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Institut de Recherche sur la Fusion par confinement Magnétique
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Centre de Cadarache, 13108 Saint-Paul-Lez-Durance, France

SUJET DE THÈSE 2021

Etude du transport de poudres de bore injectées dans les plasmas du tokamak WEST et de son effet sur les performances
Study of transport of boron powders injected in the WEST tokamak and its effect on plasma performance

Nom du responsable (ou codirecteur) de thèse : MOREAU Philippe	**e-mail :**	alberto.gallo@cea.fr philippe.jacques.moreau@cea.fr
	page web :	
	téléphone :	+33 (0)4 42 25 36 39
	secrétariat :	+33 (0)4 42 25 62 25
Équipe de Recherche :	**STEP/GPAM, Bernard Pegourie (SPPF/GDIPP)**	

Nom du Directeur de thèse :	**e-mail :**	
	page web :	
	téléphone :	+33 (0)4 42 25
	secrétariat :	+33 (0)4 42 25
Équipe de Recherche :		

Résumé du sujet en Français :
10-15 lignes. Utilisez un style accessible à un étudiant de niveau Master 2 (jargon proscrit) en précisant le contexte scientifique, le travail proposé (théorique/expérimental, jalons, orientations possibles, collaborations, etc.) et les résultats attendus.

L’interaction des plasmas avec les parois de la chambre à vide des tokamaks libère des impuretés dont la présence peut affecter leurs performances. Différentes méthodes de conditionnement sont alors utilisées pour contrôler l’état de surface de l’enceinte à vide, et donc les flux d’impuretés. Celles-ci utilisent principalement des plasmas basses températures (décharges luminescentes ou radiofréquences) en hydrogène ou en hélium, mais aussi des procédés de dépôts de films en couches minces d’éléments tels que le bore, en raison de sa capacité à piéger par affinité chimique des impuretés tels que l’oxygène. Avec l’avènement des composants face au plasma métalliques et l’allongement de la durée des plasmas dans les machines supraconductrices, comme WEST, de nouvelles techniques de conditionnement des parois pendant le plasma pour maintenir un état de surface et des performances optimales tout au long de la décharge plasma font leur apparition.
L’objectif de cette thèse est de caractériser et d’évaluer la pertinence pour WEST d’une méthode d’injection de poudre de bore directement dans les plasmas. Le travail consistera d’une part à participer à des expériences sur WEST (voire sur ASDEX-Upgrade en Allemagne) et à analyser des données expérimentales (localisation des dépôts, effet sur les performances des plasmas). Afin de comprendre le transport du bore, le candidat travaillera avec des codes de plasma de bord (p.ex. SOLEDGE-2D) et de transport d’impuretés (p. ex. GITR). Ce travail, combinant expériences et simulation numérique, devra

consolider la compréhension de la physique du conditionnement en environnement métallique et à prévoir les conséquences pour les futurs dispositifs de fusion.

Résumé du sujet en Anglais :

Interaction of plasmas with the inner walls of the vacuum chamber of tokamaks releases impurities whose presence can affect their performance. Different conditioning methods are used to control the surface state of the vacuum chamber, and thus impurity fluxes. These mainly use low-temperature plasmas (glow or radio-frequency discharges) in hydrogen or helium, but also deposition of thin layers of elements such as boron, because of its ability to trap by chemical affinity impurities like oxygen. With the advent of metallic Plasma Facing Components and the extension of plasma duration in superconducting devices, like WEST, innovative wall conditioning technics operated during plasma to maintain optimal surface state and performances are under development.
The aim of this thesis is to characterize and evaluate the relevance for WEST of a boron powder injection method directly into plasmas. The work will consist on the one hand to participate in experiments on WEST (also on ASDEX-Upgrade in Germany) and to analyze experimental data (location of the deposits, effect on plasma performances). In order to understand the transport of injected boron, the candidate will work with plasma edge (eg. SOLEDGE-2D) and impurity transport code (eg GITR). This work, combining experiments and numerical simulation, will aim at consolidating the understanding of the physics of wall conditioning in a metallic environment and predicting consequences for future fusion devices.

Formation recherchée / recommandée : Master en physique des et /ou interactions plasma-surface. Expérimentation, modélisation. Le sujet requiert une capacité à travailler dans un cadre fortement collaboratif avec des Instituts de recherché en Europe et aux Etats-Unis.

Intitulé du master préconisé :

Description détaillée du sujet :

8 000 caractères au maximum.
Présenter les objectifs et la problématique du sujet, de manière à convaincre entre autres les évaluateurs (HC + Ecole Doctorale) de la pertinence du projet de recherche et de son adéquation avec les exigences d'un projet de thèse (objectifs scientifiques réalisables en 3 ans, objectifs de formation, disponibilité de l'encadrement, ouverture vers le monde scientifique et professionnel, etc.)

Wall conditioning of tokamaks is a common tool to influence fuel - and impurity recycling and to improve plasma performance and reproducibility [1]. Wall conditioning occurs either before plasma operation after torus vacuum vessel openings, or during operation, between or during plasma pulses, for reliable discharge initiation, control of fuel and impurity recycling or recovery after disruptions. Hence, baking, glow or RF assisted discharge cleaning, as well as deposition of thin layers on inner wall surfaces of the vacuum vessel, are routinely used in present days devices.

In tokamaks with tungsten (chemical symbol W, or other high-Z elements) Plasma Facing Components (PFC), the control of tungsten influx by depositing thin film coatings with boron (boronization) or other low-Z elements (lithiumization, siliconization) is essential to achieve high performance plasmas. In WEST with tungsten PFCs (or ASDEX-Upgrade with tungsten, Alcator C-MOD with molybdenum), regular boronizations are performed by operating a glow discharge in a 10-15% Diborane into Helium mixture during a few hours. They allow reducing carbon and oxygen contamination, mitigating the W influx, and thus enlarging operational space in plasma density and injected power. However, the technique has several drawbacks, the first of which being that diborane is both toxic and explosive. Boronizations with glow discharge must also be done in the absence of the intense toroidal magnetic field, which makes it less attractive in a superconducting device like WEST or the future ITER tokamak. Last but not least, lifetime of coatings and their beneficial effects are limited by the erosion by the plasma and last typically a few tens of discharges in WEST and ASDEX-Upgrade.

With the extension of the pulse duration in superconducting devices, and the associated increase of particle and power fluence to the walls, has emerged the need for real-time wall conditioning (i.e. during plasma) to maintain an optimum surface state throughout long discharges. Experiments using low-Z powders injection have demonstrated the capability to effectively reduce high-Z impurity influx, in EAST (China) and ASDEX-Upgrade (Germany). In this aim, an Impurity Powder Dropper (IPD) [2] has been developed to provide real-time particulate injection. Preliminary results on the injection of boron and boron nitride powders during ASDEX-Upgrade plasmas show the potential to control tungsten influx in subsequent plasmas, similar to conventional boronization methods.

The aim of this thesis is to determine if this low-Z impurity delivery method can be used as an efficient wall conditioning technique in WEST benefiting from its long discharge duration capability. The work will consist in participating in dedicated experiments using the Impurity Powder Dropper in WEST (possibly in ASDEX-Upgrade, Germany, as well), and analyzing data in order to assess its efficiency. A comparison with the conventional boronization methods used in both WEST and AUG (glow discharge in a Helium-Diborane mixture) will be done.
In this aim, the candidate will have to get familiar with diagnostics yielding all relevant data for the assessment of the conditioning efficiency, such as density, optical spectroscopic signals, radiated power…, but also for modeling.

Indeed, in order to understand transport of the injected boron, the candidate will also work with edge plasma codes such as SOLEDGE-2D and migration at the surface with codes such as GITR or ERO, with the aim to predict transport of boron and of other impurities in the plasma edge, as well as deposition area. The simulation results will be compared with experiments. This work, combining experiments in fusion devices and numerical simulation, should aim at consolidating the understanding of the physics of wall conditioning in a metallic environment and predicting consequences for future fusion devices, such as ITER.

[1] J. Winter, Plasma Phys. Control. Fusion 38 (1996) 1503–1542
[2] A. Nagy et al., “A multi-species powder dropper for magnetic fusion applications” Rev. Sci. Instr. 89 (2018) 10K121

Collaborations scientifiques et/ou partenariats industriels envisagés :

- Nom du collaborateur: Ahmed Diallo, PhD.
  Deputy Director - INFUSE program
- Organisme/Société: Princeton Plasma Physics Laboratory
  Princeton, NJ 08543-0451
  Office: LSB B234
  Phone:+1.609. 243.2560.
- Raison de la collaboration:
  De1 000 caractères au maximum.