

EUROfusion and F4E collaboration for the European Test Blanket Module

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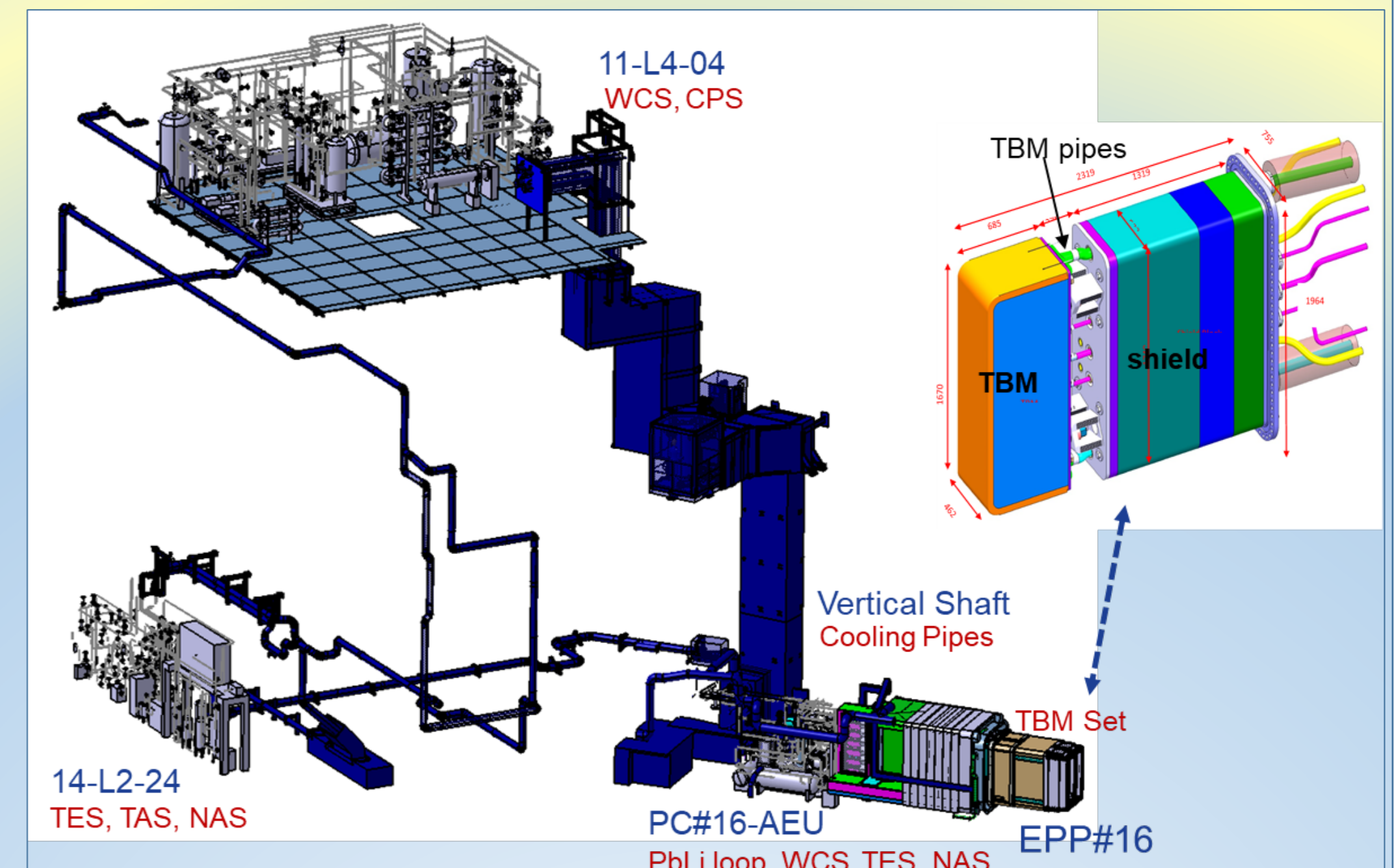
In 2017, a technical and programmatic assessment of both the EUROfusion DEMO Breeding Blanket and the Fusion for Energy Test Blanket Module programmes was undertaken with the objective of streamlining them and ensuring full consistency. Fusion for Energy and EUROfusion have agreed on the need to rationalise and coordinate the use of European resources to facilitate the achievement of the Fusion Roadmap objectives, proposing an enhanced R&D programme. This agreement allows to avoid duplication of work while, at the same time, exchange of data and technical requirements insure coherence between the two projects. Furthermore, specialised technical competences and dedicated test facilities are mutualised, selected activities are prioritised to secure the R&D needed for the Test Blanket Module programme. The paper describes the joint execution of such R&D activities and the ongoing EUROFER97 structural material qualification for both the Helium-Cooled Pebble-Bed and Water-Cooled Lead-Lithium Test Blanket Module systems. This joint effort focuses on the development and qualification of functional materials, predictive tools, and sensors, integrated testing of the main relevant technologies, safety analyses as well as EUROFER97 base material and weld qualification and experimental campaigns in support of design rule validation. These activities have been then grouped in four packages: (i) System Modelling, (ii) Technology R&D, (iii) Safety and (iv) Materials. An overview of the main activities performed in the period 2021-2022 is presented.

MODELLING

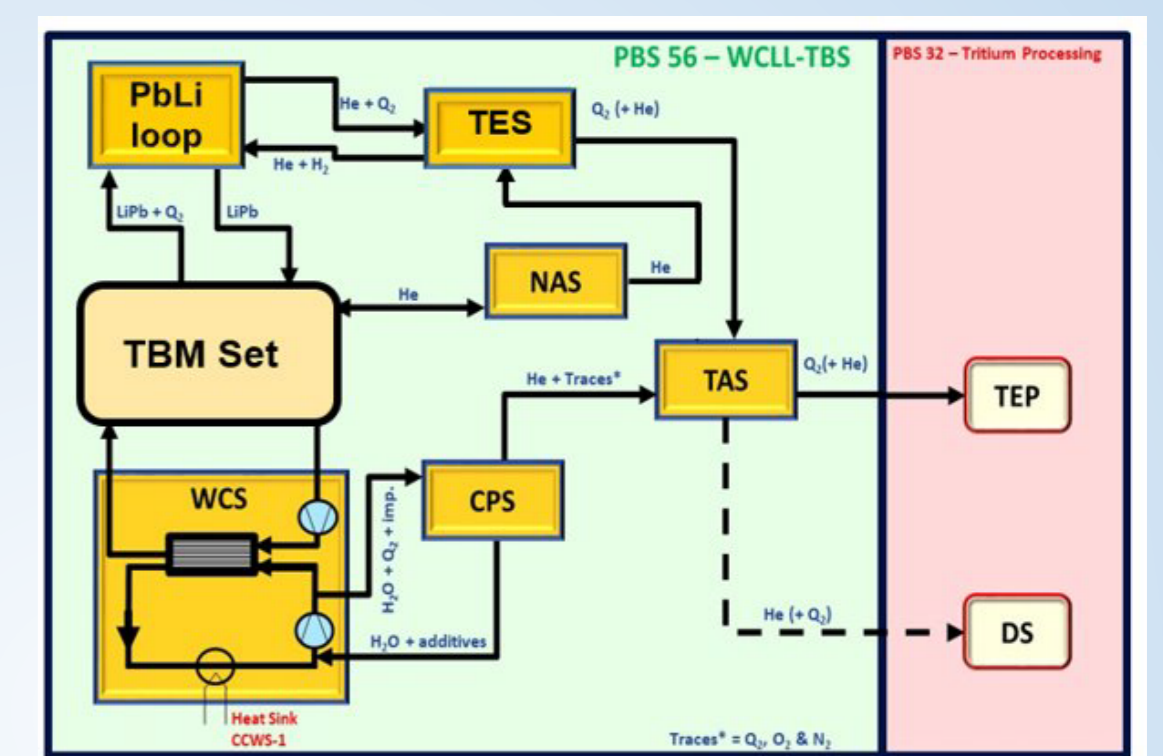


- HCPB Modelling:** Preliminary Studies on dust formation and fragmentation; Modelling of dust formation/re-suspension mechanisms experiments; Simulation studies on dust formation and fragmentation inside HCPB-TBM granular material
 - Tritium transport modelling:** HCPB-TBM advanced tritium transport model: system level model upgrade *✓ Carried out 21/22*
 - MHD modelling:** Full numerical MHD analysis for PbLi flow across the shield and manifolds coupled to BU; Installation of the mock-up in MEKKA and instrumentation and results of the mock-up experiments in MEKKA
 - PbLi flow modelling:** HTC correlations and ONB relevant for WCLL; Pressure drop correlations involving MHD effects, evaluation of pressure drop vs. Re and Ha; Development of a multi-physics coupled tool for WCLL-TBS; Implementation of working fluids in RELAP5 PbLi and molten salt and Coupling of SIMMERIV/RELAP5 for the sim. of the WCLL-TBS; Transport models for solid particles; Feasibility study of a magnet system coupled with LIFUS5
 - Thermal-hydraulics of Water flow modelling:** Preliminary study of flow-induced vibrations in double-wall tubes
- Work in Progress*
- Development of a common RELAP5/Mod3.3
 - Transport models for unmixed species in PbLi in relevant WCLL-TBS configuration
 - Numerical simulation of the LIFUS5/Mod2 and Mod3 experimental tests
 - Study of the WCLL-TBS behavior under selected operating scenarios
 - Study of flow-induced vibrations in double-wall tubes for the WCLL-TBM
 - Water Chemistry specification and impact on the CPS Design
 - Water Loop safety related activities

WCLL TBS Architecture



- TBM box in EUROFER97 (RAF6M)
- Breeder: Pb-16Li
- Neutron multiplier: Pb-16Li
- Coolant: pressurized water, inlet pressure 15.5 MPa, 295-328 °C inlet/outlet temperature
- Thermal power extraction in BU: pressurized H2O through channels in horizontal cooling plates
- Thermal power extraction in FW: pressurized H2O through channels
- T extraction: gas-liquid contactor, He+H2 stripping gas



TECHNOLOGY

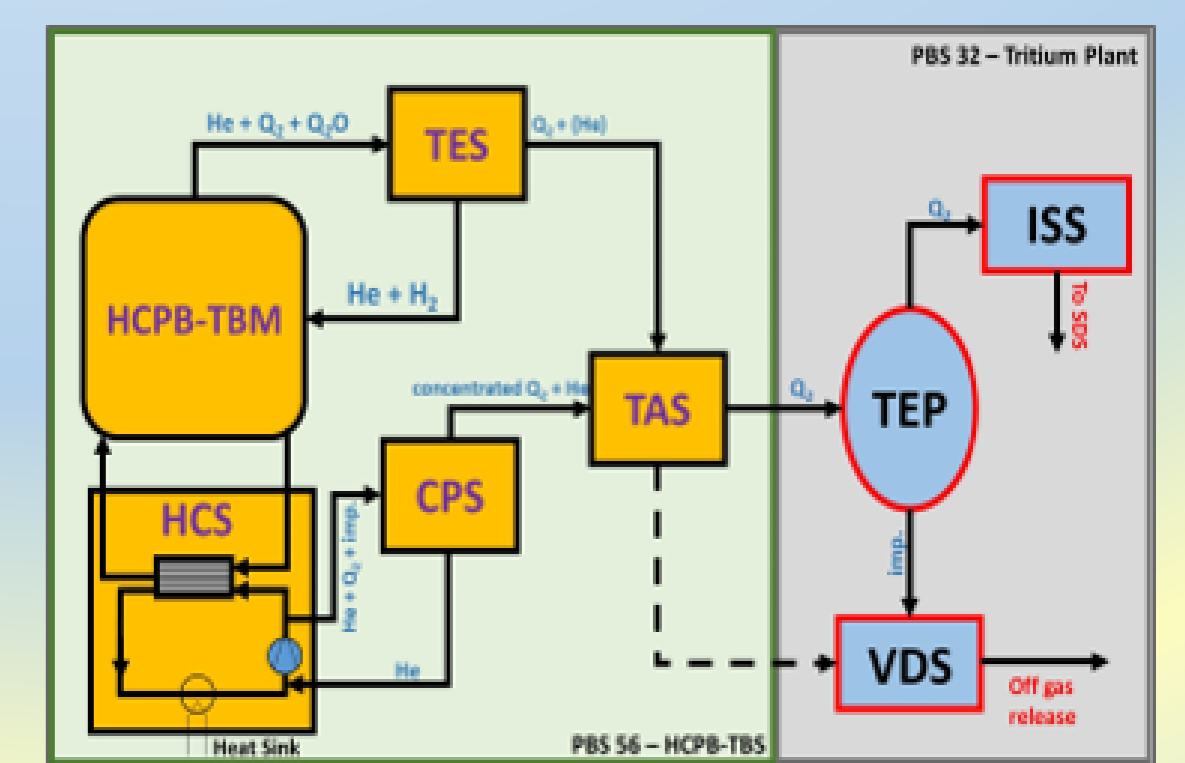
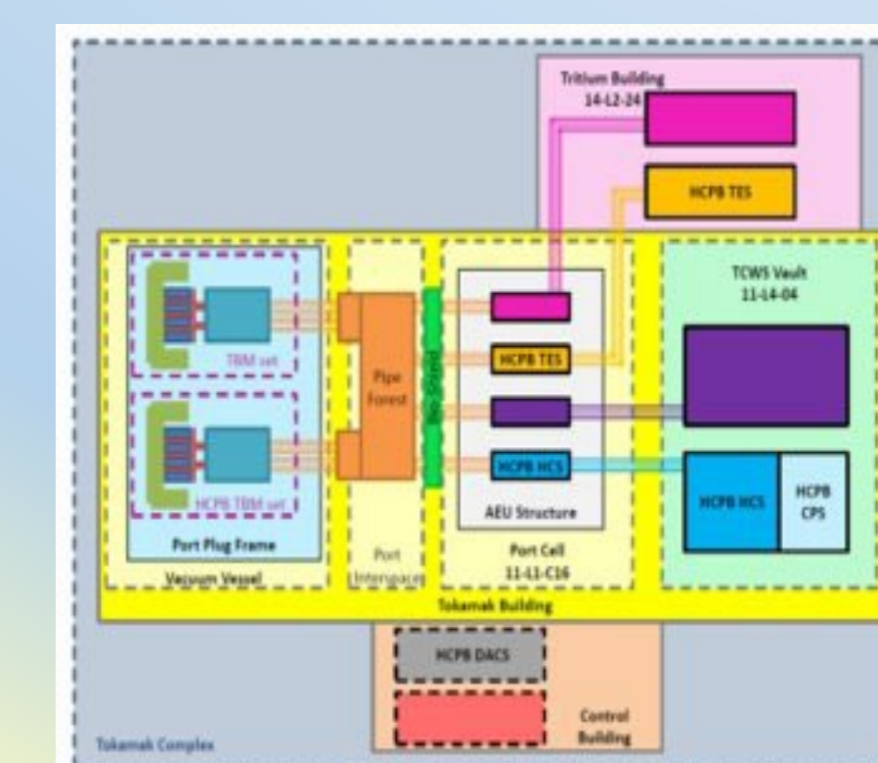
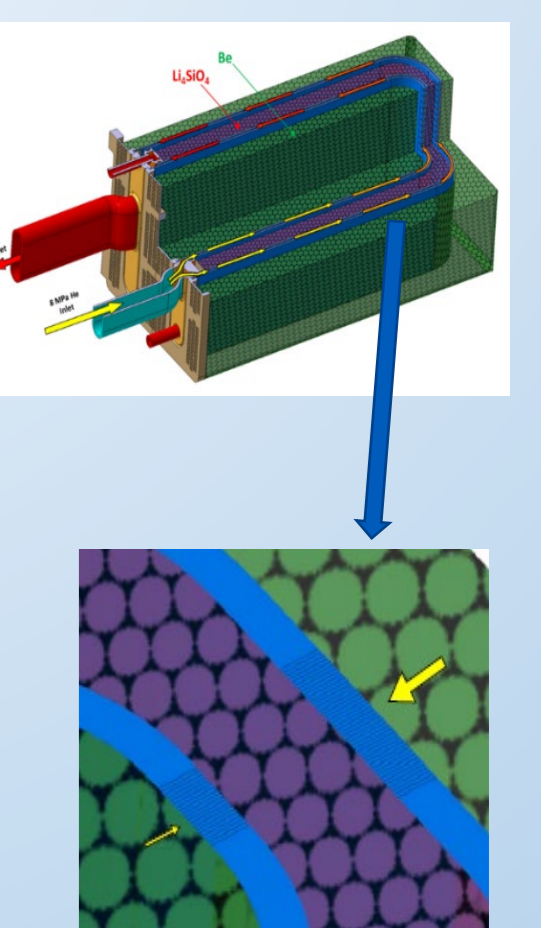


- HCPB TBM specific R&D - Solid Breeder development (fabrication, charact. and supply):** Definition of quality control and Definition of a specification for ACB pebbles; Preparation of Li-6 enriched ACB samples; ACB Material Property Handbook – Update; Be-based neutron multiplier development; Characterization of Be pebbles and Be chips; Tritium extraction from Purge Gas; Experimental results on the ZAO Getter Bed characterization; Ceramic breeder production Facility Upgrade; Upscaling of KALOS facility; Testing campaign on exposure of EUROFER97 samples to ACB pebbles under a specified ceramic breeder environment
 - WCLL Specific R&D - TBM Sensor Testing:** Pressure Sensors and Microwave level-meters; Assessment of H sensors for liq. met.&PbLi; Preparation work for the upgrade/modification of the TBM systems maintenance platform and for testing of maintenance operations
 - PbLi breeder development (fabrication, characterization and supply):** Technical Requirements for the production and characterization of Pb-16Li alloy; Production trial in TBM; Update of the existing PbLi materials properties database following specific QA requirements
 - Tritium extraction from PbLi:** GLC characterization for WCLL TBS
 - Coating development:** Activities on Li diffusion in alumina coatings; Transmission Electron Microscopy Measurements of Li content Determination of Li content with XPS, He content threshold and alternative coatings; Neutronic analyses to assess of the He production in Alumina coating
- Work in Progress*
- Advanced Ceramic Breeder and Neutron Multiplier Material Irradiation
 - Characterization of Be-materials for their use in TBM
 - Verification and optimization of the PbLi production process
 - Verification and validation of the PbLi properties database
 - Post-test analysis on GLC characterization for WCLL TBS
 - Development of sensors for PbLi: Pressure sensors, thermal mass flow meter, electrochemical
 - Tritium Sensors Experimental campaign to characterize hydrogen isotopes permeation sensor and post tests analysis, assessment of available Ion Chambers and strategy for performances qualification

HCCP TBS Architecture

- EUROFER 97 structural material
- FW actively cooled with 15x15 mm² square channels
- Breeder: KALOS pebbles beds
- Neutron multiplier: Be in pebble beds
- Coolant: He at 8 MPa, 300-500 °C inlet/outlet temperature
- Power extraction through curved cooling plates
- Purge gas for T extraction: He + H₂, 0.4 MPa

HCPB-TBM



SAFETY



- Safety analyses:** ACP determination for the TBM water cooling system (PACTITER-OSCAR); Assessment of ACPs in TBS WCS and CPS; FMEA Analysis; Definition of the Accidental Analysis Specifications and parametric studies; Description of the MELCOR input decks
 - Lithium Lead reaction modelling:** PbLi/water interaction phenomenology
- Work in Progress*
- Continuation of activities on PbLi/water interaction phenomenology: methodology, modelling and analysis plan

MATERIALS



- Experimental Testing In support of Design Rules validation:** Uniaxial ratchetting and tension-torsion ratchetting tests; Immediate Plastic Flow Localization tests; Creep-fatigue interaction tests
 - Experimental Testing for Base Material qualification:** Creep-fatigue and fatigue-relaxation tests; Low cycle fatigue; Fracture toughness
 - Irradiation and PIE for Base Material:** Tensile properties tests after irradiation; Creep pipes tests; Fracture toughness after irradiation
- Work in Progress*
- Ratchetting, Uniaxial ratchetting and tension-torsion ratchetting
 - Creep-fatigue and fatigue-relaxation experiments
 - Fatigue crack growth
 - Experimental testing for Welds qualification in non-irradiated and irradiated conditions (Tensile, Fatigue properties and Fracture toughness)
 - Material data file
 - Immediate Plastic Flow Localization tests (after irradiation): Plain and notched tensile specimens, plain and notched bars
 - Fracture toughness additional data before and after irradiation

Conclusions

Starting in 2020, EUROfusion and F4E are implementing the joint execution of the Helium-Cooled Pebble-Bed (HCCP) and Water-Cooled Lead-Lithium (WCLL) Test Blanket Module (TBM) Systems projects, the related R&D and the EUROFER-97 TBM Material Qualification.

The collaboration fosters the synergies of competencies and roles between EUROfusion, EFLs and F4E, the reciprocal understanding of R&D, programs and design and manufacturing needs. The technical exchanges, including the areas of implementation of regulatory obligations, systems engineering, risks assessment represent an important return of experience in fields of ITER TBM Systems and DEMO Breeding Blankets.

During 2021 and 2022 already more than 150 Deliverables have been launched of which 70% are already completed. In 2023 more than 50 new deliverables have been launched. In the period 2021-2025 around 60 Tasks will be implemented by the activities.

Planned Deliverables 21-23

