Research Program for IAEA Joint Experiment in TJ-II
20th to 24th June 2022.

Basing on experience from previous JEs, we suggest to enhance the group work efficiency by changing the concept 'One researcher – one program' to the formation of topical groups, focused on a few topics in which the hosting device is advanced. Within the chosen topical group a researcher is welcome to take, or to suggest, a subtopic for individual or subgroup work. Therefore we propose an experiment, plus one backup, that should be undertaken at TJ-II during the JE week. These experiments fit within the TJ-II operation capabilities and current set-up.

With regard to the JE, it is necessary to consider some schedule, operational and technical issues at TJ-II (as of 28th March 2022):

1) The winter/spring campaign at TJ-II began on the 22^{tnd} of February and will continue until the 24th of June 2020. After the 24th of June the TJ-II will undergo technical work and will not be available again until early 2023. The dates 20th to 24th June are fixed and cannot be changed.

2) The TJ-II is operated on Tuesdays, Wednesdays and Thursdays (9 am to 5:30 pm with no interruption for lunch). The TJ-II experimental hall is closed at 9 am, the next 60 to 90 minutes are dedicated to start-up technical checks and achieving a suitable plasma discharge. The first experimental plasmas are achieved around 10:30 am and after that plasma discharges occur around every ~10 to 12 minutes (when pellets are injected). Access to TJ-II during the day is very limited (only for short periods between some discharges). Typically around 40 plasmas are created during a day of operation. This number will be less for these experiments. As the JE has a training element to it, the time between plasma discharges will be increased so that attendees can follow and understand the data more easily.

3) Plasmas are generally created with hydrogen (changing to deuterium takes several days of operation to achieve a situation where %D > %H). Plasmas are created using two gyrotrons (500 kW total) operating at the 2nd harmonic (53.2 GHz) of its 1 T magnetic field. It is possible to have one or both ECRH beams off-axis and to module the power. The typical line-averaged electron densities and central electron temperatures achieved with ECRH are 4 to 6x10^{18} m^{-3} and 1.5 keV, respectively. Two Neutral Beam Injectors (NBI) can be used to achieve higher densities ≤4x10^{19} m^{-3} but with lower central electron temperatures (<0.4 keV). The maximum overall plasma duration is 300 ms, with the final ≤110 ms of this being NBI.

4) Currently, the heating systems and most diagnostic systems are currently operational on TJ-II. However technical issues that can limit experimental parameters, or result in the

cancellation of experiments, can occur at any time. These could include the failure of a heating system or a particular diagnostic, thereby limiting an experiment, or a major failure, e.g. to the generator, that can result in cancellation of TJ-II operation. For your information, at present, March 2022,

i) Both ECRH gyrotron (ECRH#1 & ECRH#2) systems are available.

ii) Both NBI (NBI#1 & NBI#2) systems are fully operational.

iii) The Heavy-Ion Beam Probe diagnostic may not be available during these experiments due to considerations outside of our control.

iv) It is not intended to open the TJ-II vacuum chamber between now and the end of the experimental campaign in June 2022. Thus, only probe heads can be interchanged as these have separate vacuum chambers (time to change and pump down is a few days). Thus it is proposed to proceed with the current set-up as several requested set-ups are not available. Also, some previously available diagnostics have been modified (CXRS (only for C^{+5}) to MSE) or are no longer operational. The vacuum chamber is regularly coated with boron and lithium to improve density control.

v) A Retarding Field Analyzer (RFA) was tested in TJ-II in December 2019 and it was found to operate successfully. Since then it has been removed and is currently being upgraded. However, it is not clear if the upgraded RFA with multiple probes will be ready for installation and operation by the end of June 2022.

vi) Available systems that have been requested include the biasing electrode (20 A/400 V) in sector A8/B1, and the 4-pellet type cryogenic pellet injector (in June one of its injection lines will be dedicated to TESPELs, hence only 3 cryogenic pellets will be available for injection). Also, for plasma edge N_e and T_e measurements we use a He beam (2 ms long once every 40 ms). A fast imaging camera is used to view pellet ablation process from two viewing ports. Given the light intensity of this process, no narrow band filters are used.

vii) At present two probe head systems are installed in TJ-II. These systems are considered to pertubative and their operation may be limited to the last day of the JE in order to avoid loss of density control.

a) An eleven-pin rake-type probe (3 poloidal & 8 radial pins) installed on a fast reciprocating arm.

b) A sixteen-pin stairs-type (4 x 4 pins) probe operated at a fixed position during discharges. It radial position can be changed between shots.

viii) In the past, TJ-II was equipped with two mobile limiters. These are now longer available.

5) TJ-II has now been operating for over 20 years and can suffer unexpected technical issues during campaigns. Every effort is made to fix such issues as quickly as possible but sometimes repairs can be delayed.

After internal discussions with the TJ-II group and after reviewing the received proposals, an experiment that can cover many of the topics of interest for the JE, and that can be undertaken in the short period available and within the limitations set by technical and other issues.

1. **Pellet injection experiments (led by KJ. McCarthy)**.

A second experiment is considered as back-up

2. **ECRH-power effect on turbulence and transport via ECRH-power modulation**

NOTE: Participants whose proposals are not reflected in the proposed topics are very welcomed to join the planned activities and of course to attend the meeting.

Topic 1. Pellet Injection Experiments

Cryogenic pellet injection (PI) is widely used to fuel the core of magnetic confinement plasmas. Other pellet types are also regularly injected into plasmas, for instance, for impurity transport studies. PI is now used on the stellarator TJ-II for pellet physics and fuel deposition studies. PI can also serve as a plasma diagnostic, for example to locate fast-electron populations or to shed new light on plasma turbulence. For instance, preliminary studies on the effects of hydrogen pellets on radial electric fields, E_r, and turbulence in Electron Cyclotron Resonance Heated (ECRH) discharges in TJ-II revealed that the level of core turbulence is reduced strongly for a short time scale (1 ms) after PI, this being followed by an increase in the evolution of plasma density and the recovery of the electron temperature. PI is performed into both ECRH and Neutral Beam heated plasma phases on TJ-II. In the latter, improved confinement is observed after a train of pellets is injected. It is intended to perform PI into both ECRH and NBI heated discharges and to investigate the physics of pellet ablation and deposition as well as plasma perturbation and response with the wide range of plasma diagnostics available. We will attempt to use magnetic configurations into which pellets have not been injected to date in order to explore their response to pellets.

Goal

To study the effects of cryogenic pellets on TJ-II plasmas.

Experiment scenario

Injection of cryogenic pellets into low and medium-density ECRH plasmas ($\tilde{N}_e$ = 4x10^{18} m^{-3} to 6x10^{18} m^3) and into high-density NBI heated plasmas ($\tilde{N}_e$ = 1x10^{19} m^{-3} to 6x10^{19} m^3).

Characteristics to be measured:

Pellet ablation and penetration into the plasma using light diodes. Pre and post-injection radial profiles of electron temperature and density can be obtained using Thomson Scattering (using shot-to-shot method) plus He beam. Measurement of edge plasma turbulence during PI with Langmuir probes and with Doppler reflectometry. Magnetic array pick-up coils will also be available to follow their response to pellets.

Plasma scenario

ECRH and NBI plasmas. A range of magnetic configurations.

Expected outcome:

New insight into the evolution and characterization of plasma performance before, during and after pellet injection.

Topic 2. ECRH-power effect on turbulence and transport via ECRH-power modulation (as back-up)

ECRH-power is an effective actuator to influence plasma confinement, turbulence and radial electric field and their intertwinement.

Goal

Characterization of the plasma electrostatic and electromagnetic turbulence (both core and edge, including SOL) coupling with ECRH power, transport characteristics and radial electric field.

Characteristics to measure:

ECRH-power modulation effect on the plasma potential in the core and edge, spectra of the electrostatic turbulence (plasma potential and density as well as edge temperature if RFA if operable), Zonal Flow / long-range correlations LRC, turbulence rotation V_{TURB}, 2D turbulence spectrum S(k,f) and turbulent particle flux, Γ_{ExB}, and turbulent energy flux, Γ^{E}_{ExB} by baffle probes, if operating.
Low and high ECRH-power radial profiles of electron temperature and density should be obtained using Thomson Scattering (using shot-to-shot method).
Low and high ECRH-power radial profiles of plasma density to be obtained using Doppler Reflectomety and He-beam diagnostics while that of plasma emission should be obtained by bolometer and SXR arrays.
Measurement of edge plasma turbulence during PI with Langmuir probes

Plasma scenario

Low-density to medium-density ECRH plasma (4×10^{18} m^{-3} to 5.5×10^{18} m^{-3}) with ECRH power modulation during a discharge.

Expected outcome:

Obtain new insight into the evolution of core and edge plasma characteristics for modelling (transport model like ASTRA (Proposal by C. Gutierrez-Tapia et al), etc), and into the coupling between plasma turbulence, cross-field transport and Er.