Annual report of the ITPA Topical Group on Energetic Particle Physics

For the period June 2009 to July 2010

The EP Topical Group held two meetings (its 3rd and 4th) during the reporting period – in Kiev – right after the IAEA TCM on energetic particles – September 24-25 and at IPP Garching April 26-28, 2009.
Minutes of these meetings and viewgraphs presented are available at the ITPA website, therefore only a summary of the main results is given here.

The work of the group concentrated mainly on the following topics:

- **Fast ion losses and the resulting heat loads to the walls induced by 3d effects (magnetic field ripple, TBMs, ELM control coils)**
- **Damping and drive of fast particle driven instabilities**
- **Influence of background turbulence on fast particles**

Fast ion losses and the resulting heat loads to the walls induced by 3d effects (magnetic field ripple, TBMs, magnetic islands, ELM control coils):
In 2009 several codes that follow drift particle orbits in three-dimensional magnetic field configurations had been benchmarked and applied to the effect of TBMs (with and without ferritic inserts). It had been found that the ferritic inserts reduce the fast ion losses significantly and thus lead to acceptable heat loads to the ITER walls.
On of the main efforts in 2010 was the application of the codes to the effect of the DIII-D TBM mock-up coils. As in the experiment, fast ion losses associated with strongly localized heat loads have been observed. The calculated heat loads are however still smaller than the heat loads needed to explain the observed temperature increase. Thus, a refined analysis (e.g., longer simulation times, better spatial resolution) is required to resolve this discrepancy. A joint effort with several codes is ongoing. The results will be reported at the forthcoming meeting in Daejon.
An investigation of the effect of the ELM mitigation coils on the heat loads to the wall has been started. Strong 3d effects have been found in the simulated fast ion losses. The resulting heat loads due to lost alpha particles were well below the limits. Heat loads caused by lost NBI particles were however quite large, depending on the phasing of the coil currents. These losses and the resulting heat loads are still below the limits (~100 kW/m^2) Further investigations including several codes are ongoing.
In 2008 concerns were raised that drift orbit simulations would underestimate the fast ion losses due to 3d effects, and thus full particle simulations would be needed. Therefore, besides the full orbit SPIRAL code also the ASCOT code was extended to full orbits. The effect of the gyro-motion in the ITER 3d magnetic field has been investigated. It was found that the gyro-motion does increase fast ion losses in case of unmitigated ripple (no ferritic inserts) by a factor of 2, but has nearly no influence for the realistic ITER magnetic field ripple (with ferritic inserts).
Plans for further work: For a reliable prediction of the heat loads to the walls, besides the 3d effects of the equilibrium fields, also perturbations by MHD activity, energetic particle driven modes and plasma turbulence have to be taken into account. For that reason the effect of magnetic islands and effective diffusion coefficients for fast ions are being introduced to the codes. First investigations do not show any significant fast ion losses due to turbulence (diffusion coefficients taken from corresponding turbulence simulations). A long-term goal is to include fast ion redistribution caused by energetic particle driven modes as calculated by

non-linear codes. The results of the fast ion losses due to three dimensional field perturbations will be summarized in an **ITPA-EP group paper at the forthcoming IAEA-FEC** in Daejon: "3D Effect of Ferromagnetic Materials on Alpha Particle Power Loads on First Wall Structures and Equilibrium on ITER" (submitted by : K. Shinohara).

TAE damping rates:

A reliable prediction of the occurrence of **fast particle driven instabilities** in ITER requires a detailed investigation of damping and drive of these modes. As a first step in this direction, a common benchmark effort was initiated in 2009. As a basis for this benchmark exercise a well diagnosed JET discharges with measured damping rates has been used.

The benchmark exercise has been performed for n=3 TAE modes with an impressive agreement of the code results. Both, frequency and structure of the TAE modes agree very well between the codes. As expected, the damping rates were larger for the fully gyrokinetic code (LIGKA) as it is best suited to correctly deal with the radiative damping (a finite Lamor radius effect). Nevertheless, also the MHD-hybrid codes (CASTOR-K, NOVA-K) are able to provide reasonable damping rates (agreement within a factor of 2), which is much better than discussed earlier in literature. The damping rates provided by the codes are still smaller than the measured ones (LIGKA: a factor of 2 smaller), but this is within the experimental error bars as the damping rates are very sensitive to the exact density and q-profiles at the plasma edge. The increase in damping rates with plasma shaping (elongation) as measured in the JET experiment could be well reproduced.

The code benchmark exercise provided additional insight to the possibility of measuring the damping rates by external antennas: It had been proposed for ITER to monitor the damping rates of the least unstable TAE modes and take adequate measures once the damping rates become too low, even before the modes are driven unstable. In the benchmark exercise it has been found that external antennas do not always couple to the least unstable modes. They preferentially couple to modes that extend to the plasma edge (those for which the TAE gap is open). Even for low-n modes these are not always the most unstable modes. For ITER medium-n modes (n~10) are expected to be most unstable. Thos modes are more localized in radius and are thus not expected to extend towards the plasma edge. It is thus very unlikely that a monitoring of the TAE damping rate in ITER is a reasonable measure to counteract fast ion driven instabilities. The results of the benchmark exercise and comparison with measured damping rates will be published in an **ITPA-EP group paper at the forthcoming IAEA-FEC** in Daejon: The Influence of Plasma Shaping Effects on the Damping of Toroidal Alfvén Eigenmodes (submitted by: S. Günter).

Plans for further work: For the near future it is planned to go to higher toroidal mode numbers as is relevant for ITER. Besides the damping rates, it is planned to perform a benchmark exercise for the drive (linear growth rates) of TAE modes. After a successful code benchmark a medium term goal is the calculation of ITER equilibria with marginal fast particle distributions functions as such distribution functions are expected to result after saturation of fast particle driven instabilities. Such distribution functions can then be used to simulate fast ion losses due to three-dimensional effects as discussed above. To improve the predictions for possibilities of MHD spectroscopy, a better antenna model should be developed an included in the relevant codes.

Fast ion redistribution due to energetic particle driven instabilities (non-linear effects):

A benchmark case for non-linear simulations was agreed on, and several codes participated in the benchmark exercise. The results of this exercise was however not satisfying. All codes found an energetic particle mode unstable for large drive, but not the TAE mode which was found in some simulations to be unstable for smaller fast particle drive. It was decided to

modify the benchmark case such that the non-linear simulations (in their linear phase) can be compared with the results of linear simulations.
Dedicated comparisons between code results and experiments have been performed on several tokamaks. On ASDEX Upgrade a numerical fast ion loss detector has been developed based on an extension of the HAGIS code. Impressive agreement between theory and experiment has been achieved both for energy and pitch angle distribution of the lost energetic ions. It has also been found that the observed ion losses are usually not those particles which are in resonance with the corresponding waves, but barely confined fast ions which can easily become lost.
A possible explanation of different saturation behaviour of TAEs for ICRH (pitchwork splitting) and NBI (bursts) has been found: the drag by collisions. Analytic theory for the bump on tail instability (Breizmann) is in qualitative agreement with experiment.
Plans for further work: Further analysis of the existing experimental data is planned using existing codes with new collision operators included. Joint experiments were proposed for this topic.

Effect of background turbulence on fast ions:
Turbulence simulations for off-axis NBI discharges on ASDEX Upgrade have demonstrated that the background turbulence can be sufficiently strong to affect energetic particles. The results are able to explain the observed mismatch between the measured NBI driven current and results from classical slowing down at high heating powers. Of particular importance can be electromagnetic transport as the resulting transport of energetic ions does not depend on their energy.
New results from DIII-D on slowing down of NBI generated fast ions have been presented where an anomalous redistribution of fast ions has been observed at high heating powers as well. It was found that in these discharges the observations are in better agreement with electrostatic transport (D~1/E) rather than with electromagnetic transport (D~const).
First simulations of turbulent transport of alpha particles on ITER have been presented. It has been found that the corresponding transport can become larger than the neoclassical one at sufficient level of electromagnetic turbulence.
Electromagnetic turbulence can also have an effect on runaway electrons. The corresponding diffusion coefficient scales as D~1/E for passing electrons.
Plans for further work: Further analysis of the existing experimental data is planned using various turbulence codes. Joint experiments were proposed for this topic using recently developed diagnostics.

Data base for energetic particle physics on ITER:
A data base with the relevant ITER data for simulations with respect to energetic particles physics has been set up. It allows in particular detailed investigations of localized heat loads onto the three dimensional wall structures.

Energetic particle diagnostics for ITER:
In collaboration with the MHG-TG a discussion on diagnostic needs and control techniques for ITER has been organized. Given that the main physics objective for ITER is the investigation of thermonuclear self-heating and alpha-particle physics, concern was raised that most of the fast ion related diagnostics is not (yet?) credited for ITER. In particular internal measurements for energetic particle driven modes (interferometry, reflectometry, ECE) will be needed for these investigations.