9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Evaluation of pellet fueling depth and its impact on fusion performances in fusion reactors

Jie Zhang[1], Ge Zhuang[1], Joseph Mcclenaghan[2], Paul Parks[2], Wen Wu[2], Lang Lao[2], Jiale Chen[3], Vincent Chan[1], Jiangang Li[3]
[1] University of Science and Technology of China [2] General Atomics
[3] Institute of Plasma Physics, Chinese Academy of Sciences
e-mail (speaker): jiez111@ustc.edu.cn

Future fusion reactors must simultaneously achieve high fusion power and tritium self-sufficiency [1]. For example, two critical missions of the Chinese Fusion Engineering Test Reactor (CFETR) are to achieve ~1 GW output fusion power and to demonstrate tritium self-sufficiency, for which purpose the tritium burn-up fraction should be greater than 3%. Deep pellet fueling offers a promising solution [2], but its realization and impact on fusion performance remain critical areas of research.

This study employs the STEP integrated modeling workflow within the OMFIT framework [3], to systematically evaluate pellet fueling depth and its effects on fusion performance. A key innovation is the incorporation of our recently developed Pellet Ablation Module (PAM) [4-6], which implements a 2D Gaussian pellet particle deposition model [5-6], enabling rapid and accurate predictions of pellet source density compared with the first-principle HPI2 pellet code.

The pellet fueling depths of both traditional and carbon shell pellets with various injection locations and velocities are predicted based on the 2D Gaussian pellet deposition model, which considers the radially outward drift of the pellet ablation material through a drift scaling law from HPI2 code.

Simulation results demonstrate that deep fueling significantly enhances plasma confinement, core plasma density, tritium burn-up efficiency, and fusion power output. Notably, carbon-shell pellets, an innovative technical proposal, can achieve substantially deeper fueling than traditional pellets. It is predicted that the shell pellet with a thin carbon shell injected from HFS midplane can achieve the required fueling depth with a pellet velocity lower than 1 km/s. The predicted deposition profiles of a such pellet and its influence on plasma temperature and density profiles are shown in figure 1.

Optimal injection parameters, such as pellet speed and launch location, are further identified for CFETR. This work provides a general framework for pellet fueling analysis. The findings offer actionable insights for next-generation fusion reactors.

References

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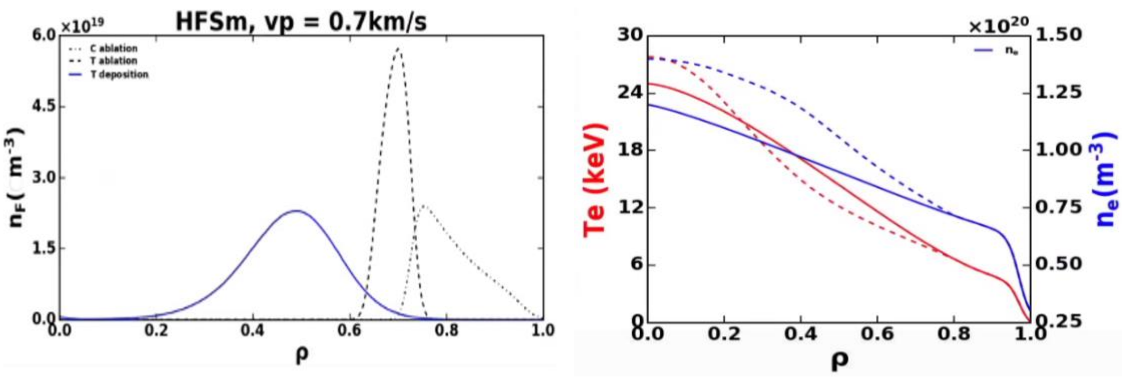

Figure 1. (a) The predicted deposition profiles of DT pellet with 200 µm carbon shell injected into CFETR hybrid mode plasma from HFS mid-plane at 700 m/s. (b) The initial (solid lines) and final electron temperature (dashed red line) and density profiles (dashed blue line) after shell pellet injection predicted by STEP.