Self-consistent calculation of the neutron emission in KSTAR power upgrade

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1. Introduction

Deuterium-tritium reaction is the most promising one in term of the highest nuclear fusion cross-section for the reactor. But the resulting reaction product, 14 MeV neutron where most of reaction energy is carried leads to combined material displacement damage and helium bubble formation in the bulk structure material and results in shortage of reactor lifetime. To solve this, world-wide program have been progressed based on the accelerator driven neutron production facility using nuclear stripping process of energetic deuterium nucleus by target.[1] In addition to the narrow area beam facilities, wide area neutron source is also required to demonstrate the function of blanket module or TBM(Test Blanket Module) which is one of the critical research items in ITER to realize the fusion reactor. KSTAR shows high performance in neutron generation as well as plasma performance. Based on beam-target fusion reaction of deuterium-deuterium, it shows the typical characteristics of beam target fusion. The feasibility study of KSTAR to wide area neutron source facility was done in term of D-D reactions from the empirical scaling law from the mixed fast and thermal stored energy using profile data as well as self-consistent absorbed power calculation.[2]

2. Methods and Results

In this section some of the techniques used to calculate neutron calculation based on simple power absorption and self-consistent power absorption way.

2.1 simple power absorption method

From the typical beam target fusion, neutron yield, Y_{bt} is calculated as,

$$Y_{bt} = \alpha_1 n_i T_b W_b = \sim \alpha_1 n_i / n_b W_b W_b \qquad (1)$$

Where, α_1, n_i, n_b, T_b, W_b is the reactivity constant, ion density, the fast ion density, and fast ion stored energy respectively.

Using confinement time of H-mode scaling, fast ion stored energy W_b is approximated as for constant plasma density

$$W_b \propto P^1 \, T_e^{1.5} \propto P^{1.17} \qquad (2)$$

Table 1 shows two reference shots for calculation(typical H-mode/#27327 and high li discharge/25691). When we extrapolate the neutron production to case of neutral beam power upgrade in KSTAR, where the beam power is doubled to present NB power with additional NB2, the fast ion pressure would be more than doubled and the electron temperature is also increased as well as ion temperature. So it is expected that the fast ion pressure is increased due to that both the incident beam and beam slowing down time increase, but the thermal energy is increased a little bit regardless of tokamak operation scenarios. According to H-mode confinement scaling, confinement time is inversely proportional to the power factor of 0.69 so that the stored thermal energy is increased to 1.23 times to present value and T_i as well as T_e is to be about 6.2 keV under assumption of constant plasma density. The stored thermal energy could reach to around 1 MJ.

2.2 self-consistent method

The neutron emission calculation following the power upgrade was performed through predictive simulation in which various plasma nonlinear phenomena were considered self-consistently. For this, an integrated simulator is required that can comprehensively consider plasma equilibrium and stability determined through plasma density, temperature, current, and momentum change. Models that can describe individual plasma phenomena should be organically combined, and computational simulations should be performed by reflecting each plasma phenomenon's temporal and spatial scales. The TRIASSIC (Tokamak Reactor Integrated Automated System for SImulaton and Computation) [3], which is the integrated suite of codes using IMAS/IDS[4], was used for neutron emission prediction in a self-consistent manner.

	NB (MW)	T_e/T_i (keV)	W_{fast} (kJ)	W_{th} (kJ)	Neutron (10^{14}/s)
#27327	5	5/5	108	702	7.56
0-D	**10**	6.2/6.2	283	863	**18.5**
Self-consistent	**12**				**28.3**

Table 1. Neutron yield(beam-target) for NUBEAM, 0-D(10MW), and self consistent way(12MW) for #27327.

3. Summary

Table 2 shows the neutron emission for NUBEAM in NBI power of 5 MW and 0-D simple power absorption and self-consistent power absorption.

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Shot#	Time (s)	N_e (10^{13}/cm^3)	T_i (keV)	T_e (keV)	W_{mhd} (kJ)	W_{fast} (kJ)	Neutron (a.u.) (Measured)	Neutron$_c$ (Calculated) (10^{14} /s)	Operation Scenario	NBI power (MW)
27327	7	5	4	5	811	108	98.2/147	7.56(8.28)	H-mode	5
25691	7.9	4	4	5	421	127	86/87	5.53(6.79)	High-li	5.1

Table 1. Neutron yield for various plasma shots(#27327, 25691), where neutron$_c$ corresponds to neutron yield of Y_{bt} using Nubeam and value in bracket correspond to the total neutron yield. Measured neutron corresponds to He^3 and fission chamber counter.