Capitalizing on the ITER Opportunity – an ITER-TBM Experimental Thrust

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New knowledge is required to understand and resolve the unique Fusion Nuclear Science and Technology (FNST) issues and challenges for DT burning plasma devices and ultimately a fusion DEMO. This new knowledge can be partially acquired through new experiments in existing, upgraded and new laboratory test stands; new intensive theory, modeling, and high-speed computation simulation efforts; and testing in plasma and neutron sources. Such research will result in advances in many scientific areas related to FNST[1]. There is no doubt that such an intensive R&D program is required to begin to rebuild lost or depleted US capabilities and human resources needed to advance FNST and fusion as an energy source.

But fusion experts agree that while a program of basic research, predictive capability development, and mockup testing in simulated conditions is necessary, experiments in the integrated DT fusion plasma environment must also be carried out. These latter tests are needed to search for, quantify, understand, and predict synergistic effects and complex interacting phenomena that tie together all the scientific areas discussed above[2]. Such effects will likely limit the performance and dominate failures in FNST components and must be addressed to meet the extreme reliability and lifetime requirements of Demo fusion components. Data from experiments in the true fusion environment can give higher order insight into the evolution of multi-scale, multi-phenomena, multi-material synergies, including possible unanticipated effects and failure modes that may ultimately change the direction of future FNS research.

ITER will provide the first such integrated magnetic confinement environment suitable for early life FNST integrated experiments and should be utilized by the US for this purpose. ITER has a FNST testing capability and supporting systems built into the machine – three mid-plane ports are reserved for this testing and each port can test two experimental modules. Such testing is a primary mission of ITER through what is known as the ITER Test Blanket Module Program or ITER-TBM.

ITER has some important features that make this testing extremely worthwhile and cost effective.

- The ITER test module size, neutron flux, magnetic field and pulse length are all significant enough to provide a suitable testing environment consisting of all important reactor environmental conditions that synergistically affect the prompt[3], early -life, physical behavior of blanket systems. The strong, spatially complex magnetic field is a key parameter, especially for liquid metal breeder blankets.
- The R&D, predictive capabilities, and test facilities needed to prepare for, license, and interpret integrated fusion environment experiments in ITER are the same as those needed to reinvigorate the US FNST program, and are

[1] For example, research is required to improve and quantify the fidelity of deep radiation penetration simulations that assimilate vast amounts of nuclear physics models and data, plasma chamber geometric detail, and strong material heterogeneity. Advanced modeling tools and fundamental experiments on non-linear MHD phenomena are required to help study self-generated Lorentz forces and modified energy dissipation effects that influence turbulence reorganization and flow instabilities. Research is needed to advance the fundamental database of tritium solubilities, diffusivities, and chemical forms in relevant materials and conditions.

[2] Some examples of anticipated synergistic effects include: (a) the spatial dependence of nuclear interactions, heating and tritium production profiles in the highly heterogeneous plasma chamber components as compared with state-of-the-art 3D simulations; (b) the impact of spatial gradients in nuclear volumetric heating and magnetic fields on liquid metal MHD flow and heat transfer through the generation of strong buoyancy-driven forces; (c) the combined effect of thermal cycling and progressive changes in material properties on the thermal performance of insulator and breeder ceramics; and (d) the integrated effects of a prototypical thermal/chemical/nuclear environment on materials behavior and tritium transport.

[3] By "prompt" we refer to phenomena that reach near steady state during the ITER burn, which can vary from several hundred to several thousand seconds depending on the ITER plasma scenario being investigated. Examples include establishment of neutron flux, surface heat flux, tritium production and neutron heating profiles, temperature profiles and thermal stress state, all He and LM MHD flow conditions, etc. Many other conditions, such as tritium concentration and permeation, reach a cyclic equilibrium over many discharges that are useful in validating predictive capabilities.

the same as will be needed for any fusion environment testing and tritium breeding enabling technology development. ITER-TBM testing can then serve as a driver to garner support for this essential FNST R&D.

- ITER will buy its tritium from non-fusion sources, which makes ITER less dependent on the successful function of these first-of-a-kind blanket experiments, reducing the bootstrap problem of requiring the successful operation of the very components that are being tested.
- ITER neutrons, hot cells, remote handling equipment, and heat rejection and tritium processing systems are already paid for as part of the ITER machine. Hence, only a modest additional cost is incurred, including the costs associated with building the specific blanket experimental modules and support systems.
- All other ITER parties will perform TBM experiments, providing good synergy and a basis for collaboration and cost sharing among the international community. Screening and comparison of various blanket/FW configurations and concepts can be done in coordination with international partners. Currently the US is the only ITER partner that has not asked for space to perform TBM experiments. And the US primary blanket option, the Dual Coolant Lead Lithium (DCLL) blanket, is not being tested by any other party because they were expecting leadership from the US on the DCLL.
- ITER fluence is relatively low and pulse length is limited, but prompt phenomena (of which there are many) and early-life radiation damage effects (especially in critical ceramics such as breeders and insulators) can and should be explored using ITER. Meaningful combined environmental and irradiation results can be obtained. Frequent opportunities for module replacement will allow several successive, customized experiments to be deployed during ITER operation. Frequent Post Irradiation Examination (PIE) of exposed modules will also aid in understanding complicated effects. Diagnostics for integrated fusion experiments can also be integrally tested as a first step to more aggressive fluence requirements in future testing (in an FNF/CTF/FDF/etc. see below).

TBM testing in ITER is designed to provide fusion "break-in" experience and scientific exploration of blanket performance and response in the complex, multi-field fusion environment. We call this typically ***Stage I*** testing. We advocate a strong leadership role in ITER-TBM, testing our own DCLL blanket concept fabricated from Reduced Activation Ferritic Steel. In this way, all critical capabilities and knowledge base will be available in the US and position us to move forward in the development of critical FNST systems. The US will also have more influence over the parameters of the TBM program so that it is implemented in the most effective way with the simultaneous physics mission.

With the TBM accomplishing the goals of Stage I, then the role of any Next Step Fusion Nuclear Facility (e.g. CTF/FDF/VNS/…) will be to establish the "Engineering Feasibility and Performance Verification"(***Stage II***) and "Component Engineering Development and Reliability Growth" (***Stage III***) for the blanket development. One of the principal objectives of Stage II is to establish the engineering feasibility of blankets, defined as satisfying the basic functions and performance up to 10-20% of lifetime. The principal objectives of Stage III include an aggressive series of Test, Analyze and Fix iterations to improve the reliability of only a select few (at most 3) blanket concepts in meeting the demanding reliability requirements of a fusion DEMO. In general, the preparation and operational experience of test blankets in a Demo size tokamak such as ITER will be directly applicable and extremely useful to develop and license FNST systems for later testing and ultimately Demo design.

Should such a moderate fluence Next Step Fusion Nuclear Facility (FNF) become available in parallel with ITER, it is recommended to perform ITER-TBM experiments in parallel in order to capitalize on the many scientific and programmatic benefits. ITER-TBM will provide additional data sets from a separate facility that may more closely approximate a Demo fusion reactor in most respects, excepting fluence and continuous plasma operating time. Additionally, collaboration, concept screening, and any reduction of early life failures of test blanket systems will ultimately reduce the total years of FNF operation at considerable cost savings.

Even if in the future, when information about FNF timing is clearer, a decision is made to discontinue TBM experiments and perform Stage I fusion break-in tests in FNF, very little if any of the R&D and preparation efforts expended for ITER-TBM could be considered wasted. These same activities will be required to prepare for FNF testing. Additionally, having ITER-TBM as an early driver to re-initiate vigorous FNST R&D in laboratories, universities, and industries will in the end accelerate the design, development, and licensing of any FNF facility and associated test modules, as well as expand the scientific user base capable to utilize the FNF for effective fusion energy development in the US.

Additional information on a plan for a US lead role in ITER TBM is available in the following reports prepared by the FNST community for the US DOE in 2007:

[1] US ITER Test Blanket Module (TBM) Program, Volume I: Technical Plan and Cost Estimate Summary,

[2] Answers to Specific Technical, Programmatic, and Logistical Questions.

Other scenarios and cost levels could be considered for a US program as well, but a lead role is most beneficial in that all needed capabilities for FNST are developed in the US for the US mainline blanket concepts.