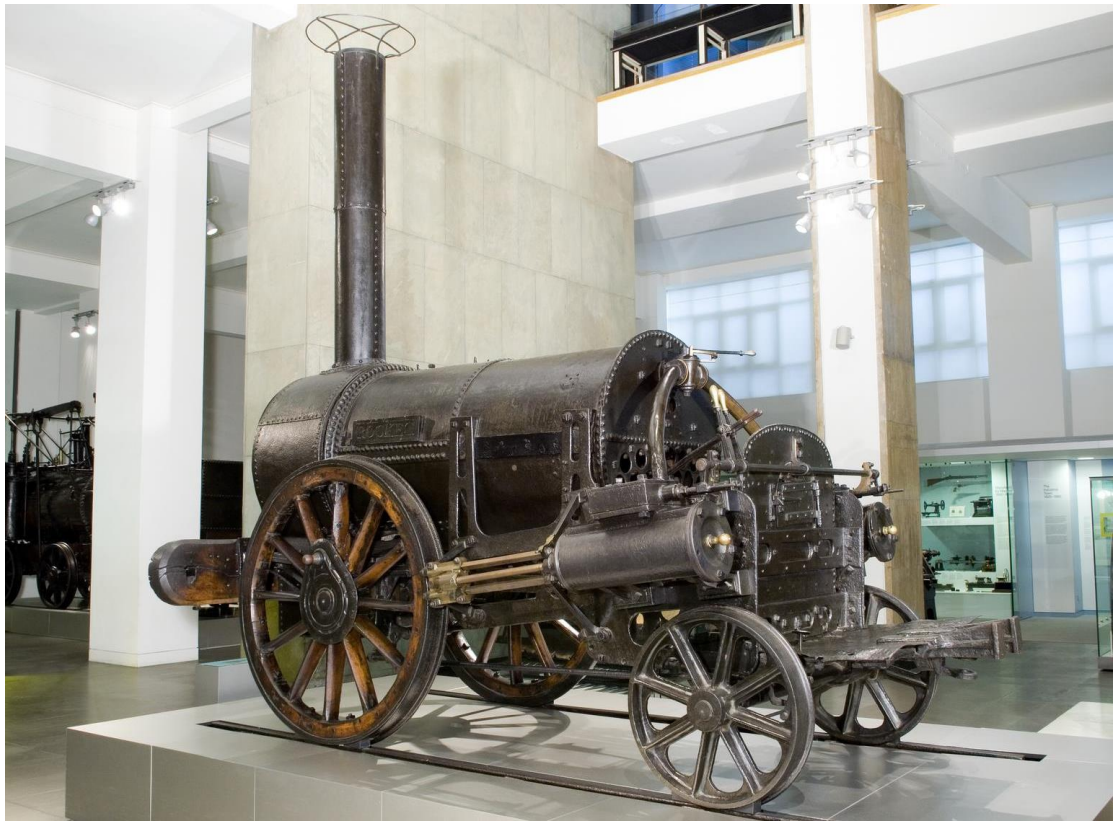
Stephenson's Rocket



Winner of trials held at Rainhill in 1829 to decide the motive power for the Liverpool & Manchester Railway.

Musk's Rocket

Depending on who you ask, the SpaceX launch was either a roaring success or an unmitigated disaster.

A 19th century approach "The Observational Method" is still applied in the 21st century

The Underlying Science

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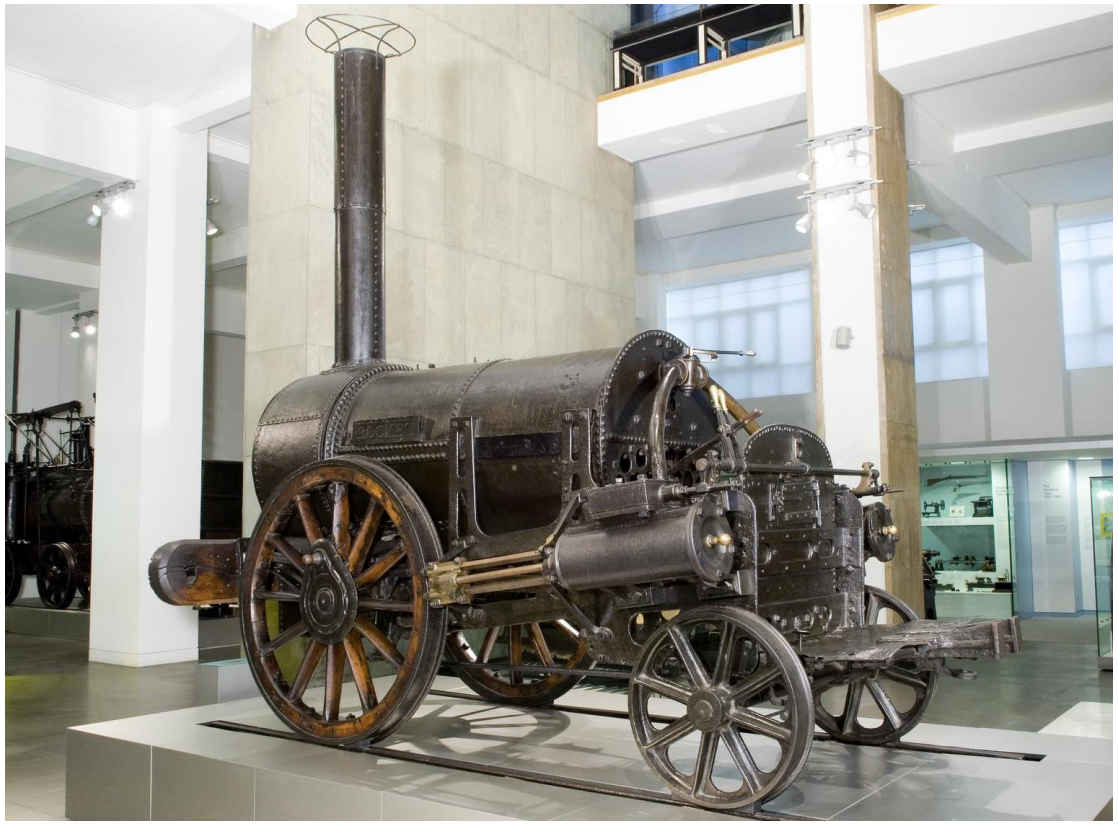
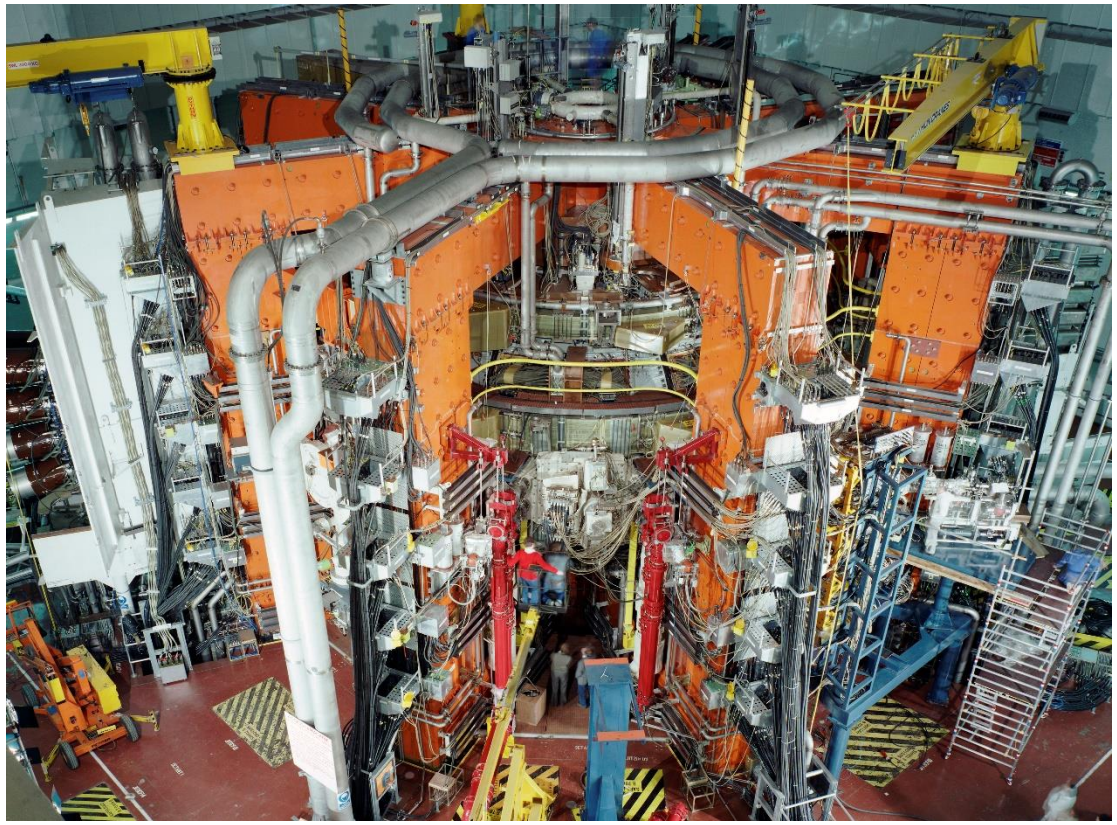
Stephenson's Rocket



The first and second laws of thermodynamics were established in 1860, thirty years after Rocket was built.

Fusion Power Plant



Many areas of science still need refining. There is epistemic uncertainty in many of the systems.

Engineers can get machines working despite a lack of formal knowledge of the science

Digitally Enabled Craft Industry

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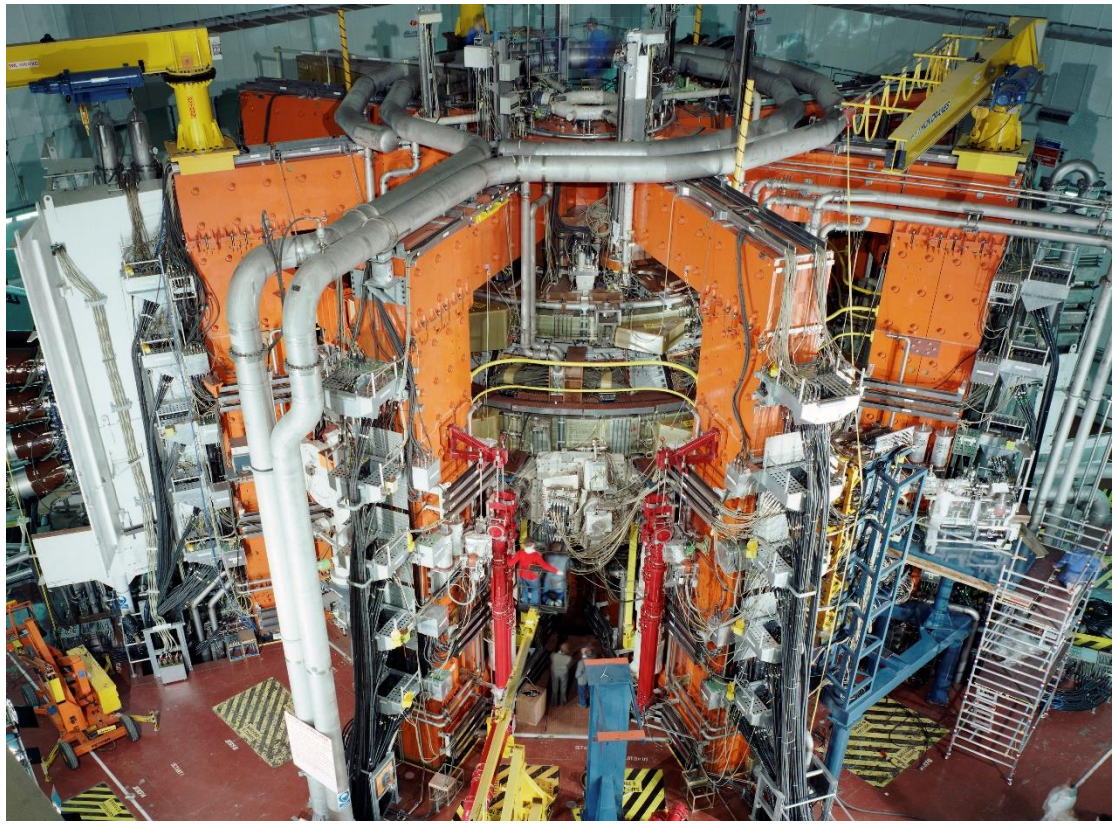
GCAP

Collaboration between UK, Italy and Japan to build a advanced jet fighter in half the time at half the cost.

Fusion Power Plant



The European Technology Platform for Power Station Suppliers has >100,000 members, using **different tools**.

Know-how exists in silos, creating barriers to automation and AI/ML in engineering

SBRI FIP Competition Objectives

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1.Accelerating fusion power plant design with next-generation digital tools

To meet Net Zero targets, there is not enough time for traditional Design-Build-Test-Learn (DBTL) approach for fusion power plants. Increasing emphasis will be placed upon emerging innovation from in silico engineering design:

✱**FIP** in slide titles
=> highlights competition objectives

Exascale artificial Intelligence era Digital Thread platform

- beyond current Product Lifecycle Management
- endures for the lifetime of the product (100 years)
- low-code
- time efficient
- scalable
- enable and promote automation
- enable design integration

Optimise the extraction of information and knowledge from experiment and simulation

- data science for experiment and simulation automation and optimisation
- decisions based upon all prior data rather than tacit knowledge
- dramatically improve extraction of information from data
- surrogate models and emulators
- improve extrapolation of simulation and empirical data

Project Delivery Team

Project Lead

Prof Lee Margetts

Prof Hujun Yin

Prof Philip Edmondson
- ✓ UKAEA Chair in Tritium Engineering

Dr Matthew Roy (Royce)
- ✓ Senior Lecturer Materials for Demanding Environments

Subcontractors

University of Oxford

Professor Paul Watry
Professor David De Roure
Professor Chris Grosvenor

digiLab

Prof Tim Dodwell
- ✓ Uncertainty Quantification
- ✓ Machine Learning
- ✓ Large Language Models

nTtau Digital LTD

Dr Simon Woodruff
- ✓ PhD in Plasma Physics
- ✓ Fusion Industry Leader
- ✓ Entrepreneur for 20+ years

MetaMorph

Vanderbilt University

Professor Ted Bapty
- ✓ META Software
- ✓ Technical Support
- ✓ Advisory Committee

Budget

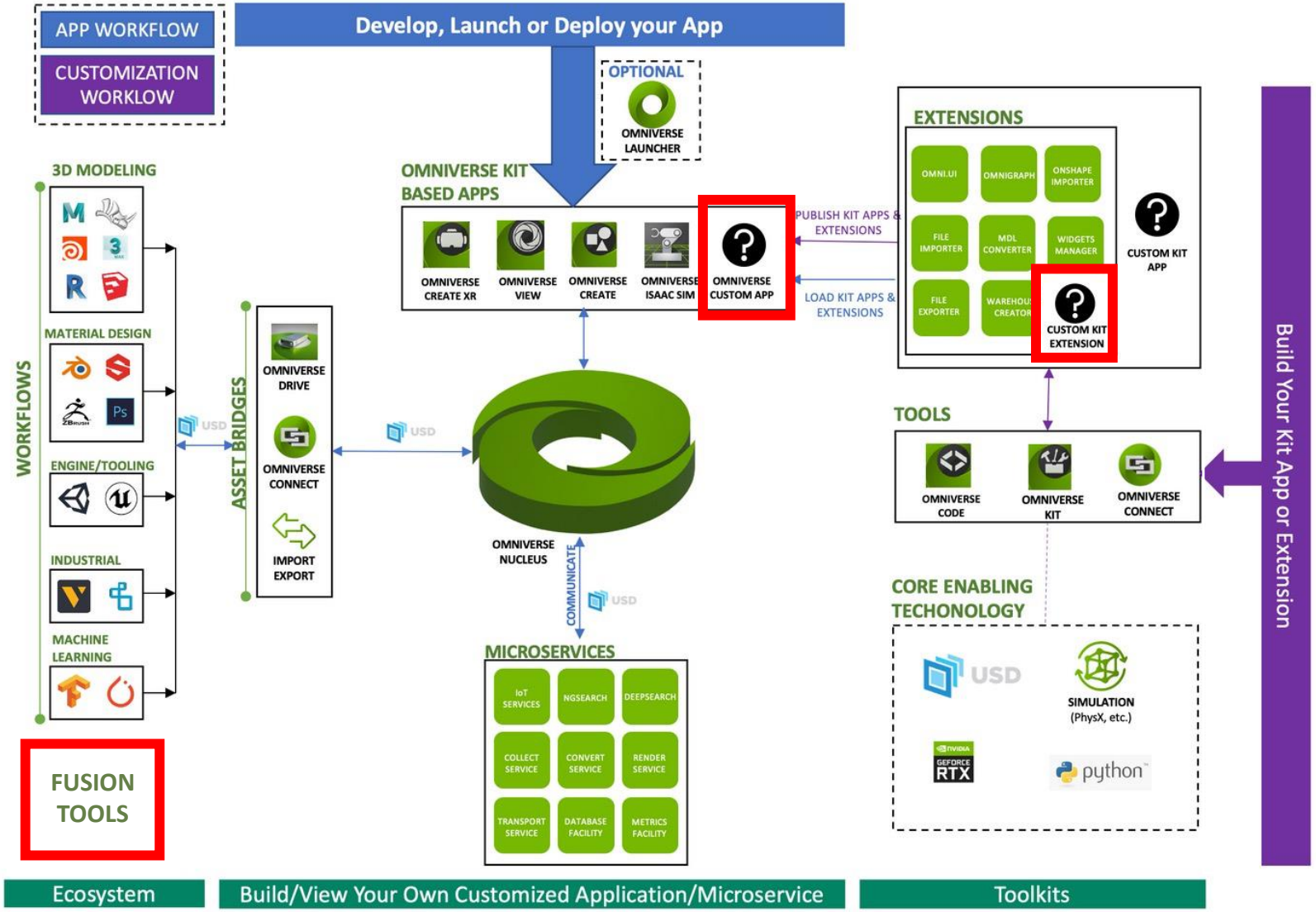
£1M
Phase 2 Award
April 2023 to March 2024

Applied for £2M Uplift
April 2024 to March 2025

£1M
Maintain Existing Team

£1M
Add Value & Extend Team
- ✓ Henry Royce Institute
- ✓ Metamorph Inc
- ✓ DigiLab Ltd

Low Code & Scalable*FIP



- ✓ ACCELERATE COMPUTE-INTENSIVE ML MODELLING AND INFERENCING JOBS
- ✓ STREAMLINE DELIVERY OF INTELLIGENT APPLICATIONS
- ✓ EASE OF DEPLOYMENT – LEVERAGE NVIDIA INDUSTRIAL METAVERSE SOLUTION
- ✓ DEPLOY AND MANAGE AI WORKLOADS IN CONTAINERS OR VMs WITH OPTIMISED SOFTWARE STACK

Time Efficient*FIP

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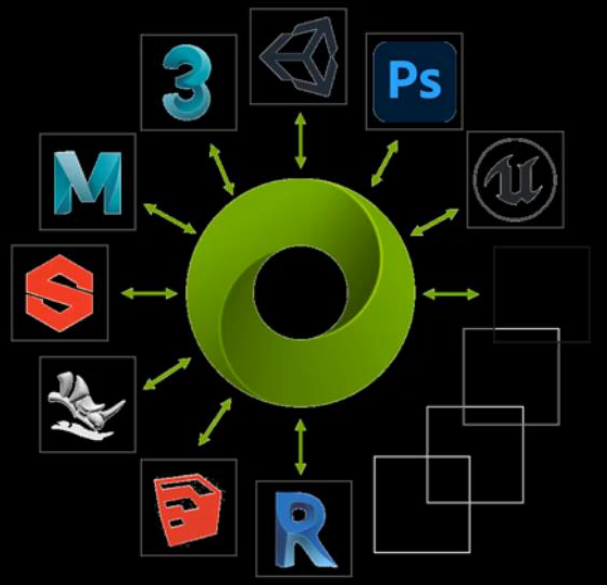
Design And Visualisation of Fusion Reactors Using
Nvidia Omniverse Enterprise – For Global Teams

- Multi-User Collaboration
- One-Way And Two-Way Connectors
- Real-Time Interaction
- Photo-Realistic Rendering
- Version Control



NVIDIA

Enable Design Integration*FIP

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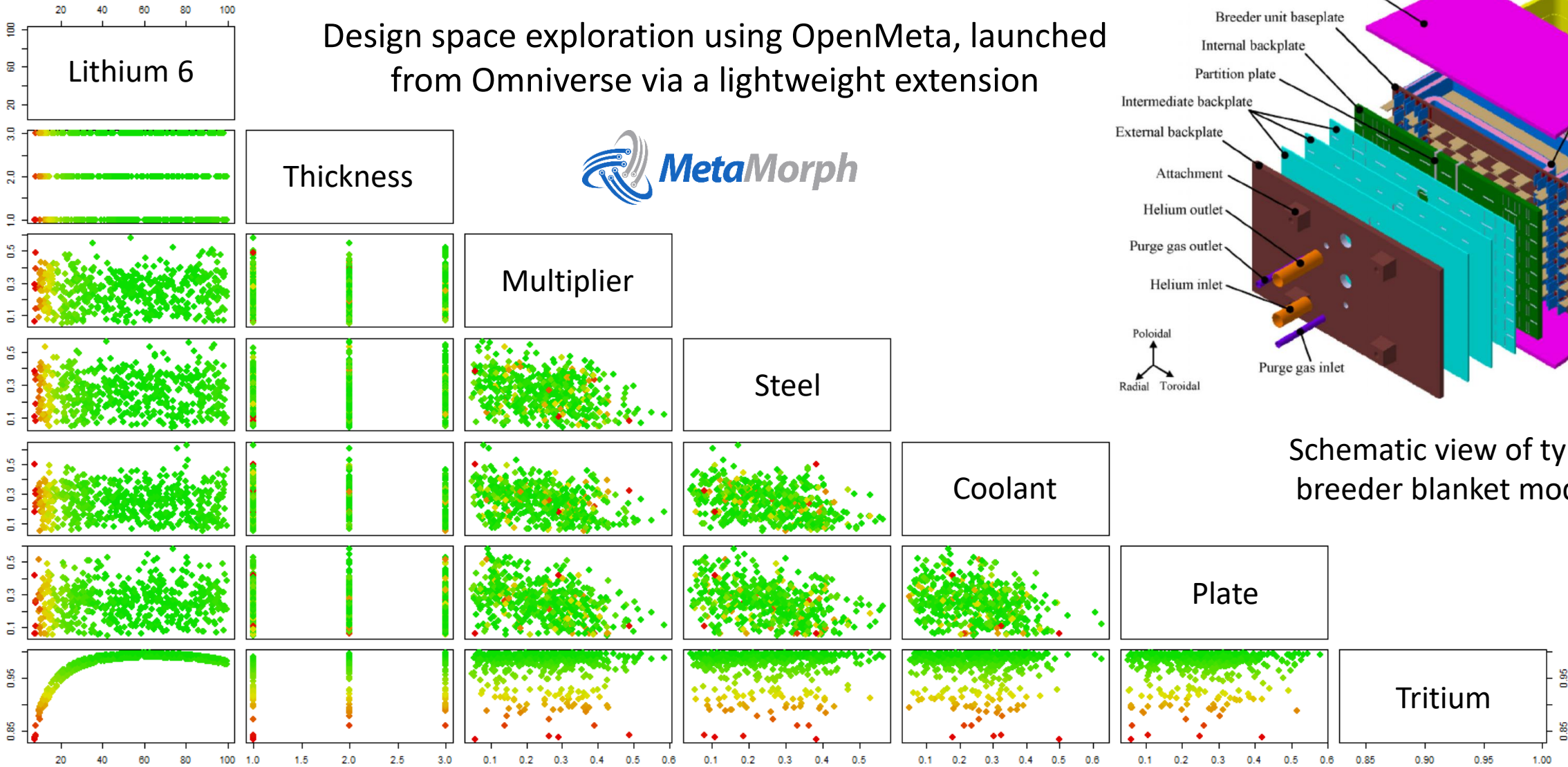
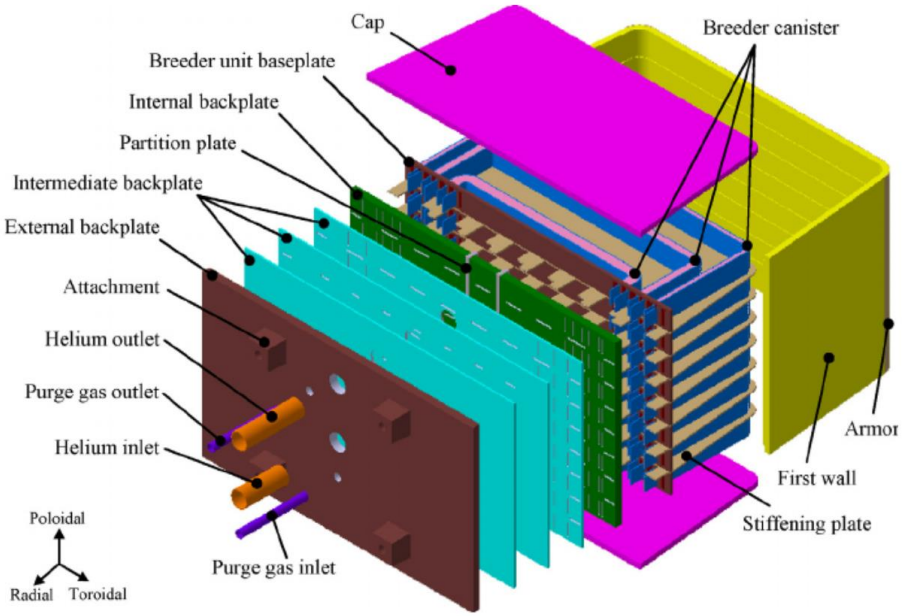
Design space exploration using OpenMeta, launched from Omniverse via a lightweight extension

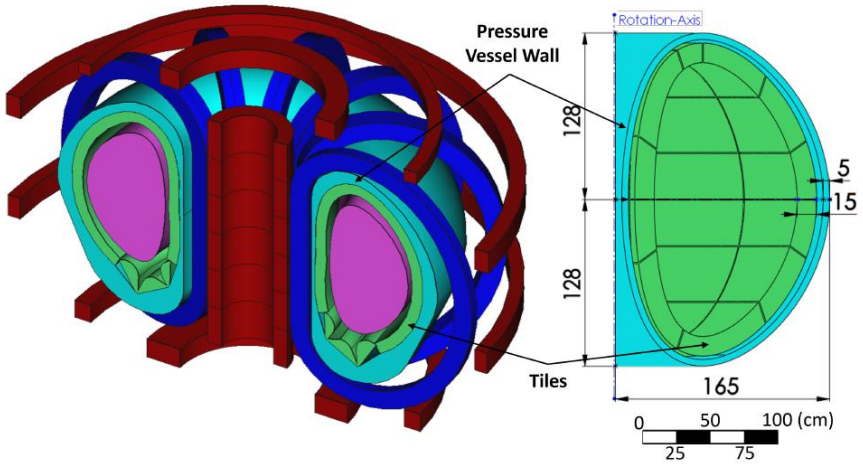
MetaMorph

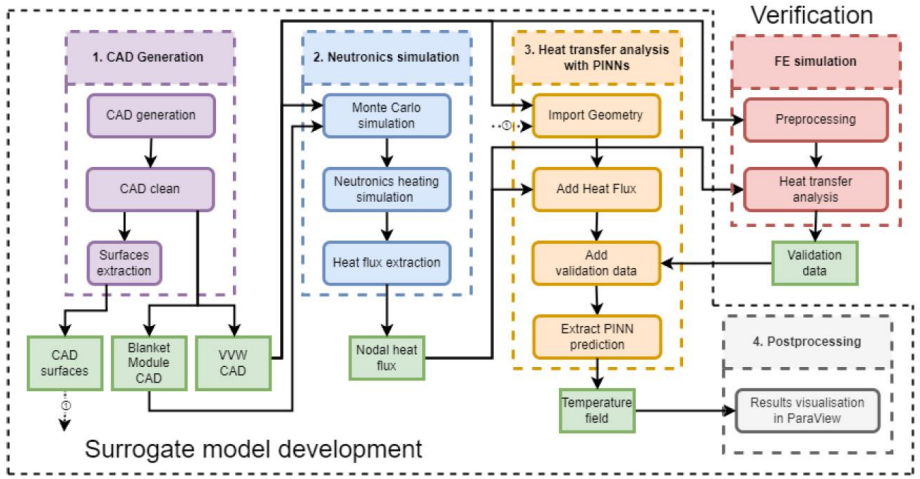


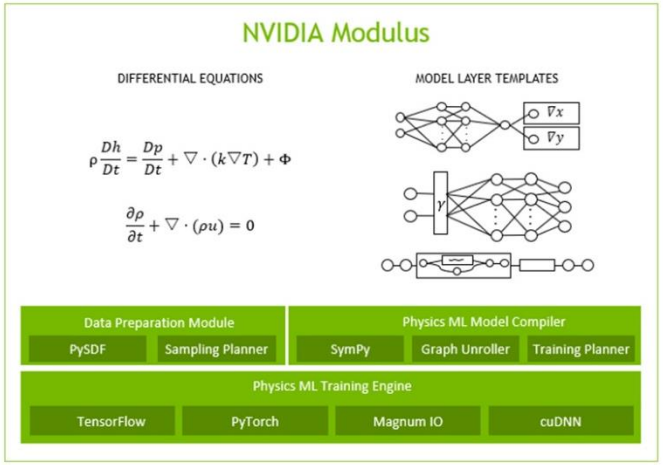


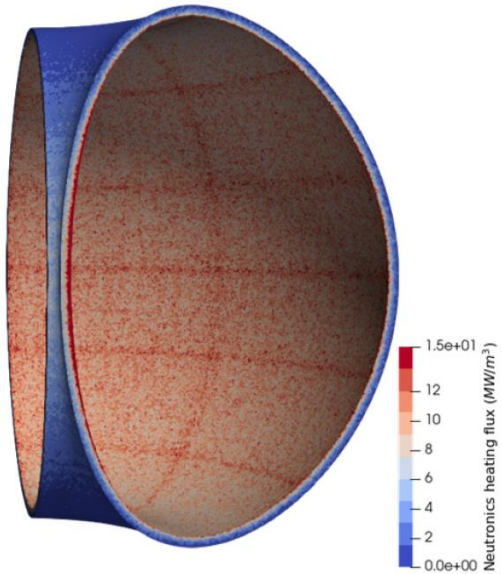
Schematic view of typical breeder blanket module

Surrogate Models and Emulators*FIP

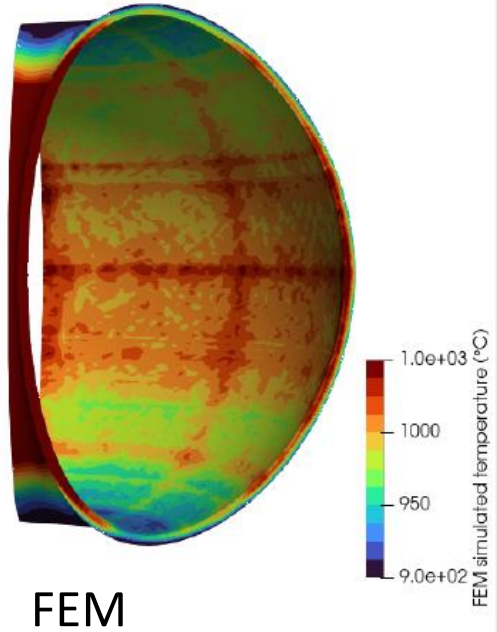




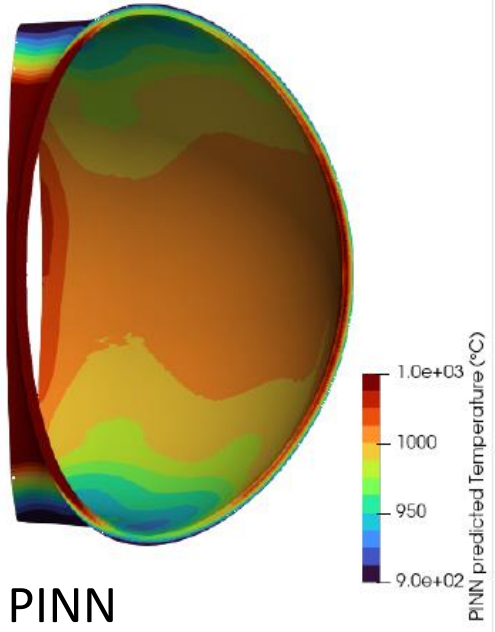




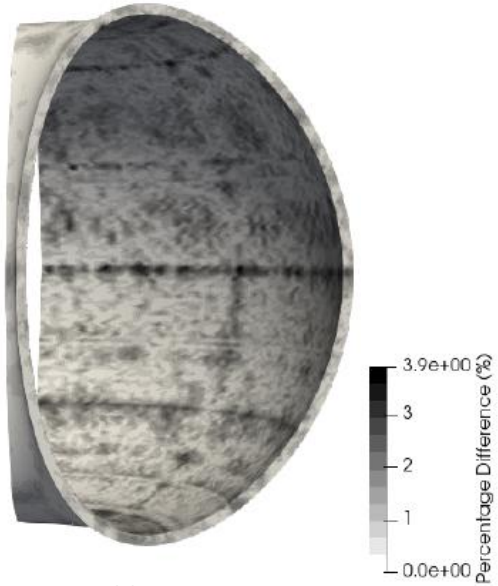
Neutronic Heating



FEM



PINN



% Difference

Enable and Promote Automation*FIP

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Galaxy Metaverse Collaboration for Fusion Energy (MCFE)

Workflow Visualize Shared Data Admin Help User

Galaxy Version 23.0

Server
- Data Types
- Data Tables
- Display Applications
- Jobs
- Workflow Invocations
- Local Data

User Management
- Users
- Quotas
- Groups
- Roles
- Forms

Tool Management
- Install and Uninstall
- Manage Metadata
- Manage Allowlist
- Manage Dependencies
- View Lineage
- View Error Logs

You may choose to stop some of the displayed jobs and provide the user with a message. Your stop message will be displayed to the user as: "This job was stopped by an administrator: <YOUR MESSAGE> For more information or help, report this error".

Time cutoff applied to query

Select whether or not to use the cutoff below.

Cutoff in minutes

5

Display jobs that had their state updated in the given time period.

Type to Search

Use strings or regular expressions to search jobs.

Galaxy PROJECT

Unfinished Jobs

These jobs are unfinished and have had their state updated in the previous 5 minutes. For currently running jobs, the "Last Update" column should indicate the runtime so far.

Encoded Job ID	Decoded Job ID	User Email	Tool	State	Handler	Job Runner	PID/Cluster ID	Last Update
f8198d287da063d3	3773	william.smith-14@postgrad.manchester.ac.uk	paramak_generator	running	handler_0	local_runner	576021	less than a minute ago
53e91f72a0297ef2	3771	william.smith-14@postgrad.manchester.ac.uk	paramak_generator	running	handler_0	local_runner	575973	less than a minute ago
35c41ccff7a7c5c6	3769	william.smith-14@postgrad.manchester.ac.uk	paramak_generator	running	handler_0	local_runner	575772	less than a minute ago
f2217a91c95336e0	3767	william.smith-14@postgrad.manchester.ac.uk	paramak_generator	running	handler_0	local_runner	575738	less than a minute ago
6563b0d504b17a97	3774	william.smith-14@postgrad.manchester.ac.uk	openmc_parametric	new	handler_0			less than a minute ago
b3cbfc617b6a3565	3770	william.smith-14@postgrad.manchester.ac.uk	openmc_parametric	new	handler_0			less than a minute ago
4a90cbda58d2116d	3768	william.smith-14@postgrad.manchester.ac.uk	openmc_parametric	new	handler_0			less than a minute ago
cc21a9712c7c5a1b	3772	william.smith-14@postgrad.manchester.ac.uk	openmc_parametric	new	handler_0			less than a minute ago

Finished Jobs

These jobs have completed in the previous 5 minutes.

Encoded Job ID	Decoded Job ID	User Email	Tool	State	Handler	Job Runner	PID/Cluster ID	Finished

Improve Extraction of Information from Data*FIP

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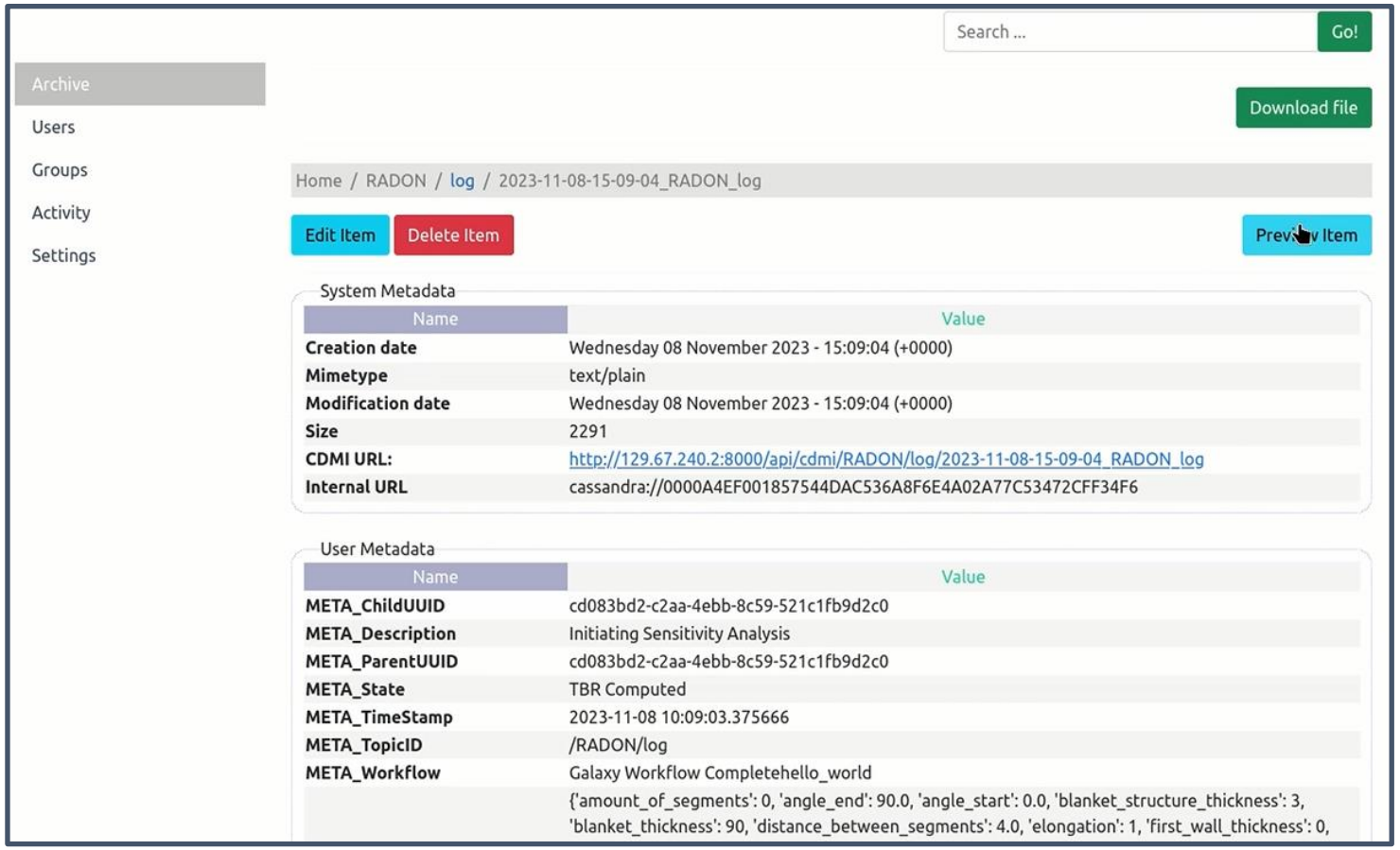
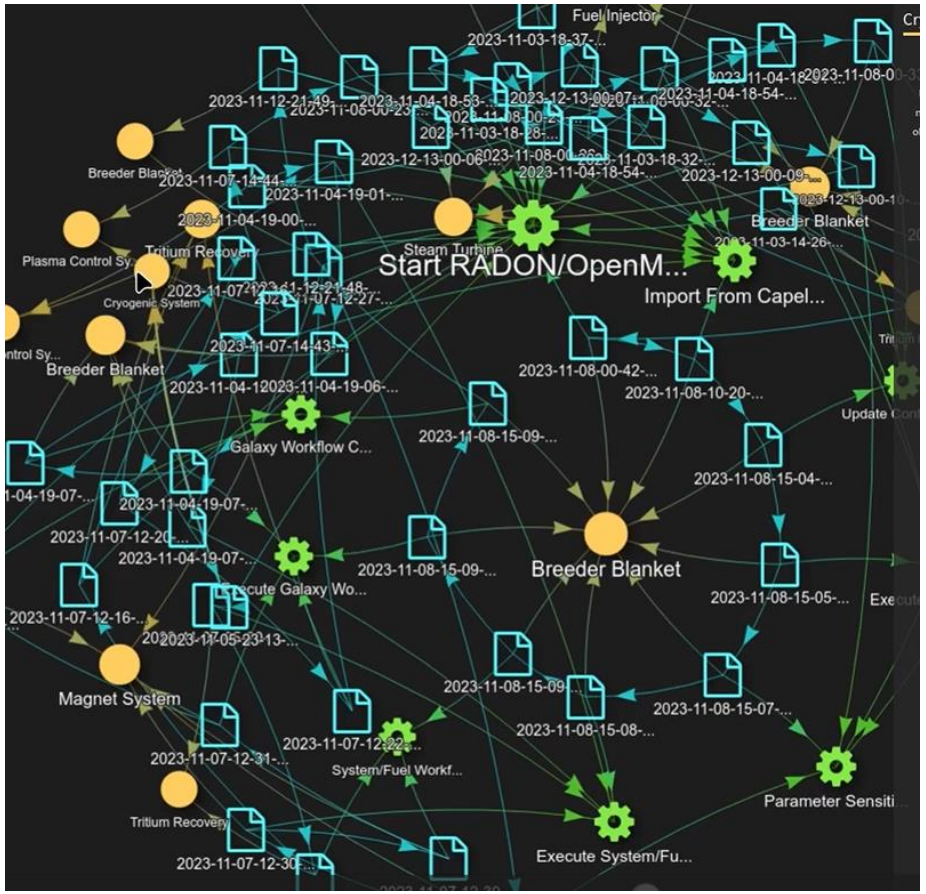
Beyond current Product Lifecycle Management and endures for the lifetime of the product (100 years).





Provenance data capture using RADON, via an IoT message broker, independent of all other software across the supply chain.
Removal of data silos supports automation and leveraging of AI/ML beyond physics-based tools to human/machine collaboration.

Data Science for Experiment*FIP

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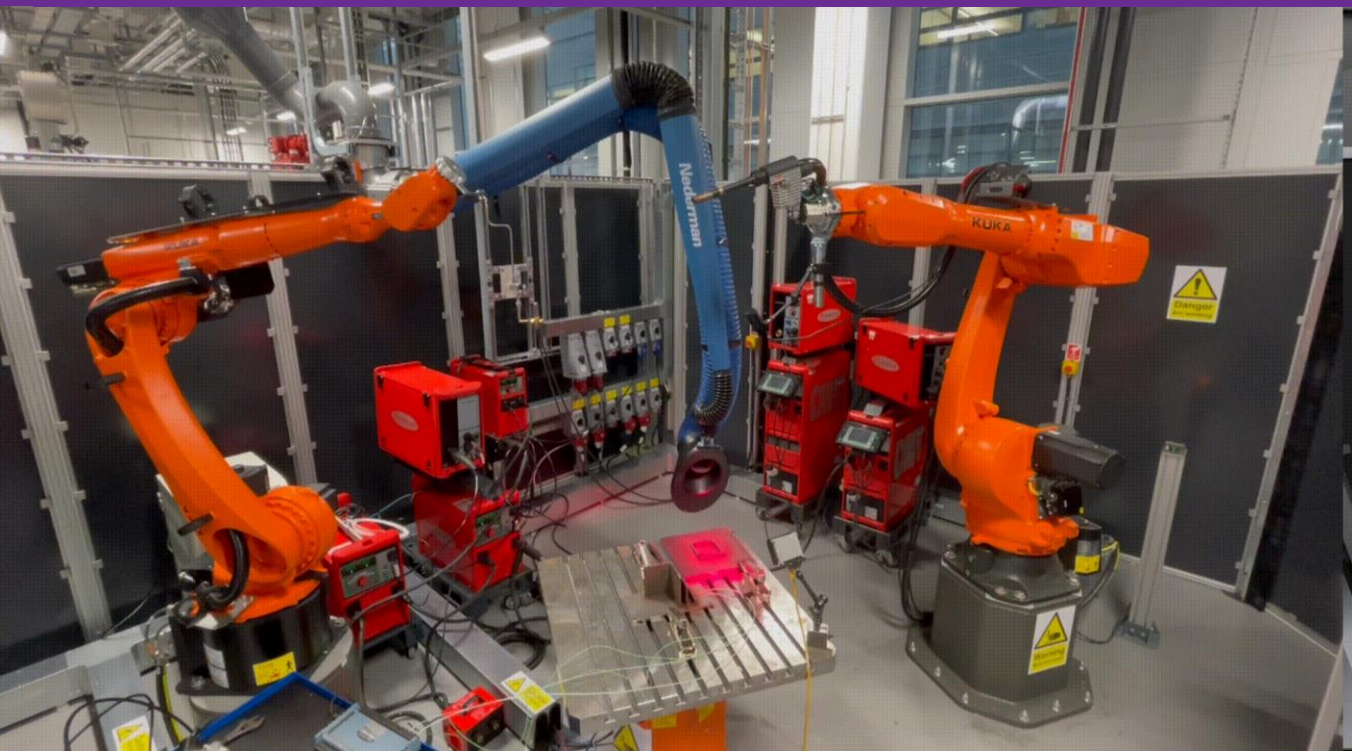

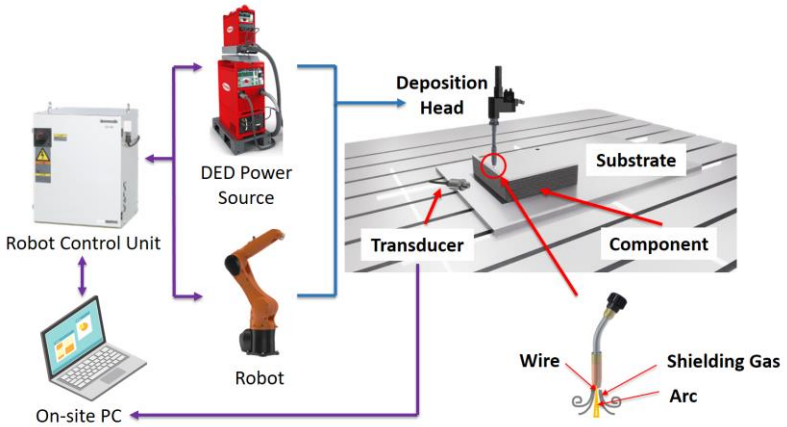

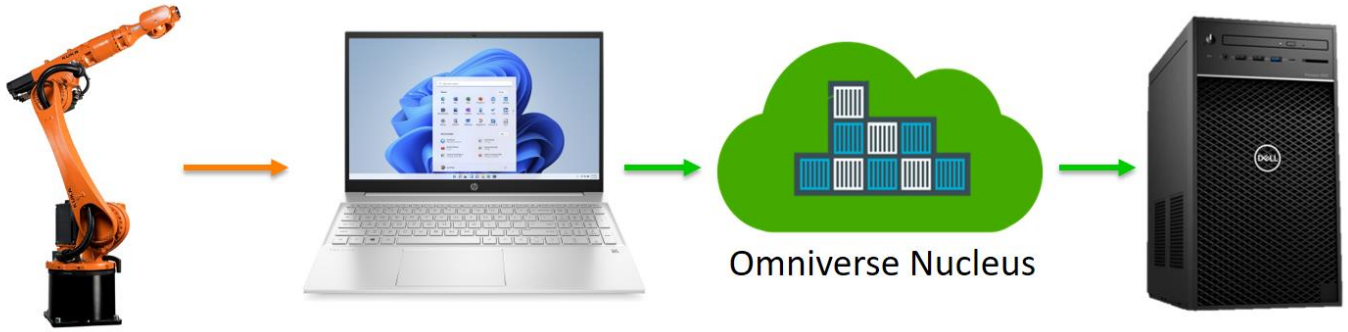

Digital twin for direct energy deposition additive manufacture

HENRY ROYCE INSTITUTE

Exascale Artificial Intelligence Platform*FIP

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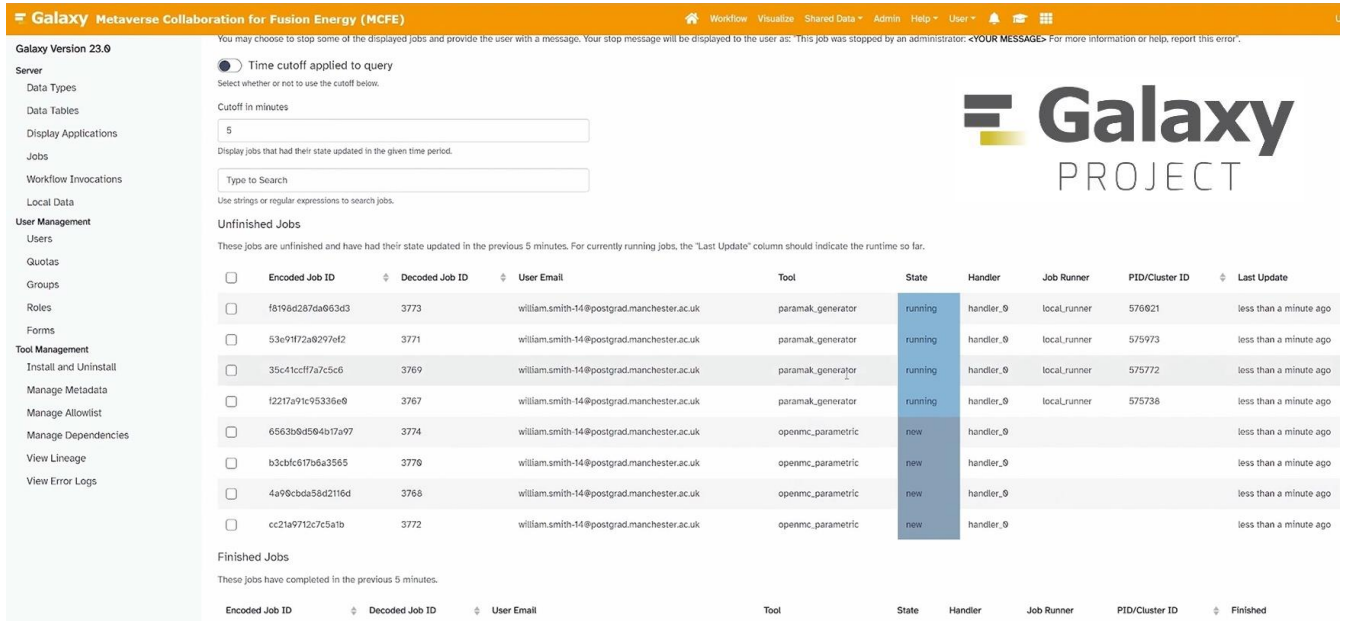

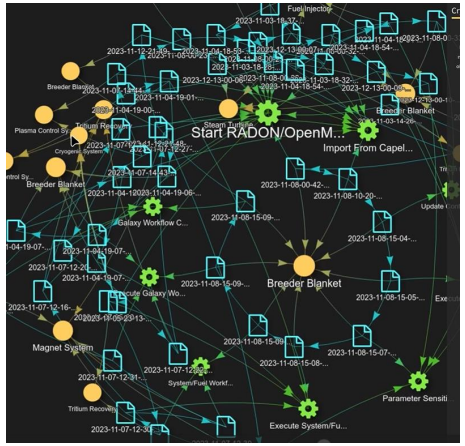

Engineers working in silos can use AI/ML tools, but this is just a “craft industry ++”.

EPCC is helping us deploy Galaxy workflows and provenance metadata capture on ARCHER2 through the CCP-WSI+ & HEC-WSI projects led by the University of Plymouth.

When we have built an AI/HPC platform for engineering simulation using the industrial metaverse, for humans and machines to co-design the engineered future together.

UK Atomic Energy Authority

UNIVERSITY OF OXFORD

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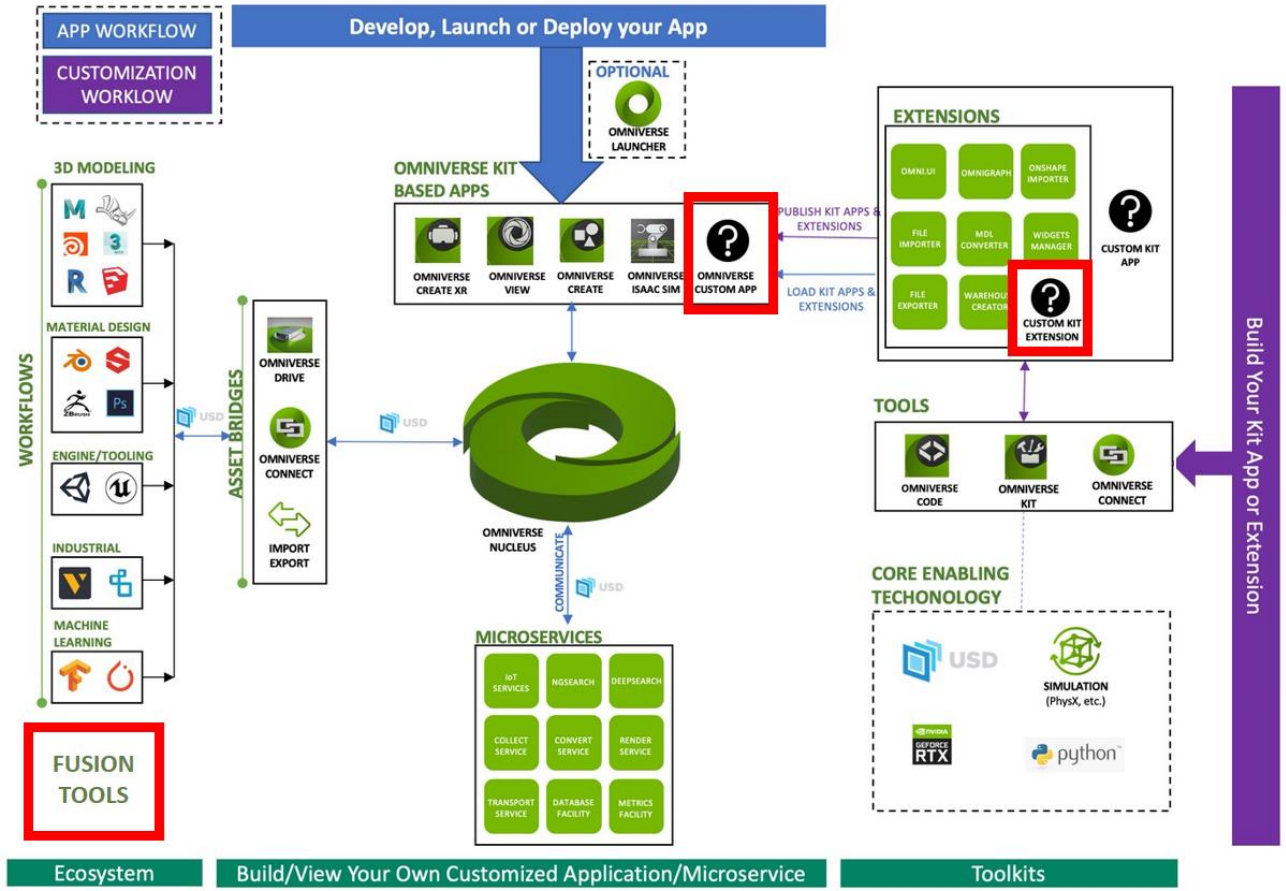
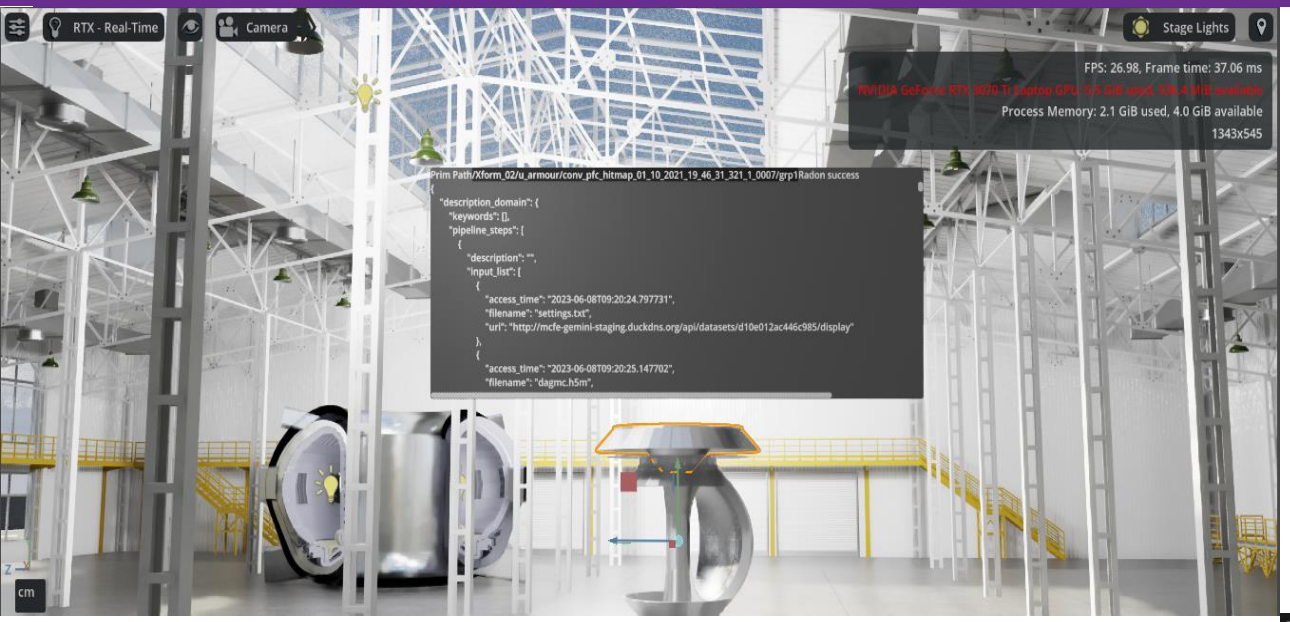
MCFELab Desktop App



Consolidates all developed tools into a single standalone application that launches FAIR workflows on AI/ML supercomputers

MCFELab VR App



Pop Up Widget

- Click on the surface of the object to trigger it
- Currently linked with the Radon server
- Able to pull an existing json file which exists in the server
- Display the file on the widget
- Interactable through VR, e.g scrolling on the widget

Custom Teleportation Widget

- Click on the Joy-con to trigger it, this is currently integrated in the VR settings widget
- Black, white and red button for teleportation
- Clicking that will teleport the user to specific location on the scene

Accelerating Fusion Power Plant Design*FIP

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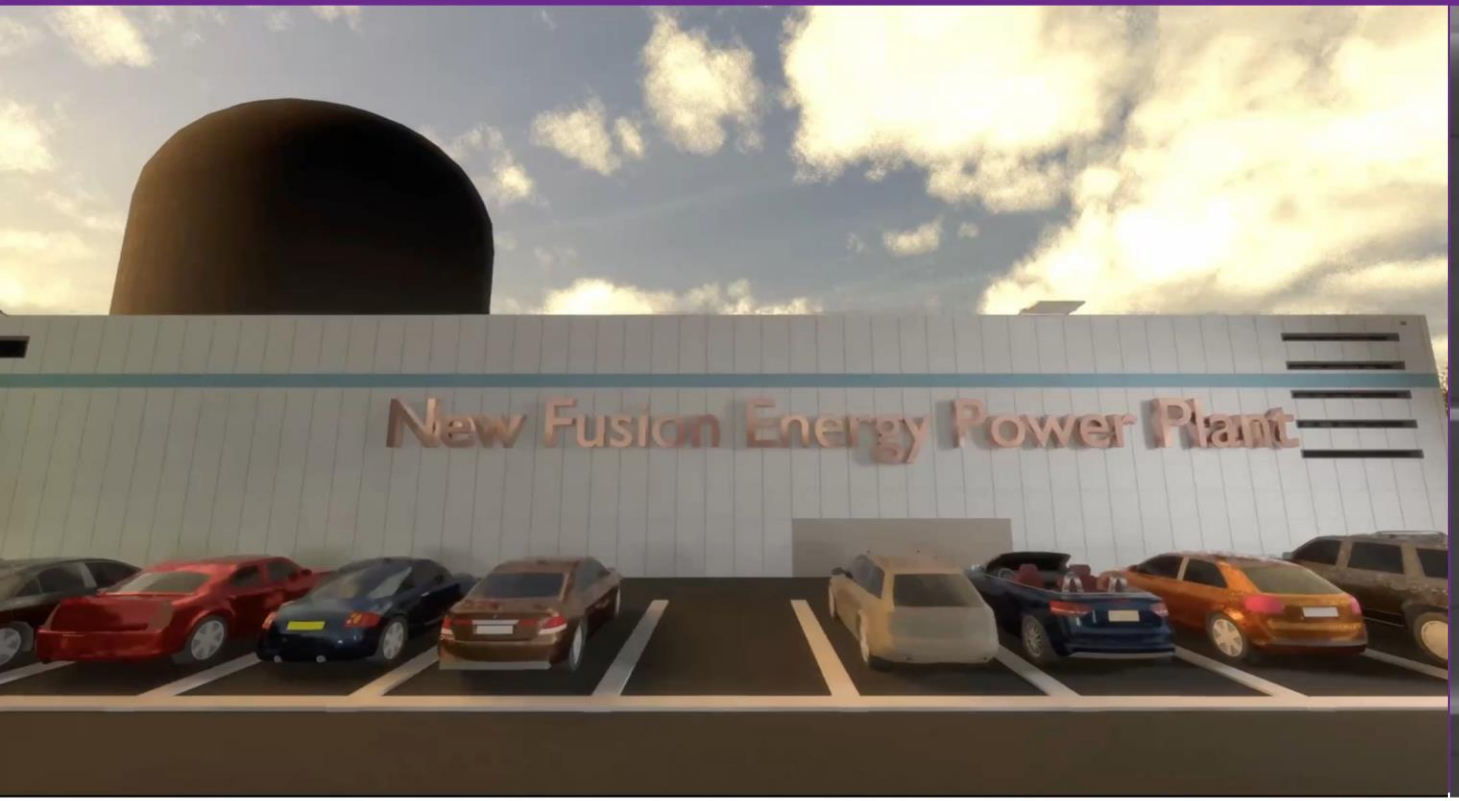
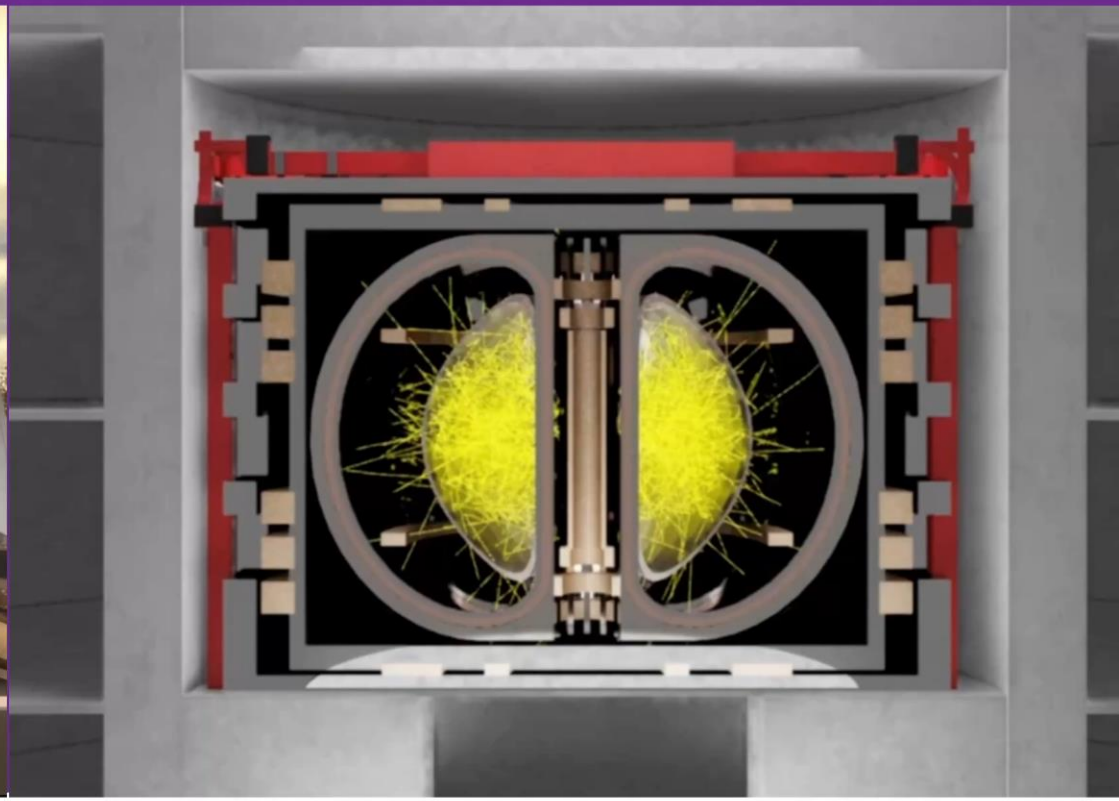
Automated Conceptual Design

- A range of parameterised simulations are run using AI/ML to select the best candidate geometries for HPC.
- These involve model based systems engineering and FAIR automated workflows launched from the Omniverse.
- Provenance data is captured from all interactions with all tools, creating a body of knowledge about the design, including simulation and experiments.
- Based on the simulation results, parameters are passed into scripts which generate the entire fusion power plant.
- Including the machine hall, turbine buildings, hot cell, heat exchanger, offices, parking areas and switchyards.
- And provides automated costing via BIM models too!

Design Build and Operation of Fusion Power Plants in the Industrial Metaverse





The University of Manchester

UNIVERSITY OF OXFORD

MetaMorph

nTtau Digital LTD SaaS

UK Atomic Energy Authority