Key Physics Uncertainties and Related Investigation Needs towards Stellarator Reactor

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EUROfusion receives funding from the European Commission under Grant Agreement No. 101052200.

Introduction

This document provides an assessment of the key physics uncertainties—referred to as *gaps*—relevant to the development of a Stellarator DEMO. It outlines the associated research needs and evaluates which of these can be addressed within the scope of **Work Package Stellarator**.

Each identified gap affects either the *performance* or the *feasibility* of the device. These uncertainties can be mitigated through: **theory (T)** or **simulation (S)** studies, **Experiments (E)** on existing facilities, or **advancements (A)**, such as:

- new experimental devices (**Ax**),
- diagnostic improvements (**Ad**)
- model or code developments (**Ac**)

To structure the analysis, the gaps are prioritised according to two main criteria:

- **Impact on Machine Design** – Gaps with potential to significantly influence the machine design must be addressed early so that any required countermeasures can be integrated without affecting the project schedule.
- **Current Knowledge Gap** – Areas that remain insufficiently explored require prompt investigation to establish a robust scientific foundation for the upcoming design reviews.

Subjective Science Readiness Levels (SSRL) for Fusion Physics

Progress toward closing each gap is tracked using **Scientific Readiness Levels (SRLs)**, which quantify the maturity of the underlying research and its relevance to the Stellarator DEMO design.

- **SSRL-1 – Hypothesis / Emerging**
  A physics gap is recognized, and first hypotheses are formulated. No systematic investigation yet. Little or no understanding yet in Stellarator devices.
  Example: the closed island divertor might be required in a reactor.

- **SSRL-2 – Conceptual understanding / Exploratory**
  Theory and simplified models provide qualitative explanations. Order-of-magnitude estimates or heuristic scaling laws are available. Physical processes are being assessed, uncertain extrapolation towards a Stellarator DEMO
  Example: estimates of impurity compression in large islands.

- **SSRL-3 – Definition of requirements / Judgemental**
  Key parameters and diagnostics are identified. Codes or models exist in simplified form. Controlling the key physical processes in stellarators has been demonstrated. extrapolation to stellarator DEMO requires scalable parameters and decision if further investigation could/should be made can be taken
  Example: definition of divertor conditions needed for helium exhaust.

- **SSRL-4 – Confidence gained but needs underpinning**
  Feasibility is indicated by initial simulations or experiments. The methods to probe the gap exist. Good understanding of the underlying physics processes but extrapolation to Stellarator DEMO requires scalable parameters and further investigation
  Example: drift-induced asymmetries in heat flux observed and reproduced with EMC3-EIRENE.

- **SSRL-5 – Partial validation / Mature needs support**
  Simulations and experiments are able to reproduce selected phenomena quantitatively. Predictive capability demonstrated in limited regimes. Good understanding across all devices, further research required exploring Stellarator DEMO relevant parameters to reduce uncertainties for extrapolations
  Example: stable detachment at W7-X reproduced by modelling.

- **SSRL-6 – Consolidated physics basis / Established**
  The understanding is sufficiently mature that results from existing devices and models can be extrapolated with confidence to a larger device. At this level, one would attempt such a scenario in a next-step experiment without considering the risk of failure as critical for the device operation.
  Example: impurity retention and detachment scaling confirmed across present stellarators, providing confidence that similar regimes can be realized in a reactor-scale machine.

- **SSRL-7 – Demonstration at reactor-like conditions**
  The key processes are reproduced at high density, high β, or long pulse operation.
  Example: long-pulse operation in detached state with stable radiation levels in ITER with Q > 1 scenario.

- **SSRL-8 – Established physics basis**
  The uncertainty margins are quantified, and the understanding is mature enough to support design decisions.
  Example: The physics basis for divertor detachment under DEMO-relevant conditions is mature. Predictive models (e.g. SOLPS-ITER, EDGE2D-EIRENE) reproduce the onset, stability boundaries, and control dynamics of detachment within quantified uncertainty margins.

- **SSRL-9 – Resolved gap / design impact**
  The gap is considered closed. Its impact on the reactor design is quantified and integrated into the baseline.
  Example: Complete understanding of heat, impurity and particle exhaust with close divertor at the HELIAS reactor with parameters allowing for detailed design of functioning divertor

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Scenario integration

Experts: Pavel Aleynikov, Arturo Alonso, Heinrich Laqua, Nerea Panadero, Felix Warmer

High Priority:

1. (T, S, E, Ac) Develop reactor-relevant plasma fuelling schemes[1] (SSRL: 1)
    a. Develop predictive capability for solid pellet ablation and penetration depth and benchmark against W7-X experiments.
    b. Develop predictive capability for detached plasmoid transport and benchmark against existing experiments.
    c. Design fuelling scenarios for DEMO including pellet injection rates and locations; develop integrated modelling tools for pellet fuelling.
    d. Understand and interpret density profile formation in present-day experiments (plasmoid drift, gyro-kinetic particle pinch).
    e. Evaluate the necessity and implications of multiple fuelling systems.

Medium Priority:

2. (T, S, E, Ac, Ad) Develop auxiliary heating scenarios with ECRH[2] (SSRL: 3)
    a. Develop high-field-side X1 ECRH scenarios for 5 T and 6–7 T configurations; experimental validation remains required.
    b. Quantify how electron-cyclotron waves used for high-field-side heating interact with the supra-thermal electron population. Assess the resulting impact on heating efficiency and plasma performance.
    c. Develop O1 low-field-side scenarios, including improved validation and risk assessment near cut-offs.
    d. Devise operational strategies to compensate finite-beta effects on deposition profiles.

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[1] Cryogenic pellet injection is envisaged as the primary fueling method for reactor conditions. Key gaps were identified in the ability to predict (i) pellet ablation/penetration and (ii) the subsequent detached plasmoid transport, both of which strongly impact density profile control and thus overall performance and confinement analysis

[2] ECRH is a primary heating method for stellarator DEMO. While X2/O2 are established in present devices, DEMO-relevant fields (≈5–7 T) motivate O1/X1 schemes, which introduce new operational and physics challenges (cutoff proximity, deposition control under finite-beta, and kinetic effects).

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   e. Quantify anomalous transport when heating at non-Bmax locations; develop transport models accounting for kinetic ECRH effects.
   f. Quantify the effect of ECRH on impurity transport and its possible role in impurity pump-out.

Low Priority:

3. (T, S, Ac) Develop integrated scenarios including start-up/ramp-up of plasmas[3] (SSRL: 2)
   a. Develop an integrated plasma ramp-up simulation tool ("flight simulator") combining core/edge transport predictions with heating and fuelling actuator models.
   b. Improve predictive capability of plasma parameters for ECRH-assisted plasma start-up.
   c. Quantify performance and constraints throughout the ramp-up phase, not only at the final operating point.
4. (T, S, E, Ax, Ac) Address influence of quenches and operation limits on reactor scenarios (SSRL: 1)

   Although large plasma-current quenches are not expected in low-toroidal-current stellarators, sudden thermal energy loss events and magnet/coil quench risks must be addressed at the reactor level.

   a. Assess the risk of quenches triggered by component failures or foreign objects (e.g., thermal quenches) and develop a Quench Mitigation System if needed.
   b. Characterize the risk of component damage due to coil quenches.
   c. Clarify the physical mechanisms limiting plasma density under DEMO conditions.

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[3] Scenario feasibility depends on the full evolution towards the target operating point. Performance along the ramp-up may be sub-optimal and can impose unrealistic auxiliary power requirements if not modelled self-consistently.

Fast Particles and Alfvén Waves

Experts: J.L. Velasco, S. Bozhenkov, A. Mishchenko, C. Slaby, I. Calvo

High Priority:

1. (S, E, Ad, Ax) Perform experimental validation of improved confinement at large β[4] (SSRL: 3)
   a. Develop experimental scenarios with high plasma beta in which the influence of the radial electric field E_r and collisional slowing-down on fast-ion confinement is minimized or well controlled.
   b. Demonstrate that existing fast-ion sources (e.g. NBI, ICRH/ECRH-driven populations) can populate the region of phase/configuration space where the predicted confinement improvement is expected.
   c. Verify that available diagnostics have sufficient spatial, temporal, and energy resolution to resolve the predicted changes in fast-ion confinement.
2. (E, S, Ac) Perform experimental measurements of AE induced FI losses and verification of model prediction[5] (SSRL: 3)
   a. Develop discharges with sufficiently high fast-ion pressure to reliably excite Alfvén eigenmodes (AEs).
   b. Quantify whether AE activity leads to increased fast-ion losses, enhanced wall loads and/or a reduction in effective heating power.
   c. Use these experiments to validate both reduced fast-ion/AE models and fully gyrokinetic approaches.
3. (E, S, Ac) Develop reliable quantitative prediction of losses to the first wall[6] (SSRL: 3)
   a. Carry out extensive benchmarking of existing codes that predict fast-ion losses to the first wall.

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[4] According to theory, finite β modifies fast ion orbits in a QI field in a very similar way as shifting inwards the configuration of LHD does; improvement in fast ion confinement has been measured in LHD in such circumstances, which is considered a first evidence of the optimization strategy working.

[5] Models of various complexity are available, most stop at the LCFS, fully gyrokinetic approaches are numerically expensive, and reduced models still need to be validated; Alfvénic fluctuations have been measured; AE induced FI losses have been measured in LHD.

[6] In W7-X, a small fraction of the fast ions is lost to the areas outside of the divertor, forming hot spots, with loads predicted to be in the MW/m^2 and measured to be lower.

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   b. Include realistic edge plasma conditions in the modelling by explicitly accounting for measured/simulated edge plasma profiles and neutral densities (including charge-exchange effects) when predicting fast-ion losses to the first wall.

   c. Identify and design experimental scenarios where fast-ion losses can be unambiguously compared with model predictions.

Medium Priority:

1. (E, S, Ac) Perform assessment of the interplay between fast ions, zonal flows, and turbulence (SSRL: 2)

   a. Develop dedicated experimental scenarios to study how fast ions, zonal flows, and turbulence interact to determine whether this interplay leads to increased wall loads and/or reduced effective heating.

   b. Model the identified scenarios using fully gyrokinetic simulations that self-consistently capture the mutual interactions between fast ions, turbulence, and zonal flows.

2. (S, Ac) Assess sensitivity of reactor-relevant plasma scenarios to error fields, β_{FI} and β_{bulk} effects, and plasma currents[7] (SSRL: 3)

   a. Develop experimental reactor-relevant scenarios, with particular emphasis on scanning the fast-ion beta

   b. Perform a broad set of nonlinear gyrokinetic simulations to quantify how error fields, fast-ion pressure, bulk-plasma pressure, and currents affect performance and stability.

Low Priority:

3. (E, Ad) Develop measurement techniques to diagnose fast ions in a reactor[8] (SSRL: 4)

   a. Identify key diagnostics needed to measure fast-ion parameters including: spatial distribution, energy spectrum, pitch angle distribution, confinement time, and loss rates under reactor-relevant conditions (high

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[7] For some aspects tools are available, datasets probably exist or can be created

[8] There are many aspects in common with tokamaks, and well-known techniques, such as collective Thomson Scattering, gamma ray spectrum, and neutron measurements, should be available

neutron flux, limited diagnostic access, long-pulse or steady-state operation).

b. Assess the technical and economic feasibility of deploying these diagnostics in a reactor environment, considering radiation hardness, remote handling requirements, and compatibility with reactor operational constraints.

Core Transport

Experts: J. M. García-Regaña, D. Carralero, A. Dinklage, J. L. Velasco

High Priority:

1. (T, S, E, Ac) Assess the dependence of turbulent transport on magnetic configuration (SSRL: 4)
    a. Validate the observed relationship between magnetic configuration, density gradients and turbulence reduction across the full W7-X configuration set, using joint power-balance analysis and turbulence measurements.
    b. Extend gyrokinetic and neoclassical simulations to the same range of configurations and scenarios and benchmark against the experimental database.
    c. Quantify configuration-dependent transport coefficients and provide reduced metrics suitable for use in stellarator optimization and DEMO scenario design.
2. (T, S, E, Ac) Bring profile predictive modelling to routine application (SSRL: 4)
    a. Integrate neoclassical and turbulent transport models into robust profile-evolution solvers (e.g. TANGO–GENE–KNOSOS, T3D–GX–SFINCS) for routine use in W7-X and DEMO-relevant studies.
    b. Validate predictive profile simulations against a broad set of W7-X discharges (standard ECRH, high-performance NBI/ECRH, different configurations), including sensitivity to edge boundary conditions.
    c. Apply validated tools to reactor scenarios to assess whether required confinement and temperature profiles can be achieved within realistic engineering limits.

3. (E, S, Ax, Ac) Develop experimental scenarios with reactor-relevant parameters to validate core transport models (SSRL: 3)
    a. Develop plasma scenarios[9] to approach reactor-relevant β, collisionalities and normalized ion gyroradius ρ_i^* as closely as possible to conditions expected in the stellarator reactor.
    b. Characterize the onset of β-driven electromagnetic turbulence and MHD activity (e.g. kinetic ballooning modes) in these scenarios and benchmark against advanced stability and turbulence models.
    c. Use the resulting experimental dataset to validate and benchmark transport models and stability predictions in order to test whether the physics models used for reactor design extrapolate correctly from present-day experimental regimes to plasma parameters expected in stellarator fusion reactor.

Medium Priority:

1. (T, S, E, Ac) Bring the understanding of multi-species transport and multi-channel impurity transport to the level required by a stellarator-reactor (SSRL: 2)
    a. Develop and apply integrated transport models that treat main ions, helium and high-Z impurities simultaneously, combining neoclassical, turbulent and classical contributions.
    b. Exploit present and future W7-X campaigns (including metallic-wall operation) to measure impurity and helium transport in regimes with varying turbulence levels, and compare with model predictions.
    c. Quantify conditions under which a finite level of turbulence beneficially prevents impurity accumulation and core density depletion, and translate these into reactor operating constraints and optimization targets.
2. (T, S, E, Ac) Establish validated turbulence models for stellarator reactor transport predictions (SSRL: 1)
    a. Assess the impact of electromagnetic sub-threshold modes, impurities and ion-temperature-gradient–driven Alfvénic activity on core heat and particle transport in stellarators, using dedicated high-fidelity simulations.
    b. Perform multi-scale turbulence simulations (coupling electron- and ion-scale turbulence, including fast-ion interactions) under DEMO-relevant

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[9] For instance by further developing low field, high performance scenarios at Wendelstein 7-X

parameters (β, ν^*, ρ_i^*) to establish which physics can be safely approximated by reduced models and which must be treated with full kinetic theory for accurate reactor predictions.

c. Identify experimentally[10], which physical mechanisms (e.g., zonal flow damping, electromagnetic stabilization, impurity effects) are critical for reactor transport modelling and must be included in integrated DEMO scenario tools.

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[10] This could be performed as coordinated validation campaigns at Wendelstein 7-X combining targeted turbulence measurements with matching simulations

MHD Equilibrium and Rotational Transform Control

Experts: K. Aleynikova, A. Alonso, J. Geiger, J. Loizu

High Priority:

1. (T, S, E, Ad, Ac) Achieve high-beta and nonlinear MHD stability[11] (SSRL: 3)
    a. Perform large-scale nonlinear MHD simulations (e.g., using JOREK, M3D-C1, FAR3D) and validate their results against existing stellarator experiments with appropriate quantitative metrics developed which allow the comparison between experiments and simulations.
    b. Assess the limits of linear stability analyses, identifying conditions where linear predictions remain reliable, and develop predictive models for high-β stability limits in 3D equilibria combining ideal and resistive MHD formulations with kinetic corrections.
    c. Benchmark stability predictions against experimental data at elevated β[12] and evaluate the relative importance of magnetic-field chaos at finite β in different configurations, determining tolerable levels of stochasticity that do not significantly affect transport.

Medium Priority:

2. (T, S, E, Ac) Address current-driven plasma terminations and bootstrap effects[13] (SSRL: 4)
    a. Develop predictive tools to determine stability thresholds for current-modified equilibria and validate these tools against measurements (for instance at W7-X).

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[11] Achieving and maintaining high-β operation is essential for stellarator reactor performance, yet predictive understanding of β limits and nonlinear stability behavior in 3D configurations remains incomplete. Current optimization and design tools rely primarily on linear stability analyses, which may not capture nonlinear effects such as mode coupling, saturation, and soft-limit dynamics that determine operational margins. A unified approach to high-β and nonlinear MHD stability is therefore needed to establish reliable design boundaries and control strategies.

[12] This analysis could be performed at W7-X provided enough experimental data at $\beta > 3\%$ can be obtained.

[13] Termination events in W7-X triggered by Electron Cyclotron Current Drive (ECCD) demonstrate the sensitivity of MHD stability to current-profile modification. Understanding the combined effect of ECCD and bootstrap current is critical for high-β reactor operation.

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   b. Create experimental scenarios, which will allow to reproduce and mitigate termination events via current-profile control.

3. (T, S, E, Ad, Ac) Ensure divertor topology resilience at high-β scenarios[14] (SSRL: 3)

   a. Quantify sensitivity of divertor strike-point geometry and island topology to β and current variations using equilibrium reconstruction, and benchmark topology changes with W7-X island-divertor measurements.

   b. Define operational windows ensuring stable exhaust conditions under finite-β effects and develop fast numerical tools for evaluating divertor topology resilience in optimization workflows.

Low Priority:

4. (T, S, E, Ac) Develop integrated core–edge MHD stability models[15] (SSRL: 2)

   a. Develop global tools capable of simulating coupled core–edge dynamics including heat-flux redistribution and magnetic-topology evolution, and identify key experimental observables for benchmarking integrated stability predictions.

   b. b. Validate simulation results through coordinated analysis of W7-X data combining core diagnostics with edge measurements, and investigate the influence of core magnetic islands on global confinement and stability.

5. (T, S, Ac) Develop advanced equilibrium solvers[16] (SSRL: 4)

   c. Develop next-generation equilibrium solvers combining high accuracy with rapid convergence in complex geometries, and benchmark solver performance using experimental equilibrium reconstructions from W7-X and data from LHD, HSX, and TJ-II.

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[14] The robustness of divertor magnetic topology under equilibrium variations (e.g. β, plasma current) within optimization loops remains uncertain, although promising experiments have been performed at W7-X. Predictive metrics for topology stability are required to ensure reliable exhaust and heat-flux control.

[15] Core and edge stability are strongly coupled: core islands and pressure perturbations can influence edge transport and divertor loads, while edge instabilities can feed back on core confinement. Predictive models capturing this interplay are currently lacking.

[16] Equilibrium solvers are the foundation of all stellarator analysis. Existing codes face trade-offs between accuracy and speed, particularly in the presence of magnetic islands and stochastic boundaries.

   d. Quantify code limitations (e.g. for VMEC, GVEC, DESC) and establish guidelines for selecting appropriate models. Assess the sensitivity of equilibrium reconstruction accuracy to uncertainties in input parameters.
   e. Define the required coil-position accuracy for controlling core and edge magnetic islands, and identify where higher geometric precision is necessary to maintain target equilibrium quality.

6. (T, S, Ac) Find optimum between optimized transport and MHD stability[17] (SSRL: 2)
   a. Benchmark trade-offs using W7-X configuration variants and synthetic equilibria that explore different optimization weightings.
   b. Validate optimization outcomes against experimental confinement and stability performance across multiple configurations.

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[17] Optimization for neoclassical transport or turbulence reduction can inadvertently compromise MHD stability (by reducing magnetic-well depth, for example). A balanced optimization framework is needed to reconcile performance and stability objectives.

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Heat and Particle Exhaust in Island Divertor

Experts: V. Winters, T. Kremeyer, V. Perseo, F. Reimold, M. Jakubowski

High Priority:

1. (S,E,Ac) Assess quantitatively influence of drift effects on heat/particle transport. (SSRL: 2)
    a. Quantify how drifts modify density build-up and heat exhaust in both open and closed island divertor concepts.
    b. Develop predictive capability (codes including drifts) and benchmark against W7-X experiments.
2. (S, E, Ax, Ad) Assess the necessity of a divertor closure for a HELIAS reactor and if so, whether there is a feasible design. (SSRL: 2)

Medium-High Priority:

3. (S, Ac, Ax) Determine the scaling of cross-field transport with device size/island geometry/plasma parameters. SSRL: 1
4. (E, S) Experimental validation of boundary physics models SSRL: 2
    a. Quantify location and severity of detailed mismatches between state-of-the-art simulation codes and experimental results in a stellarator.
    b. Determine whether the level of mismatch is within feasible uncertainty of constructing a stellarator fusion reactor.
5. (T, E, S, Ax, Ac?) Core/Edge compatibility and extrapolation to different devices[18]. SSRL: 1
    c. Quantify upstream parameters required to maintain divertor heat fluxes <10 MW/m^2 (LCFS ne, Te, and impurity content)
    d. Quantify Helium enrichment at the safe heat flux operational point and whether it is compatible with requirements to avoid fuel dilution of the core.

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[18] The following points are dependent on divertor target geometry and therefore should be tested for W7-X as-built. But ideally other target geometries should be considered (any W7-X divertor upgrade or a new stellarator experiment would be required)

   e. Compare upstream parameters from edge codes with LCFS parameters from core codes to determine core/edge compatibility

Medium Priority:

6. (E, S, Ax?) Island/SOL geometry for optimal heat/particle exhaust performance (SSRL: 4)
   f. Quantify concentration of seeding impurities in the divertor required to maintain heat loads <10MWm-2. Quantify enrichment of impurities in the divertor (Ne, Ar, Kr, Xe).
   g. Evaluation of basic SOL/divertor geometric requirements to maintain easily controllable radiation levels without reattachment.
   h. Quantification of basic physical processes determining maximum achievable divertor densities in a stellarator island divertor

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Plasma-Wall Interaction & Plasma-Facing Components in the Stellarator Divertor

Experts: J. Romazanov, S. Brezinsek, D. Naujoks, J. Fellinger, M. Jakubowski

High Priority:

1. (S, E, Ax, Ad, Ac) Predict gross erosion of tungsten (SSRL: 5)
    a. Develop predictive capabilities (including collection of experimental data for extrapolation and model validation) of global W sources considering specific erosion mechanisms for divertor targets, main chamber components and remote areas.
    b. Alignment with tokamak DEMO: Medium – basic PWI physics are similar, but irradiation conditions differ (spatial and energy/angular distributions of particle fluxes); global-scale codes/models available for axisymmetric devices not applicable.
2. (S, E, Ax, Ad, Ac) Predict migration & core influx of tungsten (SSRL: 2)
    a. Develop predictive capabilities (including collection of experimental data for extrapolation and model validation) to describe transport of eroded tungsten in the edge plasma. In particular, quantify difference between gross and net erosion considering prompt re-deposition and other transport mechanisms (drifts, friction, thermal forces), as well as the contribution of unscreened W flux into the confined plasma from divertor and main chamber components.
    b. Alignment with tokamak DEMO: Low – 3D geometry of the island divertor in stellarators and island physics lead to substantial differences in edge transport. Still no reactor relevant scenario have been identified.
3. (E, Ax) Qualify closed island divertor with tungsten targets in terms of PWI (SSRL: 3)
    a. Confirm desirable tungsten erosion & screening (see items 1-2) in closed island W divertor with improved baffling.
    b. Alignment with tokamak DEMO: Low – see items 1-2.
4. (E, Ad) Qualify reactor-compatible W-based materials and components (SSRL: 4)

   a. Design transition from plasma-facing material (W) to heat sink material (e.g. Cu); assess W composites (e.g. W/Ni/Fe alloys) in place of pure W.
   b. Alignment with tokamak DEMO: High – material physics is the same, synergy available in EUROfusion work package WP-DIV.

Medium-High Priority:

5. (S, E, Ax, Ac) Develop strategy for wall conditioning on W PFCs (SSRL: 4)
   c. Assess B layer lifetime and redistribution. Test boronization on W components by GDC, ECWC, powder/pellet injection; optimize for homogeneous B layers and low-Z plasma (relevant especially during reactor start-up).
   d. Alignment with tokamak DEMO: Medium – basic PWI physics of boronization is the same, but differences in transport between tokamak and stellarator affect boronization homogeneity in powder/pellet injection, as well as redistribution of eroded B.
6. (S, E, Ax, Ac) Quantify T retention and develop strategy for cleaning (SSRL: 5)
   a. Estimate short and long-term retention by implantation/co-deposition + diffusion, trapping, permeation (affects wall pumping, outgassing, fuelling and density control). Assess fuel removal efficiency by different cleaning techniques incl. baking, cleaning discharges, GDC, ECWC. Develop fuel retention mitigation and removal strategies.
   b. Alignment with tokamak DEMO: Medium – basic PWI physics is the same, but (as in item 1) fluxes may be qualitatively different and global models not applicable.

Medium Priority:

7. (S, E, Ax, Ac) Assess effects of 14 MeV neutrons on materials (SSRL: 3)
   a. Consider influence of neutron damage (dpa, transmutation) at DEMO-relevant fluence on retention, thermo-mechanical properties, diagnostics degradation; assess effect on other items.
   b. Alignment with tokamak DEMO: High – material physics is the same.
8. (S, E, Ax) Predict dust, flaking, arcing and melt damage on W PFCs (SSRL: 2)

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a. Estimate effects of dust, flaking, arcing, melting on PFC lifetime, W sources, T retention, environmental hazard of dust; estimate contribution of fast particles.

b. Alignment with tokamak DEMO: Low – significant reduction of transient damage in stellarators compared to tokamaks expected.

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