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Modelling of Be transport in PSI experiments at PISCES-B

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ABSTRACT

Light emission patterns of BeI and BeII in the PISCES-B divertor simulator were simulated using the 3D Monte-Carlo code ERO. Many additional physical effects, e.g. Be collisions with neutral particles, were implemented into the code and tested alongside with the underlying data (e.g. ionization rates) by detailed comparison with experimental observations. This analysis is important to fully understand the Be impurity transport, deposition and re-erosion in PISCES-B, which will form the basis to model the Be behaviour in the JET ILW project and ITER.

1. Introduction

Erosion and deposition processes of plasma-facing components (PFC) in ITER, which will be made of beryllium (Be), tungsten (W) and carbon (C), determine the long term tritium retention rate and their lifetime. A detailed understanding of these processes and validated modelling is needed to make reliable predictions for ITER, understand experimental observations and develop control mechanism. Of particular importance is to understand the interplay of erosion, material transport, and material mixing in PFCs including chemical processes [1].

Modelling of PISCES-B (linear divertor simulator) experiments plays a particular role, because this is the only device, which allows relevant plasma experiments with toxic Be. In addition, it has a simple geometry and continuous plasma operation. PISCES-B has an exchangeable and cooled target with variable biasing, which defines the impinging energy of plasma ions. Beryllium is introduced into the plasma column using either a Be-effusion cell or by erosion from the Be target.

ERO is a 3D Monte-Carlo code, which simulates erosion, deposition, local impurity transport and their light emission. Recently, a special version was developed for PISCES-B and first modelling results were presented in [2]. Several additional effects were added to the code and proved to be of importance, e.g. elastic collisions (EC) of Be with the neutral background gas of the plasma constitute (D_2) and physical sputtering by molecular ions (D_2^+, D_3^+). To reproduce the mitigation of chemical erosion of the carbon target by Be deposition, which is of large importance for ITER operation [3], a model has been used in which Be–C carbide formation appears instantaneously. This assumption could reproduce qualitatively some experimental observations. The main disagreement is the much larger experimental time scale of the mitigation, which we account to slow changes of surface morphology and chemical reactions in the surface affected by diffusion. The complete mitigation, which is observed experimentally, can be reproduced by modelling only at larger Be plasma concentrations than in the experiment (several percent in modelling versus less than 1% in experiment).

This work presents improved modelling of experimentally measured BeI and BeII line intensity profiles in PISCES-B. Spectroscopy is used to characterise the Be transport through the plasma, which is a key part in understanding the beryllium flux to and from the target and thus plasma surface interaction (PSI) processes. Spectroscopic measurements allow also tracking the temporal evolution, whereas surface analysis characterises usually only the final state of the system.

2. Simulations, comparison with experiment, discussion

2.1. PISCES-B experiments

PISCES-B has a cylindrical vessel with a radius of about 20 cm. The plasma column confined by axial B-field impinges on an exchangeable target (Fig. 1). The electron density n_e slightly drops approaching the target and has a Gaussian profile in radial direction with a characteristic width of 50 mm. The electron temperature is constant along the axis and has a 72 mm wide plateau in radial direction. The data used are an approximation from multiple experimental data [4] resulting in fitting formulas that are anchored to the value at the axis at $z = 150$ mm, which is measured routinely. Typically $n_e \sim 1 \div 3 \times 10^{12}$ cm^{-3}, $T_e \sim 4 \div 12$ eV.

Be is injected from side using a special oven (effusion cell). The spectroscopic patterns of BeI, BeII and other species are measured

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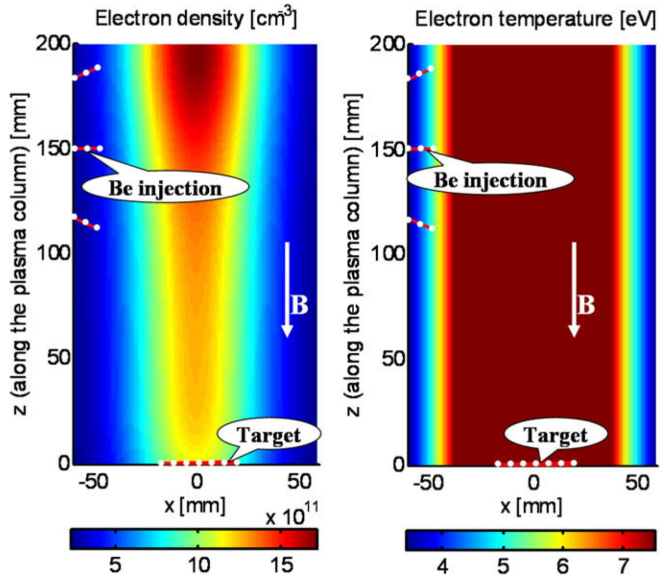

Fig. 1. Plasma parameters in the cross-section of PISCES-B taken through the axis [4]. The target and the Be injection from the oven (situated at 195 mm from the axis) are marked. The remaining part of the vessel is filled with neutral gas.

with a 2D camera with narrow band filters and also with a spectrometer. The latter allows taking linear profiles both along and perpendicular to the magnetic field (PISCES-B axis).

2.2. Elastic collisions with neutrals

Elastic collisions (EC) with neutral D_2 gas play an important role for the transport of neutral Be. They lead to a broad distribution of Be along the whole PISCES-B volume. As a result of EC, the influence of initial angle and energy distribution of the injected Be becomes mostly negligible. As only the Be impurities are tracked by ERO the velocity vector of D_2 is randomly generated with a Maxwell distribution at room temperature. The oppositely directed velocity directions after the collision are assumed to be isotropically random in the centre of mass system.

The ERO EC model and the underlying data were tested by the modelling of dedicated experiments in which Be was seeded into the volume but without plasma. The Be oven aperture has a cone-like shape with a very sharp angle of about 12° such that the Be stream entering the PSICES-B device is strongly collimated. Thus, the Be flux that can impinge on the target itself is only due to EC (Fig. 2). The ERO simulations were used to correlate the seeding rates with the Be-deposition on the target, assuming full sticking of Be. The Be rate estimation based on this correlation and the exper-

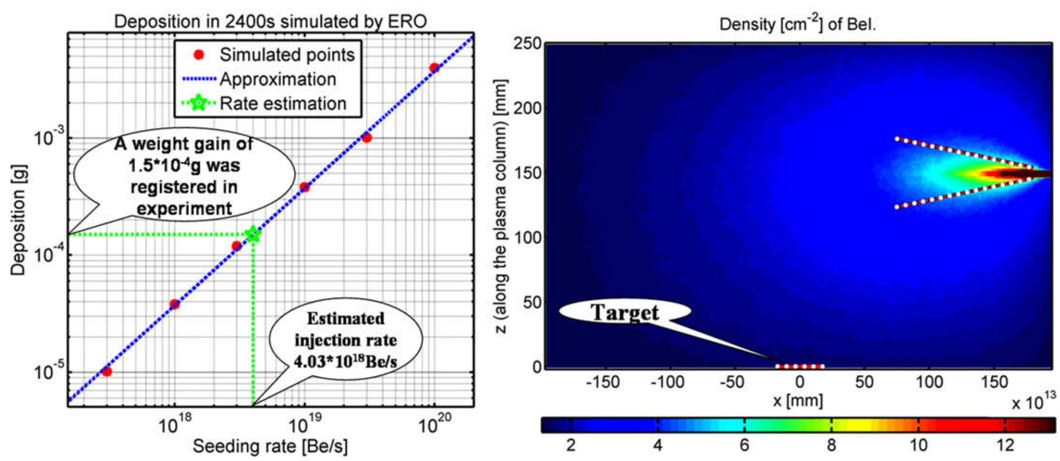

Fig. 2. Density of neutral Be inside PISCES-B vessel (right) illustrating the transport of injected Be to the target. The calibration of deposition to the injected rate based on ERO simulations determines the injection rate corresponding to the experimental weight gain.

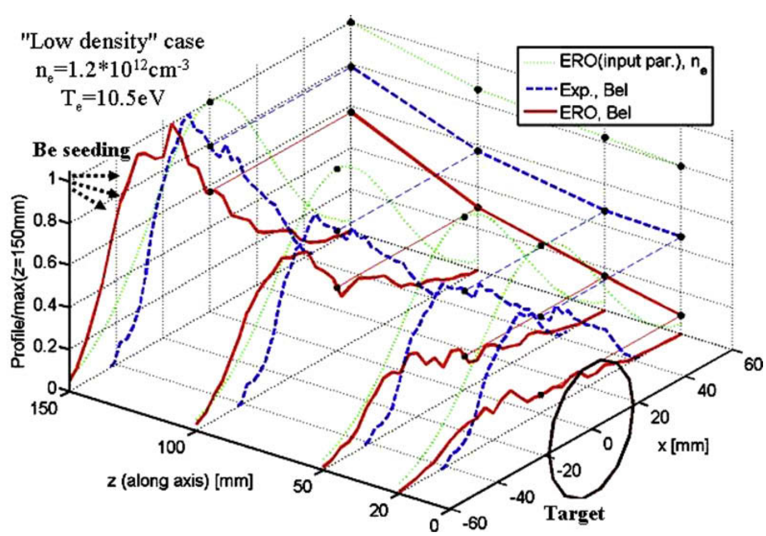

Fig. 3. Comparison of normalized to maximum BeI line intensity profiles. The electron density used as input for ERO is also shown to illustrate plasma column position and width. The target and Be seeding direction are marked.