KINETIC MODELING OF TUNGSTEN TRANSPORT INDUCED BY LOW-N X-POINT MODE

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1. ABSTRACT

This study investigates the transport of tungsten impurities induced by the LNXM (low-n X-point mode) in plasma, utilizing the full-orbit particle code PTC[1] and the turbulence code Hermes-3[2]. LNXM, a low-frequency mode observed during boron and carbon injection experiments in EAST[3,4], enhances plasma transport and exhibits potential for impurity expulsion in small or no-ELM regimes. Our findings reveal that LNXM induces both inward and outward radial transport of W impurities, with a predominant outward transport. Notably, LNXM demonstrates superior shielding capabilities compared to ELM[5]. The radial distribution range of LNXM is relatively narrow and is influenced by the impurity distribution. Effective management of impurity distribution might further enhance LNXM's transport efficiency and shielding effectiveness.

2. KEY RESULTS

(1) LNXM drives radial transport of W impurities, exhibiting both inward and outward transport capabilities, with outward transport being dominant. This mechanism enables effective expulsion and shielding of W impurities.

(2) As shown in Fig. 1, the region with the most significant particle reduction over time is concentrated in the narrow range $0.82 < \psi_{nor} < 0.90$, influenced by the C impurity distribution. Particles initially transport both inward and outward from this region due to differences in transport efficiency. Outward transport dominates, resulting in temporary particle accumulation within the LCFS, followed by gradual escape beyond the boundary.

(3) Regarding the shielding of W impurities, as illustrated in Fig. 2, LNXM's inward transport may cause short-term accumulation of wall-sputtered W particles in the edge region. However, its stronger outward transport ensures these particles remain confined to the edge region, preventing deeper penetration into the core.

3. IMPACT AND NOVELTY

Exploring high-confinement operational regimes characterized by small or no edge-localized modes (ELMs), coupled with efficient energy and impurity expulsion mechanisms, is a critical objective for future fusion reactors. The recently identified LNXM instability, emerging in small or no-ELM regimes, shows promise as an alternative to ELMs for radiative energy dissipation and impurity control. However, its underlying mechanisms remain under investigation, and its impact on impurity transport has yet to be explored. This study aims to compare LNXM and ELM characteristics, assessing the viability of achieving stable small or no-ELM operational scenarios. Our findings provide fundamental insights and motivate further experimental exploration. Notably, LNXM exhibits a narrower perturbation range than ELM and demonstrates stronger sensitivity to impurity distribution. Precise control of radial impurity profiles that trigger LNXM might enable enhanced regulation of impurity transport, particularly for high-Z elements like tungsten. This study will next focus on characterizing LNXM's impact on tungsten particle velocity distributions and their temporal evolution, alongside a comparative analysis of ELM effects on tungsten particle distribution and velocity profiles.

4. METHODOLOGY

The LNXM induced by C injection is simulated by Hermes-3 based on [6], and the perturbed electric field during the instability is interpolated as a background field into the PTC. 10,000 tungsten particles distributed in the scrape-off layer with ψ_{nor} = 0.75 ~ 1.0 and 0.85 ~ 1.0 are simulated, where ψ_{nor} is the normalized poloidal magnetic flux. Based on the ADAS database[7], a non-coronal equilibrium model with $n_e\tau = 0.5 \times 10^{20}\ m^{-3}ms$ is adopted, and all tungsten particles are simplified as W^{20+} ions. The initial velocities of the particles are randomly generated according to the Maxwellian distribution based on the local temperature.

5. FIGURES

To investigate the impact of LNXM on W particle transport and shielding effectiveness, this synopsis presents the temporal evolution of the W particle density profiles under two initial distributions. Since the Hermes-3 simulation region covers ψ_{nor} = 0.85 ~ 1.05, it can be assumed that the perturbation is confined to this region.

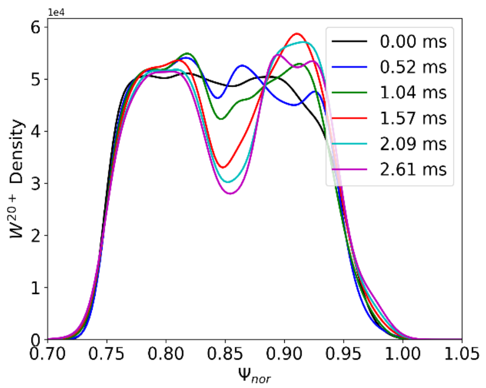

Fig. 1 Evolution of the W^{20+} density profile initially distributed in the range of ψ_{nor} = 0.75 ~ 1.0, recorded every 0.52 ms after the initiation of LNXM.

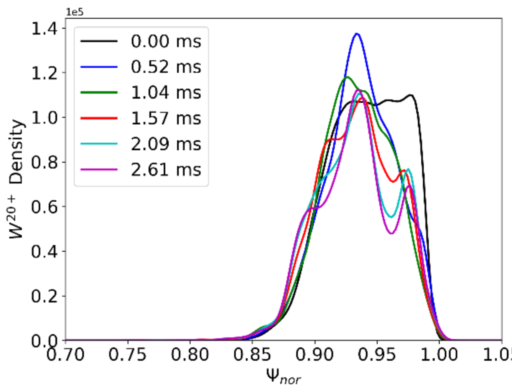

Fig.2 Evolution of the W^{20+} density profile initially distributed in the range of ψ_{nor} = 0.85 ~ 1.0, recorded every 0.52 ms after the initiation of LNXM.

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