# Call for proposal of Digital Twin pilot projects.

DSD, 16.12.2024

A **Digital Twin** for fusion is a virtual model of a fusion reactor that simulates and monitors its real-world counterpart. It uses real-time data from sensors and other sources to replicate the reactor's physical structure, plasma behavior, material interactions, and engineering systems. The goal is to improve predictions, optimize performance, reduce risks, enhance efficiency, and support decision-making by creating a comprehensive, real-time, and actionable representation of a system.

The **EUROfusion Digital Solution for Fusion Department (DSD)** coordinates efforts to achieve this ambitious goal. Various elements of the EUROfusion work programme, including **TSVVs** and **ACHs**, contribute to the development of Digital Twins.

The realization of a comprehensive Digital Twin requires **fully integrated simulations** that cover:

* **Different fidelity levels**: From detailed physics-based models to fast Artificial Intelligence based (AI) approximations.
* **Complexity and reliability**: Including plasma dynamics, external systems, control actuators, interactions with materials, and engineering functionalities.

The aim is to address identified **gaps and opportunities** through targeted **Proof of Concept (PoC)** projects. These projects will link **data from science and engineering** to build integrated solutions that meet current needs and advance future capabilities.

With the present call DSD is aiming to implement several PoC projects as identified below.

## Breading Blanket

**General topic:**

* **Component Integration:** Developing a reliable integrated workflow that includes various physics (tritium implantation, transport, neutron behaviour, material properties), processes, and tools involved in Breeding Blanket (BB) simulations.
* Efficient coupling of standalone (validated) commercial tools is essential for building a robust integrated system.

**Key challenges:**

* Understanding and predicting **implantation**, **transport**, and **trapping of tritium** within the materials is essential for BB predictions. The embrittlement and other structural changes of the materials due to nuclear damage is a key aspect.
* Approach resembles a **system design code**, where the pilot project could focus on combining existing elements efficiently.
* **Tritium Breeding Ratio** (TBR) modelling in an integrated way.

**Scope for Pilot Project(s) in 2025:**

* Identifying **known vs. unknown components** and focusing on addressing the critical unknowns.
* The coupling of standalone commercial codes for these processes could be streamlined for greater efficiency.
* Pinpoint where existing tools fail and prioritize coupling them effectively.
* Concentrate on efficient coupling of standalone codes rather than developing entirely new tools.

**Collaboration Potential:**

* A **synergy with TSVV-07** could provide valuable input, especially regarding tritium behaviour inside materials.
* **ACH support** on assisting the efficient coupling of workflow components
* **UKAEA** is building a novel simplified however integrated code instead of linking existing ones to reduce the complexity.

## Divertor Development

**General topic:**

* **Physics-Based Preliminary Optimization** of the Plasma-Facing Component (PFC) contour configuration.
* Development of an **integrated simulation framework** to couple **CAD layouts / SOLPS** / **DIVGAS**
* Establish a foundation for future multi-physics, integrated divertor design tools.

**Key challenges:**

* Bridging the gap between fast-running codes (e.g., DIVGAS, CAD tools) and computationally heavy tools like SOLPS or EIRENE
* Ensuring **scalability and robustness of the framework** to handle complex divertor geometry

**Scope for Pilot Project(s) in 2025:**

* Couple stand-alone codes into a consistent workflow
* Use surrogate models for SOLPS to accelerate optimization and reduce computational cost.
* Include ERO simulations in the workflow to address erosion/redeposition processes, providing more accurate predictions of PFC lifetime and behaviour

**Collaboration Potential:**

* A Significant related work has been partially addressed by **WPPWIE**, **EnR** and **TSVV** projects.
* **ACH support** on assisting the efficient coupling of workflow components

## Flight simulator/ Pulse design tool

**General topic:**

* Develop a **machine-generic plant simulator** that provides a **realistic, predictive, and optimization-driven framework** for pulse design and control.
* **Demonstration** of predictive **control feasibility** in a tokamak

**Key Challenges:**

* Ensure real-time performance for applications like pulse planning and adaptive control.
* Implement and test predictive control algorithms to optimize pulse parameters and mitigate risks in real-time operations
* Investigate incremental learning techniques to refine predictive models over time based on operational data.

**Scope for Pilot Project(s) in 2025:**

* Inclusion of diagnostic data for predictive control and incremental learning, especially in refining NN models based on real-time observations.

**Collaboration Potential:**

* **Core overlaps with PDT**; this project could act as an **extension to TSVV-15** by broadening the scope
* With **TSVV-11** on the use of **NN models**

## Disruptions and machine details

**General topic:**

* xxxxxxxxxxxxxxxx

**Key challenges:**

* xxxxxxxxxxxxxxxx

**Scope for Pilot Project(s) in 2025:**

* xxxxxxxxxxxxxxxx

**Collaboration Potential:**

* **Core overlaps**

## Model Based Systems and Control

**General topic:**

Beyond standard control techniques, these systems aim for advanced reference tracking and disturbance rejection. focused on:

* Development and integration of **domain controllers, sensors, actuators, and plasma models**.
* Utilization of **model predictive controllers** for key **subsystems, including magnetics, kinetics, exhaust systems, and stochastic event management**.
* Synthesis of supervisory **controllers with automated fail-safe mechanisms**.

**Key challenges:**

* Ensure robustness and resilience under dynamic operational conditions, not restricting more than necessary.
* Ensure streamlined design, testing, and operational efficiency across all system components.
* Interaction with VERY large discrete state-spaces.
* Extensive V&V will be needed

**Scope for Pilot Project(s) in 2025:**

* Prototype synthesized supervisor for reduced model (SC synthesized in < 10s on a std. laptop. Evaluated ~1ms )

**Collaboration Potential:**

* The project might benefit from interactions with previously concluded **EnR project (MIMO)**
* **ACH support** on utilisation of AI/ML techniques

## Proposal Requirements

Each proposal should include:

1. **Project Title:** along with one of PoC projects identified above
2. **Abstract**: A brief description of the proposed PoC project, its goals, and significance.
3. **Technical Description**:
   * Key scientific and engineering components.
   * Models, tools, and software to be integrated.
   * Data sources (e.g., sensors, simulations).
4. **Expected Outcomes and Deliverables**: Clearly state the expected results at the end of the 1-year pilot project.
5. **Proposed Resources**:
   * Manpower and skills of the proposed team
   * Estimated request on computational resources.

## Expected Deliverables

At the end of the 1-year pilot project, proposals are expected to deliver:

* A **Proof of Concept** for a well-defined tool or system.
* Preliminary validation and results.

## Indicative Timeline

* End Jan. 2025 – release of the call
* 21.02.2025 – Deadline for submission of proposals
* 07.03.2025 – Project Selection announced
* 15.03.2025 – Earliest start date for PoC projects