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# Tritium fuel cycle modeling and tritium breeding analysis for CFETR

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## HIGHLIGHTS

- A modified tritium fuel cycle model with more detailed subsystems was developed.
- The mean residence time method applied to tritium fuel cycle calculation was updated.
- Tritium fuel cycle analysis for CFETR was carried out.

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ABSTRACT

Attaining tritium self-sufficiency is a critical goal for fusion reactor operated on the D–T fuel cycle. The tritium fuel cycle models were developed to describe the characteristic parameters of the various elements of the tritium cycle as a tool for evaluating the tritium breeding requirements. In this paper, a modified tritium fuel cycle model with more detailed subsystems and an updated mean residence time calculation method was developed based on ITER tritium model. The tritium inventory in fueling system and in plasma, supposed to be important for part of the initial startup tritium inventory, was considered in the updated mean residence time method. Based on the model, the tritium fuel cycle analysis of CFETR (Chinese Fusion Engineering Testing Reactor) was carried out. The most important two parameters, the minimum initial startup tritium inventory ($I_m$) and the minimum tritium breeding ratio ($TBR_{req}$) were calculated. The tritium inventories in steady state and tritium release of subsystems were obtained.



## 1. Introduction

The scarcity of natural tritium sources and the difficulty of tritium storage lead directly to the need to breed tritium inside the fusion reactor itself operated on DT fuel cycle. Subsequently, attaining tritium self-sufficiency is a critical goal for DT fusion reactors. Therefore, carefully evaluating the conditions for attaining self-sufficiency is necessary to define the selection criteria for design concepts and the range of acceptable performance parameters. In order to assess the feasibility of the parameters, many tritium fuel cycle models [1–3] have been developed based on mean residence time method [1]. However, the existed models did not incorporate some important subsystems and parameters, such as the independent fueling system and the detailed tritium waste treatment system, leading to imprecise calculation results.

Trying to make the calculation results of the tritium fuel cycle model more precise and reliable by keeping the model consistent with the real fusion plant as much as possible, in this paper, a modified tritium fuel cycle model and an updated mean residence time method was developed based on ITER tritium model by detailing the model of the tritium plant. Theoretically, the calculation results should be more reliable by this way, but a lot of work still needs to be done to carefully verify the reliability of the model in the future.

Specifically, the model considers fueling system and storage system separately. The first wall of blanket and the plasma facing material of divertor were taken into account independently. Besides, the tritium waste treatment system was modeled in detail. In addition, the tritium inventory in fueling system and in plasma, supposed to be important as part of the initial startup tritium inventory, were considered in the updated mean residence time method.

Based on the model, the tritium breeding analysis for CFETR was carried out. The most important two parameters, the minimum initial startup tritium inventory $I_m$ and the minimum tritium breeding ratio $TBR_{req}$ were calculated. The tritium inventories in steady state and tritium release of the subsystems as well as the transient inventories of subsystems were also obtained.

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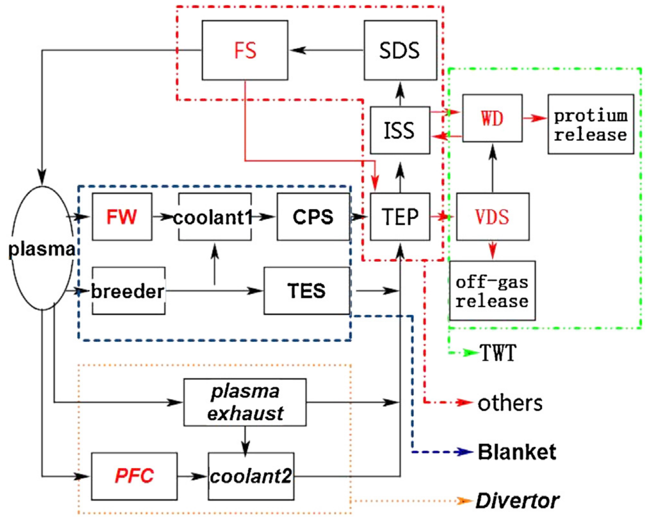


**Fig. 1.** Simple tritium block diagram of the model.

## 2. Model description

Based on ITER tritium plant [4], the model is divided into four parts including Blanket, Divertor, tritium waste treatment system (TWT) and other subsystems, and each of these parts is composed of some specific subsystems. The tritium flow between subsystems is also shown (Fig. 1).

The innovation points of this model are illustrated as follows:

Contrast to the existed model, in which the fueling system and the storage system were modeled into one module, the fueling system in this model was independently taken into account, separated with the storage system, which allows the tritium that is not injected into the plasma to be recycled into the Tokamak Exhaust Processing (TEP).

The blanket first wall (FW) and the plasma facing material of divertor (PFC), usually modeled with the blanket and the divertor together respectively by the existed model, were modeled independently to make it available to evaluate the tritium retention in FW and PFC.

This model modeled the TWT in detail to consider the Water Detritiation (WD) and Atmosphere and Vent Detritiation (VDS) to make the calculation more reliable, instead of modeling the tritium waste treatment system (TWT) into one module as the existed models did.

The tritium fuel cycle process of this model is introduced as follows.

Before the startup of the fusion plant, certain amount of tritium is supposed to be stored in the storage system (SDS). The fueling system (FS) and the plasma are also required to be filled with certain amount of tritium before startup due to the required ignition condition of the plasma [5]. The tritium supply rate from the SDS is required to be constant to ensure the continuous burning of the plasma. Only a part of the tritium can be injected into the plasma with remained tritium recycled into the Tokamak Exhaust Processing system (TEP) when considering the fueling efficiency.

The tritium in plasma will permeate into the blanket and the divertor through the blanket first wall (FW) and the plasma facing material of divertor (PFC) respectively.

The neutrons generated by fusion reaction get into the breeder to produce tritium and the tritium not burned is to be recycled by divertor. All the tritium will be directed into the Tokamak Exhaust Processing system to be treated and subsequently refills the storage after purification and separation by the tritium waste treatment system (TWT) and the Isotope Separation System (ISS).

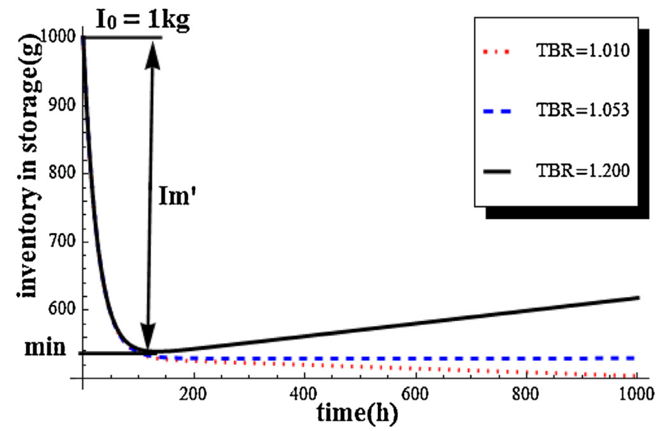


**Fig. 2.** Tritium inventory in SDS as a function of time.

Three functions are available through this model.

1. Calculation of the minimum tritium initial startup inventory ($I_m$) and the minimum tritium breeding ratio ($TBR_{req}$) required by tritium self-sufficiency.
2. Calculation of tritium inventories, tritium handling capacity and tritium release rate of subsystems in steady state.
3. Calculation of transient inventory of each subsystem.

## 3. Calculation method

The mean residence time method was generally adopted by tritium cycle calculation. However, the original method was not able to take into account the tritium inventory in fueling system and in plasma that was supposed to be incorporated as part of the initial startup tritium inventory. The mean residence time in this paper was updated to consider the tritium inventory in fueling system and in plasma, which leads to the modification of the calculation method of $I_m$.

### *3.1. Update of mean residence time method and calculation of* $I_m$

Before the introduction of the update of the mean residence time method, it is necessary to know the original calculation method of minimum initial tritium startup inventory.

In order to start the fusion plant, certain amount of tritium $I_0$ must be put in the storage system before the startup of the fusion plant and $I_0$ is supposed to be higher than the minimum initial startup tritium inventory $I_m$ due to the tritium retention in the subsystems of the fusion plant. Hence, an assumed initial startup tritium inventory $I_0$ is needed before the calculation since $I_m$ can be known only after the calculation. After calculation, as long as the minimum tritium inventory of storage system is bigger than zero, the assumed $I_0$ will be suitable. Finally, a value ($I'_m$) calculated by the model to be modified is equal to $I_0$ minus the minimum value of tritium inventory in storage, shown in Fig. 2 in Section 3.2. It is meaningful to underscore that the value ($I'_m$) directly calculated by the model used to be thought as the minimum initial startup tritium inventory by the original method, which is clearly not correct due to the omitting of the tritium inventory in fueling system and in plasma.

Obviously, the update of the mean residence time method is to consider the tritium inventory in fueling system and in plasma as part of the minimum initial startup tritium inventory. As for fueling system and the plasma, only the inflow and outflow tritium were taken into account by the model, leaving the tritium inventory in fueling system and the plasma not considered. And the tritium