



## Validation of the isotope model in the PENN neural network code using European Transport Simulator

D. Yadykin<sup>1</sup>, A. Gillgren<sup>1</sup>, B. Brandström<sup>1</sup>, P. Strand<sup>1</sup>, D. Coster<sup>2</sup>, P.A. Schneider<sup>2</sup>, F. Auriemma<sup>3,4</sup>, J.M. Fondcabaa<sup>5</sup>, M. Maslov<sup>6</sup>, S. Menmuir<sup>6</sup> and JET Contributors<sup>8</sup>

<sup>1</sup> Department of Space, Earth and Environment, Chalmers University of Technology, Gothenburg, Sweden

<sup>2</sup> Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching, Germany

<sup>3</sup> Consorzio RFX-CNR, ENEA, INFN, Università di Padova, Acciaierie Verite SpA, Padova

<sup>4</sup> CNR-ISTP, Corso Stati Uniti 4, 35127 Padova, Italy

<sup>5</sup> Laboratorio Nacional de Fusión Ciemat, E-28040, Madrid, Spain

<sup>6</sup> United Kingdom Atomic Energy Authority, Culham Science Centre, Abingdon Oxon OX14 3DB, United Kingdom of Great Britain and Northern Ireland

<sup>8</sup> See the author list of "Overview of T and D-T results in JET with ITER-like wall" by C.F. Maggi et al, Nuclear Fusion Special Issue: Overview and Summary Papers from the 29th Fusion Energy Conference (London, UK, 16-21 October 2023).

### SUMMARY

- Isotope extension in the PEdestal Neural Network (PENN) code is validated using JET experimental data using European Transport Simulator (ETS) integrated workflow.
- Standalone predictions of the pedestal top values of electron density and electron temperature are obtained.
- Kinetic profile simulations in the plasma core are performed using ETS with TGLF-SAT2 turbulence transport model.
- Reasonable agreement is seen for electron density profiles while electron and ion temperature profiles are underpredicted that can be caused by the switched off stabilization effects in TGLF implementation in ETS and by the nature of the edge profile model adopted in PENN (mtanh).

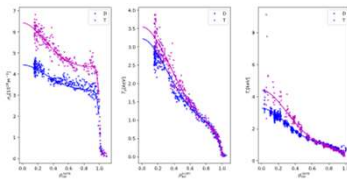
### EXPERIMENTAL DATA AND SIMULATION SETUP

#### Experimental scenario

- Two H-mode pulses with different isotope content: #97036 (Deuterium), #98795 (Tritium)
- Similar engineering parameters

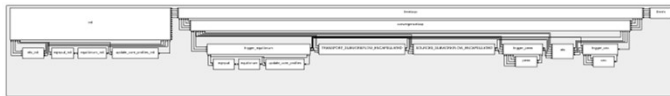
	Deuterium #97036	Tritium #98795
$I_p$ (MA)	1.5	1.5
$B_t$ (T)	1.6	1.6
$\Gamma$ ( $10^{22}$ 1/sec)	0.8	0.9
$\delta$	0.28	0.28
$Z_{eff}$	1.7	1.3
$P_{NBI}$ (MW)	10	10
$\beta_N$	1.34	2.23

Kinetic experimental profiles



#### Simulation setup

##### ETS with PENN integrated



##### Simulation parameters

- Core simulations up to  $\rho_{tor}^{norm} = 0.85$
- Edge profiles are given by PENN or taken from experiment
- Predictive channels:  $n_e$ ,  $T_e$ ,  $T_i$
- Quasineutrality:  $n_i$
- Impurities: Be (to match  $Z_{eff}$ ), W (to match radiation)
- Equilibrium: CHEASE (fixed boundary)
- Core transport:
  - TGLF-SAT2 (electrostatic)
  - NCLASS
- Sources:
  - NBI Heating: BBNBI, NBISIM
  - Radiation: coronal equilibrium
  - Ohmic

##### PENN model (Deuterium)

- Neural network model for prediction of  $n_e$  and  $T_e$  at the pedestal top.
- The profiles of  $n_e$ ,  $T_e$ ,  $T_i$ ,  $n_i$  at the edge are calculated using modified tanh function.
- Model is trained on the Deuterium JET pedestal dataset (Type I ELMy H-modes).
- Small set of (mostly) engineering parameters is used as input. The parameters relevant for this work are: plasma current ( $I_p$ ), total power ( $P_{tot}$ ), plasma triangularity ( $\delta$ ), electron density at separatrix ( $n_e^{sep}$ ), fueling rate of main ion ( $\Gamma$ ), normalized pressure ratio ( $\beta_N$ ).
- Free parameters should be prescribed (pedestal width, pedestal bottom values, position of the pedestal center).
- Two different neural network (NN) versions are used in this work that differ by the input selection:
  - NN using  $I_p$ ,  $P_{tot}$ ,  $\delta$ ,  $n_e^{sep}$  (**nn\_nesep**)
  - NN using  $I_p$ ,  $P_{tot}$ ,  $\delta$ ,  $\Gamma$  (**nn\_gas**).

##### PENN model (isotope extension)

- Model is extended to be able to make predictions for the plasma with different main ion isotopes
- Small set of the data from Tritium pulses is used in addition to the main data set for Deuterium for extension (transfer learning)
- The best prediction accuracy is obtained for the extension of the type (for electron density):

$$n_{e,ped}^{target} = n_{e,ped}^D * \left(\frac{A_{eff}}{Z}\right)^c$$

$n_{e,ped}^{target}$  — electron density at the pedestal top for plasma with given isotope as a main ion

$n_{e,ped}^D$  — electron density at the pedestal top for plasma with Deuterium as a main ion

$A_{eff}$  — effective mass

$c$  — constant

c values for different NN versions

	$n_{e,ped}^{target}$	$n_{e,ped}^{target}$
<b>nn_nesep</b>	$0.30 \pm 0.16$	$-0.18 \pm 0.15$
<b>nn_gas</b>	$0.41 \pm 0.16$	

##### PENN model, power scaling

For **nn\_gas** model no satisfactory extension model is found for  $T_{e,ped}^{target}$ . Therefore, power scaling law is used (**power\_nesep**) in the form

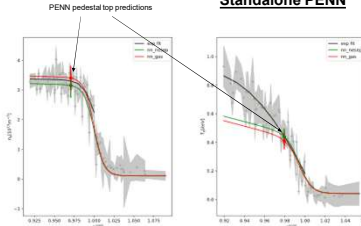
$$T_{e,ped}^{target} = (0.29 \pm 0.07) n_{e,sep}^{-0.39 \pm 0.13} \beta_N^{0.63 \pm 0.18} I_p^{1.13 \pm 0.21} \left(\frac{A_{eff}}{Z}\right)^{-0.37 \pm 0.14}$$

### RESULTS

- Two pulses #97036 (D) and #98795 (T) are used. The following scheme is applied:
  - 'Standalone' PENN model is used to predict the pedestal top values of electron density and temperature using different NN models.
  - Edge kinetic profiles are calculated and compared to the experimental data.
  - Core profiles are simulated with ETS using PENN prediction or the experimental values (**exp\_bc**) as a boundary condition and compared with experimental results.

#### Deuterium pulse #97036

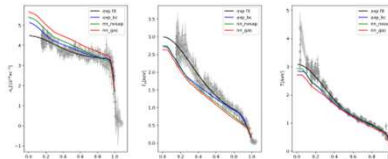
##### Standalone PENN



- Free parameter values are set:
- Pedestal width (in  $\rho_{pol}^{norm}$  units): 0.025 (both  $n_e$  and  $T_e$ )
  - Pedestal bottom values:  $1.0e18 \text{ m}^{-3} (n_e)$ ,  $40 \text{ eV} (T_e)$
  - Pedestal center position:  $0.99 (n_e)$ ,  $0.985 (T_e)$

Slope inside pedestal top is calculated using the 'core' profiles ( $\rho_{pol}^{norm} < 0.92$ )

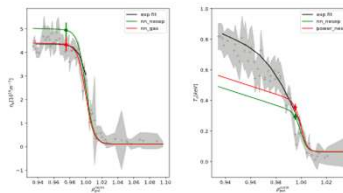
##### Core profiles



- Slight overprediction of  $n_e$
- Slight underprediction of  $T_e$ ,  $T_i$
- Good agreement with ETS simulations using experimental values as boundary conditions (**exp\_bc**)

#### Tritium pulse #98795

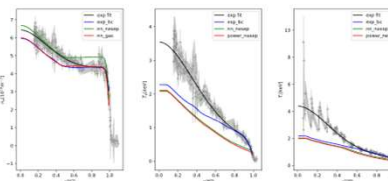
##### Standalone PENN



- Free parameter values are set:
- Pedestal width (in  $\rho_{pol}^{norm}$  units): 0.02 ( $n_e$ ), 0.01 ( $T_e$ )
  - Pedestal bottom values:  $1.0e18 \text{ m}^{-3} (n_e)$ ,  $46 \text{ eV} (T_e)$
  - Pedestal center position (in  $\rho_{pol}^{norm}$  units):  $0.99 (n_e)$ ,  $0.99 (T_e)$

Slope inside pedestal top is calculated using the 'core' profiles ( $\rho_{pol}^{norm} < 0.94$ )

##### Core profiles



- Reasonable agreement of  $n_e$
- Underprediction of  $T_e$ ,  $T_i$
- Good agreement with ETS simulations using experimental values as boundary conditions (**exp\_bc**)