



Digital Solutions for Fusion Office (DSO)

Physics Project Board #7 | October 27-28, 2025

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Thanks to Denis Kalupin, Xavier Litaudon, and the E-TASC SB



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Formula: DSO = WPAC – TSVVs

The DSO will drive and coordinate EUROfusion digital innovation activities, including the provision and management of computational and data storage resources. It will support the development of research and engineering software, with a focus on integrating computational tools into a common environment. The DSO will provide digital services tailored to the specific needs of other WPs and departments.



Digital Twin Environment

Predictive capabilities, real-time control, coupled physics-engineering simulations, and analysis tools for next-generation facilities.



Advanced Computing Hubs

Support for code developers:

- High-Performance Computing;
- Modelling Frameworks and Standardized Workflows.



Data Management Plan

Unified access to experimental data using FAIR principles.
Support further development and maintenance of existing multi-machine databases.



Computing & Data Storage Systems

Management & distribution of dedicated computing resources (PITAGORA HPC system, collaboration with Japan, new Gateway, Long-Term Data Storage Facility).

What is a Digital Twin (DT) and a Digital Twin Environment (DTE)?



- The notion of a Digital Twin first emerged around 2002 in the context of Product Lifecycle Management. It was later adopted as a conceptual basis in aerospace engineering and many other disciplines.
- Excellent source: “Foundational Research Gaps and Future Directions for Digital Twins” (National Academies of Sciences, Engineering, and Medicine, 2024): <http://nap.nationalacademies.org/26894>
- **A Digital Twin (DT) is a set of virtual information constructs that mimics the structure, context, and behavior of a natural, engineered, or social system, is dynamically updated with data from its physical twin, has a predictive capability, and informs decisions that realize value.**
 - The key elements that comprise a DT include (1) a virtual representation of a physical counterpart, and (2) a bidirectional interaction between the virtual and the physical. This bidirectional interaction forms a feedback loop that comprises **dynamic data-driven model updating** (e.g., sensor fusion, inversion, data assimilation) and **optimal decision-making** (e.g., control, sensor steering).
 - A DT should be defined at a **level of fidelity and resolution that makes it fit for purpose**. Important considerations are the required level of fidelity for prediction of the quantities of interest, the available computational resources, and the acceptable cost. This may lead to the DT including high-fidelity, simplified, or surrogate models, as well as a mixture thereof.
- **A Digital Twin Environment (DTE) is an integrated, multi-domain physics application space for operating on DTs for a variety of purposes** (according to Michael Grieves & John Vickers: <https://rdcu.be/d1wRu>)

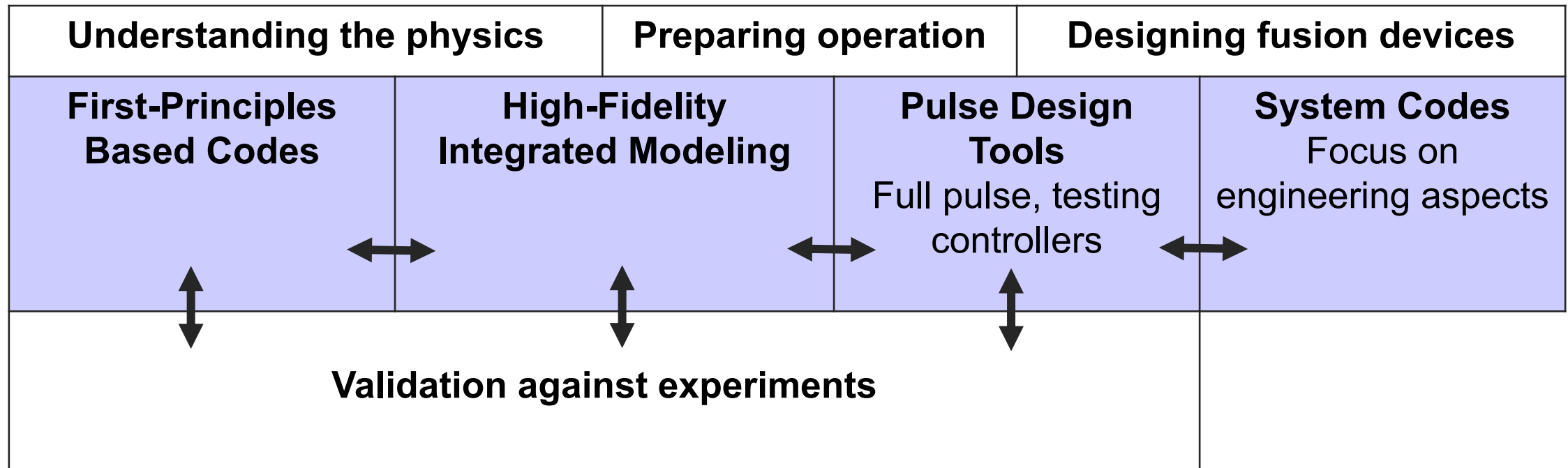


HPC and AI allow researchers to simulate complex, multi-scale, multi-physics plasma dynamics with unprecedented realism and reliability.

The ultimate goal is to create digital twins of fusion systems, thereby saving cost and time.

To be effective, the fidelity level of a digital twin must match its intended purpose.

New research areas include multi-fidelity techniques and uncertainty quantification (UQ).





Integration of various related activities into a unified **Digital Twin Environment** program

Ref.	Area Title	Objectives	Link to 2021-2025 programme
PDT	Pulse Design Tool Extension	Expand PDT for real-time, high-fidelity plasma forecasting and virtual control testing	TSVV-15
DDM	Data-Driven Predictive Modelling	Apply AI/ML for faster, validated simulations and real-time analysis/control	AI/ML – pilot projects
ENG	Integrated Physics/Engineering Framework	Develop coupled physics-engineering tools (e.g., breeding blanket, divertor models) and synthetic diagnostics	DTE PoC projects
VIS	Advanced Visualisation Tools	Create intuitive, interactive visualization for model validation and decision support	ACHs

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DMP	Data Management Plan	Develop coupled physics-engineering tools (e.g., breeding blanket, divertor models) and synthetic diagnostics	DMP
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Active collaboration and liaison with ITER on the IMAS development and F4E on utilization of AI/ML techniques			ACH-IPPLM
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nature reviews physics

<https://doi.org/10.1038/s42254-025-00837-1>

F. Jenko, Nature Reviews Physics 7, 365 (2025)

Perspective

<https://rdcu.be/ex2Eb>

 Check for updates

Accelerating fusion research via supercomputing

Frank Jenko ^{1,2} 

Abstract

The pursuit of fusion energy is gaining momentum, driven by factors including advances in high-performance computing. As the need for sustainable energy solutions grows ever more urgent, supercomputing emerges as a key enabler, accelerating fusion power toward practical realization. Supercomputers empower researchers to simulate complex plasma dynamics with remarkable precision, aiding in the prediction and optimization of plasma confinement and stability – both essential for sustaining burning plasmas. They also have a critical role in assessing the resilience of materials exposed to the

Sections

Introduction

Developments and challenges in fusion research

Supercomputers in fusion research

Current research directions

The emergence of digital twins

Outlook



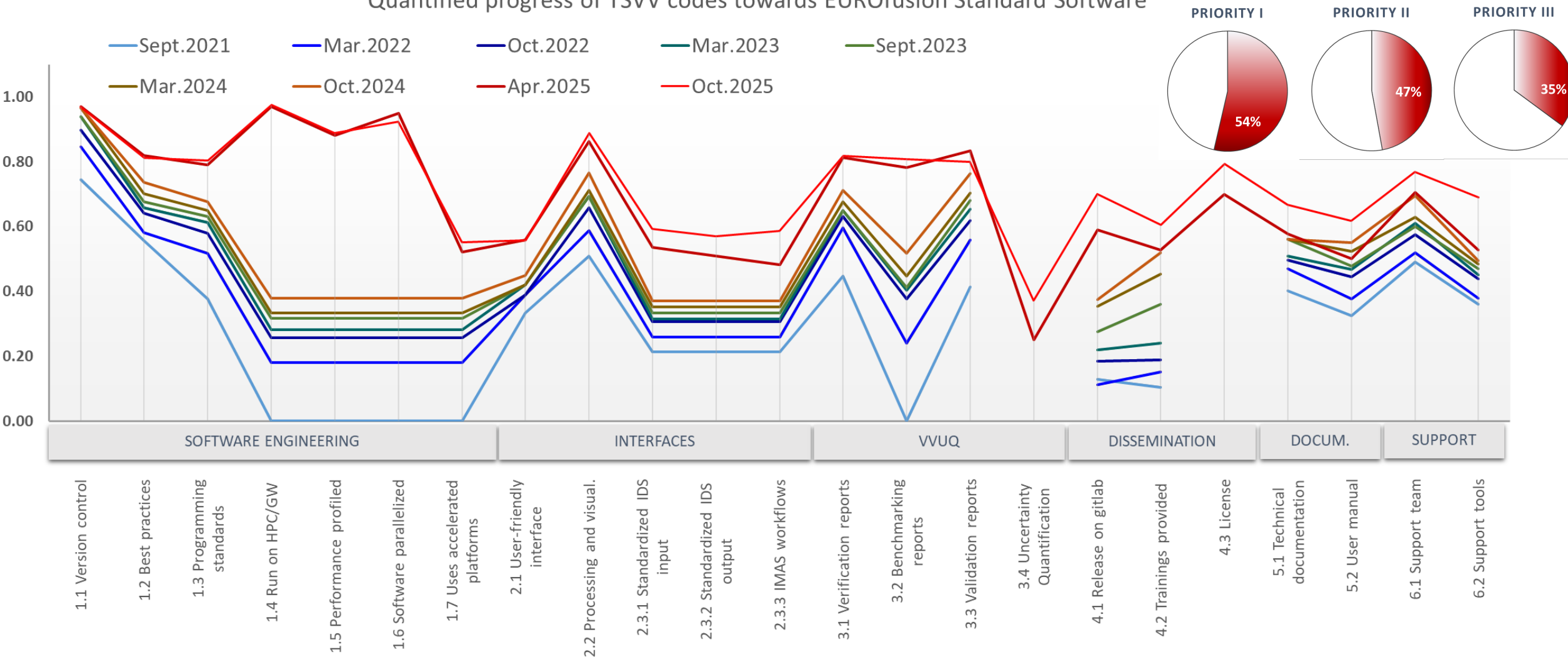
EUROfusion standard software will be developed with a very rigorous, consistent quality assurance process that is common across the E-TASC initiative; it is designed to benefit a wide range of users across EUROfusion, well beyond the team of code developers, and will adhere to the following guidelines and criteria:

- Free availability (within EUROfusion) of an up-to-date release version of the source code used for production runs
- Good software engineering practices (version control, regression/unit testing, shared development rules etc.)
- High-quality code documentation via user manuals and reference publications (including, in particular, a detailed description of the underlying model)
- Excellent support of users, co-developers, and support staff within EUROfusion (via contact person, mailing list, issue tracker, and the like)
- Specific plans for code verification and validation (involving a third party), in particular within EUROfusion, including aspects of uncertainty quantification
- User-friendly, intuitive interfaces and visualisation/post-processing tools, including interfaces to the IMAS Data Dictionary (where applicable)
- Specific plans for code dissemination and user training within EUROfusion

Progress towards EUROfusion Standard Software



Quantified progress of TSVV codes towards EUROfusion Standard Software



The quality assurance framework for EUROfusion Standard Software (endorsed by the E-TASC SB on March 12, 2025)
<https://idm.euro-fusion.org/?uid=2Q72WQ&version=v2.2>



Key goals

- Build a vibrant, collaborative **ecosystem** that integrates physics, engineering, and digital technologies
- Develop and employ **digital twins** of fusion systems (**helping to save cost and time**)
- Emphasize **development & dissemination** of EUROfusion Standard Software (**opportunity to build user bases**)
- Close **coordination with various departments and WPs**, particularly the newly established **WPTM**
- Collaborations with **colleagues in the UK and the U.S.** (see General Meeting in Nov 2024)

Recent and ongoing activities in preparation of 2026/27

- Selection of **ACHs** (down from 5 to 4 due to a ~30% budget reduction w.r.t. 2021-25 values)
- Selection of **TSVVs** (down from 15 to 11 due to a ~30% budget reduction w.r.t. 2021-25 values)
- Selection of **DTE projects** (replacing the 7 Proof of Concept projects, since April 2025)
- Selection of **DATA projects**

Upcoming activities

- **December 4-5, 2025:** Selection of ACH projects for 2026 (with the help of the E-TASC SB)
- **January 14 & 28, 2026:** EUROfusion Science Meeting - TSVV Final Reports (2021-2025)
- **February 9-13, 2026:** 2nd E-TASC General Meeting (organized by DSO & WPTM)



Pulse Design Tool (PDT) Extension Towards Digital Twin Functionality

- Simulator-agnostic DTE integration – towards a consolidated framework with an ITER relevance
- Development of generic coupling between transport and free-boundary equilibrium codes with breakdown modules for PDTs
 - *Development and validation of PDTs*

Data Driven Predictive Modeling for Real-Time Feedback

- A machine-agnostic DT framework towards fast simulation and real-time plasma prediction and control
 - *AI/ML-enhanced DT for real-time predictive simulation and control of breeding blanket systems*
- A novel ML-based DT architecture for real-time monitoring, integration, and control of the breeding blanket

Advanced Visualization

- Verification-oriented interactive visualisation and decision support for the DTE

Integrated Physics/Engineering Simulation Framework for Fusion Devices

- A highly scalable and flexible DT of fusion power plants and photorealistic renderer based on physically accurate models
- DT platform for integrated design of tokamak components – case studies on EU-DEMO divertor and ITER divertor
- Integrated DT framework for breeding blanket systems: Coupling plasma, fuel cycle, and thermal-hydraulics dynamics
- A comprehensive numerical platform for advanced thermal protection of tokamaks
 - *Develop integrated multi-diagnostic data analysis tools for ITER operation at the WEST data and IMAS environment twin*
- An integrated validation and benchmarking framework for the EUROfusion DTE
- Development of a DT framework for fusion



Very small **core team**:

- **Frank Jenko (Head, DSO)**
- **Denis Kalupin (Coordination Officer, DSO)**
- **NN**

Supported by the **E-TASC Scientific Board** (co-chaired by Xavier Litaudon & Frank Jenko):

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