Synopsis **EX-OV**

Overview of ASDEX Upgrade Results

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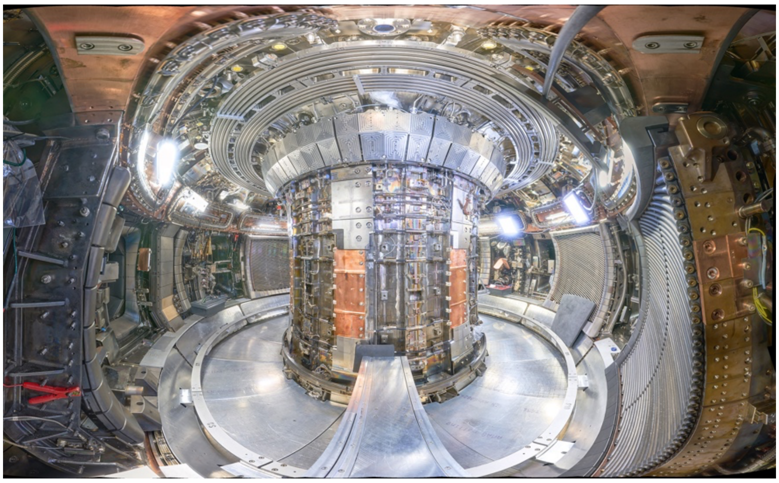
The ASDEX Upgrade (AUG) program focuses on addressing key physics challenges relevant to ITER operation and advancing plasma scenarios for the EU DEMO project. The AUG plasma (R_0 = 1.65 m, a = 0.5 m, $I_p \leq 1.4$ MA, $B_t \leq 3.2$ T) is heated using up to 20 MW of neutral beam injection (NBI), 6 MW of electron cyclotron resonance heating (ECRH), and 5 MW of ion cyclotron resonance heating (ICRH), enabling a diverse range of plasma scenarios. Since 2007 AUG operates with a full tungsten wall pioneering as a divertor tokamak the ITER decision towards a full W-device. This gives AUG a special role as unique experience and continuous supports can be provided for related decisions and the preparation of ITER operation.

From mid-2022 until September 2024 a major enhancement of the upper divertor in AUG was implemented featuring a new separate cryo pump, additional in-vessel coils and gas valves. While the additional pumping and gas valves allow for a full-featured upper divertor use, the additional coils enable magnetic equilibria ranging from divertors with several X-points to configurations with multiple times higher flux expansion than the standard single null (SN). The tiles are shaped and not tilted allowing for a helicity independent operation at small incidence angles (< 2°) of the magnetic field lines. The aim of such advanced divertors is the reduction of the localized power fluxes in combination with radiative cooling via impurities. The extensions of machine capabilities are accompanied by a comprehensive set of diagnostics including a dedicated divertor Thomson scattering system, two-color gas-puff-imaging system, bolometry and spectroscopy. Naturally, in a long vessel vent countless maintenance and upgrade measures where performed making the successful restart a remarkable accomplishment.



During vent: upper divertor conductors installed, cryo pump behind metal protection

Results from the first campaign after this upgrade focus to a major fraction on the performance of the new divertor. In a stepwise manner, first the neutral and impurity compression and pumping of the divertor was characterized for standard SN configuration and the performance of various scenarios, in particular, radiative scenarios such as the X-point radiator-regime (XPR) and small ELM scenarios such as quasi-continuous-exhaust scenario

(QCE) are compared to the respective data from lower SN. Of specific interest is the He exhaust, as the new cryo pump features a charcoal coating, which is able to pump helium unlike the cryo pump for the lower divertor. As a next step the magnetic configurations of the advanced divertors were investigated and wherever possible the performance is compared to detailed SOLPS predictions. Such predictions helped designing the divertor upgrade and thus their test is now of particular interest.

In support of ITER, investigations on the boronization performance have been conducted at AUG. These compare the restart, i.e. break-down, burn-through and wall conditions, without a boronization to that with a boronization and to that using a toroidally asymmetric boronization. For better predictions during the limiter phase of ITER, tungsten erosion and concentration data was gathered during respective phases for the AUG plasma discharge ramp-ups. Further, the impurity transport at the edge pedestal is quantitatively evaluated for various ELM-free- or small-ELM-regimes and compared to that during type-I ELMy H-modes. In particular, the impurity edge transport during phases with resonant magnetic perturbations is studied due to its high relevance for ITER. A detailed investigation on the necessary core heating to avoid W-accumulation is modelled with TGLF-SAT2 and FACIT combining edge transport with core transport allowing for credible predictions to ITER. It is found that core localized W-accumulation is not of relevance in ITER, but rather the total radiated power due to the edge transport poses the main challenge.

The experiments on shattered pellet injection and their analysis is ongoing and led not only to a large experimental knowledge base, but are now also modelled with the MHD-code JOREK. An additional interest of ITER lies in the detrimental potential of runaway electrons for PFCs, an effect which will be studied at the end of the ongoing campaign 2025.

On the physics side, the understanding of small ELM regimes is progressing such that predictions towards ITER and EU DEMO gain credibility. Pedestal stability analyses suggest that QCE will naturally develop for strongly shaped, elongated plasmas at high separatrix densities $n_{e,sep}$, as this leads to ballooning instabilities at the separatrix preventing the occurrence of the more global peeling-ballooning type-I ELM. As high $n_{e,sep}$, is a boundary condition from power exhaust ITER and EU DEMO possibly feature a QCE edge naturally.

An alternative scenario for power exhaust is the XPR-regime featuring no ELMs and low power to the divertor, which is modelled using SOLPS and EMC3-EIRENE including neutral densities and pumping. The turbulence in the XPR-regime is investigated with GRILLIX and the MHD edge stability is studied with JOREK.

Further experiments and analyses are on the way, and will be reported depending on the course of the ongoing campaign, which will be finished before the IAEA FEC conference 2025.

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