The Connection between Burning Plasma MHD Science and Fusion Development

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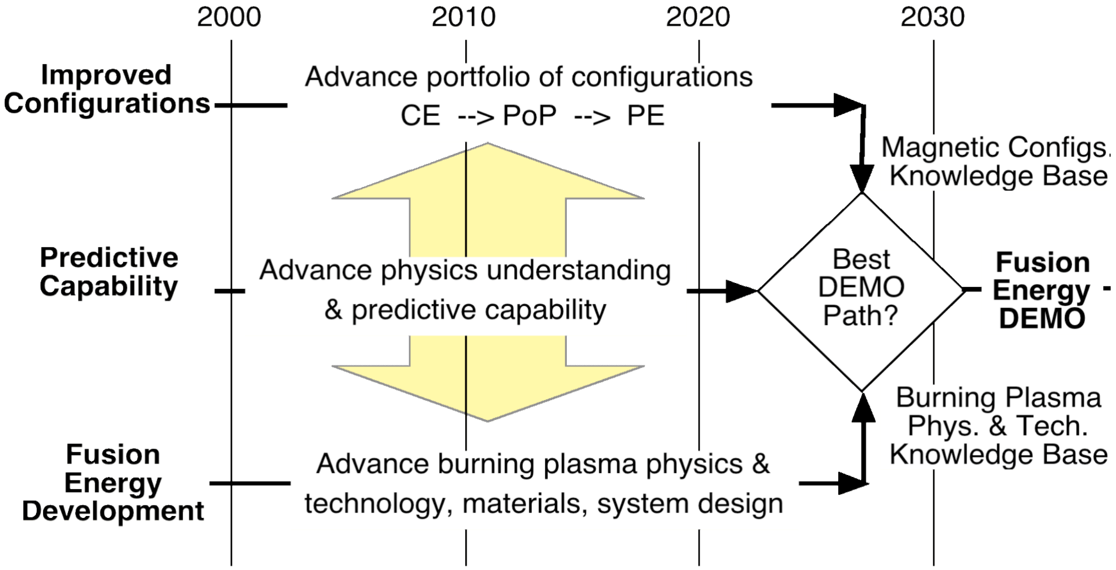
A valuable outcome from a tokamak burning plasma experiment would be the generation of MHD science (and associated technology) applicable to the broad range of concepts in the fusion "portfolio." Those concepts which are close relatives of the tokamak tend to share issues that would be studied in the proposed burning plasma experiments. It stands to reason that close relatives of the tokamak would therefore enjoy significant knowledge and technology transfer from a burning plasma experiment. However, even relatively small changes in magnetic configuration can profoundly affect plasma behavior. The formulation and validation of MHD theory and modeling which are not tokamak-specific should therefore be a target of opportunity for a burning plasma experiment. Such an approach would maximize the development of predictive capability in MHD science when major configuration knobs are adjusted, such as the aspect ratio, addition of 3D shaping, or variation of the applied toroidal field strength. These are, of course, the knobs which distinguish toroidal configurations in the fusion concept portfolio. For non-toroidal fusion concepts which strive to greatly alter the approach to fusion, to the degree MHD science is important, validated predictive capability will provide the basis for transferring crucial burning plasma MHD science gained from a tokamak burning plasma experiment. In order for predictive capability in MHD science to be achieved, it is crucial that any tokamak burning plasma experiment be well diagnosed and flexible in operation so that critical information will be available to develop and test scientific understanding.

In preparation for the Snowmass Summer Study, breakout sessions on several physics topics were held at the 2002 Innovative Confinement Concepts (ICC) Workshop held at the University of Maryland, one session dedicated to MHD science. Several experts were asked to summarize critical MHD issues appearing in ICC concepts. This quickly exposed the similarity (and dissimilarity) of MHD issues. Not surprisingly, there are many commonly appearing MHD-related issues. Some examples are the stabilization of MHD modes by conducting walls (which can develop into resistive wall modes), neoclassical effects on tearing modes, kinetic effects (including alpha-driven instability), stabilization by plasma flow, and profile control for maximum stability. Also not surprisingly, there are MHD-related issues that are not likely to be studied in a tokamak burning plasma experiment, yet critical to the development of some ICC concepts. An example is super-sonic or Alfvenic speed flows to control gross MHD instability. Nevertheless the overlap of scientific issues across concepts is particularly strong in MHD science. Given the unlikelihood of multiple burning plasma experiments in many different magnetic configurations, it is vital to manage any tokamak burning plasma experiment such that it works with ICC experimental research, coupled through theory and modeling, to develop validated predictive MHD science. The tokamak burning plasma experiment could be the only source of information on alpha-heated plasmas in the next 25 years. An understanding of possible new kinetic effects and the coupling of MHD stability to transport and self-heating must be made as general as possible to permit further optimization of toroidal magnetic fusion for low-cost energy production without many expensive follow-on steps to a tokamak burning plasma experiment.

Although MHD is an area where there is obvious similarity of issues across concept boundaries, no unique "MHD perspective" has been identified in regard to the relationship between a tokamak burning plasma experiment and fusion development. In fact the charge to the MHD group to "assess the applicability of MHD physics from the proposed burning plasma experiments to future fusion devices including alternate concepts" is equally valid and important with the replacement of "MHD physics" by "transport physics," or "boundary physics," etc. The impact of a tokamak burning plasma on fusion development was discussed in more general terms in the (E4) Development Path working group. A recurrent theme is the need for a flexible, well-diagnosed burning plasma experiment that helps build predictive capability in fusion science. Clear examples from MHD provide evidence that such predictive capability is possible. Key points from the Development Path working group discussions are summarized below. (The final report and associated appendices cover this in more detail.)

A useful graphic which generally describes the path to demonstrated magnetic fusion energy is shown below. Advancing in parallel are (1) research to identify improved magnetic configurations (both tokamak and ICC), (2) development of predictive capability, and (3) fusion energy development research in burning plasma physics and the development of fusion technologies. These elements meet in the future, probably no sooner than 2025, to define the subsequent magnetic fusion demonstration step(s). The large up-down arrow emphasizes a need to continually connect and integrate the three elements to guarantee evolution toward the best future magnetic fusion product. One of the greatest challenges for the fusion program will be maintaining parallel development of specific magnetic configuration alternatives. It is probable that there will be only one burning plasma physics experiment during the next 25 years. Predictive capability is



therefore essential to provide a scientific basis for choosing the best DEMO path. With predictive capability in hand, in principle DEMO could be based on a magnetic configuration substantially different from that studied in the tokamak burning plasma experiment. Moreover, predictive capability could *define* the optimum magnetic configuration, which might look different from any present day experiment. If the tokamak path to fusion falters for any reason, more likely a high cost of electricity than a technical failing, the fusion program must have ready an argument for continuation that convincingly demonstrates an alternate path that will produce a better magnetic fusion product. Validated predictive capability spanning major configuration knobs is the corner stone for making this argument. All three elements described in the figure must therefore mature together, synchronous with a burning plasma experiment in particular.

In summary, a tokamak burning plasma experiment will best maximize the development of MHD science—indeed fusion science in general—if it is well diagnosed and has flexible operational capability. Coordinated through theory and modeling, a burning plasma experiment together with ongoing ICC and tokamak optimization can achieve validated predictive fusion science. Predictive fusion science will provide the strongest base to propel magnetic fusion beyond a burning plasma experiment to a demonstration of clean, low cost electricity.