Feedback by the E-TASC SB on TSVV and ACH activities in 2026-2027

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on behalf of the E-TASC Scientific Board

Importance of E-TASC

Excerpt from a submitted IAEA Synopsis

TOWARDS DIGITAL TWINS OF FUSION SYSTEMS **OV: Overview**

Achievements of the E-TASC initiative

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Background. Bridging the gap to next-step devices – while saving valuable time and resources – requires more than semi-empirical models, which struggle to **predict plasma behavior in unexplored parameter regimes**. Instead, validated simulation tools are essential, leveraging high-fidelity exascale computing and multi-fidelity models, including AI-based surrogates. To address these challenges, the "**EUROfusion Theory and Advanced Simulation Coordination (E-TASC)**" initiative was launched in 2021 [1]. It includes 15 TSVV (Theory, Simulation, Verification, and Validation) projects supported by 5 Advanced Computing Hubs. This "team of teams" has made substantial progress toward developing digital twins of fusion systems, with **key scientific achievements** to be presented.

Predicting MHD transients in next-step devices. MHD-induced transients pose a significant risk to the operation of tokamak-based fusion power plants. Disruptions have been extensively studied using state-of-the-art codes such as JOREK and DREAM. Research on disruption mitigation via shattered pellet injection has identified the mechanism by which it reduces the global vertical force [3,a]. Additionally, runaway electron dynamics and their impact on mitigated disruptions in JET, ITER, and DEMO have been analyzed [4,b,c]. Also, new insights have been gained into the control of H-mode pedestal instabilities (e.g., ELMs) via external magnetic perturbations or X-point radiators [d].

Predicting core performance. In recent years, it has become increasingly evident that a nonlinear interplay exists between turbulence, energetic particles, and MHD modes in the plasma core. Key findings based on comprehensive gyrokinetic (GK) simulations highlight the turbulence suppression by energetic particles, the interaction between

E-TASC SB: Level of cuts first proposed would be devastating

The indicated budget reduction for the TSVVs and ACHs represents a:

- **54% decrease compared to the 2021–25 average values**
- **63% decrease compared to the 2025 values**

Such cuts would severely limit EUROfusion's ability to address key programmatic questions and mitigate risks associated with the construction of next-generation fusion devices.

E-TASC SB: Ensuing damage from this cut would be severe

Some examples:

- The TSVV ecosystem tackles many strategically important topics. Its **predictive capabilities help guide fusion research, saving time and resources**. The TSVVs provide direction and foster collaboration in Theory & Modeling. TSVV support is a smart investment – this is why the U.S. supports such efforts on a level of ~ $50M per year.

- Considerable time, resources, and commitment went into launching the five ACHs, including efforts to attract and retain experts in HPC and data science – despite strong competition from industry. If discontinued by the end of 2025, **ACHs cannot be restarted**.

- ACHs play a crucial role in maximizing the efficiency of EUROfusion's substantial HPC investments. **Significant reductions in ACH personnel would be counterproductive**.

- Severe **cuts would particularly affect smaller RUs**.

E-TASC SB: Possible consolidation measures

While fundamentally opposed to such drastic cuts, the SB has made a prioritization of activities which could serve as a basis for subsequent decisions.

In this context, it is essential to maintain the TSVVs and ACHs at a "critical mass" to preserve the integrity of the entire E-TASC program and protect past investments.

Possible consolidation measures

- **Consolidate the TSVV ecosystem**: Several TSVVs reaching maturity could transition to a new implementation phase, prioritizing code application over continued code development.
- **Reduce ACH support** currently allocated to software from mature TSVVs.
- **Restrict ACH tasks** to TSVV-developed software, discontinuing support for non-TSVV requests.
- **Comparable cuts across all other DSD activities** (apart from hardware investments).

Current TSVV ecosystem (2025)

01: Physics of the L-H Transition and Pedestals
02: Physics Properties of Strongly Shaped Configurations
03: Plasma Particle/Heat Exhaust: Fluid/Gyrofluid Edge Codes
04: Plasma Particle/Heat Exhaust: Gyrokinetic/Kinetic Edge Codes
05: Neutral Gas Dynamics in the Edge
06: Impurity Sources, Transport, and Screening
07: Plasma-Wall Interaction in DEMO
08: Integrated Modelling of MHD Events
09: Dynamics of Runaway Electrons in Tokamak Disruptions and Start-Up
10: Physics of Burning Plasmas
11: Validated Frameworks for the Reliable Prediction of Plasma Perf. and Op. Limits in Tokamaks
12: Stellarator Optimization
13: Stellarator Turbulence Simulation
14: Multi-Fidelity Systems Code for DEMO
15: Pulse Design Tool

Focus of proposed WPTM activities in 2026-2027

- H-Mode and Small/No-ELM Pedestals
- Plasma Particle/Heat Exhaust: Fluid Simulations
- Plasma Particle/Heat Exhaust: Gyrokinetic and Fully Kinetic Simulations
- Plasma-Wall Interactions in DEMO
- Impurity Sources, Transport, and Screening
- Tokamak Disruptions and Runaway Electrons
- Burning Plasmas
- Validated Frameworks for the Reliable Prediction of Plasma Performance and Operational Limits in Tokamaks
- Stellarator Optimization
- Stellarator Core Turbulence

Work Package Theory & Modelling

To sustain the pace of code development under significantly reduced financial support, it is crucial to keep TSVV projects unified under the same "roof."

OBJECTIVES

Code Development

- Foster advances in code verification, validation, and uncertainty quantification to develop reliable predictive capabilities for ITER operations as well as DEMO and stellarator design.
- Promote the evolution of research software towards EUROfusion Standard Software.

Simulation Integration & Predictive Modelling

- Develop and employ state-of-the-art theory and simulations to help address outstanding open questions in fusion research, in line with the EUROfusion Roadmap.
- Consolidate the integration of validated codes into larger simulation frameworks, supporting experimental data analysis and applying them for predictive simulations (even into unexplored parameter regimes).

Other Activities: Data Management Plan

Main objective: "Scenario C" – Builds on the previous stages and allows for enhanced data provenance and referencing through PIDs [F,A,I,R].

Status 2025: "Release and expand"

- Adaptation to user needs and further performance improvements of various elements of the existing infrastructure
- Continuous updates to the released metadata catalogue
- Extended set of use cases supported for direct data access on a full(er) set of devices
- Demonstrate integration of IMAS based modelling /simulation data into the existing infrastructure

Continued collaborations with ITER (and UKAEA) on UDA, SimDB, and IMAS.

Other Activities: Artificial Intelligence

The primary objective is to improve data analysis efficiency and accelerate simulation timescales.

Status 2025

- Several **pilot projects implemented** across various WPs.

Outlook 2026-2027

- Consolidate AI & ML efforts by **reinforcing the most advanced projects**, as identified in the 2025 project review.
- **Secure AI & ML expertise** within one of the newly established ACHs to support these developments.

Infrastructure Requirements

- Large datasets accessible via **Long-Term Data Storage (LTDSF)**.
- High-speed connection between **LTDSF, HPC, and Gateway** to support AI-driven research.

Role of the E-TASC SB

The E-TASC SB is composed of 12 appointed experts in the area of computer simulations and theory from different RUs. Its collective expertise spans the full spectrum of software developed and utilized within EUROfusion. Currently, no other body, including STAC, can provide this level of specialized knowledge.

The continued operation of the E-TASC SB is critical to the success of E-TASC. It plays a key role in advising STAC and supporting the PM and HoDs on essential actions such as:

- Overseeing the overall progress in code development, particularly with regard to EUROfusion Standard Software, as well as code applications to important open science problems.
- Selecting new activities and determining the continuation, adjustment, or termination of TSVVs.
- Managing the transfer of TSVVs from WP TM to other WPs, depending on the maturity level of the codes within the TSVV.
- Distributing support activities for TSVVs provided by the ACHs.

E-TASC SB: Proposed Budget Cuts (2026-27)

Rationale

Group 1: Fixed Costs

- Hardware expenses (HPC + LTDSF) *must* remain at 12.8 M€.

Group 2: TSVVs & ACHs

- Consolidation and restricting ACH support exclusively to TSVVs result in a budget reduction of ~ 3.3 M€, equating to 30% of the 2025 allocation.

Group 3: Other Activities (AI, DT, DMP)

- A 30% reduction in these areas translates to savings exceeding 0.5 M€.

Total Expected Savings: ~ 4 M€

Mitigation plan by the E-TASC SB

EC Contributions 2026-27 [k€]

Activities	From GA, 12/2024 **DSD**	From GA, 12/2024 **PSD**	Consolidation of TSVV / ACH activities	Closure of ACH support to other WPs	Additional reduction, 30%	Activity Budget 2026-27	Group	DSD relevant Budget 2026-27
ACH	3,872		861	597		2,414	Group 1	2,414
DMP	334				100	234	Group 1	234
TSVV	9,715		1,831			7,884	Group 2	788
AI (in PSD)		786			236	550	Group 2	550
DT	653				196	457	Group 2	457
HPC	12,249				n.a.	12,249	Group 3	12,249
LTDSF	552				n.a.	552	Group 3	552
SUBTOTAL	27,375	786	2,692	597	532	24,340		17,244

Comments:

SAVINGS	*2,692 (consolidation of TSVV / ACH activities), 3,289 (add. ACH cut), 3,821 (add. 30% cut)*	**3,821**
TSVVs	*Currently in DSD-WPAC; to be transferred to new PSD-WPTM (except for TSVV-15)*	
AI	*Currently distributed over PSD and DID; to be transferred to DSD-WPAC*	
DT	*Will combine activities from TSVV-15, PoC DT projects, and synthetic diagnostics projects at PrIO*	

Proposed cuts are still damaging

Several critical activities essential to the broader EUROfusion program cannot be accommodated within the revised budget.

Sustaining these activities would provide significant benefits by ensuring continuity in key research areas, maximizing past investments, and advancing EUROfusion's long-term objectives.

Specifically, these activities include:

- **Further advancing, applying, and disseminating EUROfusion Standard Software** developed within the TSVVs since 2021 with support from the ACHs.
- **Retaining ACH teams** to provide vital support across a broad range of computational activities and ensure the efficient use of EUROfusion's investments in HPC infrastructure. These teams are very difficult to assemble due to highly attractive offers from the private sector.
- **Keeping pace with the integration of AI methodologies into fusion research**, including numerical simulations, plasma diagnostics, machine operation, and real-time control.
- **Fully implementing the EUROfusion Data Management Plan**, up to scenario "D."

Appendix

Focus of proposed WPTM activities in 2026-2027

- **H-Mode and Small/No-ELM Pedestals**
  - Ability to perform self-consistent, robust, and validated gyrokinetic (GK) simulations of L-H transitions, enabling accurate H-mode pedestal profile predictions.
  - Development of fast reduced transport models for core-edge predictive modelling.
  - Application of GK simulations and reduced models to natural or controlled small/no-ELM regimes, assessing their transferability to ITER and DEMO.

- **Plasma Particle/Heat Exhaust: Fluid Simulations**
  - Develop a comprehensive modelling capability (involving anomalous transport) for the plasma edge based on fluid/gyrofluid equations, including the physics of neutrals as well as a realistic description of plasma-wall interactions, leveraging synergies with other TSVVs.
  - Ensure that these tools scale efficiently on high-performance computing systems, enabling reliable and accurate results for experiment preparation, interpretation, and fusion power plant design.
  - Generalize these tools to non-axisymmetric geometries, validate them, and apply them to key questions in the physics of tokamaks and stellarators.

Focus of proposed WPTM activities in 2026-2027

- **Plasma Particle/Heat Exhaust: Gyrokinetic and Fully Kinetic Simulations**
  - Develop the capability to predict plasma particle/heat exhaust based on GK equations under conditions relevant to a collisional plasma edge and scrape-off layer (SOL), leveraging synergies with other TSVVs.
  - Use fully kinetic approaches to develop realistic boundary conditions in the SOL, and establish a multi-fidelity model hierarchy for the physics of neutrals, ranging from first-principles models to reduced representations.
  - Ensure that these tools are implemented efficiently and scale well on high-performance computing systems, to enable applications to large fusion systems.
  - Generalize these tools to non-axisymmetric geometries, validate them, and apply them to key questions in the physics of tokamaks and stellarators.

- **Plasma-Wall Interactions in DEMO**
  - Develop an integrated modelling suite to predict steady-state plasma-wall interactions (PWI) in DEMO.
  - Provide safety-critical insights for DEMO reference scenarios, including first-wall erosion, dust generation, and fuel inventory.
  - Enhance modelling capabilities to accurately simulate DEMO-relevant transient events.

Focus of proposed WPTM activities in 2026-2027

- ## Impurity Sources, Transport, and Screening

  - Develop an integrated modelling suite to predict the tungsten (W) impurity distribution in DEMO (including sources, transport, and screening), and assess its impact on plasma performance.
  - Create 3D kinetic transport models for heavy impurities (including W) and seeding species such as Ar, Kr, and Xe in the SOL and pedestal regions of DEMO.
  - Evaluate the effects of 3D perturbations and ELM suppression techniques on W impurity distribution in ITER reference scenarios and their implications for DEMO.

- ## Tokamak Disruptions and Runaway Electrons

  - Advance the understanding and predictive capability of tokamak disruptions.
  - Develop a self-consistent, robust, and validated model for runaway electron (RE) dynamics and mitigation in the presence of shattered pellet injection and 3D magnetic fields.
  - Create and validate a model for RE beam generation and losses, to be integrated into modelling tools and nonlinear MHD codes for accurate predictions of both mitigated and unmitigated disruptions.

Focus of proposed WPTM activities in 2026-2027

- **Burning Plasmas**
  - Develop a self-consistent description and corresponding simulation tools for the mutual interaction of energetic particles with MHD modes and turbulence, and their interplay with kinetic plasma profiles in both tokamak and stellarator geometries.
  - Develop a theoretical understanding and validated interpretative/predictive capabilities of burning plasma physics in both tokamak and stellarator geometries.
  - Develop strategies to optimize alpha heating to enhance reactor performance.

- **Validated Predictive Tools for Plasma Performance and Operational Limits in Tokamaks**
  - Establish an integrated modelling framework by coupling core and edge physics modules using validated models, including predictive transport solvers. This framework will enable the simulation of complete plasma operational scenarios, from breakdown to termination, under metallic wall conditions similar to those on ITER and DEMO.
  - Integrate and/or advance state-of-the-art models (from WPTM activities or the wider scientific community) for core transport; pedestal and SOL physics; heating and fueling; impurity transport; energetic particle transport; and the stability of burning plasmas in ITER/DEMO operational regimes.
  - Refine and expand these models with input and feedback from users working with existing machines, ensuring continuous improvement and, most importantly, their eventual adoption by the wider scientific community.

Focus of proposed WPTM activities in 2026-2027

- **Stellarator Optimization**
  - Develop a new, advanced European stellarator optimization code, based on improved algorithms for enhanced speed and greater scope.
  - Generate a number of highly optimized stellarator configurations which could form the basis for future stellarator devices and support the decision on how to progress with a next-step stellarator device.

- **Stellarator Core Turbulence**
  - Validate 3D gyrokinetic turbulence codes against stellarators like W7-X and tokamaks with broken axisymmetry, transcending the flux tube approximation and self-consistently treating multiple particle species.
  - Apply these codes (and theory) to advance the basic understanding of turbulent transport in the core region of stellarators under different plasma conditions.
  - Develop reduced transport models which can be incorporated in optimization efforts.