Energetic Particles Break-Out Session Summary

B.N. Breizman and J.A. Snipes

The energetic particle physics area was represented at the workshop by one plenary talk and 14 topical talks. The talks are posted on the BPO web page

http://www.burningplasma.org/agenda.

All of the US research groups working on energetic particle issues participated in the workshop. Also there was remote participation from Culham Laboratory.

The present summary is structured as an integrated response from the energetic particles break-out session to the six questions posed at the meeting.

Recent Developments:

1. What major BP-related developments (in theory, modeling, experiment and technology) have occurred in the energetic particle area since the Snowmass 2002 study?

- Extensive new measurements of Alfvén cascades in shear-reversed plasmas have been performed. Alfvén cascades are reasonably well understood theoretically. They have become a robust diagnostic tool for measuring the safety factor at the shear-reversal location.
- Modeling of damping mechanisms for Alfvén modes has been improved to allow predictions of the instability thresholds and calculations of marginally stable equilibria.
- Theoretical scenarios for nonlinear evolution of a single unstable mode driven by energetic particles have been verified in several independent experiments. This includes verification of a frequency chirping mechanism.
- New experiments confirm the role of multiple modes in producing anomalous losses of fast particles. Self-consistent nonlinear simulations of energetic particle dynamics in the presence of multiple unstable modes have been generalized to describe joint effects from kinetic and fluid nonlinearities.
- Significant advances in core fluctuation diagnostics (phase contrast imaging, interferometry, reflectometry, …) have revealed the internal structure of unstable modes that are not visible with external magnetic probes alone.
- A 2D γ-ray diagnostic can measure the spatial profiles of confined high-energy ions and their time evolution.

Implications and Outstanding Issues:

2. What issues remain to be resolved for a successful BP experiment in ITER?

- Experiments on present devices should explore fundamental physics limitations on fast ion confinement and the means to control fast ion losses. This effort implies unambiguous identification of the underlying physics mechanisms, conclusive interpretation of the existing data, and assessment of their scalability to burning plasma experiments**.** It is essential to make significant progress in quantitative modeling of the observed energetic particle phenomena in various magnetic configurations, including spherical tokamaks and stellarators, which can also provide insights into the underlying physics.

- Fundamental understanding of energetic particle physics needs to be integrated with:
  - MHD analysis of plasma equilibrium
  - Modeling of bulk plasma transport
  - Current drive modeling
  - Burn dynamics analysis
- The idea to improve plasma confinement and facilitate creation of transport barriers via fast ion redistribution by rf waves needs to be examined.
- There is a need to better understand fast electron behavior, especially runaways. Instabilities generated by fast electrons may be used for diagnostic purposes.
- It is critical to broaden the arsenal of fast particle diagnostics that can be used in burning plasma experiments. Improved techniques are needed for measuring:
  - Fast ion distribution in phase space
  - Lost fast ions
  - Energetic particle driven modes (fishbones, Alfvén eigenmodes, ion cyclotron modes)

3. What are the consequences of resolving these issues, or not, in the next ~10 years?

Resolving the issues (listed in #2) prior to ITER operation will help identify the most favorable scenarios for fusion burn, reduce the risk of first wall damage by fast particles, and provide a credible physics basis for reactor extrapolations.

4. What issues should be resolved by a successful BP experiment?

In addition to its primary goal of achieving self-sustained fusion burn, a successful burning plasma experiment should show how to avoid excessive wall loading from energetic particles. The experiment will test the developed capabilities to predict, diagnose and control energetic particle behavior, especially their energy deposition into the bulk plasma. Such experiments should address the existing concerns about how energetic-particle-driven instabilities would affect plasma performance in reactor-relevant regimes.

What should the U.S. fusion community do:

5. What contributions can/should the U.S. fusion program make to resolve these issues?

- Use existing experiments to study energetic particle effects and to test control schemes, including:
  - Investigation of unstable Alfvén eigenmodes and their impact on fast ions produced by ICRF and NBI
  - Measurements of Alfvén eigenmode damping rates for externally excited modes
  - Experiments aimed at measuring energetic particle distribution functions with the objective of phase-space engineering

- Further develop energetic particle diagnostics, especially those compatible with ITER.

- Convert linear codes to well-documented user-friendly tools to allow quick and comprehensive stability analysis for burning plasma devices.

- Develop predictive numerical models based on first-principle theory and test them in dedicated energetic particle experiments on present devices, including non-tokamak experiments
    - Use flexible reduced codes to probe essential physics mechanisms
    - Move toward realistic integrated modeling of energetic particle behavior in burning plasmas

- Blend energetic particle physics with that of the bulk plasma. A combined description of kinetic and MHD resonant phenomena is of particular interest for the broader physics community. This effort requires closer scientific interaction between different topical groups dealing with transport, flows, rf-heating, etc.

- Enhance national and international collaborations, lower institutional barriers within the US, and enhance educational activity in plasma physics, with strong links to other areas of physics.

6. How should the BPO be structured to best help the community make these contributions?

- Given the key role of alpha particles in burning plasmas, it is natural to have an energetic particle topical group as an element of the BPO structure.
- Temporary multidisciplinary task groups can be very efficient in addressing specific scientific and technological problems.
- The BPO should identify and promote fundamental scientific aspects in burning plasma research, emphasize intellectual values, and be responsive to fusion technology challenges.
- The BPO should be constituted so that it is "of the scientists, by the scientists, and for the scientists." It should be open to broad participation and cross-disciplinary activities. It is of vital importance to instill an atmosphere of cooperation – team spirit.
- BPO should make a strong effort to generate scientific motivations for creative young people to enter the field.
- International collaboration on burning plasma research should be an inseparable part of BPO activities

Energetic Particles Break-out Session

Thursday, 8 December 2005

N. Gorelenkov	Alfvén eigenmode stability with beams and α-particle profile quasilinear relaxation in BP
D. Brennan	ICRF interactions with fast ions and effects on MHD stability
E. Fredrickson	Collective fast ion transport in a "sea of MHD"
B. Heidbrink	The importance of internal fluctuation & fast-ion profile measurements
K-L. Wong	My view on the new direction for energetic particle physics research
L. Berry	Self-consistent calculation of quasilinear interaction between ICF waves and energetic ions
D. Brower	Core fluctuation measurements (of energetic particle driven modes) in a burning plasma
T. Peebles	Microwave-based measurements of fast particle driven Alfvén modes in burning plasmas
H. Berk	A view of energetic particle physics issues related to ITER
L. Sugiyama	Alpha particle effects on MHD modes in ITER: hybrid simulations
D. Spong	Alpha particle physics modeling issues for burning plasmas
M. Porkolab	Detection of Alfvén waves with phase contrast imaging diagnostics in Alcator C-Mod and potential applicability to ITER
G. Wurden	Intense diagnostic neutral beam for ITER and triton burn-up measurements before DT operation
D. Hutchinson	Infrared laser scattering diagnostic for confined α-particles