STUDY ON TRITIUM-FREE START-UP SCENARIOS OF FUSION POWER PLANT CONSISTENT WITH CORE PLASMA DESIGN AND PLANT POWER BALANCE
Helical Fusion Pilot Plant as an Example

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1. MOTIVATION AND CALCULATION METHOD

Initial tritium loading is often assumed at the start of D-T fusion reactor operation. However, in the operation of fusion power plants in the early stages of installation such as pilot plants, the possibility of start-up without an external supply of tritium should be considered to ensure the operation independent of external factors and expand the installation scale as soon as possible. On the other hand, a large external power supply will be required until sufficient tritium is produced. To minimize the external power supply, it is necessary to optimize the plasma operation scenario in a manner consistent with the core plasma design. In this study, we have realized the calculations consistent with all of the tritium balance, core plasma physics, and plant power balance.

In this study, a helical fusion pilot plant [1] was selected for the analysis. This is because the helical system has no plasma current and the pressure profile follows a simple scaling, which makes the core plasma design relatively simple and the interpretation of the analysis result easy. Of course, similar methods can be applied to other confinement concepts. Consistent calculations are achieved by improving and combining three calculation tools developed in past helical fusion reactor design activities. The tritium balance analysis is performed with newly developed model for the prediction of the inventory and intersystem mass flow of each subsystem in the fuel cycle [2]. This model is based on the model proposed by Asaoka et al. [3] with modifications so that the effect of direct internal recycling (DIR) and direct fuel recovery from liquid metal free surface flow of liquid blanket system (In-VV recycling) can be reflected. The flow of tritium handled by the model is shown in Figure 1. The prediction of the time evolution of the core plasma radial profile is performed using the direct profile extrapolation method developed for the integrated physics analysis of helical fusion reactors [4, 5], extended to be applicable to arbitrary fuel tritium-to-deuterium (T/D) ratios. The plant power balance analysis is based on the model used in systems codes (e.g., TPC for tokamak reactors and HELIOSCOPE for helical reactors), which includes a detailed estimation of the recirculating power consumed by each plant system (e.g., cryoplant, blanket coolant pumping, vacuum pumping & fueling, diagnostics, buildings, and power supplies, etc.). The combination of these calculations enables the first evaluation of tritium production scenarios and external power requirements in a manner consistent with the power balance of the core plasma, which also takes into account electron-ion energy relaxation.

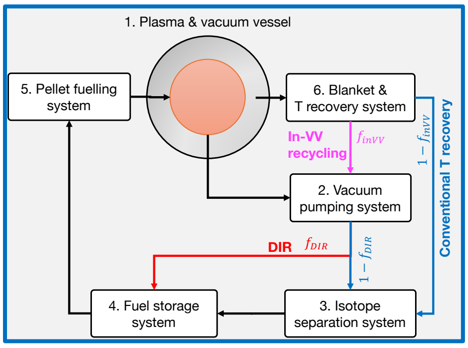


Figure 1: Tritium flow model of this study.

2. CALCULATION RESULT

The primary design parameters of the helical fusion pilot plant in rated D-T operation are shown in Table 1. Only ECH is assumed as auxiliary heating, and the heating power is assumed to maintain the same value as in the D-T rated operation (24 MW). Helium ash fraction is assumed to be 2.5%. Three cases of tritium breeding ratios (TBR) of the D-T reaction (1.15, 1.10, 1.05) are examined. TBR of D-D reaction is assumed to be 0.5. The tritium processing time and tritium loss rate in each

Table 1: Primary design parameters of the helical fusion pilot plant under rated D-T operation

Helical coil major radius R_c [m]	7.8
Helical coil minor radius a_c [m]	2.278
Magnetic field at R_c, B_c [m]	8.0
Average plasma minor radius a_p [m]	1.13
Peak electron density n_{e0} [10^{20}m^{-3}]	3.9
Peak electron temperature T_{e0} [keV]	8.41
Peak ion temperature T_{i0} [keV]	8.36
Auxiliary heating power P_{aux} [MW]	24
Fusion power P_{fus} [MW]	260

subsystem are referred to the values in [3], except for the fuel storage. In order to maintain the fuel T/D ratio of 1, the flow of the tritium from the storage to the fuelling system is assumed to be shut off when the fuel T/D ratio exceeds 1.

To maximize the fusion reaction rate, the electron density is controlled to maintain the rated electron temperature (8.41 keV at peak). Figure 2 shows the relation between the fuel T/D ratio and the achievable electron density; a lower T/D ratio results in lower achievable density due to lower alpha heating. Figure 3 shows the time evolution of fuel T/D ratio, fusion power, net electric power, cumulative tritium loss, and total tritium inventory. For reference, the results are also plotted for the case where TBR=1.15 and both density and temperature are maintained at rated operation values from the start-up point. Fusion power and electric power increase with the increase of the fuel T/D ratio. It takes 600 days to reach D-T rated operation, which is longer than the reference case (300 days) due to the low fusion reaction rate at the early phase. Net power generation turns positive earlier than the D-T rated operation is reached, about 470 days after the start of operation. This time required is also about twice as long as in the reference case, but the maximum external power requirement can be roughly halved instead. The required time increases as the TBR decreases and increases rapidly as the TBR approaches 1. Therefore, an accurate estimation of TBR is important for plant operation scenario studies.

The developed model is useful not only for examining start-up scenarios without an external tritium supply, but also for studying the overall plant operation scenarios, including restart after maintenance and analysis of output fluctuation due to load-following, and so on. The analysis results can be used to derive design requirements such as necessary TBR and tritium processing time for each system, which can be fed back to the overall plant design. Consequently, this calculation model is expected to be utilized in the development and safety analysis of fusion power plants.

Figure 2: Achievable electron density as a function of fuel T/D ratio of core plasma

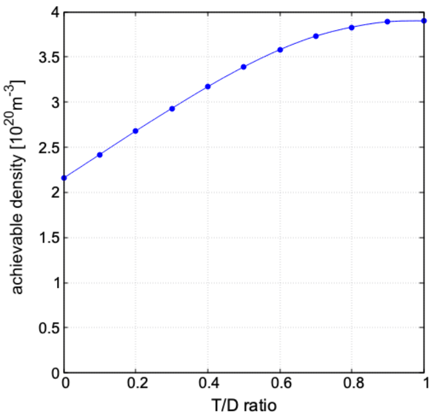
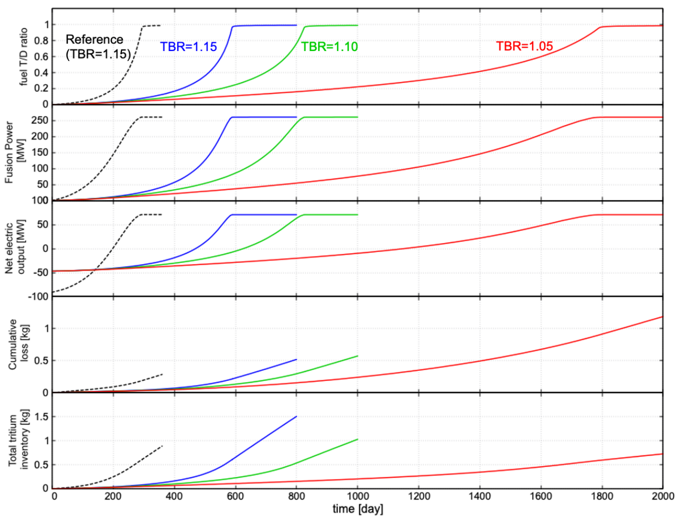


Figure 3: Time evolution of fuel T/D ratio, fusion power, net electric output, cumulative tritium loss, total tritium inventory (solid lines) and those in the reference (broken lines).



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