Pellet fuelling and impurity seeding for the STEP powerplant

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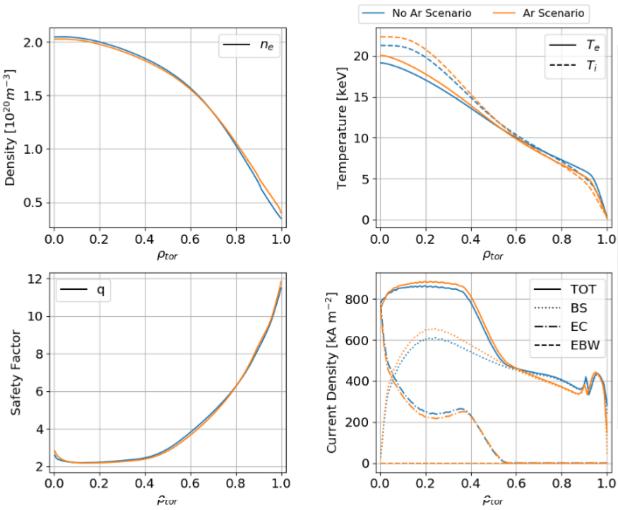
1. Introduction

The STEP (Spherical Tokamak for Energy Production) programme [1] aims to develop a prototype fusion power plant with the capability to generate net electric power to the grid. The compact spherical tokamak (ST) design has the potential to operate in high beta β, high elongation κ regime at a relatively low toroidal field [2]. The primary fuelling method for core plasma fuelling in STEP will be pellet injection. Using this method delivers deep fuel to plasma penetration into the core and provides higher fuelling efficiency, which will be necessary for achieving high fusion power. STEP will have multiple pellet fuelling lines, some of which will inject seeded pellets that contain small amounts of a high-Z impurity alongside the DT fuel. Impurity seeding is an essential aspect of future fusion reactor designs, as impurity-induced radiation is needed to lower the heat load on the divertor target and distribute the power more isotropically over the reactor [3].



	No Ar Scenario	Ar Scenario
I_P [MA]	20.31	20.10
P_{FUS} [GW]	1.55	1.49
f_{BS} [%]	87.8	87.8
P_{EC} [MW]	150.0	150.0
P_{EBW} [MW]	0.0	0.0
P_{TOT} [MW]	150.0	150.0
ECCD [kA/MW]	15.1	14.4
EBWCD [kA/MW]	0.0	0.0
CD [kA/MW]	15.1	14.4
Q	10.4	9.9
$<n_e>$ $[10^{20} m^{-3}]$	1.44	1.44
f_{GW} [%]	95.4	96.4
$<T_e>$ [keV]	10.54	10.48
$<T_i>$ [keV]	11.19	11.18
Zeff	2.13	2.64
f_{rad} [%]	68.65	70.62
P_{sep}/R [MW/m]	40.04	36.54
q_{min}	2.19	2.17
q_0	2.60	2.82
β_N [%]	4.40	4.40
Li(3)	0.29	0.31
H98 Avg	1.42	1.44

Figure 1: *Summary of the STEP-EC-HD-v10 scenario (EC = Electron Cyclotron, HD = High Density). There are two cases shown, one has no Ar and the other has a small fraction of Ar included. These profiles are taken at the flat-top operating point.*

Understanding how impurity seeding and pellet fuelling affects our plasma scenarios is necessary for optimising the core plasma performance. To optimise fuelling pellet performance, the pellet penetration into the core must be maximised while minimising the density perturbation that occurs during pellet injection, whilst still being compatible with engineering constraints. As well, predictively modelling impurities into our scenarios helps to improve our knowledge of how it will affect plasma performance. In this work, the JETTO core modelling tool [4] and HPI2 pellet code [5] are used to explore these concepts within one of STEP's high-density plasma scenarios. A summary of this scenario can be seen in Fig. 1. JETTO uses a Bohm/gyro-Bohm transport model, which is retuned to account for the dominant electron heat transport that is found in transport simulations for STEP and other STs [6], with fixed anomalous transport assumptions for every ion. However, the neoclassical transport is computed self-consistently with NCLASS. The confinement time τ_e is assumed as 3.8s and compared to confinement scaling laws. The ratio of τ_p/τ_e~4 is assumed similar to that seen in JET,