Need for Online Adjustment/Control of Tritium Bred in Blanket

L. El-Guebaly[1] and S. Malang[2]

[1]*Fusion Technology Institute, University of Wisconsin, Madison, WI, USA*
[2]*Consultant, Fliederweg 3, D 76351 Linkenheim-Hochstetten, Germany*

Scope: This white paper stresses the need to control the tritium bred in the blanket during operation of Demo and power plants. This is a relatively easy task for liquid breeder blankets by online adjustment of Li enrichment, but difficult to envision for solid breeder blankets.

Rationale: One of the design requirements for Demo and power plants is to demonstrate a closed fuel cycle. In other words, such devices should breed the tritium (T) needed for plasma fuelling and supply the start-up inventory for a successor plant as external sources of T are insufficient, impractical, and/or inaccessible. The T bred in the blanket should be estimated fairly accurately as an uncertainty as small as 1% translates into 1-2 kg of T per FPY for 2-3 GW fusion power. This has a significant impact that is important for a shortage of T as well as for a surplus of T. The real question is not whether any blanket design could eliminate the danger of a T shortage or surplus – it should – but whether it offers a practical solution for breeding adjustment (up or down) during plant operation. It is less risky to produce more T during operation with the understanding that an online adjustment of breeding level is feasible for power plants employing liquid breeders through fine-tuning of the ^{6}Li enrichment.

The Net tritium breeding ratio (TBR) during plant operation could be as low as 1.01 in advanced designs, much lower than the calculated TBR [1]. Early generations of fusion plants may require a Net TBR > 1.01 for shorter doubling time while a mature fusion system may call for 1.002 < Net TBR < 1.01. Moreover, fusion plants may not operate in a uniform manner, generating more/less T during operation according to the need for variable doubling time, the need for higher/lower breeding over a certain time period (with the same integral amount of T over blanket lifetime), and/or the availability of T recovered from the detritiation system. These issues support the argument that an online adjustment of breeding is highly desirable for all fusion power plants.

How to adjust TBR of LiPb blanket online with high accuracy?

In the past, most LiPb blankets utilized 90% enriched ^{6}Li to maximize the breeding. Only recently, in the ARIES-CS study [2,3], the design point has been moved to 70% enrichment in order to provide some extra margin to increase the TBR online, if needed. In ARIES-AT [4], the reference design point is 90% enriched ^{6}Li with a calculated TBR of 1.1 [5]. The sensitivity of the calculated TBR to the ^{6}Li enrichment is shown in Fig. 1 for the ARIES-AT LiPb/SiC blanket. To illustrate the online TBR adjustment scheme, we examined an extreme case of over-breeding where the 1.1 calculated TBR should actually be equal to the 1.01 Net TBR. This means the blanket delivers much more T during operation than actually needed for plasma fueling. To fix this over-breeding problem, the ^{6}Li enrichment of LiPb can be reduced to ~50% in order for ARIES-AT to provide a TBR of 1.01 (refer to Fig. 1). How can this be accomplished in practice? This is explained in the following simple example. Assuming a total LiPb breeder volume in the entire plant of ~500 m^3, we have:

Total Pb-17Li mass ~5000 tons

Li content in $Li_{17}Pb_{83}$ with 90% enrichment (0.6 wt%) ~30 tons

Starting 90% ^{6}Li enrichment ⇒ ^{6}Li content in 90% enriched LiPb ~26.6 tons

Required 50% ^{6}Li enrichment ⇒ ^{6}Li content in 50% enriched LiPb ~14.7 tons

Required Li adjustment: 11.9 tons of ^{6}Li need to be replaced by ^{7}Li.

Here, we examine the feasibility of two practical methods for TBR adjustment through combining two Pb-17Li eutectics with different enrichments:

a) Replace 2226 tons of the 90% ^{6}Li enriched Pb-17Li by 2226 tons of Pb-17Li with 100% ^{7}Li. For practical reasons, the amount of replaced Pb-17Li would be higher if ^{7}Li concentration is < 100%.

b) Remove 13.5 tons of Li with 90% ^{6}Li enrichment from the eutectic alloy and replace it with 13.5 tons of ^{7}Li.

Which method is more suitable for the online adjustment of the ^{6}Li enrichment?

- Method-a is straightforward but requires an additional storage volume for the eutectic alloy (~200 m^3 in this example).
- Method-b does not require such large storage, but needs a practical method to remove about half of the Li with 90% ^{6}Li enrichment from the eutectic and feed the Li back with 100% ^{7}Li. The first step of separating the Li from the eutectic alloy is feasible by oxidizing the Li content in the alloy. The second step has already been investigated for the online replenishment of the ^{6}Li burn-up by adding small amounts of Li-rich Pb-Li alloy (LiPb, Li_3Pb, or Li_7Pb_2) to the eutectic alloy [6,7].

Note that this example pertains to an extreme case where the reduction of the Net TBR is assumed to be from 1.1 to 1.01. By the time a Demo blanket is manufactured and built and with the support of a dedicated breeding-related R&D program, the margin between the calculated and Net TBRs will be < 9% (probably on the order of 2-3%). This would reduce the amount of Li to be exchanged in the above example by 3-4 fold.

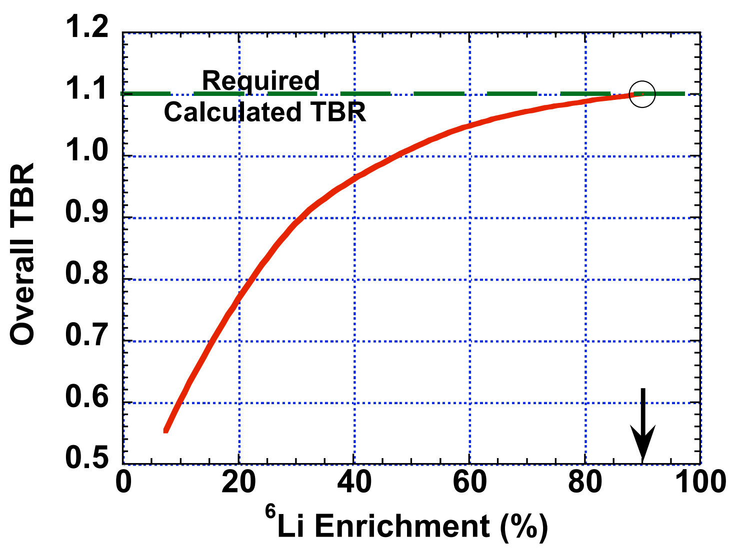

Figure 1. Sensitivity of TBR to ^{6}Li enrichment for ARIES-AT LiPb/SiC blanket [5].

Summary

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 T fuel shortage and because of potential problems handling the surplus of T. To avoid such potential risks, this white paper underlines the need for an on-line adjustment of TBR and describes this possibility for LiPb blankets by adjusting the ^{6}Li enrichment during plant operation. Such an online adjustment is not feasible for solid breeder blankets.

Since Demo is the last step before commercialization of fusion energy, the online adjustment/control of T bred in the blanket should be demonstrated on Demos employing liquid breeders to gain high confidence in this approach and to assure the first commercial fusion power plant meets the strict breeding requirement.

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