Development of tools for understanding, predicting and controlling fast-ion-driven instabilities in burning plasmas

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The performance of burning plasmas (e.g. in ITER and FNSF) will largely depend on the dynamics of energetic ions that originate from fusion reactions (alpha particles), Neutral Beam (NB) injection and RF wave heating. Energetic particles (EP) play a critical role in heating, current drive, and momentum input, yet are subject to transport or loss by a variety of instabilities and toroidal symmetry-breaking fields. Of particular concern are instabilities driven by the energetic particles themselves, such as Alfvén eigenmodes (AEs), fishbones, and energetic particle modes (EPMs). In the presence of AEs or other EP-driven instabilities, EP transport is enhanced, resulting in (presently) unpredictable variations in the NB driven current profile, loss of macroscopic stability and – ultimately - degraded performance. Progress has been made in recent years to understand the coupled and predominantly non-linear dynamics of fast ions and fast ion related instabilities. The challenge for the next decade is to build on that foundational knowledge to develop validated integrated tools and techniques for reliable prediction and real-time control of the EP population and associated instabilities, with the goals of both minimizing risk and maximizing fusion energy output.

To fully address this challenge, strong programs in both experimental as well as computational EP physics are a necessity. For instance, recent experiments have indicated the potential of applied 3D fields, RF injection and electron cyclotron heating (ECH) to exert some desirable influence over EP driven instabilities including AEs. Dedicated effort is still required to advance this research from the stage of semi-empirical observation to one of actuator development. Computationally, efficient/fast algorithms for stability and EP transport analysis and prediction will be required. Experimentally, tools for the improved diagnosis of instability and energetic particles will be necessary with a focus on reactor relevant technologies. Future experiments must employ improved diagnostics that facilitate high fidelity measurements of instabilities and EP transport levels while considering the possibility of application in reactor relevant scenarios.

Since no control tools are available (or envisioned) yet for the mitigation or suppression of EP driven instabilities, unlike for other phenomena such as ELMs and NTMs, the highest priority is to develop - and demonstrate experimentally - the reliability of both predictors of mode stability and actuators for mode control. With a modest increase in their overall budget, the major US fusion facilities and computational centers will be well positioned to address these issues in the next 5 years (FY15-20). Over the next five years, the JET D-T campaign presently scheduled for FY17-18 would provide a unique test bed for predictions and control schemes of EP-driven instabilities, informing on specific needs for conditions closer to those expected in ITER, FNSF, and future burning plasmas. Results from the first 5-year period will then be projected to ITER and FNSF in the following 5-year time frame (FY20-25). Contribution from Universities and basic plasma physics devices must also be strengthened during the next 10 years to advance fundamental science of EP and associated instabilities in well-controlled experiments and train a new generation of EP scientists.

Success of the proposed research enables the US Fusion Program to maintain and even strengthen its forefront position in the international EP research community. A comprehensive understanding of energetic particle physics coupled with the operational ability to manipulate EP transport will prove indispensable as we approach the ITER era and start planning for next-step devices.