The Tritium Breeding Reality and

Need for Near-Term Breeding-Related R&D Programs

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This white paper proposes that an opportunity be given to testing and validating the breeding capacity of the front-runner blanket concept – the dual-cooled lithium-lead (DCLL) blanket. The pertinent question is: could we achieve the required tritium breeding ratio (TBR) in the presence of several design elements that compete for the best available space for breeding? This question has puzzled the fusion community for decades. The answer could be provided theoretically with sophisticated 3-D analyses [1] and experimentally with dedicated R&D programs to reduce the uncertainties in the TBR prediction [2].

Theoretical Prediction of TBR: Just recently, we at UW have overcome a major limitation in the 3-D neutronics analysis, allowing fully accurate modeling of complex devices by integrating the CAD geometry directly with the 3-D MCNP code, allowing more accurate 3-D modeling in much less time than was previously possible. Moreover, we developed a novel scheme to point out the terms that contribute to a decrease/increase in the TBR value for the DCLL blanket by adding the various blanket components "step-by-step" (e.g., first wall, side/top/bottom/back walls, cooling channels, flow channel inserts (FCI), stabilizing shells, assembly gaps, penetrations, etc.) and evaluating the impact of each component on the TBR. The bottom line results are displayed in Fig. 1 with the individual 15 steps listed on the right of the figure. Our findings provide insight into the understanding of how the individual design elements degrade the TBR and what conditions or changes are more damaging/enhancing to the breeding. As noticed, a significant reduction in TBR (~18%) results from the inclusion of the first/side/top/front/back walls, cooling channels, and FCIs. The R&D program could provide guidance regarding the steel structural content, the ability of the cooling channels to remove the nuclear heating, and the effectiveness of the SiC FCI as thermal/electric insulator.

The details of this 3-D analysis are as important to many fusion scientists as is the answer to the question: will the DCLL blanket over-breed or under-breed? Because many uncertainties in the operating system govern the achievable breeding level, the Net TBR (of ~1.01) will not be verified until after the operation of a Demo with fully integrated blanket, T extraction system, and T processing system. Thus, it is necessary for any blanket design to have a more flexible approach such as operating the breeder with ^{6}Li enrichment < 90% and developing a feasible scheme to adjust the ^{6}Li enrichment online shortly after plant operation [3]. Such a scheme helps deal with the shortage or surplus of tritium obtained as a consequence of the actual operational life.

Breeding-Related R&D Programs: A large gap exists between the near-term fusion experiments (that generate a few grams of T) and the Demo (that produces ~100 kg of

T/y). Dedicated breeding-related R&D programs are needed to close the gap, improve the prediction of the minimum required TBR, and develop design elements that help maximize the TBR [2]. Lab-based studies are necessary to validate the analytical predictions of T production rates, to demonstrate the online adjustment of tritium breeding, and also to demonstrate the T generation, recovery, storage, and fuel cycle that eventually lead to T self-sufficiency for fusion power plants. Small-scale lab testing facilities, fission reactors, and continuing 3-D neutronics code development are all necessary elements for the near-term R&D programs to enable operating the FNSF with breeding blanket. In addition to the domestic program, the US could restart the international collaborative program with Japan and/or initiate new research activities with Italy and Germany since active breeding-related R&D programs have been ongoing for decades in Europe and Japan.

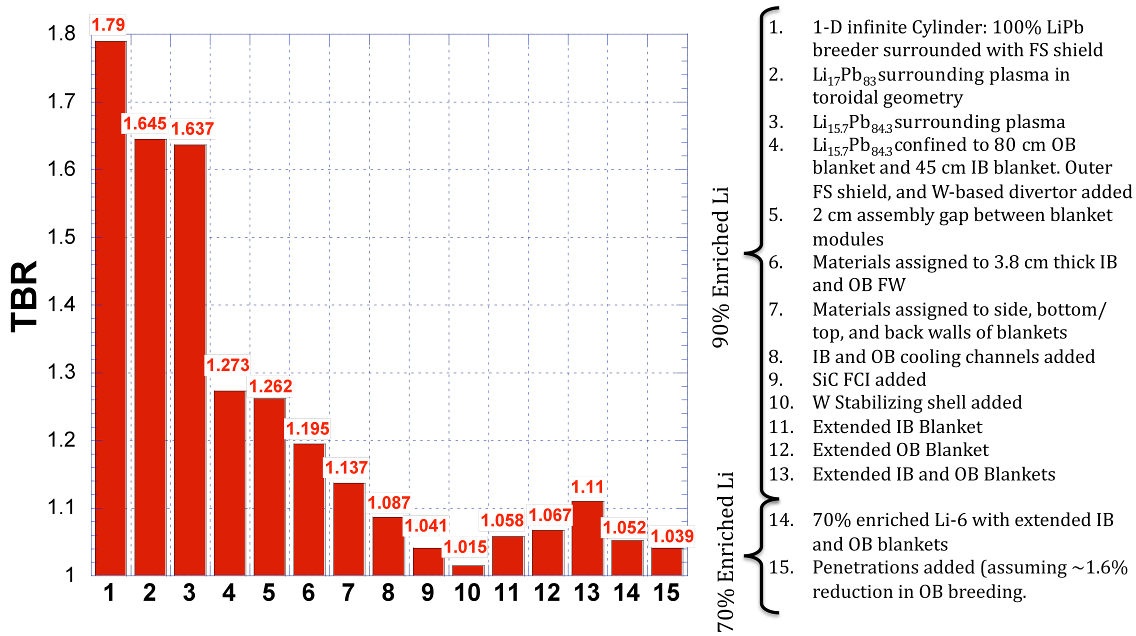

Figure 1. Bar chart showing the reduction of TBR from 1.8 to 1.04 upon including the internals of the DCLL blanket and its surrounding components.

References:

1. L. El-Guebaly, A. Jaber, and S. Malang, "State-of-the-Art 3-D Assessment of Elements Degrading the TBR of the ARIES DCLL Blanket," Fusion Science and Technology 61, #4 (May 2012) 321-331.
2. L. El-Guebaly and S. Malang, "Toward the Ultimate Goal of Tritium Self-Sufficiency: Technical Issues and Requirements Imposed on ARIES Advanced Fusion Power Plants," Fusion Engineering and Design 84 (2009) 2072-2083.
3. L.A. El-Guebaly and S. Malang, "Need for Online Adjustment of Tritium Bred in Blanket and Implications for ARIES Power Plants," University of Wisconsin Fusion Technology Institute Report, UWFDM-1372 (2009). Available at: http://fti.neep.wisc.edu/pdf/fdm1372.pdf.