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A system dynamics model for tritium cycle of pulsed fusion reactor

Zuolong Zhu[a,b], Baojie Nie[a,b], Dehong Chen[a,*]

[a] Key Laboratory of Neutronics and Radiation Safety, Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences, Hefei, Anhui, 230031, China

[b] University of Science and Technology of China, Hefei, Anhui, 230027, China

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ABSTRACT

As great challenges and uncertainty exist in achieving steady plasma burning, pulsed plasma burning may be a potential scenario for fusion engineering test reactor, even for fusion DEMOnstration reactor. In order to analyze dynamic tritium inventory and tritium self-sufficiency for pulsed fusion systems, a system dynamics model of tritium cycle was developed on the basis of earlier version of Tritium Analysis program for fusion System (TAS). The model was verified with TRIMO, which was developed by KIT in Germany. Tritium self-sufficiency and dynamic tritium inventory assessment were performed for a typical fusion engineering test reactor. The verification results show that the system dynamics model can be used for tritium cycle analysis of pulsed fusion reactor with sufficient reliability. The assessment results of tritium self-sufficiency indicate that the fusion reactor might only need several hundred gram tritium to startup if achieved high efficient tritium handling ability (Referred ITER: 1 h). And the initial tritium startup inventory in pulsed fusion reactor is determined by the combined influence of pulse length, burn availability, and tritium recycle time. Meanwhile, tritium self-sufficiency can be achieved under the defined condition.

1. Introduction

Fusion energy has been attracting considerable research interests owing to its characteristics of safety, non-carbon emitting and virtually limitless energy. Among various kinds of fusion fuels, deuterium (D) and tritium (T) has long been touted as the promising fuels for the first generation fusion energy because of high fusion reaction cross section [1]. Given that fusion reactor will consume tritium at a very large rate of 55.6 kg/GW per full power year operation [2]. In fact, it has been demonstrated that only 3.5 kg nature tritium resource are available and mainly distribute in the atmosphere and ocean. In the past few year of fusion fuels research, many efforts have been focused on manual tritium production through using CANDU reactor, accelerator, commercial light water reactor and fusion breeding blanket [3–7]. Considering the unacceptable economy of tritium (about 30,000 dollars/g [8]) produced by fission reactor and accelerator, breeding blanket scenario has been widely accepted as the best path to produce tritium needed in the operation of fusion reactor. In the blanket scenario, produced tritium must be equal to or greater than the consumed tritium (burn, retention, decay). Thus, tritium self-sufficiency is a fundamental issue on the way to achieve acceptable earlier fusion energy.

As great challenges and uncertainty exist in achieving steady plasma burning [9], pulsed plasma burning scenario can be a potential scenario for fusion reactor (e.g. ITER, Europe DEMO). ITER will adopt three pulsed operation scenarios, the pulse length of plasma will be around 300–500 s, 1000 s and 3000 s respectively [10]. Therefore, it is a key issue to analyze dynamic tritium inventory and tritium self-sufficiency for pulsed fusion reactor.

In the past, several efforts have been dedicated to the development of tritium cycle model, such as TRIMO [11], UCLA model [12], SD-TFE model [13] and TAS1.0 model [14]. However, the TRIMO model is mainly developed for ITER without blanket breeding, SD-TFE is for double D fuels scenario, UCLA and TAS1.0 model assumed steady burning of plasma and failed to assess dynamic tritium inventory for pulsed fusion reactor. Thus, on the point of tritium cycle analysis for pulsed fusion reactor, this study aims to develop a dynamic tritium cycle model with the functions of tritium self-sufficiency and dynamic tritium inventory assessment. Further, the tritium cycle analysis for typical fusion engineering test reactor was performed using the system dynamics model.

* Corresponding author.
E-mail address: dehong.chen@fds.org.cn (D. Chen).

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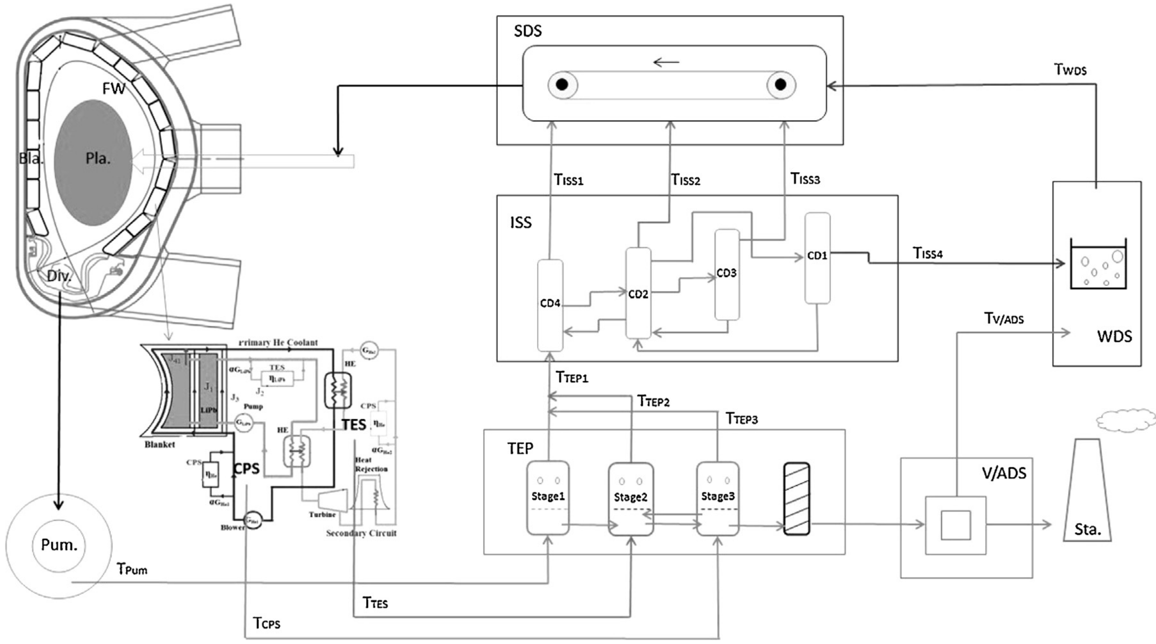

Fig. 1. Dynamic tritium cycle model scheme.

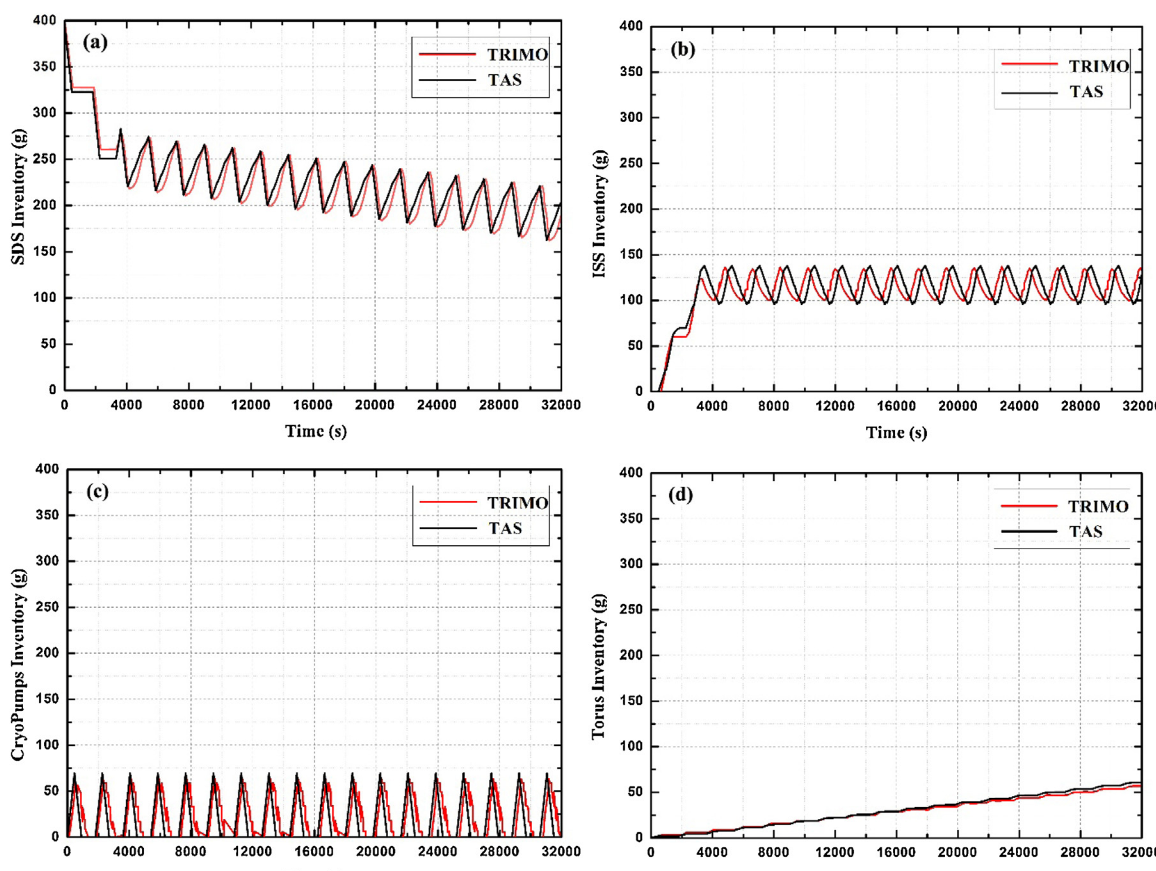

Fig. 2. Inventory comparison of TAS with TRIMO (a) SDS, (b) ISS, (c) Cryopump, (d) Torus.

2. Model description

System dynamics (SD) method is an approach to understand the nonlinear behavior of complex systems. By using SD, tritium cycle model can be built through drawing a graphical pipe diagram which consists of stock and flow. Meanwhile, rate-equations are automatically generated from the pipe diagram and are numerically calculated with the fourth order Runge-Kutta method. The basic tritium flow can be described as Eq. (1), tritium flow at a stock $N_T(j)$ from upstream stock $N_T(i)$ and tritium outflow at $N_T(j)$ to a