EG-6
Fusion technology developments

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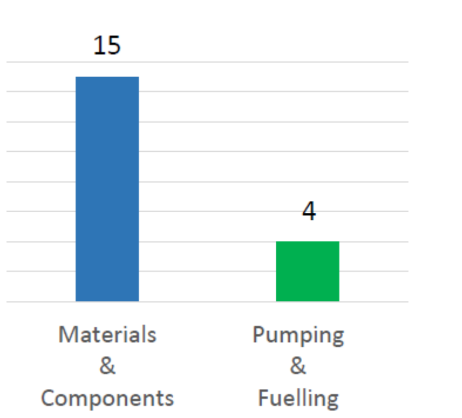
DTT Research Plan - 3rd meeting

13-15 Dec 2023

Where we stand

- The current chapter reflects 19 proposals that have been developed together with the community (Meetings with the expert group)



- Characterisation of materials:
  - Coatings, alloys, composites, printed [PWI characterisation measurements]
- Characterisation of well-defined pre-damaged materials:
  - Artificial defects, cracks,
- Testing of new components:
  - 2nd divertor, FW module
- Validation of DEMO fueling/gas processing technology (pumping, pellet injection)

Outline Structure of chapter 9 (8 chapters)

Chapter rationale

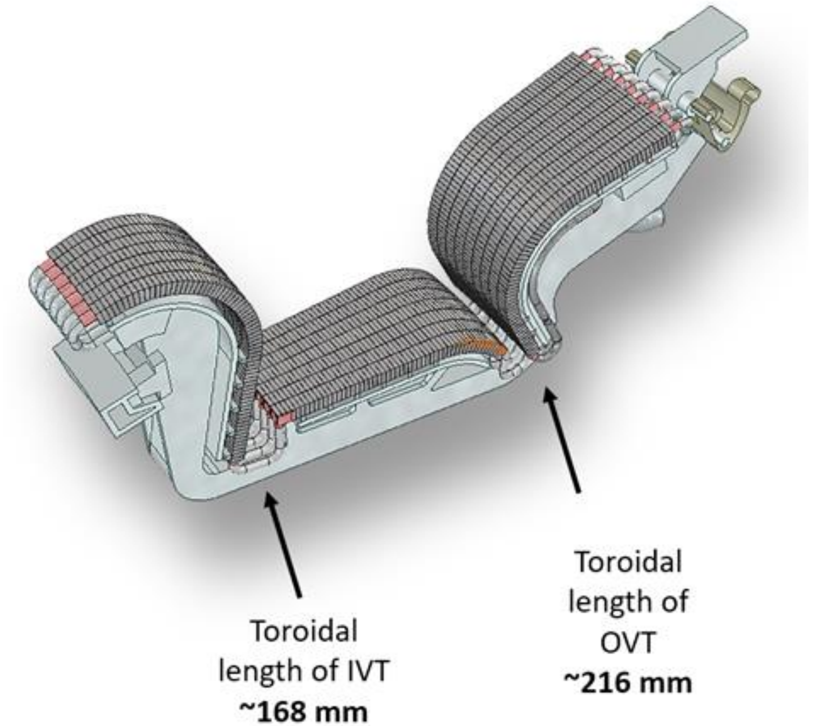
- Focus on PFCs
- Support ITER and DEMO
- Test of materials and components within and beyond specification
- Second divertor options (ADC, LM, W) in view of DEMO alternatives
- For matter control:
  - ITER: Fuelling and pumping actuators are decided, designed, and ready to be manufactured.
  - DEMO: Both fueling and pumping actuators will follow a novel technology, in the maturation of which DTT can play a vital role.
  - In addition, divertor particle exhaust depends also on the pumping system, which has not been validated in the past (and will not happen at ITER).

The role of DTT in PFC/PFM testing

- Ensure save DTT divertor operation in standard SN arrangement (characeterisation etc. / DTT purpose)
- DTT uses standard full W divertor monoblock (MB) solutions with reference W, but
  - ITER MB qualification completed
  - DEMO MB qualification close to completion

  => Impact lowish on „standard solutions" due to start of DTT operation

- Utilisation of a sector of the divertor (divertor test module) addressing a few open scientific topics with smart MB elements:
  - roughness variation (technical to polished surface)
  - shaping and alignment variation (with IR view)
  - PWI tiles (FIB cuts, erosion/deposition marker etc.)
- Only INTEGRAL information and can be done with reduced operational DTT parameters (first phase of DTT)



Similar approach for first wall materials. Test bed for ITER and DEMO FW solutions. Enhance this part?

The role of DTT in PFM qualification

- DTT can be use to qualify novel W-based materials (from EU research): divertor
  - Fiber-reinforced tungsten composites (WfW, WfCu)
  - Tungsten alloys based on nanostructuring
  - Functionally graded materials (W/Fe, W/Cu) with optimised spatial fraction in order to minimise the local stresses under the plasma exposure
  - 3D printed tungsten (latticed W)
  - CPS-Sn test module
  - ….

=> Use of all divertor test modules and dedicated campaign phases with „reliable & moderate solutions to compare" => Need to fit into MB design not disturb rest of the divertor

=> Comprehensive diagnostic and pre- and post-analysis program => bridge to lab. research

- DTT can be use to qualify novel W-based materials (from EU research): first wall
  - self-passivating tungsten alloys (W-Cr-Ti, W-Cr-Y)
  - thick tungsten coatings (plasma sprayed W)
  - porous tungsten (or other refractory material) as self-healing materials

OPEN to other partners to TEST PFM within given first divertor shape and capabilties!

The role of DTT in divertor PFC testing

- “Unexplored” field of PFC testing in a tokamak: damage evolution / degraded / repaired PFCs / new designs
  - Explore damage evolution and performance in comparison with reference material
  - Utilise divertor test module with “pre-damaged” MBs for dedicated campaign
  - Focus on repetitive plasmas to study damage evolution
  - All damages also simulated in laboratory experiments => DTT is bridge to DEMO lifetime

- W divertor damages to be addressed:
  - artificial damage and cracks (pre-cracked or damaged by melting events by e-beam/laser/plasma loads)
  - irradiation damage simulated by using synchrotron-irradiation (30 MeV)
  - interfacial defects
  - W-ion self-damage and/or He-damage
  - melting/solidification/recrystallization evolution
  - W transmutation material mix performance (Os, Re)

- Repaired damaged MB, new designs, and testing in DTT
  - Laser-repaired W MB
  - W-coated pre-damaged W MB
  - New PFC designs

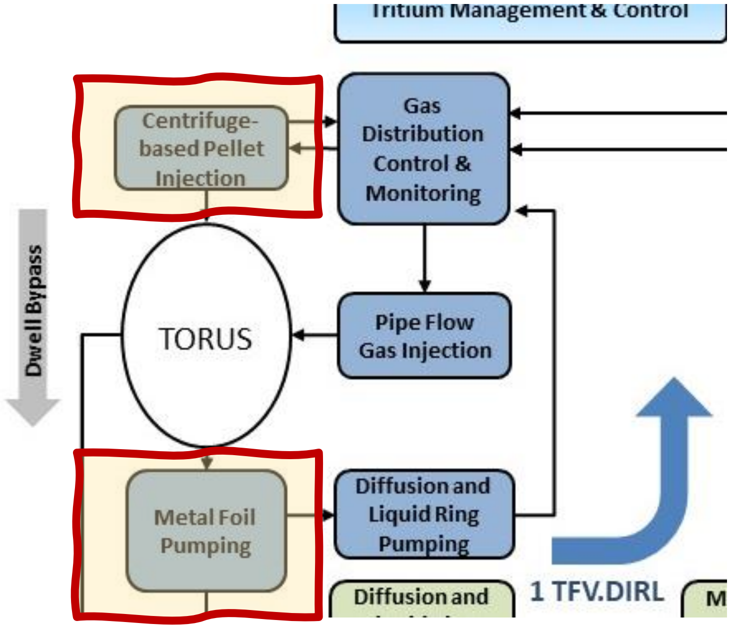
Phase of testing to be identified:
=> requires dedicated phase
(campaign) of programm

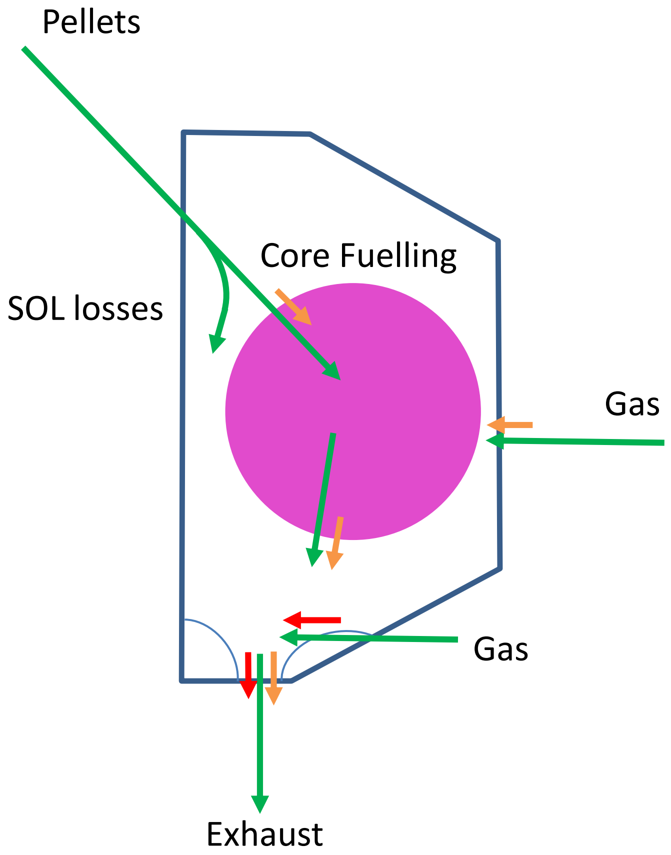
FW module testing / the second divertor

- A dedicated FW module with separate cooling should be designed to perform “full-size” component testing
- Technically DEMO-like size module could be installed and instrumented for PWI studies
  - Critical questions about first wall fluxes (CXN and Ions)
  - Critical questions about local re-deposition (lifetime)
  - Critical questions about retention and permeation through module (fuel cycle, barriers)
  - Critical question about cooling (mimic DEMO backside design)
- Operation of DTT in full specs required => beyond present research plan of 10 years

- PEX Studies and DTT ADC tests will result in a decision about the (most promising) 2nd divertor option for DTT
- Several options:
  - Traditional “DEMO” MB solutions with optimised shape and magnetic configuration
  - Novel components solutions arising from European Research program (DEMO baseline)
  - Alternative divertor based on liquid metal solution (e.g. Sn CPS) developed (e.g. European PRD program)
- Decision point needs to be defined
  - before or after full performance of DTT is achieved (lifetime of 1st divertor ?)
  - Final development, qualification, manufacturing, installation requires about 5 years

Driven by the need for technology maturation

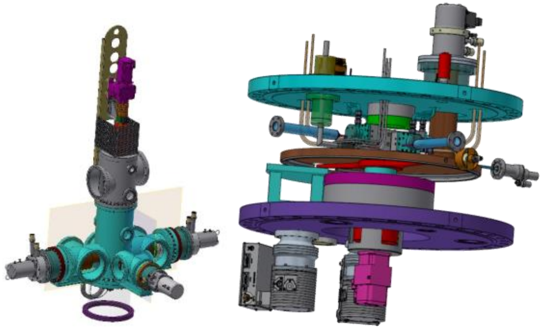




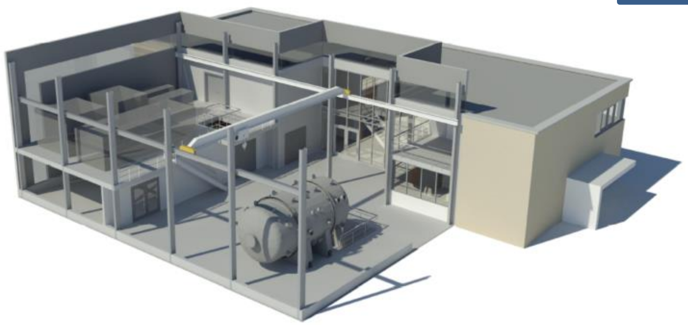
- DEMO novel fueling and pumping technologies have been rated with low technical maturity.
- DTT provides central opportunities to demonstrate reactor relevant technology.

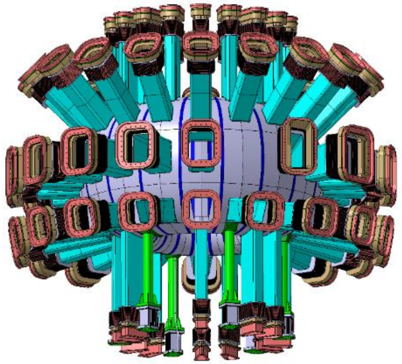
The role of DTT for reactor relevant Fueling

- EU-DEMO is developing a (cryogen-free) EU design for pellet injection for core fueling, based on screw extrusion + centrifuge.
- Different technology than at ITER



DIPAK
The DIR Integrated Development Platform Karlsruhe





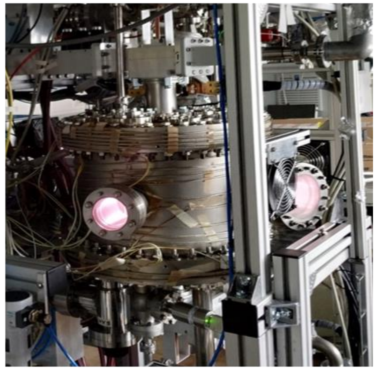
Phase 1 –
Pre-experiment
2024-2026

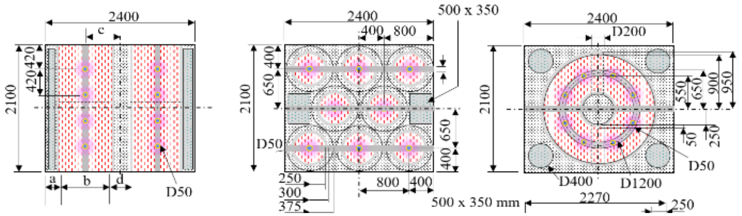
Phase 2 –
Integration of verified injector with guiding tube
2027+2028 → increase fidelity

Phase 3 –
Integration with plasma
From Day 1: 2028+

The role of DTT for reactor relevant Pumping

- The only solution to achieve acceptably low operational tritium inventories in EU-DEMO is the Direct Internal Recycling via a metal foil pump.
- Different technology than at ITER





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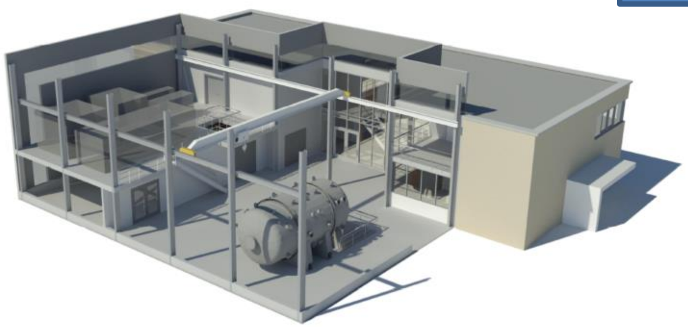
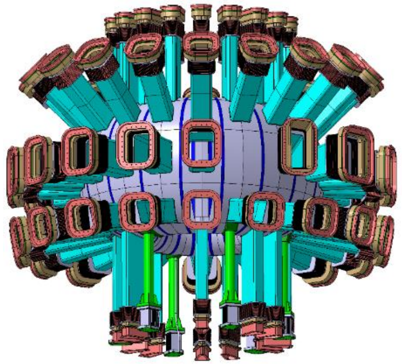




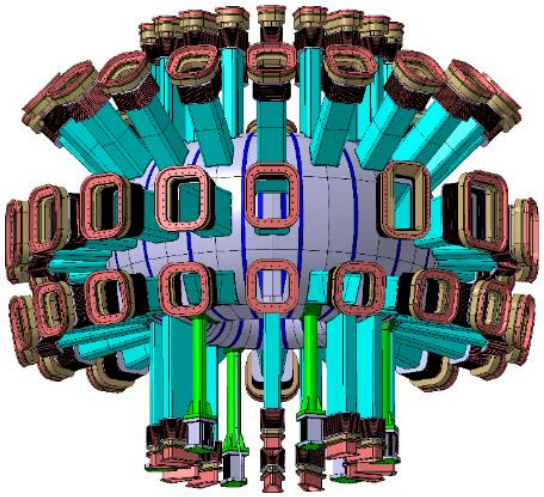
Phase 1 –
Design completion and build
2024-2026

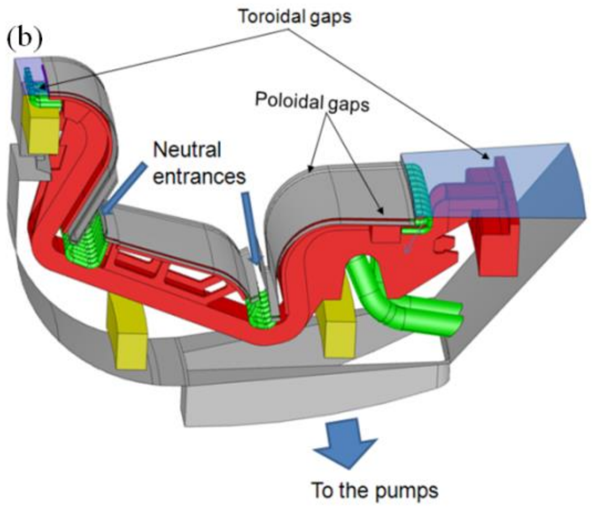
Phase 2 –
Operation of metal foil pump
2027+2028 → increased reliability

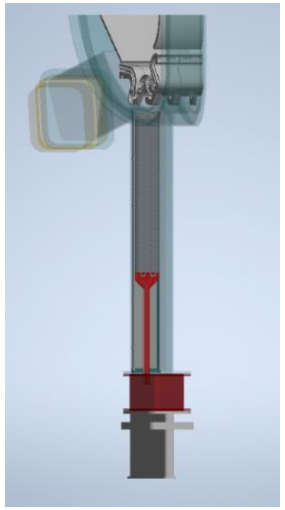
Phase 3 –
Integration with real tokamak external gradient mag field
2028+

The role of DTT to learn technical divertor operability

- For translation of the particle exhaust capability of the DTT divertor under the specific DTT pumping technology to any other integrated divertor solution, we need a validated translation tool that describes neutral gas dynamics → 3D DIVGAS.
- → Detachment control, divertor buffering, and associated requirement on divertor actuators.







Case 1: basic scenario (incl. toroidal and poloidal leakages)