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Alpha particle generation and confinement in D-^{3}He scenarios in JT-60SA

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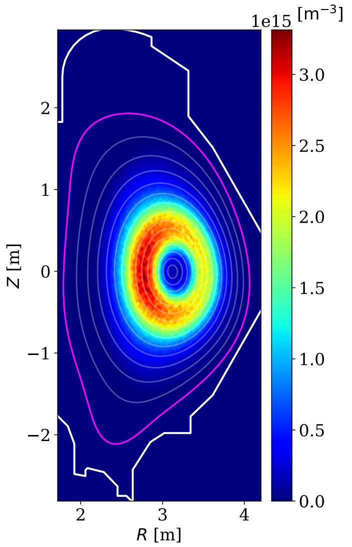
JT-60SA is a fully superconducting tokamak collaboratively designed and constructed by Japan and Europe. Its role is to serve as a supporting device for the ITER experimental program while advancing progress toward the future DEMO fusion reactor [1,2]. Building on the experience gained from JET and on superconducting tokamaks like WEST, EAST, and KSTAR, JT-60SA seeks to push the boundaries of superconducting tokamak technology and operational regimes by providing essential insights for creating steady-state, high-performance operational scenarios [3]. In particular, JT-60SA aims to achieve and control high-β, high-bootstrap current fraction (f_{BS}) and high normalized plasma density (to Greenwald density) plasmas, a critical step towards economically viable steady-state DEMO reactors [4]. Pivotal to achieve such goals, JT-60SA offers a range of versatile possibilities for controlling heating, current, and momentum inputs. Its capabilities encompass tangential off-axis negative ion source based neutral beam (N-NBI) injection of 10 MW at 500 keV, positive ion source based neutral beams (P-NBI) at 85keV with 2 units of co-tangential beams (4MW), 2 units of counter-tangential beams (4MW) and 8 units of near perpendicular beams (16MW). With additionally 7 MW of electron cyclotron resonance heating (ECRH), JT-60SA is poised to address the development of full non-inductive steady-state operation scenarios and to sustain weak/negative magnetic shear plasmas in high-beta advanced tokamak (AT) configurations.

Although JT-60SA is not foreseen to operate with DT fuel mix and thus not aiming explicitly at alpha physics studies, the beam-thermal fusion cross-section of the reaction D_{beam}+^{3}He → ^{4}He (3.6MeV) + p (14.7 MeV) has its maximum close to 500keV for fast deuterium (still one order of magnitude smaller than peak thermal DT fusion cross section). It is thus an excellent option for downscaled alpha particle studies of, e.g., the effect on core turbulence, MHD and electron dominated heating regimes. This approach avoids tritium manipulation and machine activation and has already been used in existing tokamaks. At JET for instance [5,6], this technique was quite successful in enabling alpha-particles studies in plasmas with experimental conditions matching $B_0 = 3.7T$, $I_p = 2.5MA$, $n_e \approx 6 \times 10^{19} m^{-3}$ and using the 3-ion ICRH scheme [7] D-D_{NBI}-^{3}He and ^{3}He concentrations of the order 20–25%. Since at JET the NBI beam ions energies are at most ~100keV, the RF power was key to further acceleration of the D-NBI ions to MeV like energies at the mode conversion layer in the plasma core. Clear evidence of alpha particle generation from the ^{3}He+D fusion reaction was made at an estimated rate $r_{alpha} \approx 2 \times 10^{16} s^{-1}$, assisted by gamma-ray spectra measurements.

In this work we investigate the birth and confinement properties of fusion born alpha particles in two JT-60SA scenarios using the ASCOT5 code suite [8]. The 10MW N-NBI beam deposition in the plasma is modelled by BBNBI, marker guiding centers followed until slowing down are modelled by ASCOT, and D+^{3}He fusion reactions are modelled by AFSI. As the first example, a hybrid scenario (scenario 4) at β_N=3, n_e/n_{GW}=0.8 and non-inductive current drive fraction of 0.58 is addressed. In this scenario the beam deposition is slightly off-axis and this results in fusion born alpha distributions also peaked off-axis (see Figure 1).



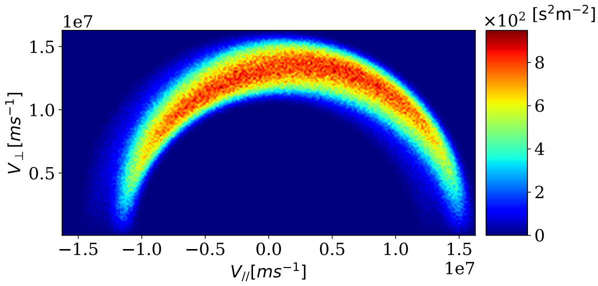


Figure 1 – Alpha birth distribution from fast deuterium from N-NBI and ^{3}He (15% concentration) fusion reactions. Both RZ (left) and velocity-space (right) distributions are shown.

An extensive parametric scan was carried out to assess optimal conditions for alpha particle generation. In particular, ^{3}He concentration, plasma position, electron density (at constant pressure) and joint electron density and temperature were considered to infer the effect on the fusion alpha birth rate. Already at very moderate (5%) ^{3}He concentration for the reference plasma, an alpha birth rate of $r_{alpha} \approx 2.5 \times 10^{16} s^{-1}$is anticipated, higher than the JET case (at 20–25% concentrations). Significant increases are achieved by slightly lowering the plasma position, decreasing the density by 20% and increasing the temperature by 20% as is evidenced by the alpha density radial profile in Figure 2 (10% ^{3}He concentration) topping at a total birth rate of $r_{alpha} \approx 8 \times 10^{16} s^{-1}$. As a second application, the forthcoming OP2 baseline scenario at 4.6 MA/2.28 T, operating at lower β_N~2, n_e/n_{GW}=0.4–0.6 is considered. Alpha birth rates using the same ^{3}He seeding are currently being investigated. For both scenarios, the calculations will be further extended to infer the confined/lost fractions and to investigate strategies to optimise the confined fraction.

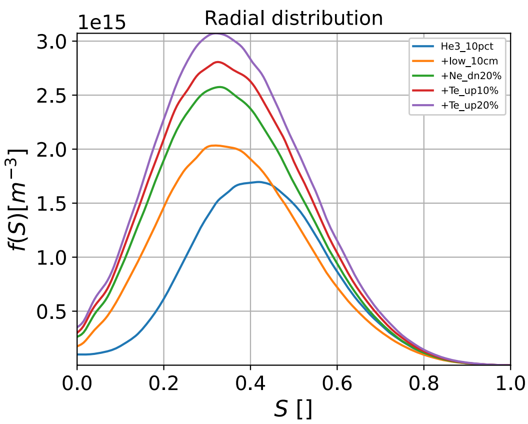


Figure 2 – Alpha particle birth density profile using 10% ^{3}He concentration for some of the different scenario variants explored (reference position, 10cm plasma downshift, 20% decrease in density at equal pressure and 10% and 20% surplus increase in electron temperature).

References

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