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Oral_3.1: Fusion alpha-particles diagnostics: from JET to ITER and DEMO

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The nuclear fusion reaction between deuterium and tritium, D(T,n)4He is the main source of energy in future thermonuclear reactors. Charged fusion products of this reaction, α-particles (4He-ions), are born with an average energy of 3.5 MeV. They transfer energy to the thermal plasma during their slowing down, providing the self-sustained deuterium-tritium plasma burn. Adequate confinement of α-particles is essential to provide efficient heating of the bulk plasma and steady burning of a reactor plasma. Investigation of fusion-born α-particles behaviour will be a priority task for the planned DT experiments on Joint European Tokamak (JET) [1] and International Thermonuclear Experimental Reactor (ITER) in order to understand the main mechanisms of their slowing down, redistribution and losses and to develop optimal plasma scenarios.
Today's JET machine has ITER-like wall (beryllium wall and tungsten divertor) and enhanced auxiliary heating systems, including NBI with power up to 34 MW and ICRF power up to 7 MW. Therefore, forthcoming DT experiments on JET are aiming to produce 10 –16 MW fusion power during a 5-second stationary state plasma. It is expected to produce significant population of α-particles to provide a step-ladder approach for extrapolating to ITER, so the experiments will give great opportunities to study fusion alphas.
The first full scale DT experiment on JET in 1997 (DTE1) has shown that direct measurements of alphas are very difficult. Alpha-particle studies require a significant development of dedicated diagnostics. What do we want to measure in the next deuterium-tritium experiments on JET? The principal priorities are the DT fusion reaction rate and the spatial α-particle birth profile. Measurement of the slowing down, diffusion, redistribution and loss of fast α-particles is another high priority requirement for optimisation of the plasma scenarios and assessment of MHD effects on the DT plasma performance. In order to make such measurements, JET, as a testbed for ITER, has now been equipped with an excellent set of fast α-particle diagnostics for operation at the high neutron and γ-ray fluxes expected in forthcoming DT experiments: γ-ray spectrometers for measuring energy distribution; 2D neutron/γ-ray camera for tomographic reconstruction of the α-particle source and the temporal evolution of its spatial profile; a fast ion loss detector with energy and pitch-angle resolution and a set of the lost α-particle collectors with poloidal, radial and energy resolution.
The confinement of fast α-particles produced in fusion reactions is of crucial importance for ITER. Indeed, it is planned to reach burning plasma at the fusion gain factor Q=10 (the ratio of fusion power to the external heating power). In burning plasmas, fundamentally new α-particle physics is anticipated. α-particles could affect the magnetohydrodynamic (MHD) stability and turbulence in plasma discharges with 10>Q>5; at Q>10, a strong non-linear coupling between alphas and a pressure driven plasma current is predicted. In future fusion reactors like DEMO with Q→∞ ignition transient phenomena will be the main issue. Some plasma instabilities may lead to significant α-particle losses and the loss of plasma heating that is not acceptable for the efficient fusion plant as it can cause problems with ignition and damage to the first wall. To keep fusion α-particles under control, a range of specific diagnostics is needed for monitoring the α-particle population in real-time.
A goal of the DEMO fusion power plant is to demonstrate that the major scientific and technological obstacles on the way to the commercial power plant have been overcome, and one of the real challenges is development of a highly robust and reliable diagnostic system. A harsh DEMO environment with a very high level of neutron and γ-ray fluxes will make some conventional ITER diagnostics unfeasible [2]. Among the restricted set of instruments, which are available for the machine protection and plasma control in DEMO, neutrons and γ-ray measurements will be useful as detectors can be placed far away from the plasma and they do not require a direct access to the vessel. Some neutron and γ-ray diagnostics developed and tested on JET and used in ITER will be the main work horses in DEMO for monitoring fusion power, the core fuel ratio and α-particle loss control.

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[1] Joffrin E. et al 2019 Nucl. Fusion 59 112021
[2] Donné A.J.H., Costley A.E. and Morris A.W. "Diagnostics for plasma control on DEMO: challenges of implementation"Nuclear Fusion 52 (2012) 074015
* See the author list of 'Overview of JET results for optimising ITER operation' by J. Mailloux et al to be published in Nuclear Fusion Special issue: Overview and Summary Papers from the 28th Fusion Energy Conference (Nice, France, 10-15 May 2021).

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