Commissioning of a DT fusion reactor without external supply of tritium

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Abstract: Commissioning of a DT fusion reactor without external supply of tritium is discussed. The DD reactions in a DT-oriented fusion reactor with external power injection by neutral beams produce tritium and neutrons. Tritium produced by the DD reaction together with that produced in the blanket by the 2.45 MeV neutron is re-circulated into the plasma. Then, the DT reaction rate increases gradually, as tritium concentration in plasma builds up towards the level of nominal operation. Time required to reach the nominal operational condition, i.e. 50 % tritium in plasma, is estimated with assumptions based on a model of fusion power plant. As a result, the start-up period of a DT fusion reactor without external supply of tritium is estimated to be approximately 55 days, with the plasma parameters of CREST having a high performance blanket and tritium processing systems. Major factors to determine the start-up period are DD and DT reaction rates, net tritium breeding gain of the plant and dead inventory in/on facing materials. Elimination of a constraint for fusion reactor deployment and operation without any tritium transportation in and out of plant through its entire life may be possible.

1. Introduction

A common scenario usually adopted for commissioning of a DT fusion reactor assumes availability of tritium fuel externally supplied. The quantity required would be at least equivalent to the inventory to be preserved for normal operation. The extra inventory would be needed to prepare for restarting at unexpected long shut down of the plant. Therefore, availability of tritium fuel may become a major constraint for fusion reactor deployment in the future [1]. If reasonable commissioning of a DT fusion reactor is possible without external supply of tritium, such a constraint will be eliminated. It means such a DT fusion reactor can operate without any tritium transportation in and out of plant through its entire life.

Possibility of DT fusion power reactor start-up without initial loading of tritium was discussed in our previous paper [2]. The DD reactions in a DT-oriented fusion reactor with external power injection by neutral beams produce tritium and neutrons. Tritium produced by the DD reaction together with that produced in the blanket by the 2.45 MeV neutron is re-circulated into the plasma. Then, the DT reaction rate increases gradually, as tritium concentration in plasma builds up towards the level of nominal operation. In the present study, time required to reach the nominal operational condition, i.e. 50 % tritium in plasma, is estimated with assumptions based on a model fusion power plant. Major factors that affect the start-up period are also discussed.

2. Model and Parameters for the Estimation of Start-up Period

A simple fusion reactor model which consists of five components, the plasma, the blanket, the exhaust-purification, the isotope separation and the storage-fueling, is used to calculate the tritium inventory in each system. The start-up period to be estimated is defined as the time required to reach the full power operation with 50% tritium in plasma. DD and DT reaction rates in the plasma, especially at low tritium concentration, are important parameters to affect the start-up period. Tritium production rate in the blanket, tritium recovery rate from the

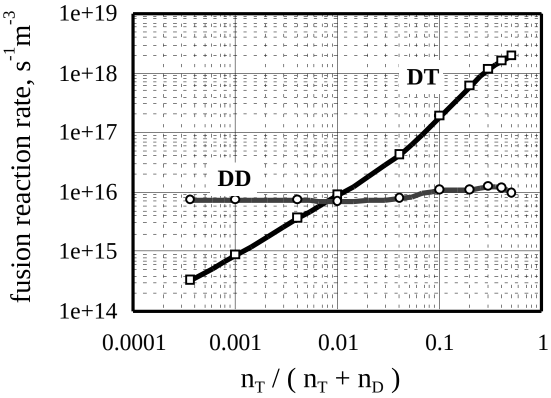

FIG. 1. DD and DT reaction rate as a function of tritium concentration in the plasma.

blanket, and performance of tritium processing systems are crucial parameters.

To estimate tritium concentration in the plasma, we need to take into account the tritium production by DD reaction, tritium from the fueling system, tritium consumption by DT reaction, exhausted tritium and tritium to become the dead-inventory deposited on and in the plasma facing materials. DD and DT reaction rates, plasma volume and effective tritium confinement time are based on the CREST reactor concept proposed as a first generation commercial reactor [3]. Major parameters of the CREST reactor, Compact Reversed Shear Tokamak reactor, are 5.4 m in major radius, 3.4 in aspect ratio and 1.16GW in net electric power generation.

The reaction rates considered here include the beam direct reaction caused by high-energy, 2.5 MeV, and large-power, 94 MW, neutral beams for plasma current drive. Figure 1 shows the DD and DT reaction rate as a function of tritium concentration in plasma. Lowest concentration in Fig. 1 is of the case that only deuterium is supplied to the plasma. Effective tritium confinement time is assumed to be 10 seconds, which is approximately 5 times of the energy confinement time.

Tritium production rate in the blanket is 1.10 per a 14.1 MeV neutron and 0.67 per a 2.45 MeV neutron. These values are also from the CREST reactor design. Tritium recovery from the blanket largely depends on the blanket temperature. In the early stage of the start-up, although fusion power is very low, the blanket is assumed to be maintained at nominal temperature by a heating device, which is necessary to remove tritium. The mean residential time of tritium in the blanket and tritium recovery system is assumed to be a half day. Other mean residential times for the tritium processing systems, the exhaust-purification system, the isotope separation system and the storage-fueling system, are assumed as summarized in

TAB. 1 MEAN RESIDENTIAL TIME OF TRITIUM AND DEAD INVENTORY IN EACH SYSTEM.

	Mean residential time (Effective tritium confinement time*)	dead inventory	exchange reaction rate
Plasma	10 sec.*	250 g	1.16×10^{-6} s^{-1} (10% / day)
Blanket & tritium recovery	0.5 day	100 g	1.16×10^{-6} s^{-1} (10% / day)
Exhaust & fuel clean-up	30 min.	50 g	1.16×10^{-6} s^{-1} (10% / day)
Isotope separation	30 min.	50 g	1.16×10^{-6} s^{-1} (10% / day)
Storage & fueling	30 min.	50 g	1.16×10^{-6} s^{-1} (10% / day)
Total		500 g	

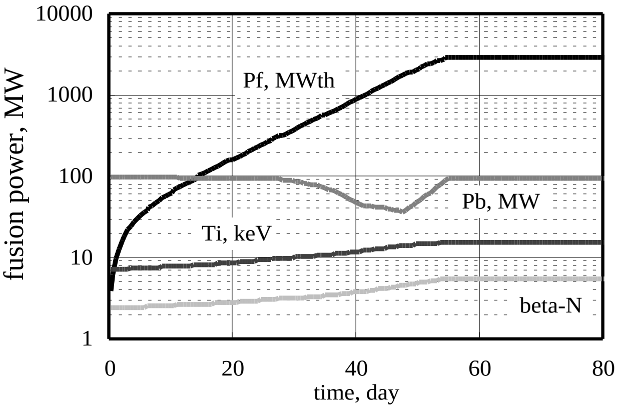

FIG. 2. Increase of the fusion power without external supply of tritium.

Table 1. Although tritium concentration in the tritium processing systems is very low in the early stage of the start-up period, mean residential times of tritium are assumed to be same as that in normal operation. It is required to detail the fuel system based on the design of tritium processing plant and the recent progress of actual devices.

The start-up period depends strongly on the "dead-inventory". The "dead-inventory", which is tritium to deposit on/in the facing material of the plasma and the process components, cannot be used in the reaction or processing. Tritium will become the dead inventory by isotopic exchange, because the dead inventory is initially saturated with deuterium. Amount of the dead inventory and time constant of isotopic exchange are considered as variable parameters in the present study. These parameters are also shown in Table 1.

3. Results and Discussion

Figure 2 shows the increase of the fusion power calculated with the plasma parameters of the CREST reactor and parameters in Table 1. In this case, approximately 55 days are required to reach full power. It means that the start-up of DT fusion reactor without tritium externally supplied is possible in less than two months.

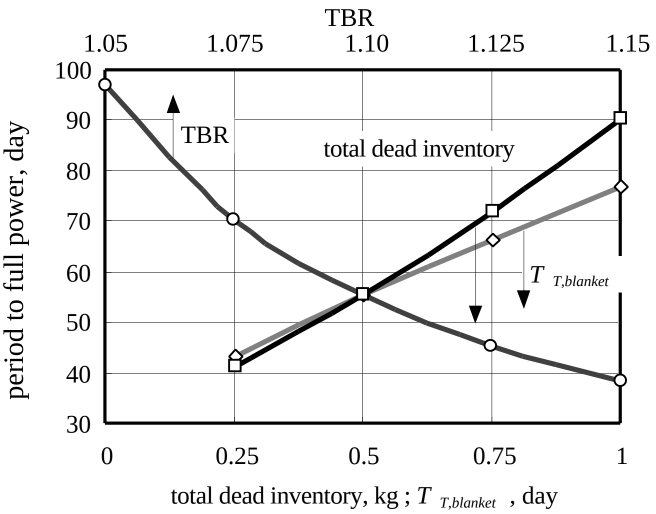

FIG. 3. Dependences of the start-up period on tritium breeding ratio, mean residential time in the blanket, $T_{T,blanket}$, and the dead inventory.

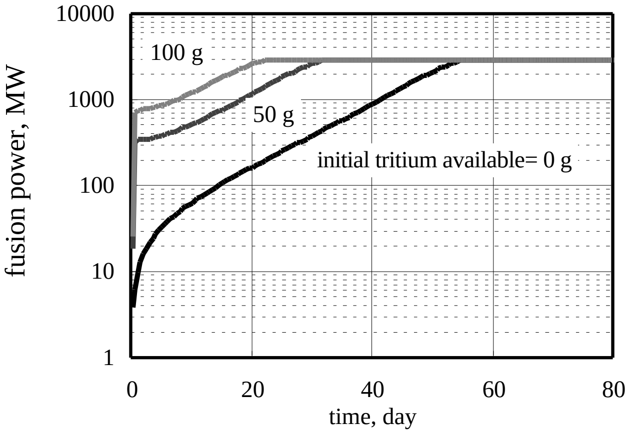

FIG. 4. Increase of the fusion power in the case that a small amount of tritium is available.

The period required to be full power depends on tritium breeding ratio, mean residential time in the blanket and the dead inventory, as well as the DD and DT reaction rates in plasma. Such dependences are shown in Fig. 3. Poorer TBR, longer mean residential time in the blanket, and larger dead inventory prolong the required start-up period. However, high TBR is required only in the start-up period. Degradation of TBR is acceptable after the start of full power operation. The analysis shows that if a small amount of tritium, e.g. several ten grams, is available at the beginning, the start-up period is shortened as shown in Fig.4.

The result in the present study implies that external supply of tritium is dispensable for commissioning a DT fusion reactor. A major constraint for fusion reactor deployment due to availability of tritium may be eliminated. It means that a DT fusion reactor has a possibility to operate without any tritium transportation in and out of plant through its entire life. As commissioning with external heating power requires significant energy cost, the scenario discussed in the present study may have some disadvantages from an economical viewpoint. However, eliminating the constraint of fusion reactor deployment and reducing the transportation of a large amount of tritium are significant advantages to overcome the economical disadvantages.

IV. Conclusions

Conclusions of the present study can be summarized as follows;

1) The start-up period of a DT fusion reactor without external supply of tritium is estimated to be approximately 55 days, with the plasma parameters of CREST having high performance of the blanket and the tritium processing systems.
2) Major factors to determine the start-up period are DD and DT reaction rates, net tritium breeding gain of the plant and dead inventory in/on facing materials.
3) The beam-plasma direct DD reaction rate at an early stage plays an important role in tritium production for fusion power increase.
4) If a small amount of tritium is available for initial loading, it shortens the start-up period drastically.

References

[1] Y. Asaoka et al., Fusion Technology, **30** (1996) 853-863
[2] S. Konishi et al., to be published in J. Plasma and Fusion Research (2000)
[3] K. Okano et al., Nuclear Fusion, **40** (2000) 635-646