Overview of ASDEX Upgrade results

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*see appendix of H. Meyer et al., (OV/P-12) Proc. 26th IAEA Fusion Energy Conf., Kyoto, Japan

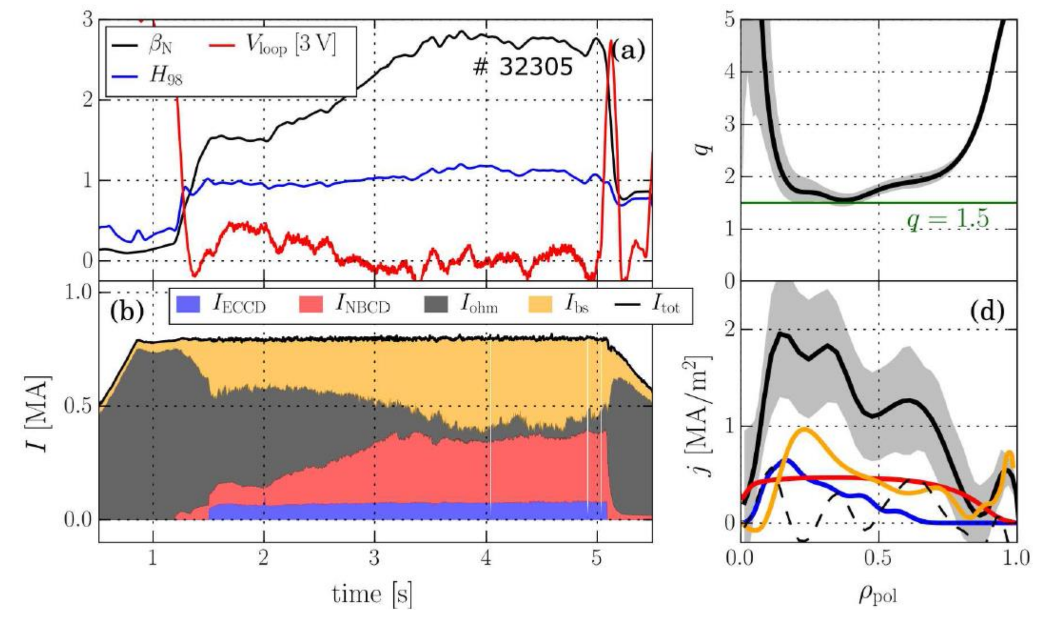
Introduction

The ASDEX Upgrade (AUG) programme is directed towards physics input to critical elements of the ITER design and the preparation of ITER operation, as well as addressing physics issues for a future DEMO design. This overview summarizes the progress in the last 2 years on the machine hardware, non-Inductiive operation, ELM suppression with magnetic perturbations, pedestal stability and confinement, power exhaust and scenario integration. Challenges caused by the presence of tungsten PFCs are addressed and trends for extra-polation to large devices are given.

Scenario development

Non-inductive operation

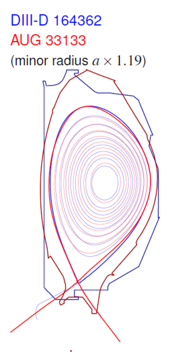
- about 40 % of I_p driven by NBCD, 50 % boostrap, 10 % ECCD
- ECCD used to tailor current profile for optimum stability and $q_{min} > 1.5$

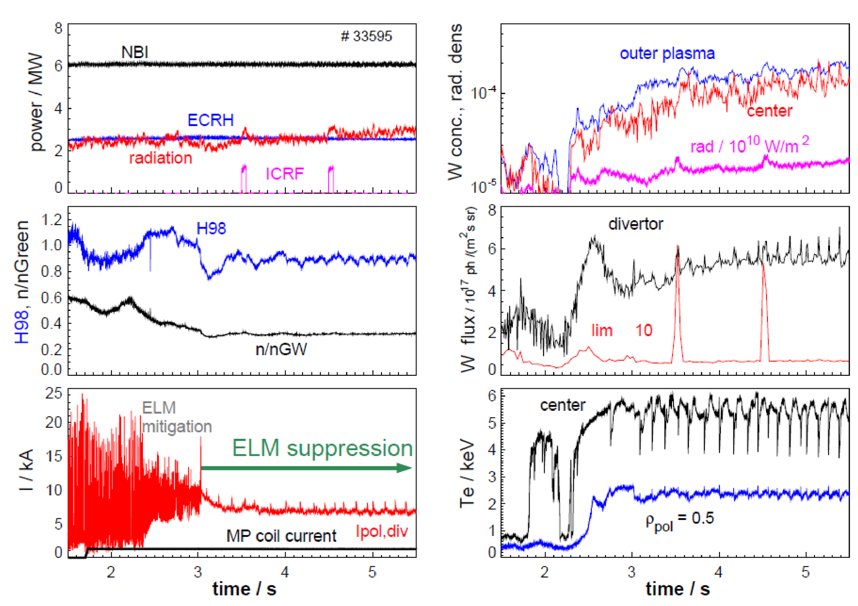


[3]

ELM suppression with RMPs

- full ELM suppression obtained in AUG.
  trick: δ-dependence of threshold as found in DIII-D
- no accumulation of W at pedestal top





quite high W conc. due to hot divertor

W blips from midplane limiter exhibit normal decay times

these low densities are only accessible with MPs

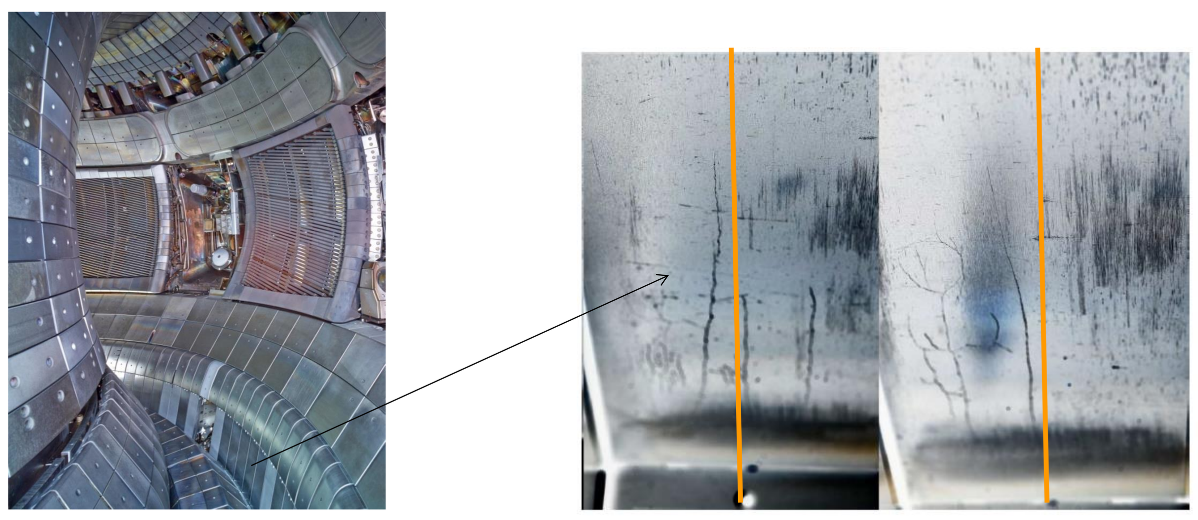
[4]

Tungsten related hardware upgrades

Massive tungsten divertor III performs without failure

Cracks formed – through tile and at the surface

- cracks not observed in high heat flux tests in GLADIS before
- forces during disruption in addition to thermo-mechanical stresses

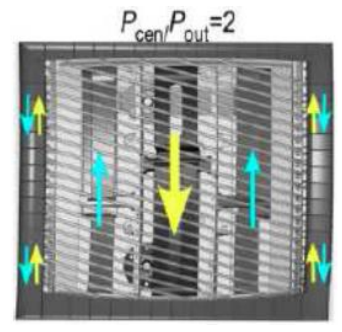


[1]

FEM calculations suggest vertical tile splitting for crack avoidance (done in current AUG vent)
¼ of tiles will be made from more ductile material 97 % W, 2 % Ni, 1 % Fe (magnetic)

3-strap ICRF antenna pair reduces W production

As predicted, cancelling of induced frame currents of central and side straps reduce W release



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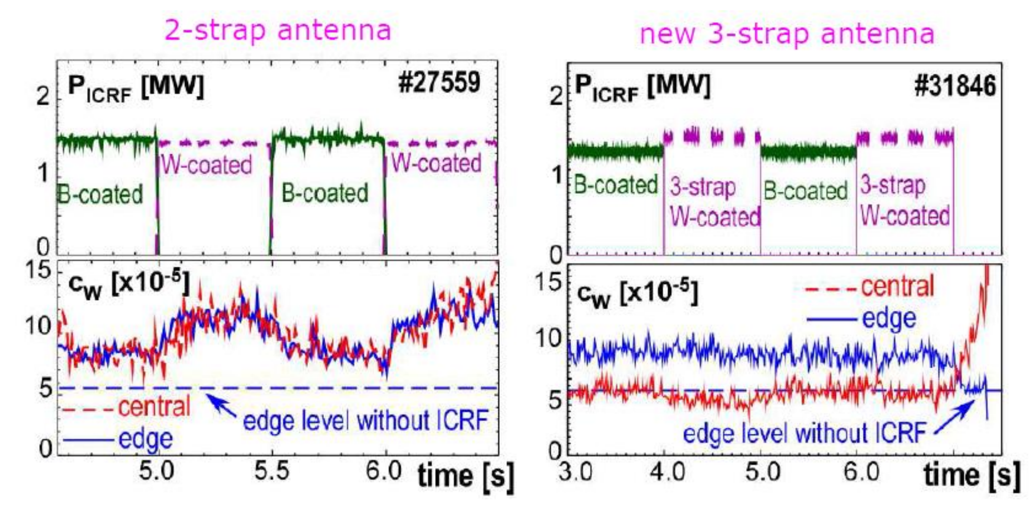
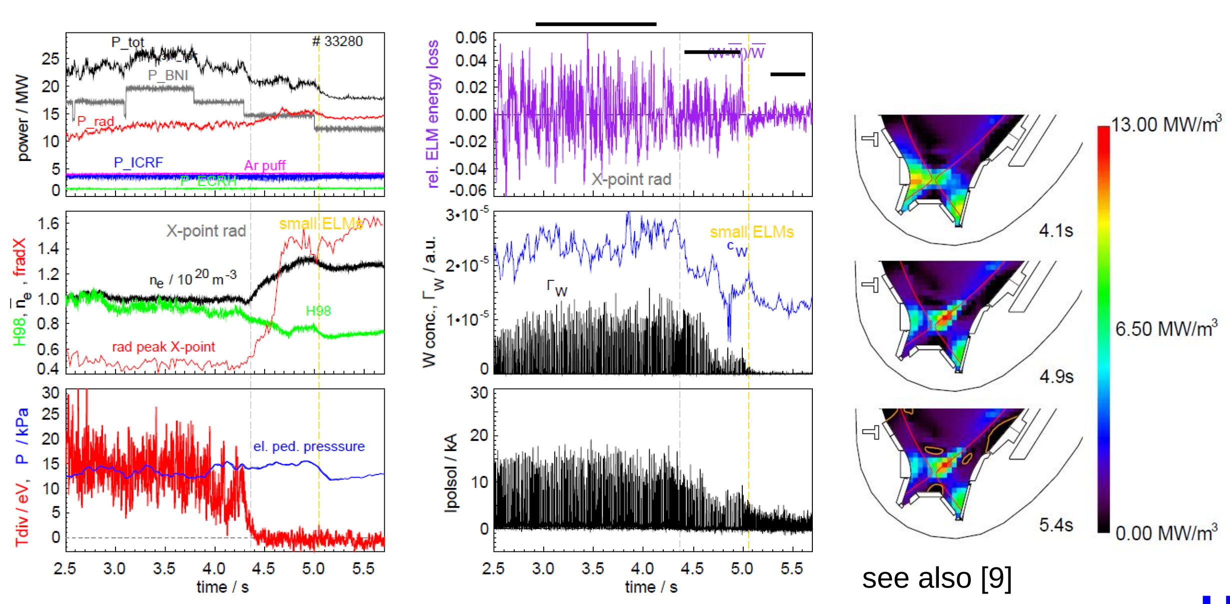


Power exhaust

Detachment studies with X-point radiator

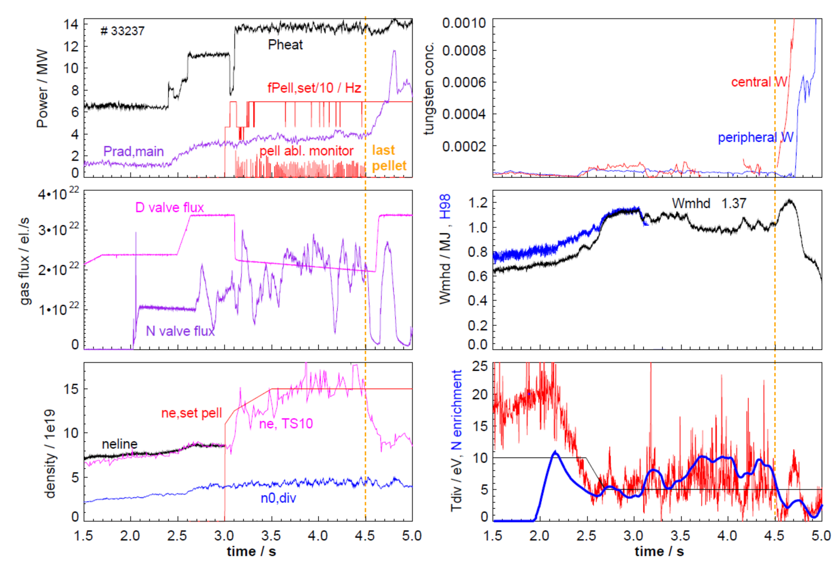
- X-point radiator at pronunced detachment with N and Ar seeding
- favourable properties: cold divertor with low power load, no W sputtering, smaller ELMs
- expected to be feedback-controllable



see also [9]

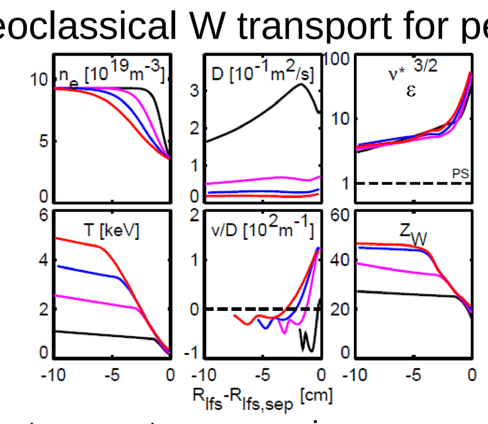
Integration of Tdiv feedback control and pellet density control

- Fb control of heat flux (N) and density (pellets) are compatible



Favourable tungsten behaviour expected in a large device

- neoclassical W transport for pedestal scaling $n_{W,ped}/n_{W,sep}$



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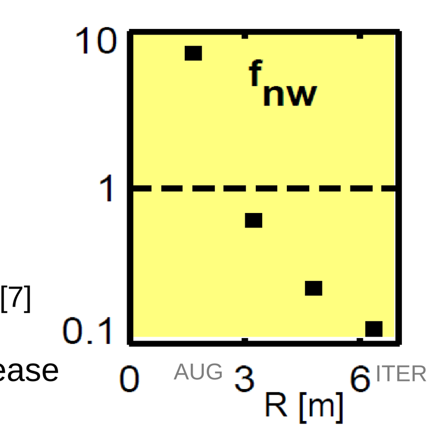


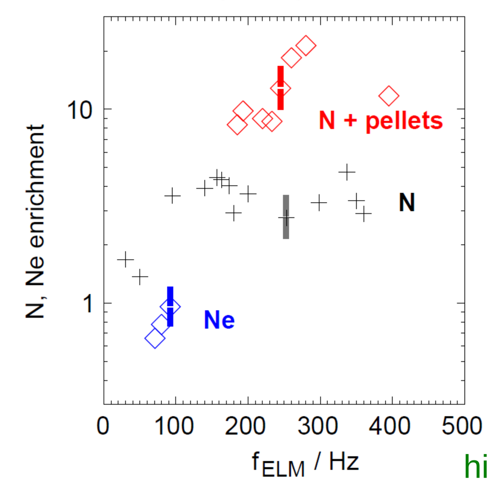
Higher temperature screening causes decrease of W density at pedestal top vs. separatrix

High nitrogen divertor enrichment achieved

ELM frequency is important for enrichment, but not exclusive

impurity divertor enrichment

$$E = \frac{\Gamma_Z}{Z\,\Gamma_D} \Big/ \frac{n_Z}{n_e}$$



Important for clean core plasma with seeding

other effects:

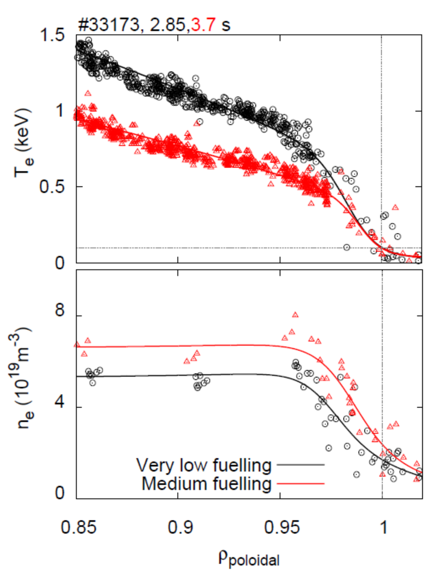
- impurity ionization length
- neoclassical pedestal inward drift

higher E for N compared to Ne seen in modelling [8]

Pedestal stability and confinement

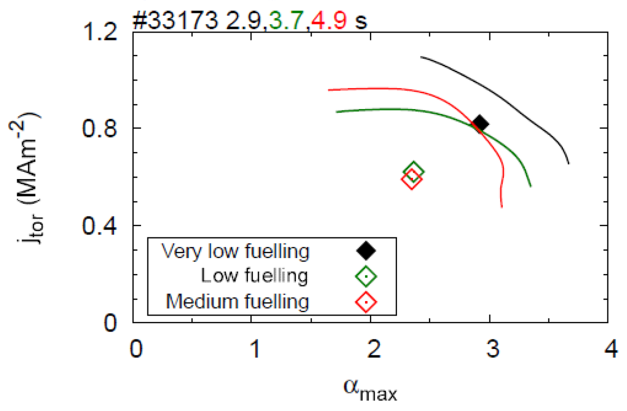
Pedestal- and global energy confinement depend on edge density profile

- D fueling shifts density profile outward – T profile anchored at separatrix



Stability analysis:

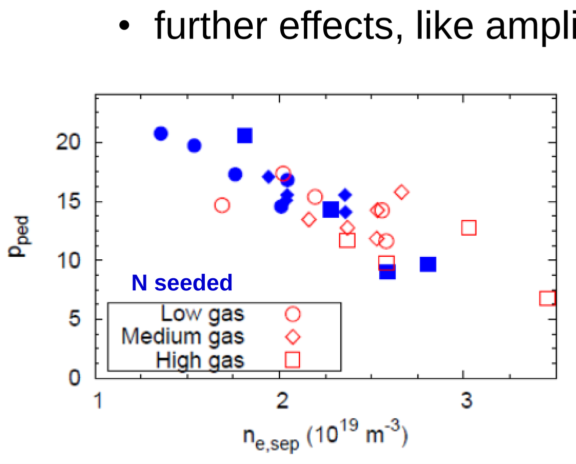
- unfavourable alignment of shear and max. pressure gradient

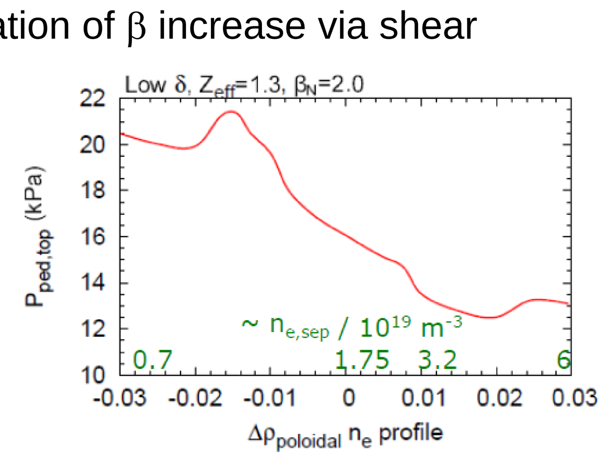


see [5]

Stability calculations confirm effect of n_e profile location on pedestal top pressure

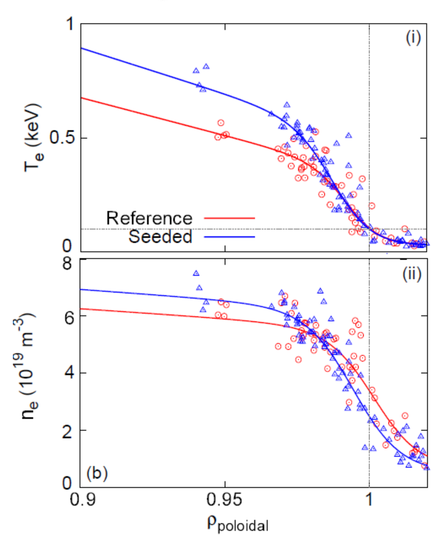
- pedestal top pressure closely linked to density at separatrix
- further effects, like amplification of β increase via shear

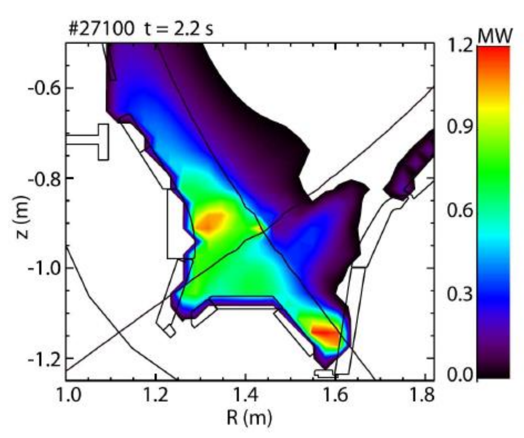




Effect of N seeding via HFSHD as heating power reduction

- N seeding effects fueling via reduction of high field side high density leading to inward shift of density profile [5, 8]

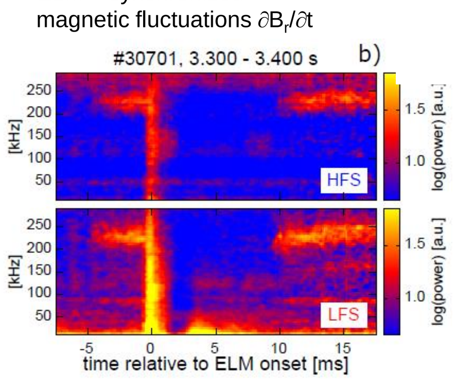




Magnetic fluctuations @ few 100 kHz in later phase of ELM cycle measured both at HFS and LFS side

- fluctuations are associated with modes responsible for pressure profile clamping (KBM in EPEd model)

ExB velocity in steep gradient region, estimated as compensating diamag. drift



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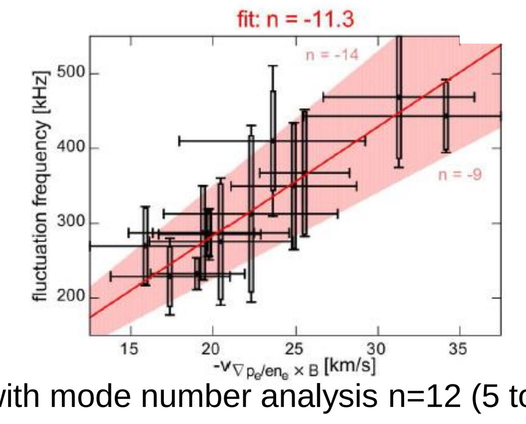

fluctuations persist over several msec – no ELM precursor

In line with mode number analysis n=12 (5 tor. pos.)

Summary

- new 3-strap ICRF antenna reduces W release as predicted
- massive W divertor performs well despite cracking
- overcoming challenges of W PFC environment
  - full ELM suppression achieved à là DIII-D
  - non-inductive operation up to Ip= 0.8 MA
- simultaneous heat flux (N) and density control (pellets)
  - high impurity enrichment obtained, essential for clean core
- relative position of pedestal density and temperature profiles
  - important for edge stability
  - reduction of HFSHD responsible for improved confinement with nitrogen
- good prospects for W in large devices with hot pedestal

References

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Acknowledgement

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.