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OBSERVATION OF ALPHA PARTICLES IN D-T AND T-PLASMAS ON JET

V.G. Kiptily[1,*)], P.J. Bonofiglo[2], T. Craciunescu[3], J. Eriksson[4], M. Fitzgerald[1], V. Goloborodko[5], M. Nocente[6], S. Menmuir[1], M. Podestà[2], M. Poradzinski[1], D. Rigamonti[7], Z. Stancar[1,8], S.E. Sharapov[1], H. Sun[1], D.M. Taylor[1], M. Tardocchi[7], P. Beaumont[1], F. Belli[9], F.E. Cecil[10], C.D. Challis[1], R. Coelho[11], M. Curuia[12], R. Dumont[13], J. Garcia[13], M. Garcia-Munoz[14], Z. Ghani[1], Ye. Kazakov[15], D. Keeling[1], E. Lerche[15], C.F. Maggi[1], J. Mailloux[1], P. Mantica[16], M.J. Mantsinen[17,18], D. Marocco[9], C. Perez von Thun[19], F. Rimini[1] , P. Siren[1] and JET contributors*

[1] *UKAEA, Abingdon, United Kingdom*
[2] *Princeton Plasma Physics Laboratory, Princeton, NJ 08543, New Jersey, USA*
[3] *National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania*
[4] *Department of Physics and Astronomy, Uppsala University, BOX 516, Uppsala, Sweden*
[5] *Kyiv Institute for Nuclear Research, ProspektNauky47, Kyiv 03680, Ukraine*
[6] *Dipartimento di Fisica, Università di Milano-Bicocca, Milan, Italy*
[7] *Institute for Plasma Science and Technology, National Research Council, Milan, Italy*
[8] *Jožef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia*
[9] *Unità Tecnica Fusione -ENEA C. R. Frascati -via E. Fermi 45, 00044 Frascati (Roma), Italy*
[10] *Colorado School of Mines, Golden, CO 80401, USA*
[11] *Instituto de Plasmas e Fusao Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal*
[12] *National Institute for Cryogenics and Isotopic Technology, Bucharest, Romania*
[13] *CEA, IRFM, F-13108 Saint-Paul-Lez-Durance, France*
[14] *FAMN Department, Faculty of Physics, University of Seville, 41012 Seville, Spain*
[15] *LPP-ERM/KMS, Association EUROFUSION-Belgian State, TEC partner, Brussels, Belgium*
[16] *Istituto per la Scienza e Tecnologia Dei Plasmi, Consiglio Nazionale Delle Ricerche, Milano, Italy*
[17] *Barcelona Supercomputing Centtre, Barcelona, Spain*
[18] *ICREA, Pg. LiuisCompanys23, 08010 Barcelona, Spain*
[19] *Forschungszentrum Jülich GmbH, Institut für Energie-und Klimaforschung -Plasmaphysik, 52425 Jülich, Germany*

**) See the author list of 'Overview of JET results for optimising ITER operation' by J. Mailloux et al 2022 Nucl. Fusion 62 042026

The fusion reaction between deuterium and tritium, *D(T,n)^{4}He* is the main source of energy in future thermonuclear reactors. Charged fusion-products of this reaction, α-particles (*^{4}He*-ions), are born with an average energy of 3.5MeV. Transferring energy to the thermal plasma during their slowing down, they should provide the self-sustained *D-T* plasma burn. Adequate confinement of α-particles is essential to provide efficient heating of the bulk plasma and steady burning of a reactor plasma. That is why the fusion-born α-particle studies have been a priority task for the second *D-T* experiments (DTE2) on JET to understand the main mechanisms of their slowing down, redistribution and losses and to develop optimal plasma scenarios. JET with the ITER-like wall (*Be*-wall and *W*-divertor) , improved energetic-particle diagnostic capabilities and enhanced auxiliary heating systems producing significant population of α-particles provided a great opportunity to study the α-particle behaviour giving a stepladder approach for modelling and extrapolating to ITER. Several new results of α-particle studies in DTE2 will be presented in this paper.

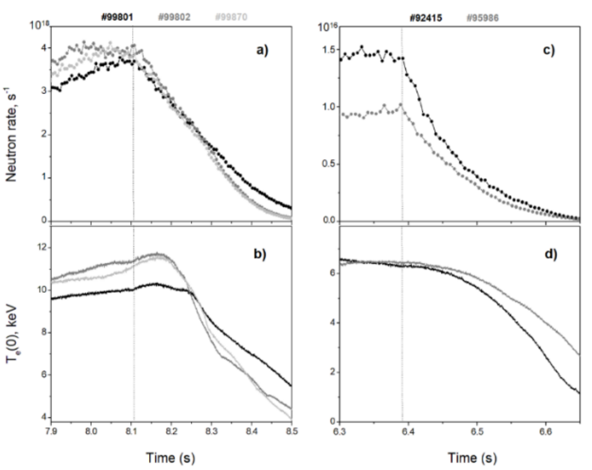

Figure 1*. (a) and (b) - waveforms of the D-T JET pulses; (c) and (d) – the deuterium JET pulses (the waveforms were shifted in time to align both NBI afterglow periods). The panels show waveforms of central electron temperatures, Te(0), and measured neutron rates, where the dash line is marking the start of the NBI afterglow period.*

Alpha-particle diagnostics. The first full scale *D-T* 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. In order to make such measurements, JET has been equipped with a set of fast α-particle diagnostics for operation at the high neutron and γ-ray fluxes in *D-T* experiments: neutron/γ-ray spectrometers; 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 (FILD) with energy and pitch-angle resolution and a set of the lost α-particle collectors (Faraday Cups) with poloidal, radial and energy resolution. These diagnostics provided novel α-particle observations in DTE2.

Alpha-particle heating. A direct evidence of α-particle self-heating plasma effect is identified in the NBI afterglow of the high-performance discharges. It was found that α-particles continue transferring their kinetic energy to plasma electrons during slowing-down after the removal of applied NBI. During the NBI afterglow period, the total neutron rate (substantially *D-T* neutrons) is decreasing while the plasma core electron temperature, $T_e(0)$, is still increasing for a short period. This evolution is in a contrast to the reference high-performance deuterium discharges, in which both T_e and *D-D* neutron rate are decreasing during the NBI-afterglow. The α-particle self-heating effect was observed in both the so-named hybrid-scenario discharges as well as in discharges with ITB. A comparison of some *D-T* and deuterium discharges with NBI cuts are presented in figure 1. Transport modelling of the relevant *D-T* and deuterium-discharges is consistent with the α-particle heating observation.

Alpha-particle losses. (A). In the high-performance discharges with NBI-only heating, a zoo of low-frequency MHD modes were observed before and during the NBI-afterglow period. Alpha-particle losses associated with these modes are observed with FILD and Faraday Cups. In the afterglow phase of the discharges, a sharp and massive expulsion of 3.5-MeV α-particles was detected. It was identified that these α-particles are coming from the plasma core causing T_e drop. We observe a loss spike, which is characterized by very high rate relative to classical first orbit rate detected, which could be linked to core α-particle redistribution triggering ELMs. Modelling with the TRANSP+ORBIT codes is ongoing.

(B). It was found that α-particle losses are coherent with fishbones (figure 2) & long-lasting modes in the baseline and hybrid scenario discharges. Similar effects have been observed and modelled in *DD*-plasmas, where losses of fusion-products, protons/tritons, were analysed [Kiptily et al 2018 NF **58** 014003].

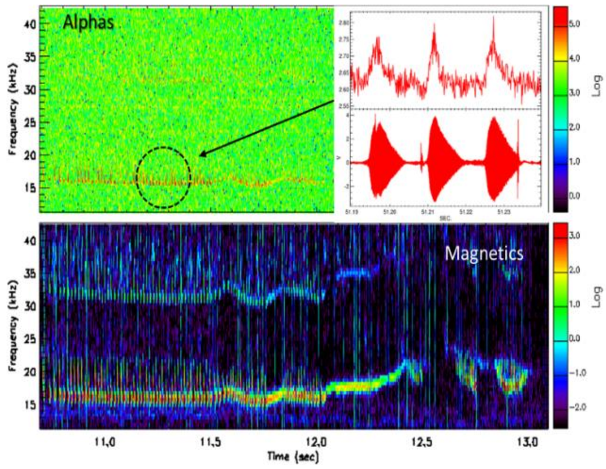

Figure 2. *Magnetics and FILD spectrograms show that α-particle losses correlated with fishbones.*

(C). The high-energy α-particle loss-spikes correlated to ELMs were found. The orbit calculations shows that the related α-particles are lost at the passing-trapped boundary. These α-particle losses were observed with FILD and Faraday Cups.

(D). Anomalous *D-T* α-particle losses have been observed in a novel heating scheme – 3-ion ICRF heating of ^{9}Be-impurity (could be used in ITER). The pitch-angle distribution of α-particle losses shows some surprises. Whereas in most of the cases a single maximum is found, two maxima at different angles are detected in dedicated toroidal current-scans. The physics reason behind this feature is being investigated.

(E). *T-T* α-particle losses in *T*-plasmas were measure with FILD – energy vs pitch-angle and FCs – poloidal distribution; It was found the losses coherent with n=2 mode [Bonofiglo et al RSI **93**, 093527 (2022)] .

Novel fusion γ-ray measurements. 17-MeV γ-rays of $D(T,\gamma)^4He$ were measured – could be used as an additional tool for *D-T* fusion-rate monitoring [Kiptily et al PPCF **48** (2006) R59]. Also, 20-MeV γ-rays from $T(H,\gamma)^4He$ reaction were measured in the H-minority heating in *T*-plasmas. Gammas from $T(p,\gamma)^4He$ and $D(T,\gamma)^4He$ reactions together are important for monitoring of the fuel-ratio and temperature in the reactor plasma core. [Kiptily et al NF **50** (2010) 084001; NF **55** (2015) 023008].

Conclusions. DTE2 experiments provided unique information on α-particle behaviour in ITER relevant scenarios. It gives opportunity for the detailed analysis and modelling that could enrich our knowledge on the α-particle physics in fusion reactors.