UKAEA-CCFE-CP(20)102

C. Challis, R. Dumont, D. Frigione, L. Garzotti, J. Graves, E Lerche, J. Mailloux, M. Mantsinen, F. Rimini, F. Casson, A. Czarneka, R. Felton, J. Garcia, C. Giroud, E. Joffrin, H.-T. Kim, M. Lennholm, P. Lomas, C. Lowry, L. Meneses, I Nunes, et al.

Scenario development for DT operation at JET

Scenario development for DT operation at JET

C. Challis, R. Dumont, D. Frigione, L. Garzotti, J. Graves, E Lerche, J. Mailloux, M. Mantsinen, F. Rimini, F. Casson, A. Czarneka, R. Felton, J. Garcia, C. Giroud, E. Joffrin, H.-T. Kim, M. Lennholm, P. Lomas, C. Lowry, L. Meneses, I Nunes, et al.

This paper has been submitted to
27th IAEA Fusion Energy Conference, Ahmedabad, India, 22-27 October 2018

SCENARIO DEVELOPMENT FOR DT OPERATION AT JET

L. Garzotti[1], C. Challis[1], R. Dumont[2], D. Frigione[3], J. Graves[4], E Lerche[5], J. Mailloux[1], M. Mantsinen[6,7], F. Rimini[1], F. Casson[1], A. Czarnecka[8], J. Eriksson[9], R. Felton[1], L. Frassinetti[10], D. Gallart[6], J. Garcia[2], C. Giroud[1], E. Joffrin[2], H.-T. Kim[11], N. Krawczyk[8], M. Lennholm[11], P. Lomas[1], C. Lowry[11], L. Meneses[12], I. Nunes[12], M. Romanelli[1], S. Sharapov[1], S. Silburn[1], A. Sips[11], E. Stefániková[9], M. Tsalas[13], D. Valcarcel[1], M. Valovič[1] and JET contributors*

[1]UKAEA, Culham, UK – [2]CEA, Cadarache, France – [3]ENEA, Frascati, Italy – [4]EPFL, Lausanne, Switzerland – [5]ERM, Bruxelles, Belgium – [6]BSC, Barcelona, Spain – [7]ICREA, Barcelona, Spain – [8]IFPILM, Warsaw, Poland – [9]Uppsala University, Uppsala, Sweden –[10]KTH, Stockholm, Sweden - [11]JET PMU, Culham, UK – [12]IST, Lisbon, Portugal –[13]DIFFER, Eindhoven, The Netherlands.
See the author list of "X. Litaudon et al. 2017 Nucl. Fusion **57 102001"*

Abstract

The JET exploitation plan foresees D-T operations in 2020 (DTE2). With respect to the first D-T campaign in 1997, when JET was equipped with a carbon wall, the experiments will be conducted in presence of a beryllium-tungsten ITER-like wall (ILW) and will benefit from an extended and improved set of diagnostics and higher additional heating power (34MW NBI + 8MW ICRH). Among the challenges presented by operations with the new wall, there are a general deterioration of the pedestal confinement (not completely explained yet), the risk of heavy impurity accumulation in the core, which, if not controlled, can cause the radiative collapse of the discharge, and the requirement to protect the divertor from excessive heat loads, which may damage it permanently. Therefore, an intense activity of scenario development has been undertaken at JET during the last three years to overcome these difficulties and prepare the plasmas needed to demonstrate stationary high fusion performance and clear alpha-particle effects. The paper describes the main achievements of the scenario developed, both from an operational and plasma physics point of view.

1. INTRODUCTION

The JET exploitation plan foresees D-T operations in 2020 (DTE2) [1]. Unlike in the first D-T campaign in 1997 (DTE1), where the main objective was to maximize the neutron yield, even if transiently, the focus of this experimental campaign will be on demonstrating stationary high-performance plasmas lasting for several confinement times. Demonstrating the readiness of JET to achieve this objective is the aim of the campaigns in pure D and pure T, which will be conducted before DTE2. In particular, JET performances will be measured against a series of key performance indicators, the most relevant of which, in terms of readiness for high-performance D-T operation, is the establishment of a reliable scenario capable of producing $5\cdot10^{16}$ neutrons/s for 5 s in D plasmas, averaged over the best 20 pulses. This would translate to 15 MW of fusion power maintained over 5s in D-T. The progress towards this target is illustrated in Fig. 1, showing the average neutron rate as a function of the averaging time.

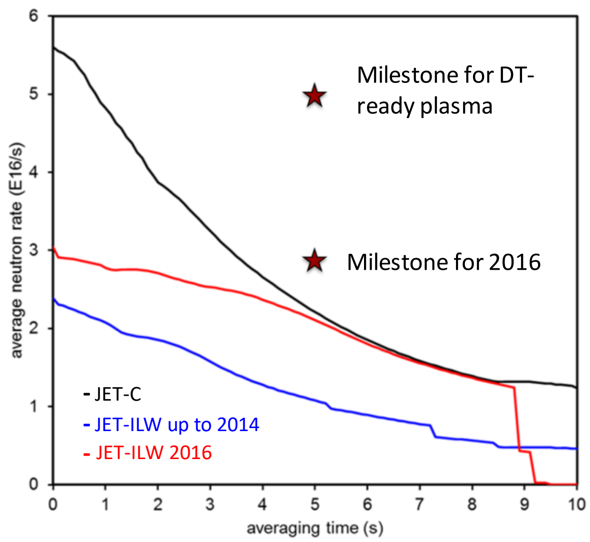

FIG. 1. Average neutron rate as function of the averaging time for the JET best performing shots. The stars show the milestones for 2016 and a for a D-T ready plasma.

It can be seen that, while JET has recovered the performance of the C wall for averaging times >5 s, it has not yet been possible to replicate the peak neutron rates achieved in the past over shorter time windows. It can also be seen that the milestone for the 2016 campaign was not met. However, the neutron rate achieved is consistent with the available NBI power being limited by operational restrictions on the maximum voltage allowed on the injector acceleration grid. These restrictions will be lifted before the next experimental campaign. Fast progress was made as soon as high power (NBI+ICRH=25-33MW) became reliably available. To achieve the key performance indicator for a D-T ready plasma mentioned above the neutron rate needs to be increased by a factor of two. This will be attempted in the upcoming campaigns, when ~42 MW of additional heating power are expected to be consistently available. An equally important scientific objective DTE2 is to conduct experiments aimed at documenting and demonstrating unequivocally the effect of α-particle physics such as α-particle heating and α-particle destabilisation of toroidal Alfvèn eigenmodes (TAE).

The fusion production targets of DTE2 represent an extension of the achievements of DTE1 [2, 3] where 16 MW of fusion power were achieved transiently and 4 MW in steady state. The possibility of extending the performance relies mainly on the increased additional auxiliary heating power available with respect to DTE1. In fact, in DTE2 ~34 MW of NBI and 6-8 MW of ICRH will be available, which represents approximately a factor of two increase in additional power with respect to 1997. Moreover, a wider and more powerful set of diagnostics will be available and will allow a more in-depth analysis of the experimental results. Among the new diagnostics there are, for example, the new high-resolution Thomson scattering [4], to measure the electron density and temperature profiles with higher spatial and temporal resolution compared to the LIDAR used in 1997 and a series of neutron diagnostics, including a time-of-flight neutron spectrometer [5], to diagnose in detail the spectrum of the D-T neutrons.

Another major difference between DTE1 and DTE2 is the installation on JET of a new ITER-like wall made of Be (limiters and main wall) and W (divertor), in place of the C wall in use at the time of previous D-T experiments. The new wall imposes constraints on plasma operations. In particular, the heat load on the divertor tiles will have to be mitigated in order not to exceed the temperature limits, which could cause the melting of the tiles. Moreover, the potential source of sputtered W from the divertor will have to be minimized and the accumulation of W in the plasma core will have to be avoided. Finally, the disruptivity of the scenario will have to be low enough to guarantee safe operation (below 20%) and disruption will have to be mitigated by means of massive gas injection (MGI).

To overcome the challenges highlighted above an intense activity of scenario development has been undertaken at JET during the last three years in preparation for the DTE2 campaign. So far, the preparation work has been conducted in pure D, but a T campaign is planned in 2019 to assess how the isotopic effects will affect the scenarios developed in D. In this paper we describe the main results achieved so far both from the operational and the plasma physics point of view. In Section 2 we describe the main results of the scenario development activity aimed at achieving steady-state, high-performance plasmas, in Section 3 we present the main results of the experimental work conducted to develop advance tokamak scenario suitable for the study of α-particle physics and in Section 4 we will draw some conclusions and illustrate the future plans leading to DTE2.

2. SCENARIOS FOR STATIONARY HIGH FUSION PERFORMANCE

Two complementary lines of research are pursued to address the problem of developing a scenario suitable for sustained high D-T fusion power: the baseline scenario (β_N~1.8, q_{95}~3) and the hybrid scenario (β_N~2-3, q_{95}~4). Both lines of research, by adopting two complementary approaches to the problem, aim at achieving a stationary scenario of the duration of 5 s featuring H_{98}>0.9, W_{th}≈10-12MJ towards the lowest values of ρ* and ν* achievable on JET. The baseline activity concentrated mainly on pushing the operation towards the high current and field limits with a relaxed current profile, whereas the hybrid experiments addressed with more emphasis the advantages of operating at high β_N with a shaped current profile and q_0>1. The performances of both scenarios are illustrated in Fig. 2, where we plot the plasma neutron yield as a function of the stored energy. It can be seen that both baseline and hybrid plasma reach a maximum yield of ~3·10^{16} neutrons/s, albeit for different values of the stored energy, indicating that the hybrid scenario is more effective in converting stored energy into fusion power. A further difference between baseline and hybrid scenario is the origin of the neutrons produced. In the baseline scenario, because of the higher

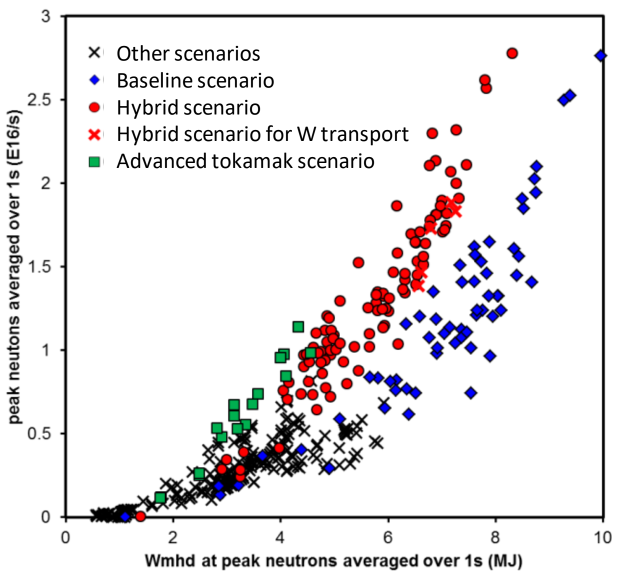

FIG 2. Neutron rate as function of plasma stored energy achieved at JET in 2016 campaigns in baseline, hybrid and advanced tokamak plasmas.

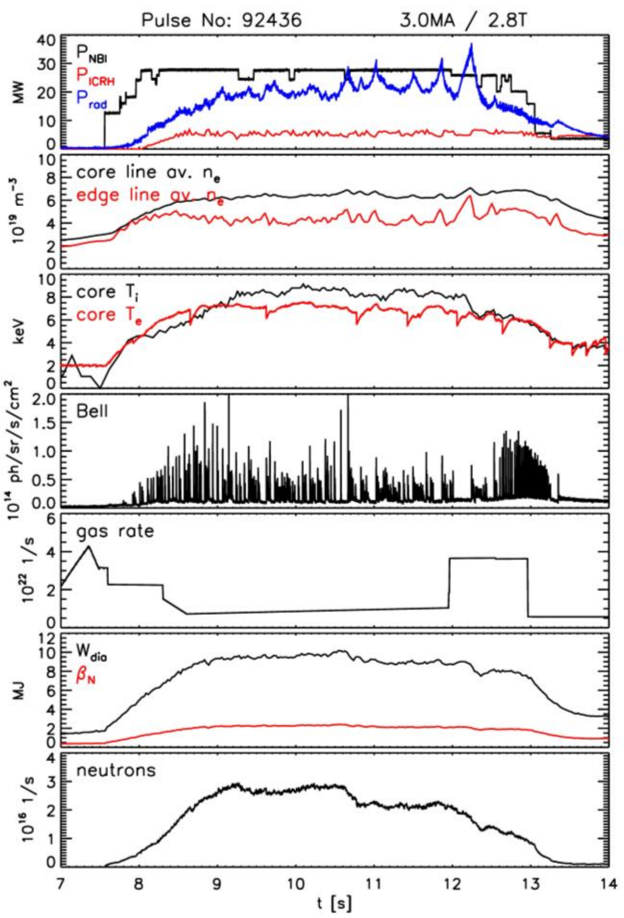

FIG. 3. Time traces for the best performing JET baseline plasma. ELM pacing pellets (mass $2.1 \cdot 10^{20}$ D atoms and frequency 41 Hz) are injected between 7.2 s and 12 s.

plasma density and the shallower penetration of the neutral beams, the fraction of thermonuclear neutrons is ~45% of the total yield, similar to the fraction of neutrons produced by beam-target reactions. On the other hand, in the hybrid scenario, since the plasma density is lower and the neutral beams can penetrate better into the plasma core, the thermonuclear reactions account for ~35% of the total yield and the beam-target reactions contribution is ~50%. In both baselina nd hybrid scenarios 10-15% of the neutrons are generated by fast ions accelerated by ICRH [6].

Detail of the best performing baseline plasma are shown in Fig. 3, where we show the NBI, and ICRH heating power, the bulk plasma radiated power, the core ion and electron temperature, the core and edge line averaged plasma electron density, the BeII emission (indicative of the plasma ELM activity), the plasma diamagnetic energy content, the normalised β, the gas fuelling rate and the total neutron yield. In this discharge, at 3 MA/2.8 T with injected power of ~28 MW of NBI and ~5MW of ICRH, H_{98}~0.9 and a neutron yield of ~3 10^{16} neutrons/s were obtained for >5 energy confinement times (~1.5 s). These results are achieved by lowering the gas throughput at high power, thus accessing low collisionality at the H-mode pedestal, high core confinement and high global performance. Indeed, the lowest particle throughput was achieved by means of a combination of gas and ELM pacing D pellets injection, which resulted in preventing heavy impurity accumulation with a more modest deterioration of the confinement than with gas fuelling alone. The pellet nominal mass was $2.1 \cdot 10^{20}$ D atoms and the injection frequency 41 Hz, leading to and additional particle throughput on top of the gas fuelling rate of $8.7 \cdot 10^{21}$ 1/s. However, due to the non-optimal transmissivity of the pellet guide tube on JET only a fraction in the region of 50-60% of the launched pellets reaches the plasmas, and approximately half of them triggers an ELM. Inspection of high temporal resolution density profiles measured with the reflectometer indicate that the effect of the pacing pellets on the plasma density is hardly visible and their contribution to the fuelling of the plasma beyond the separatrix is close to the gas puff. It should also be noted that ELM pacing pellets cause the nature of the ELMs to change radically from regular type-I ELM with a well-defined frequency to more erratic type-I ELMs with a compound character and without a clearly defined frequency. This is true also for bigger fuelling pellets reaching further into the plasma and with a visible effect on the fuelling and the density profile, used early in the experimental campaign to test their fuelling and ELM pacing capabilities. The physics behind this achievement is still under investigation, including the effect of pacing pellets injection on the ELM behaviour, the flushing of the impurity and, more in general, on the plasma performance. Preliminary analysis suggests that, at lower collisionality and higher NBI power, a synergy may exist between higher T_i/T_e, ITG stabilization and central NBI ion heating, which could explain the improved performance [7]. However, a clear causal relation between these effects has not been established yet and it is not clear how changes affecting the plasma scrape-off layer (SOL) or the region close to the separatrix can propagate and results in a better core confinement. The baseline experiment confirmed also that high ICRH power and an optimised fuelling scheme to obtain good power coupling to the plasma is essential to control the accumulation of W in the plasma core.

However interesting, the record baseline plasma deviates somehow from the typical baseline route to high confinement insofar it has a higher than average β_N (2.2 rather than 1.8) and shows signs of MHD activity (NTMs) after 1.5 s. Moreover, it is not clear whether it can be extrapolated to higher current (4 MA or above) due to the limited amount of heating power available JET (which will limit β_N achievable at higher current and field) and the

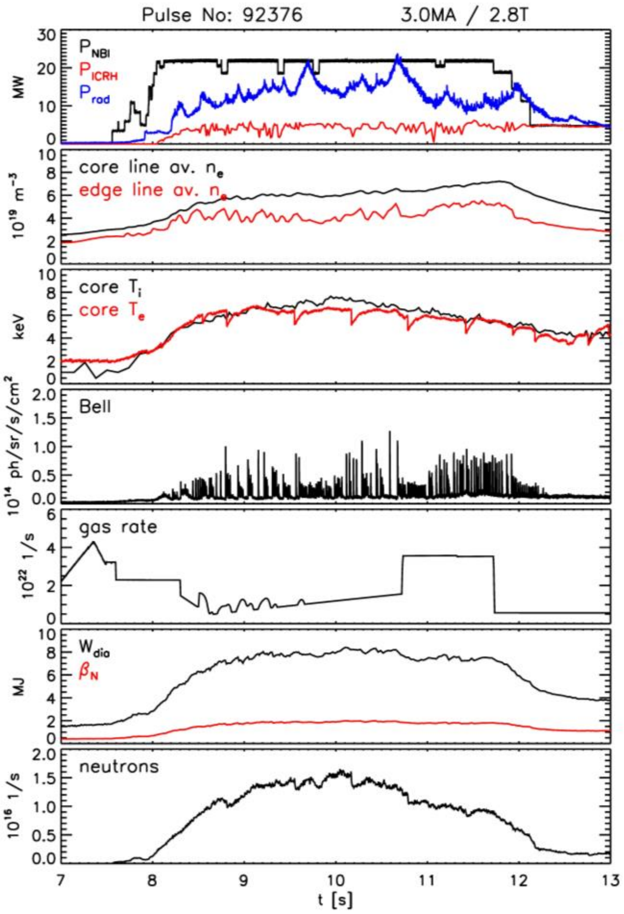

FIG. 4. Time traces for an average β_N JET baseline plasma, but with the potential of extrapolating to 4 MA. ELM pacing pellets (mass $2.1 \cdot 10^{20}$ D atoms and frequency 41 Hz) are injected between 7.2 s and 11.3 s.

fact that at higher current the plasma density is also higher, T_i/T_e will be ~1 and the beneficial effect of operating in a regime with $T_i>T_e$ could be lost. Therefore, other discharges at 3 MA but lower β_N are being considered as potential candidates for a baseline D-T scenario at high current. One of such discharges is shown in Fig. 4 and, although producing only $1.5 \cdot 10^{16}$ neutrons/s has a potential to be extrapolated, at constant β_N, to 4 MA / 3.7 T and 40 MW of additional heating power and give $\sim 5 \cdot 10^{16}$ neutrons/s.

The problem of extending the duration of the high-performance phase was also considered in the experiments. The divertor power load was controlled by sweeping the strike point on the divertor tile. Even though an optimization of the location and the amplitude of the sweeping could not be completed, the experiments indicated that sweeping the divertor strike point by a few centimetres allowed us to handle 35 MW of additional power for 5 s without compromising the divertor plates. Further experiments are planned to confirm this result and to assess whether sweeping alone will be enough to handle the divertor power load or Ne injection will be necessary to increase the fraction of power radiated at the plasma edge, reduce the conductive power load and avoid exceeding the divertor tile temperature limit once more auxiliary power is injected in the plasma. Moreover, the extension of the high-performance phase to 5 s requires the avoidance of heavy impurity accumulation both during the plasma flat-top and the plasma termination. Indeed, it has proved challenging to operate at low gas throughput and low ELM frequency and, at the same time, to detect impurity accumulation during the flat-top early enough to be able to react and take remedial actions to prevent the discharge from disrupting. In addition, it was observed that the H-L transition and the plasma termination were affected by impurity accumulation because the ELM activity stops and therefore the impurities are not flushed anymore. To overcome these difficulties, several ideas will be tested in the following campaigns, notably better impurity accumulation detection and disruption prediction algorithms, real time control of the plasma β and optimisation of ICRH during the H-mode exit and the extension of ELM pacing pellet injection during the H-L transition to promote the flushing of the impurities.

As mentioned previously, similar results in terms of neutron yield were obtained at reduced plasma current in the hybrid scenario (2.2-2.5 MA/2.8-2.9 T). Details of the best performing hybrid plasma are shown in Fig. 5. In this discharge, at 2.2 MA/2.8 T with injected power of 27 MW of NBI and 5 MW of ICRH, H_{98}~1.1, β_N~2.5 and a neutron yield of 2.9 10^{16} neutrons/s for ~1s were obtained. It is interesting to note that this and similar discharges were limited by the appearance of hot spots on the divertor tiles. However, other factors can limit the duration of the high-performance phase in hybrid plasmas. The most important is the evolution of the q profile towards a shape that allows the onset of MHD instabilities driven by the high β_N. At β_N=2.4 (feed-back controlled using NBI power) m=1 MHD activity and tearing modes were avoided for 3.5 s using q profile tailoring by means of beam timing and current overshoot. Further q profile optimization for MHD stability is planned for the upcoming experimental campaigns to delay the onset of MHD activity even more and achieve a 5 s window of high-performance, MHD free hybrid scenario. Another aspect that could make difficult the extension of the discharge to 5 s is the tendency of the density profile to peak because of a more central beam particle source and therefore to induce impurity accumulation due to neoclassical transport [8] and a radiative collapse of the plasma. The density peaking was partially reduced by ICRH heating driving turbulence near the plasma core and flattening

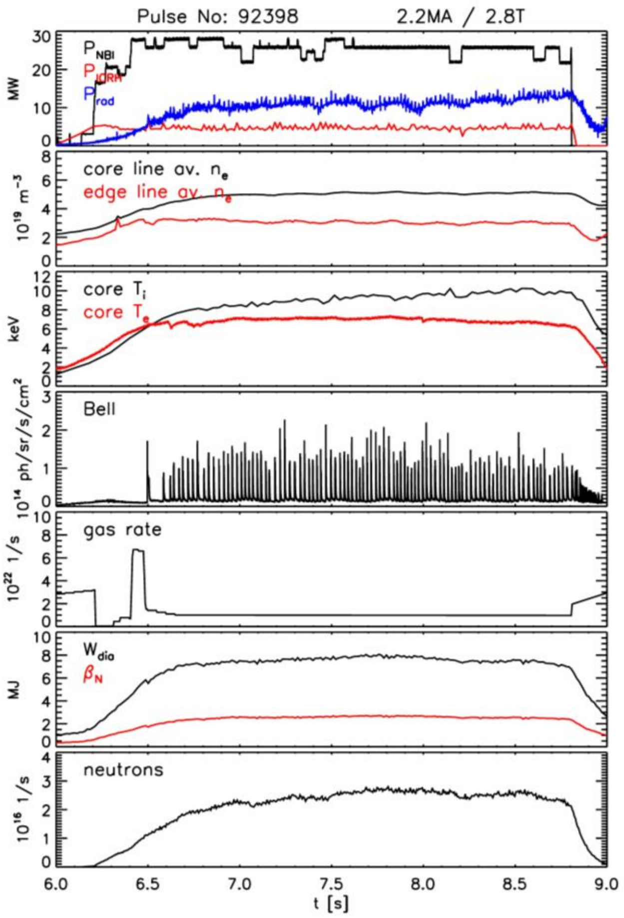

FIG. 5. Time traces for the best performing JET hybrid plasma.

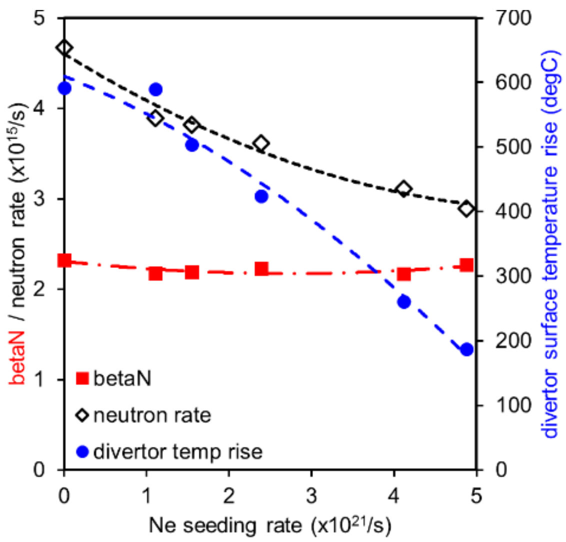

FIG. 6. β_N, neutron rate and divertor temperature rise for a series of hybrid plasmas with increasing Ne seeding rate.

the density profile. As in the baseline scenario, also in the hybrid scenario, ICRH was used in combination with real time control of the ELM frequency by means of gas puff to help flush the tungsten. The results are similar to the baseline case and show that ICRH located within 15 cm from the plasma magnetic axis reduces impurity accumulation and MHD activity. The impurity behaviour does not appears to be very sensitive to the minority H concentration [9-12]. Finally, the problem of controlling the divertor power load was addressed by systematic tests to optimise the strike point central position on the divertor tile and the sweeping amplitude proved that high power operations (P_{IN}=30 MW for 5 s) are compatible with 3.5 cm sweeping [13]. Ne seeding was also used as an additional method to mitigate the divertor heat load. Although efficient in reducing the temperature of the divertor tile by a factor of three, Ne had the detrimental effect of increasing the central density thus reducing the central temperature and resulting in a non-negligible penalty on the fusion yield, which would not be expected in high temperature plasmas if thermal reactions are dominant. This is shown in Fig. 6 where we plot the temperature rise of the divertor tile, the plasma β_N and the neutron rate as a function of the Ne seeding rate. It can be seen that, while the confinement remains constant, the neutron yield drops by nearly 40% when the Ne seeding is increased to $5\cdot10^{21}$ 1/s to limit the temperature increase of the divertor tile to 200 °C. Therefore, strike point sweeping is at present the main method to handle high exhaust power, but the use of low neon seeding is not ruled out if needed and might be reconsidered in tritium plasmas if tungsten sputtering by tritium becomes intolerable over 5 s.

The results of the baseline and the hybrid scenarios have been the object of an extensive activity of code validation and modelling [14]. In particular, semi-empirical transport models such as the Bohm/gyro-Bohm transport model [15] and physics-based transport models such as TGLF [16] and QuaLiKiZ [17] have been used to model existing discharges and to extrapolate their potential performance in D-T. The key trends of the plasma behaviour and fusion performance have been successfully reproduced using coupled core-pedestal simulations, where consistency between core confinement and pedestal stability was achieved by iterating between core transport simulation and edge pedestal stability analysis. The main results are summarized in Fig. 7, where we show the expected D-T fusion power according to different models for the baseline and the hybrid scenario. All predictions fall

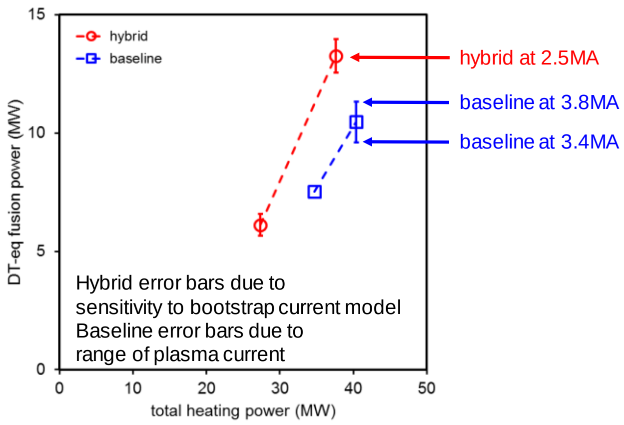

Fig. 7. D-T fusion power extrapolated to higher current and additional heating power from the best baseline and hybrid plasmas. The error bars quantify the uncertainties on the maximum achievable current (for the baseline case) and the estimate of the bootstrap current (for the hybrid case).

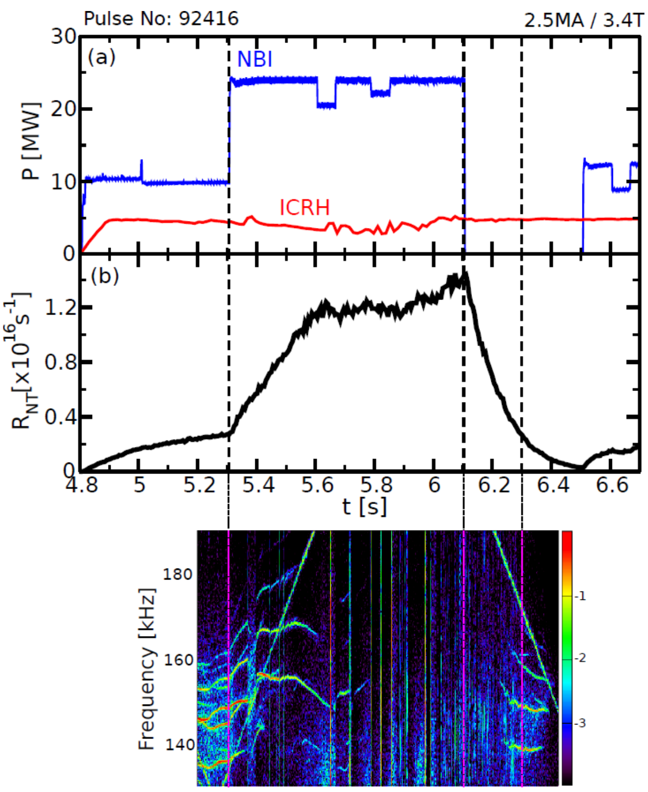

FIG. 8. Time traces of NBI and ICRH power, neutron rate and Mirnov coils spectrogram for a JET plasma developed for the observation of α-particle driven TAEs. ICRH induced TAEs appear with a slowing-down time delay after the switching-off of the beams.

broadly in the range 11-14 MW but there are uncertainties due for example to isotope effects (not considered in the simulations presented here), maximum current achievable in each scenario, model adopted for the calculation of the bootstrap current. These uncertainties will be investigated in the next experimental campaigns, where the database of D plasmas will be extended to higher current, magnetic field and heating power, thus providing a wider basis for model validation in D. Moreover, D plasmas will be replicated in T to investigate the physics of isotope effects that can affect the SOL, edge and core properties and shed some light on the performance that can be expected in D-T.

SCENARIOS FOR α-PARTICLE STUDIES

The JET D-T campaign will provide a unique opportunity to further study α-particle effects, such as α-particle heating and α-particle driven MHD, with respect to past results obtained in TFTR and JET D-T plasmas. These experiments require dedicated scenarios to ensure clear α-particle physics observations. So far, the scenario development activity has concentrated on plasmas suitable for the study of α-particle driven TAEs in an upcoming D-T campaign of JET, with the aim of validating the codes used for ITER, thus providing better confidence in the predictions of stability, fast particles redistribution and loss to the first wall [18, 19]. The scenario needs high plasma performance for only 1-2 s to generate a significant population of α-particles, thus relaxing the requirement of a 5 s high performance phase, and deliberately avoids ICRH heating in D-T to avoid creating RF driven fast particles, which could mask the effect of the fusion-generated α-particles. To maximize the α-particle drive one needs to maximize q_0, β_α and the α-particle pressure gradient, and minimize the damping provided mainly by fast beam ions. Plasmas with high additional power, high T_i (to maximize the fusion yield), relatively high T_e and low n_e (to increase the α-particle slowing-down time) were produced. The selected plasma current is 2.5 MA, which has been found to constitute a good compromise between low density operation and satisfactory α-particle confinement. The toroidal magnetic field was set at 3.4 T, which allowed probing the TAE stability of the best performing discharges by means of well-confined energetic hydrogen ions generated by ICRH injection at 51 MHz, for which the fundamental hydrogen cyclotron layer is located close to the magnetic axis. The NBI beam energies were optimised to minimise the shine-through at the start of the heating phase and allow access to lower density plasmas, whereas the timing of the NBI switch-on was optimised to slow down the current profile relaxation and maintain an elevated q profile for the duration of the experiment.

The resulting q profile exhibits an extended region of low positive shear which is favourable for the triggering of an internal transport barrier (ITB). Indeed, plasmas with clear ITBs were obtained for the first time since the installation of the ILW in JET. The presence of an ITB results in a significant enhancement of the thermonuclear contribution to the neutron rate. Central ion temperatures ~13 keV with 25 MW of NBI power were obtained, resulting in a neutron yield $\sim 1.2\times10^{16}$ neutrons/s, with a significant thermonuclear contribution (up to ~40%). Subsequently, the NBI power is switched-off to suppress the TAE damping mechanism and allow the destabilisation of TAEs driven by the population (the so-called afterglow scenario, originally adopted on TFTR [20]). After the NBI switch off, with a delay consistent with the beam fast ion slowing-down time, TAE, induced by ICRH fast ions in this case, were observed in the range 100–200 kHz when P_{ICRH}~1-2 MW. Linear MHD calculations and the absence of any edge TAEs on reflectometry measurements for these discharges show that these modes are core-localised. This phenomenology is illustrated in Fig. 8, where we show, for a typical α-particle scenario plasma, the NBI and ICRH injected power, the total neutron yield and the spectrogram from the Mirnov coils. It can be seen that the TAEs visible when the NBI power is ~10 MW disappear after it is increased to ~25 MW. Two hundred millisecond after the NBI switch-off (at the peak of the neutron yield) TAEs driven by the fast ions generated by the ICRH reappear at ~150 kHz.

Interpretative integrated simulations of the best performing discharges have been performed using various hypotheses in terms of impurity content, and then extrapolated to D-T plasmas. They predict that α-particle normalised pressure could be comparable or even slightly larger than the one measured in successful α-driven TAE experiments in TFTR. We plan to develop this scenario further by performing discharges at higher NBI power in an upcoming deuterium campaign and to consolidate extrapolations to D-T by performing similar pulses in pure tritium plasmas before applying this scenario to the next JET D-T campaign.

3. CONCLUSIONS

In this paper we have described the scenario development activity carried on at JET in preparation for a D-T campaign in 2020. Good progress has been made towards reaching the key performance indicators establishing the D-T readiness of a scenario. In particular, the baseline and hybrid scenario have demonstrated the capability of producing $\sim 2.5\cdot10^{16}$ D-D neutrons/s over 5 s, a result which, although a factor of two below the target of $5\cdot10^{16}$ neutrons/s, is consistent with the limitations on the additional NBI power and will be substantially improved when 34 MW of NBI at 120 keV and 6-8 MW of ICRH power will be reliably available. Moreover, the advanced tokamak scenario, developed for the study of α-particle effects, has demonstrated the potential of creating a plasma with α-particle pressure high enough to destabilize TAEs in the afterglow scenario, with a slowing-down time delay after the NBI switching-off.

In next experimental campaigns, the scenario development effort for DTE2 will continue. All three scenarios established so far will be improved with the aim of consolidating and improve existing results. In particular, the baseline scenario will be pushed towards higher current and field both at intermediate (1.8-2) and higher (>2) β_N values. The hybrid scenario will also be extended to higher current (compatibly with the need to tailor the current density profile before the high-performance phase), but greater emphasis will be placed on improving the MHD stability of the discharge to extend the MHD free phase to 5 s. Further optimization will also be objective of the development of the advanced tokamak scenario. All scenarios will be replicated in T to investigate the impact of possible isotope effects.

Finally, in the coming campaign we will also develop and test real time control schemes to control various plasma physics and machine operational parameters such as β_N, ELM frequency, plasma isotope composition and divertor temperature. A ‘dud’ detection system will also be developed to stop poorly performing plasma and save T consumption and minimize the neutron production.

In conclusion, the encouraging results obtained so far indicate that it should be possible to have successful D-T campaign on JET in 2020 in presence of an ITER-like wall and taking advantage of the widely extended set of diagnostics with respect to what was available in 1997.

ACKNOWLEDGMENTS

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053 and from the RCUK Energy Programme (grant number EP/I501045). The views and opinions expressed herein do not necessarily reflect those of the European Commission.

REFERENCES

[1] JOFFRIN, E., et al., Overview of the JET preparation for Deuterium-Tritium operation, this conference (2018)
[2] KEILHACKER, M., et al., High fusion performance from deuterium-tritium plasmas in JET, Nucl. Fusion **39** (1999) 209
[3] JACQUINOT, J., et al., Overview of ITER physics deuterium-tritium experiments in JET, Nucl. Fusion **39** (1999) 235
[4] PASQUALOTTO, R., et al., High resolution Thomson scattering for Joint European Torus (JET), Rev. Sci. Instrum. **75** (2004) 3891
[5] GATU JOHNSON, M., et al., The TOFOR neutron spectrometer and its first use at JET, Rev. Sci. Instrum. **77** (2006) 10E702
[6] LERCHE, E., et al., Optimization of ICRH for core impurity control in JET-ILW, Nucl. Fusion **56** (2016) 036022
[7] KIM, H.-T., et al., High fusion performance at high T_i/T_e in JET-ILW baseline plasmas with high NBI heating power and low gas puffing, Nucl. Fusion **58** (2018) 036020
[8] ANGIONI, C., et al., Tungsten transport in JET H-mode plasmas in hybrid scenario, experimental observations and modelling, Nucl. Fusion **54** (2014) 083028
[9] MANTSINEN, M. J., et al., The role of combined ICRF and NBI heating in JET hybrid plasmas in quest for high D-T fusion yield, European Physical Journal Web of Conferences **157** (2017) 3032
[10] MANTSINEN, M. J., et al., Optimising the use of ICRF waves in JET hybrid plasmas for high fusion yield, Europhysics Conference Abstracts **41F** (2017) O3.110
[11] GALLART, D., et al., Modelling of combined ICRF and NBI heating in JET hybrid plasmas, European Physical Journal Web of Conferences **157** (2017) 3015
[12] GALLART, D., et al., Modelling of JET hybrid plasmas with emphasis on performance of combined ICRF and NBI heating, accepted for publication in Nucl. Fusion
[13] SILBURN, S., et al., Mitigation of divertor heat loads by strike point sweeping in high power JET discharges, Physica Scripta **T170** (2017) 014040
[14] GARCIA, J., et al., First principles and integrated modelling achievements towards trustful fusion power predictions for JET and ITER, this conference (2018)
[15] ERBA, M., et al., Development of a non-local model for tokamak heat transport in L-mode, H-mode and transient regimes, Plasma Phys. Control. Fusion **39** (1997) 261
[16] STAEBLER, G., M., et al., Gyro-Landau fluid equations for trapped and passing particles, Phys. Plasmas **12** (2005) 102508
[17] BOURDELLE, C., et al., Core turbulent transport in tokamak plasmas: bridging theory and experiment with QuaLiKiz, Plasma Phys. Control. Fusion **58** (2015) 014036
[18] DUMONT, R. J., et al., Scenario development for the observation of alpha-driven instabilities in JET DT plasmas, Nucl. Fusion **58** (2018) 082005
[19] SHARAPOV, S., et al., Plasma and diagnostics preparation for alpha-particle studies in JET DT, this conference (2018)
[20] NAZIKIAN, R., et al., Alpha-particle-driven toroidal Alfvén eigenmodes in the Tokamak Fusion Test Reactor, Phys. Rev. Lett. **78** (1997) 2976