Need for High Tritium Burn-up Fraction in Plasma to Relax Tritium Breeding Requirement for Demo and Fusion Power Plants

L. El-Guebaly

Fusion Technology Institute, University of Wisconsin, Madison, WI, USA

Purpose and Motivation: Due to the lack of external tritium sources, all fusion power plants must breed their own T needed for plasma fuelling. The Net tritium breeding ratio (TBR) during plant operation should be around 1.01. Such a low Net TBR is potentially achievable with advanced physics and technology where the T fractional burn-up in the plasma exceeds 10%.

Rationale

For many researchers involved in fusion power plant development, the issue of T self-sufficiency is of particular concern because of the danger of placing the plant at risk due to a T fuel shortage. To avoid such a problem, the calculated TBR must exceed unity by a margin. The magnitude of this margin is design and breeder-dependent. It accounts for well-known deficiencies in the nuclear data libraries, limitations of the 3-D computational models, and additional T that must be bred in excess of T consumed in plasma. The first two items tend to lower the breeding such that, during plant operation, the Net TBR is less than the calculated TBR, but still exceeds unity by a relatively smaller margin (~1%). For the most attractive LiPb blanket system, the minimum level necessary for reliable breeding in ARIES power plants is a calculated overall TBR of 1.1 and a Net TBR of 1.01 [1]. Such a low Net TBR is practically achievable in fusion designs employing advanced physics and technology where the T fractional burn-up exceeds 10%, the T inventory is minimal, and the T extraction and reprocessing system are highly reliable. Even though it seems small, the 1% margin translates into 1-2 kg of excess T generated per year for 2-3 GW fusion power. This amount of T bred in excess of the amount consumed in the plasma can be divided into three main categories:

1. T required to provide the start-up inventory for a new fusion power plant – a strong function of T burn-up fraction in plasma
2. T necessary to compensate for the decay of the total T inventory
3. T lost to the environment (atmosphere, cooling water, etc.).

Impact of T fractional burn-up on Net TBR

Any power plant should provide the required start-up inventory for a new power plant to be built every few years. To quantify the start-up T inventory for future plants, the ARIES-CS compact stellarator [2] and ARIES-AT advanced tokamak [3] are used as examples. Both designs employ $Li_{17}Pb_{83}$ as the breeder/coolant. For 12% and 36% T fractional burn-up in ARIES-CS and ARIES-AT plasmas, the T start-up inventories are ~4 kg and ~2 kg, respectively. As Fig. 1 illustrates, the fractional burn-up has a notable impact on the required T start-up inventory. Plasmas with relatively low T fractional burn-up (5% or less) require substantial T start-up inventories that LiPb blankets cannot provide for future power plants as the excess breeding margin is very limited. For instance, the ongoing ARIES-AT-DCLL study (that combines the advanced physics of ARIES-AT [3] with the DCLL blanket concept) indicated a marginal breeding even without including the stabilizing shells and despite an effort made to enhance the breeding through the use of thin SiC inserts [4].

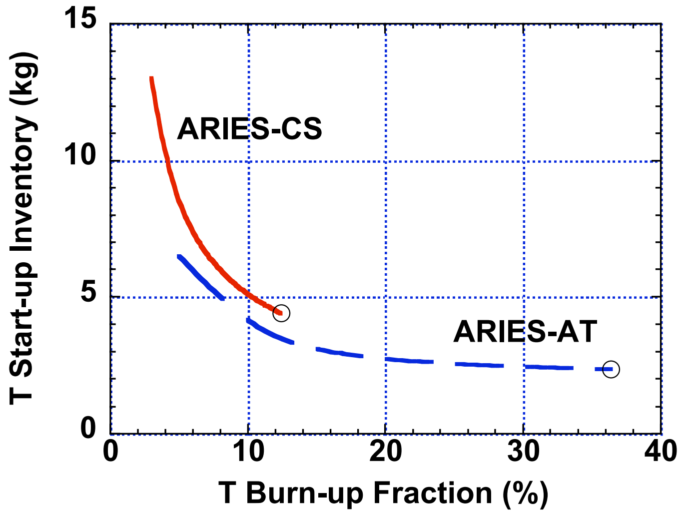

Figure 1. Impact of T burn-up fraction in plasma on start-up T inventory for new power plants [1].

Reference 5 outlines the implications for plasma physics, stating "plasma edge physics modes that lead to higher T recycling are needed. The complexity here is that high T recycling may also lead to high alpha-particle recycling, which would reduce the sustainability limit of beta, and hence would lower the achievable fusion power. Therefore, schemes that lead to preferential pumping of the alpha particles and preferential recycling of T into the plasma, need to be investigated."

Summary

The knowledge base for several plasma physics and technology-related conditions impacting the breeding requirement needs to be addressed. These include exploring plasma operating scenarios with high plasma-edge recycling mode and high T fractional burn-up exceeding 10%. Such a high T fractional burn-up helps relax the breeding requirement for the most attractive LiPb blanket concept.

References

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