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ICRF heating and turbulent transport modelling of the WEST L-mode plasma using ets: interpretative and predictive codevalidation

Philippe Huynh, E. Lerche, D. Van Eester, Jeronimo Garcia, Frazzoli G, Patrick Maget, Jean François Artaud, Ferreira J., Johnson T., D. Yadykin, et al.

► To cite this version:

Philippe Huynh, E. Lerche, D. Van Eester, Jeronimo Garcia, Frazzoli G, et al.. ICRF heating and turbulent transport modelling of the WEST L-mode plasma using ets: interpretative and predictive codevalidation. 48th EPS Conference on plasma physics, Jun 2022, Maastricht (virtual event), Netherlands. cea-03736757

HAL Id: cea-03736757

<https://cea.hal.science/cea-03736757>

Submitted on 29 Jul 2022

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¹ CEA, IRFM, F-13108 Saint Paul-lez-Durance, France.

² CCFE, Culham Science Centre, Abingdon OX14 3DB, United Kingdom,

³ Laboratory for Plasma Physics, ERM/KMS, B-1000 Brussels, Belgium,

⁴ IPFN, Instituto Superior Tecnico, Universidade de Lisboa, 1049-001 Lisbon, Portugal,

P. Huynh¹, E. Lerche^{2,3}, D. Van Eester³, J. Garcia¹, G. Frazzoli¹, P. Maget¹, J.F. Artaud¹, J. Ferreira⁴, T. Johnson⁵, D. Yadykin⁶, P. Strand⁶ and WEST team*

⁵ KTH, Royal Institute of Technology, Stockholm, Sweden,

⁶ Chalmers University of Technology, Gothenburg, Sweden

* see <http://west.cea.fr/WESTteam>

Introduction & Background

- WEST [1,2], superconducting device, equipped with actively cooled divertor in full tungsten environment. D-D L-mode discharges in the flat top phase with ICRH additional heating are considered.
- European Transport Simulator (ETS) [3,4] can simulate full plasma discharges of any Tokamak device. Two main modules are concerned:
 - Cyrano [5] and StixRedist [6,7,8] as ICRF module
 - TGLF [9,10] as turbulent transport module
- Goals
 - Understand the core plasma dynamics in WEST with focus on the role of ICRH and plasma discharge optimization (efficient electron heating, avoid tungsten accumulation)
- First Steps
 - Verify and validate ICRF modules.
 - Determine the electron/ion heating ratio with minority and power scans
 - Compare predictive simulation with experiments and characterize the turbulence

ICRF modules used in interpretative mode

Verification & Validation

- Cyrano/StixRedist was compared to EVE/AQL on the shot #55799 giving a good agreement on the heating profiles (not shown).
- Comparison with Break In Slope (BIS) experimental profiles from ECE data with PICRF=1MW.
- To interpret the experimental power deposition profile in WEST needs to invoke the impact of transport. Figures below show that reasonable agreement can be obtained when a characteristic time of the order of few tens of ms is considered.
- Good agreement is obtained on the volume integrated power absorbed by the electrons (fig 1. left).

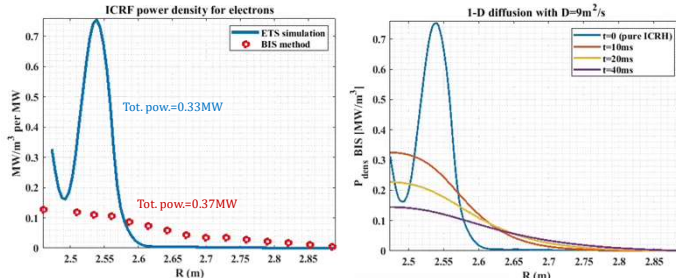


Fig. 1: shot #54633 at 39s. (Left) comparison of ICRF electron power density profile between BIS method and ETS interpretative simulation and their integration over the plasma volume. (Right) Imitating BIS method with 1-D diffusion equation. Diffusion coefficient estimated at 9 m²/s from radial propagation of a sawtooth crash. ICRF electron heat diffusion for various time slice.

Neutron rate sensitivity to the ion temperature

- Ion temperature measurement is not yet available at WEST. An estimate is made based on the measured neutron rate (assuming Maxwellian ion distribution functions) [11]. Table 1 shows the high sensitivity of the neutron rate for typical T_i values in WEST due to the steep D-D fusion cross section as shown in fig. 2.

	Experiment	100% T _i	90% T _i	80% T _i	~60% T _i
Neutron rate (10 ¹¹ neutrons/s)	~27	~57	~32	~17	~2
Discrepancy		111%	18%	-37%	-92%

Table 1: shot #55607 at 39s. Neutron rate sensitivity according to ion temperature amplitude.

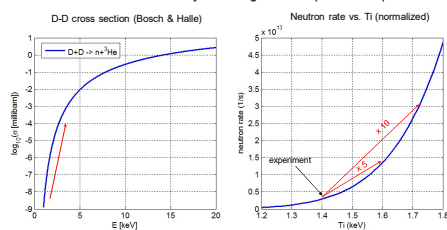


Fig. 2: shot #55607 at 39s. (Left) Stiff D-D cross section at the interest region. (Right) Variation of neutron rate according to ion temperature.

- A minimization loop with Cyrano/StixRedist accounting for ICRF heated deuterium distributions and neutron rate computations suggests T_i to be 12% lower than the value obtained assuming purely Maxwellian distributions.

References

- [1] Bucalossi et al 2014 *Fus. Eng. and Design* vol. 89 pp. 907-912
- [2] Bourdelle C. et al 2015 *Nucl. Fusion* 55 063017
- [3] Kalupin D. et al 2013 *Nucl. Fusion* 53 123007
- [4] Huynh P. et al 2021 *Nucl. Fusion* 61 09601
- [5] Lamalle P.U. 1994 *PhD Thesis Université de Mons LPPER/KMS Report 101*
- [6] Van Eester D. and Lerche E. 2011 *Plasma Phys. Control. Fusion* 53 09200
- [7] Huynh P. et al 2020 *AIP Conf. Proc.* 2254 060003
- [8] Van Eester D. et al 2021 *J. Plasma Phys.* vol. 87 855870202
- [9] Staebler G.M., Kinsey J.E. and Waltz R.E. 2007 *Phys. Plasmas* 14 055909
- [10] Staebler G.M et al 2021 *Plasma Phys. Control. Fusion* 63 015013
- [11] Maget P. et al Understanding Tungsten Accumulation during ICRH operation on WEST this conference. Q4.129

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 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Acknowledgements



Scan in power and H minority concentration

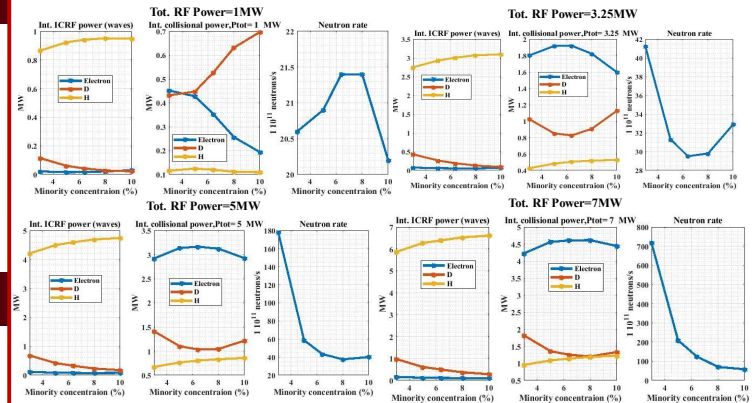


Fig. 3: shot #55607 at 39s. H Minority scan for various ICRF power. For each power, plots of integrated direct absorption power, integrated collisional power and neutron rate.

- Figure 3 shows that for low power (1MW), the collisional ion heating is dominant but the power is too low to impact the D-D neutron rate.
- For higher power (>3MW), electron heating is dominant but ion heating is strong enough to enhance the neutron rate, in particular at low concentration (enhanced N=2 D absorption). The neutron rate is limited at large H fraction due to dilution.
- The neutron enhancement comes from ICRF induced deuterium tails (thermal T_i constant). Finite orbit width effects and ripple losses not taken into account.

Transport modelling

Predictive simulation

- The kinetic profiles are predicted with NCLASS and TGLF respectively for computing the neoclassical and turbulent transport coefficients. The values of T_e, T_i, N_e and N_i are imposed at normalized $\rho=0.8$ as boundary condition. Impurity radiation profiles are prescribed from the bolometry data. Due to the presence of sawteeth up to $\rho=0.35$, ad-hoc transport coefficients are manually set to fit the electron temperature and density experimental data in that region.
- The initial T_i profile is provided by the method described in the previous section.

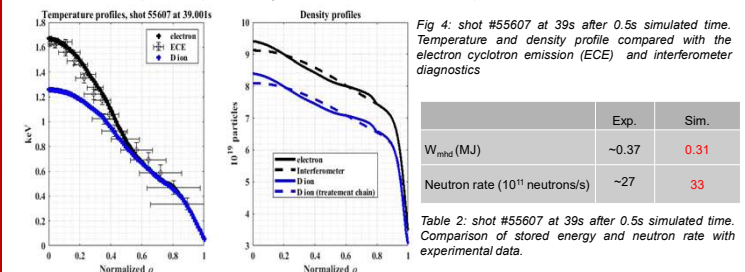


Fig. 4: shot #55607 at 39s after 0.5s simulated time. Temperature and density profile compared with the electron cyclotron emission (ECE) and interferometer diagnostics

Table 2: shot #55607 at 39s after 0.5s simulated time. Comparison of stored energy and neutron rate with experimental data.

Turbulence characterization

- Figure 5 (a) and (b) show the presence of the high-k_z electron temperature gradient (ETG). The influence of trapped electron mode (TEM) is small (fig. 5 (a) and (d)). As shown in fig. 5 (a) and (c), the turbulence is dominated by the ion temperature gradient (ITG) instability at low-k_z.

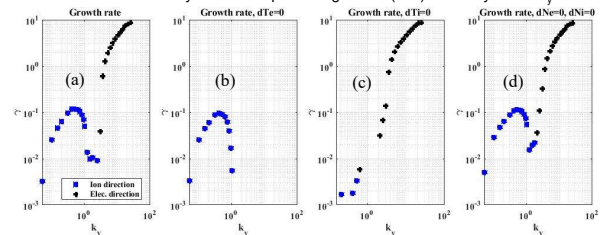


Fig. 5: shot #55607 at 39s and normalized $\rho=0.5$. (a) Turbulent linear growth rate γ . (b) Turbulent linear growth rate when T_e gradient is set to 0. (c) Turbulent linear growth rate when T_i gradient is set to 0. (d) Turbulent linear growth rate when N_e and N_i gradients are set to 0. γ is in units of c_s/R with c_s = $\sqrt{T_e/m_i}$, m_i the main ion mass and k_z is the poloidal wave number.

Conclusion and Perspectives

- First validation of ICRF computation with BIS method show an agreement on the total electron heating at low ICRF power. Further investigations are ongoing.
- Power and minority scans show that electron heating is always dominant for PICRF>2-3MW in the studied conditions in particular with X(H)=5%-7%. Enhanced D-D neutron rate can be achieved at low H concentrations due to direct N=2D absorption.
- Predictive simulation yields a good agreement with available measurements (electron and density temperature profiles, stored energy and neutron rate).
- The simulation suggests that turbulence is dominated by the ion temperature gradient (ITG) instability at low k_z.
- The next step would be to perform self-consistent impurity transport modelling.