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Effect of Outer Tritium Supply to Tritium Balance of a D-T Fusion Power Reactor

核融合炉のトリチウムバランスに与える外部供給源の効果

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$(TBR)_{BS}$ attainable, which is obtained from the neutron usage and the recovery efficiency of bred tritium in the blanket system, must be larger than the required tritium breeding ratio, **$(TBR)_{BS}$ required**, which represents the whole tritium consumption in a D-T fusion reactor. Recent plasma-wall interaction studies have revealed that a considerable amount of tritium is trapped when a re-deposition layer forms. The effect of tritium trapping on the tritium balance is discussed in this study. Effect of tritium addition from the outer tritium supply to assist the maintenance of tritium balance is also discussed in this paper.

1. Introduction

Recent plasma-wall interaction studies have revealed that a considerable amount of tritium injected into the plasma vacuum vessel is trapped when the re-deposition layer forms and that the time constant of trapping phenomena is rather long as reported by Roth et al.[1] The tritium balance in a D-T fusion reactor has been discussed by the present author by comparing the amount of tritium consumed in the vacuum vessel with the amount of tritium supplied from the blanket system taking the effect of tritium trapped to re-deposition layer into account.[2-5] The author proposed the way to recover tritium from co-deposits periodically to ease the tritium balance.[3] It is recognized that the initial tritium inventory of the first reactor must be supplied from an outer tritium supply. Then, use of this tritium source is a possible way to compensate the lack of tritium in a fusion reactor considering that the target value of the **Net *TBR*** is only 1.05 in design of DEMO reactors in JAEA.[6, 7]

2. Theoretical consideration of tritium balance

The way to evaluate the required value for the tritium breeding ratio, **$(TBR)_{BS}$ required,** is compared with the way to obtain the attainable value of the tritium breeding ratio in the blanket system, **$(TBR)_{BS}$ attainable**, in **Figure. 1**.

The value of **$(TBR)_{BS}$ attainable** is decided from the usage of neutron in the blanket system and the recovery efficiency of the bred tritium.[4]

$$(TBR)_{BS} \text{ attainable} = (TBR)_0\, \beta_{VV}\, \beta_{MD}\, \beta_{BT} \ . \qquad (1).$$

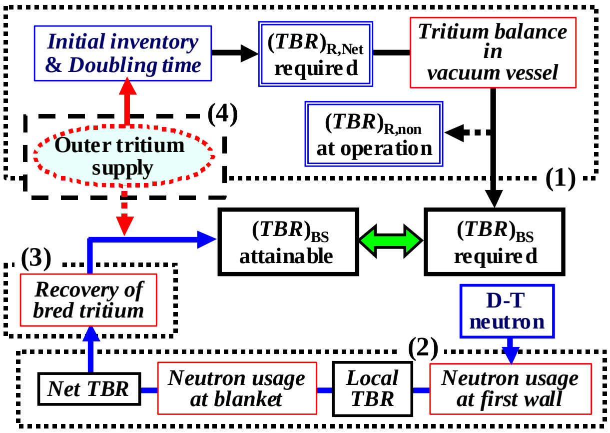

Fig. 1. **$(TBR)_{BS}$ attainable** and **$(TBR)_{BS}$ reqired**.

The reactor base tritium breeding ratio in Fig. 1, **$(TBR)_{R,Net}$ required,** is decided when the amount of tritium to be prepared for a next reactor and the time for preparation are decided.[4]

$$(TBR)_{R,Net} \text{ required} = n_{total}/(T_{WT}\, f'_{Decay}). \qquad (2)$$

Here, n_{total}, T_{WT} and f'_{Decay} are equivalent burning days corresponding to total inventory in a fusion reactor, tritium doubling time and correction factor for the beta decay in storage with constant accumulation rate, respectively.

Then, **$(TBR)_{BS}$ required** is evaluated from the tritium balance as follows.

$$(TBR)_{BS} \text{ required} = (TBR)_{R,Net} \text{ required} + (\delta_T)_{overall}/(\eta)_{overall} + (\theta_P)_{overall}/(\eta)_{overall} + (Q_T)_{Decay}/Tburn - \{(\delta_T)_{overall}/(\eta)_{overall}\} f'_{Decay}\, (\beta_{trap})_{VV} \ . \qquad (3)$$

Some tritium will be trapped to the re-deposition layers in the vacuum vessel and the overall trapping factor is represented by $(\delta_T)_{overall}$.

The overall permeation factor $(\theta_P)_{overall}$ represents the permeation phenomena in the fusion reactor .

The overall burning efficiency of tritium in the plasma vacuum vessel $(\eta)_{overall}$) is defined by Eq. (4) from the burning rate of tritium ***Tburn*** and the flow rate into the plasma vacuum vessel.[4]

$$(\eta)_{overall} = Tburn / (Q_T)_{VVin}$$
$$= \eta_{PL1}\, \eta_{TR1}\, \eta_{BUP1}\, (Q_T)_{VVin}\,, \qquad (4)$$

where η_{PL1}, η_{TR1} and η_{BUP1} are efficiency in plsmadization of tritium in the vacuum vessel, efficiency in transportation of plasmadized tritium to the burning core and tritium burn-up in the core, respectively.[4]

3. Discussion on tritium balance

Change of $\Delta(TBR)$ (=$(TBR)_{BS}$ **required** –1) with change of the overall burning efficiency of tritium is shown in **Figure 2**. The overall trapping factor of $3\text{x}10^{-4}$ is evaluated for the condition of all tungsten first wall and $3\text{x}10^{-3}$ for the condition of Be wall with tungsten divertor by the author[4] using the report by Roth et al for ITER operation.[3] Recent discussion among material scientists implies that the trapping factor may become below one-tenth of the ITER condition at the wall temperature of a power reactor.[8,9] Then, the trapping factors used in Fig 2 ,$3\text{x}10^{-5}$, may corresponds to the trapping factor at the condition of all tungsten first wall in a power reactor though the effect of neutron irradiation is not considered. It is known from this figure that the tritium balance in a reactor cannot be maintained even when the trapping factor is so low as $3\text{x}10^{-5}$ if the $(TBR)_{BS}$ **attainable** is 1.05-1.07.

Contribution of tritium breeding ratio required for (1) preparation of the initial inventory of the next reactor, (2) that for beta decay of the tritium inventory, (3) that for the loss due to permeation through the wall of vacuum vessel, and (4, 5) that for compensation of tritium trapped to co-deposits are also compared in this figure. It is shown that

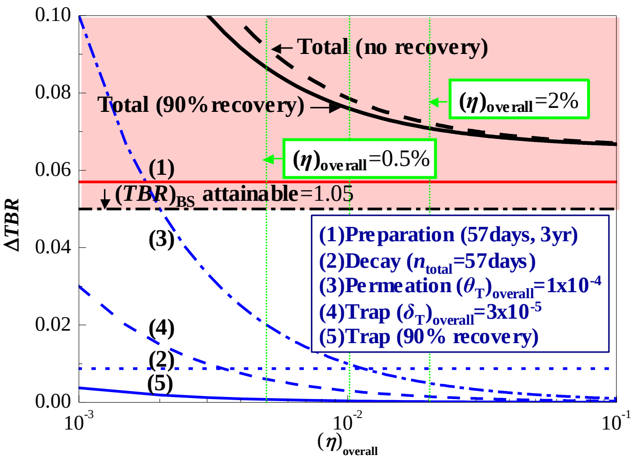

Fig. 2. Tritium balance. (Trapping factor:$3\text{x}10^{-5}$)

contribution to preparation for the next reactor is much larger than the contribution to trapping to co-deposits in the condition of this figure.

Effect of the capacity of outer tritium supply is compared in **Figure 3** for the case when the trapping factor is $3\text{x}10^{-4}$. It is known from this figure that addition of tritium from the outer tritium supply is helpful to maintain the tritium balance of a D-T fusion reactor at the beginning stage of the fusion era. Even in the case when the attainable overall burning efficiency of tritium turn out to be 0.5%, the tritium balance of a 3GWth power reactor with $(TBR)_{BS}$ of 1.05, $(\theta_P)_{overall}$ of $1\text{x}10^{-4}$, T_{WT} of 3 years and $(\delta)_{overall}$ of $3\text{x}10^{-4}$ can be maintained if 6.3 kg/y of tritium which corresponds to the breeding ratio of 0.043 is obtained from an outer tritium supply as known from Fig. 6.

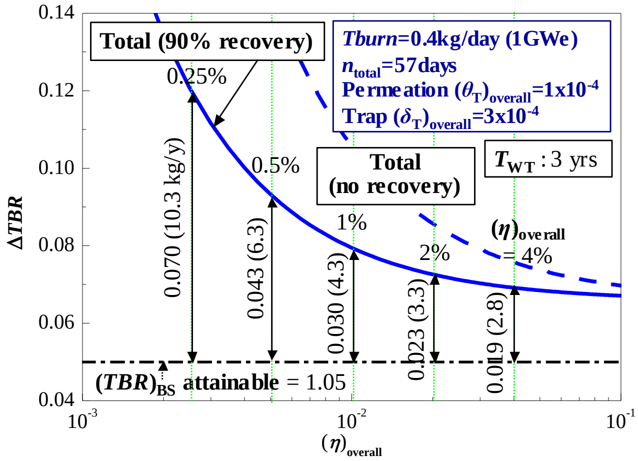

Fig. 3. Tritium required from outer tritium supply.
(Trapping factor:$3\text{x}10^{-4}$)

4. Conclusion

It is effective to have an outer tritium supply with the capacity of annual production rate of 5-10 kg/y. Then, it becomes possible to use the first wall material of which trapping factor is $3\text{x}10^{-4}$ to keep the tritium balance even when the overall burning efficiency of tritium in plasma is 0.5%

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