Annual report of the ITPA Topical Group on Energetic Particle Physics

For the period June 2008 to July 2009

The EP Topical Group held two meetings (its 1st and 2nd) during the reporting period – at CRPP Lausanne, from 20th-22nd October 2008, and at Daejon from 21st -24th April 2009. Both meetings were held in conjunction with the MHD TG, the Lausanne meeting also with the IOS TG. A full summary of these meetings and viewgraphs presented are available at the ITPA website, therefore only a summary of the main results is given here.

Summary of the results of the 1st meeting of the Energetic particle Topical Group, CRPP, Lausanne, Switzerland, 20-22, October 2008

As it was the first meeting, the **scope and tasks** of the newly formed group TG has been discussed. The approved version can be found on the webpage.

During the meeting the group concentrated very much on the most urgent ITER need: the prediction of **the fast ion losses and the resulting heat loads to the walls induced by the magnetic field ripple and the TBMs.** Various code results have been presented. Agreement was found for the beneficial effect of the recent designs for ferritic inserts in ITER to reduce the field ripple. Great differences between code results have been found however for the influence of the TBMs on fast ion losses. As a possible reason, a problem with the input data provided by F4E was identified: the ferromagnetic response of the TBMs was considered there onto the vacuum field produced by the coils only. A correct treatment should include, however, the magnetic field produced by the plasma currents as well. The difference between the two approaches is mainly the pitch angle of the magnetic field lines in front of the TBMs. It was thus decided to repeat the calculations based on a correct background magnetic field (with the vacuum magnetic field calculated by the FEMAG code).
A strong amplification of the n=1 error field at high plasma beta was reported (Spong) resulting in the need for 3d equilibrium reconstructions. It was decided to repeat these calculations with the correct background field ripple and perform correct free boundary simulations.
Nazikian discussed a strong increase in fast ion losses for full orbit simulations with the recently developed SPIRAL code (due to the cyclotron resonance in the ripple field). Strong losses have been predicted, in particular for the ITER scenario 4, if the full particle orbits are followed for several milliseconds. It has been decided to perform benchmark simulations with the full orbit CUEBIT code.

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. As a basis for this benchmark exercise well diagnosed JET discharges (to be done) with measured damping rates for low n (1 and/or 2) and intermediate n (~5) shall be used. The group as well decided to perform a benchmark exercise for the redistribution of α particles. For this complex physics problem as a first step a simple benchmark case should be chosen (Gorelenkov).

During the common session with the IOS-TG the recent experiments on **NBI current drive** on DIII-D and MAST have been discussed. It has been proposed to repeat the DIII-D experiments for higher heating power and to investigate the evolution in the electron temperature profile during on- and off axis NBI phases.

Summary of the results of the 2nd meeting of the Energetic particle Topical Group, Daejon, 21-24, April 2009

The plan to set up a **data base for ITER** (Putvinski) was very much welcomed by the group as consistent data sets are very important, in particular for the predictions regarding the fast ion losses caused by the field ripple and the TBMs.

The **benchmark exercise for the effect of TBMs on fast ion losses** between F3D, OFMC, (Shinohara, Tani) ASCOT (Kurki-Suonio) for the “correct” (FEMAG) background field has been successful: heat loads to the ITER walls caused by 3d effects have been found to be well below the critical level.
The **discrepancy between full orbit and guiding centre simulations** (Kramer) has been resolved. For realistic ripple values drift orbit simulations are sufficient for ITER (which is in agreement with recent CUEBIT results.

For the **effect of TBMs on the equilibrium**, it has been shown that the difference between full 3D free boundary equilibria and considering a 2D equilibrium + vacuum perturbations is very small. No significant error field amplification can be observed (Günter). (This is in agreement with recent results by Spong). TBMs induce however magnetic islands in the vacuum magnetic field (Kurki-Suonio, Günter) of the size of 1-2 cm, they might act as seed islands for NTMs if not shielded by plasma rotation. The effect of the n=1 perturbation induced by the TBMs on MHD stability has to be discussed further, in particular for scenario 4, high beta equilibria, where these perturbation fields might lower the threshold for RWM onset.

The **runaway electrons** have been discussed in a common session with the MHD-TG. The presentations were give by members of the MHD-TG and are therefore not summarized here. The outcome of the discussion was that the MHD-TG continues to lead the effort on runaway physics. The EP-TG will focus on possibilities for runaway suppression by external perturbation fields.

The influence of **fast particle effects on MHD stability** has been discussed. A main topic was the strong effect of fast passing ions on sawtooth stability. Interesting new results of off-axis NBI for sawtooth destabilization were shown. The destabilizing effect of ICRH in JET (explained earlier by local current drive) has been shown to be caused by fast ion effects, too (Chapman).

First results of the TAE benchmark exercise have been shown. However, the JET equilibria for the linear benchmark case had not been ready yet. For the “simple” non-linear benchmark case further discussions are needed to allow all relevant codes to participate. Besides tokamak codes we will as well include stellarator codes in the benchmark exercise.

The results of the joint experiments have been discussed, the main points being:

- **EP-1: Active excitation of TAEs** (Fasoli)
  - JET- antenna excitation
    - mode selection and coupling improved
    - increased damping rate at JET measured with increasing elongation for n=1 and medium n modes (in contrast to earlier Alcator C-Mod results)

- MAST: antenna excitation successful, but overlapping modes, no damping rates yet
- ASDEX Upgrade: beat-wave excitation of TAEs on ASDEX Upgrade experiments demonstrated

- **EP-2: Fast ion losses and redistribution** (Pinches)
    - JET: no losses caused be fishbones observed, but strong losses caused by TAEs and tornado modes
    - ASDEX Upgrade: good agreement between measured and simulated fast ion losses induced by BAEs/TAEs
    - DIII-D: interesting new fast ion diagnostics: FIDA

The **effect of background turbulence on fast ions** has so far been considered very small. Recent experiments on NBI current drive on ASDEX Upgrade put a question mark to this “believe”. New results based on turbulence simulations with the GENE code (Günter, Fasoli) show that

- For electrostatic turbulence the transport of fast ions is small due to the energy dependence of the diffusion coefficient (~1/E)
- Transport caused by electromagnetic turbulence can be significantly higher as at high energies the diffusion coefficient for particles moving parallel to the field lines does not depend on energy
- Results might explain ASDEX Upgrade data for NBI current drive (Günter) and affect α particle heating (Fasoli)

Work plan for 2009/10

- Further codes to be included in the benchmark of fast ion losses caused by the ripple field. Detailed investigations of remaining discrepancies between code results.
- Prediction of the heat loads to the ITER walls on the basis of the relevant codes. ***The new design of the ferritic inserts is needed here.***
- Investigate the effect of ELM mitigation coils on fast particle confinement
- Perform a common benchmark exercise to compare damping rates and (if measurable) corresponding eigenfunctions for low n (1-2) modes based on a realistic experimental equilibrium (JET).
- Perform a common benchmark exercise to compare the non-linear redistribution of fast ions based on a simple analytical test.
- Further investigations of fast ion redistribution by background turbulence and first predictions for NBI current drive and α particle heating in ITER.
- First simulations of the effect of the ELM mitigation coils on runaways.

First answers to the ITER high priority research tasks (Stambaugh October 2010)

Requests by ITER-IO **main results**

▪ TF Ripple: timescale: 2 years • require an improved predictive basis for fast particle confinement effects of TF ripple - in particular localized ripple such as that associated with TBMs	• TF ripple with design for FIs as presented by ITER-IO so far reduce fast ion losses significantly • Heat loads to the walls well below the limits according to OFMC and ASCOT simulations (further codes to be included) • No full orbit simulations required (good agreement with drift orbit simulations) • ***New design of FIs needed for definitive answer***
• Localized ripple due TBMs:timescale : 2 years • ferromagnetic structural material used in TBMs will produce an additional component of at 3 locations	• Effect of TBMs on fast ion losses demonstrated to be small • No 3d equilibria needed to describe the effect of TBMs • TBMs create n=1 magnetic field perturbation (magnetic islands, error field for RWM locking)

Next meeting(s)

The next meeting will be held in conjunction with the IAEA-TCM in Kiev (Ukraine), September 24/25. The spring meeting 2010 is planned to be together with the MHD-TG.