§6. Concept of Simplified Fuel Cycle System Adapting the Cryogenic Engineering for Helical-type Fusion Reactor

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Tritium, which decays with a half-life of 12.32 years by emitting a beta particle to produce ^{3}He, is the only radioactive isotope of hydrogen and comprises about 10^{-16} % of natural hydrogen. The quantity of tritium for fusion reactor is not sufficient from natural resources at all. Therefore, tritium in the fusion reactor has to be bred and unburned tritium is reused. On the other hands, an amount of tritium inventory in the fusion reactor plant should be minimized from the viewpoint of tritium safety. The tritium inventory in the reactor system is represented as follow[1]:

$$M_0 = \frac{\dot{M}_1}{TBR \times \eta f_b / t_p - \gamma_s - \gamma_r} \quad (1)$$

$$\approx \frac{t_p \dot{M}_1}{\eta f_b}, \quad (2)$$

$$\dot{M}_1 = 56 P_F \; kg/y/GW_{th}, \quad (3)$$

where, M_0 is the time-independent, recirculating tritium inventory, M_1 is tritium mass consumption rate, P_F is an average fusion thermal power, *TBR* is tritium breeding ratio, η is fueling efficiency by a pellet injection, f_b is tritium burnup fraction, t_p is a mean time of tritium reprocessing, γ_s is loss rate and γ_r is radioactive decay of tritium. Assuming the tritium breeding ratio is large compared to tritium loss, $\gamma_s + \gamma_r$, and *TBR* is ~1, M_0 become simple equation (2). It indicated that the tritium inventory M_0 is proportional to mean time of tritium processing and inversely proportional to tritium burnup fraction. The tritium burnup fraction in the helical type fusion DEMO reactor is estimated to be less than 1 %. Thus the tritium inventory would be larger when a conventional fuel processing technique is introduced. A conventional fuel cycle system such as ITER fuel processing system is shown in Fig. 1(a). It consists of a Pd diffuser and a membrane reactor for impurity processing, a cryogenic distillation system [CD] for hydrogen isotope separation, storage beds and a pellet injection system. The CD system usually has a long processing time. To reduce the tritium inventory, the tritium processing system will be designed to reduce the mean time of processing to a minimum. Then, we propose the simplified fuel cycle system to reduce the tritium inventory as shown in Fig. 1(b). The main concept is the small recirculation system to minimize the hydrogen isotope separation system. As the tritium burnup fraction is extremely low, the ratio of deuterium and tritium in vacuum exhaust gas will be almost same as the supplied DT fuel gas. In our concept, the vacuum exhaust gas is purified by a simple cryocondensation system as impurity processing system to remove the hydrogen compounds and helium gas, and circulated not to separate hydrogen isotope. It can reduce the mean time of tritium reprocessing.

As hydrogen isotope separation system, the CD usually has large tritium inventory because the gaseous hydrogen has to be liquefied at ~20K. Then, we propose to adapt the cryogenic pressure swing adsorption system [PSA] as the hydrogen separation system. The system can be operated at liquid nitrogen temperature [77K]. Hydrogen isotopes can be separated in the gas phase based on differences in adsorption properties. Thus, the tritium inventory of PSA would be lower than that of CD. Also, the PSA system has a character to preferentially separate hydrogen atom [H] in the mixture gas of hydrogen isotopes. To demonstrate the proposal system, the testing device has been manufactured as shown in Fig. 2. We will investigate the feasibility of proposal system by use of these testing devices under the collaborative research with universities.

1). McMorrow, D. : JSR-11-345, (2011).

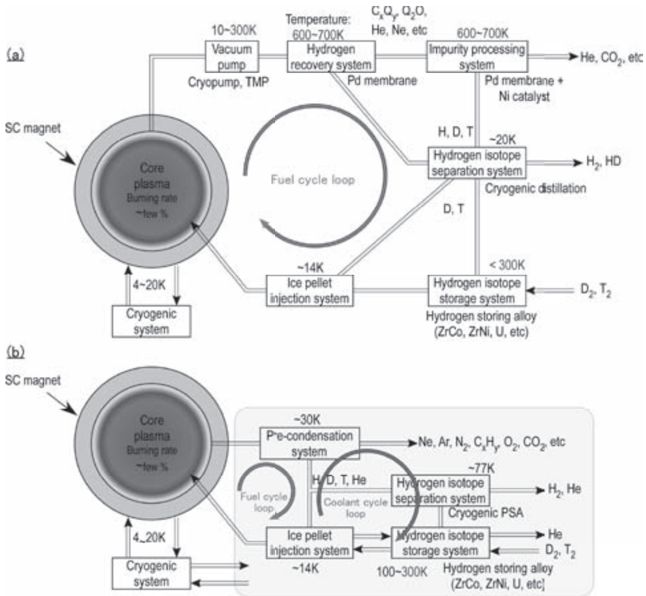

Fig. 1. A schematic diagram of the fuel cycle system for fusion reactor; (a) a conventional system, (b) a proposal simplified system using the cryogenic engineering.

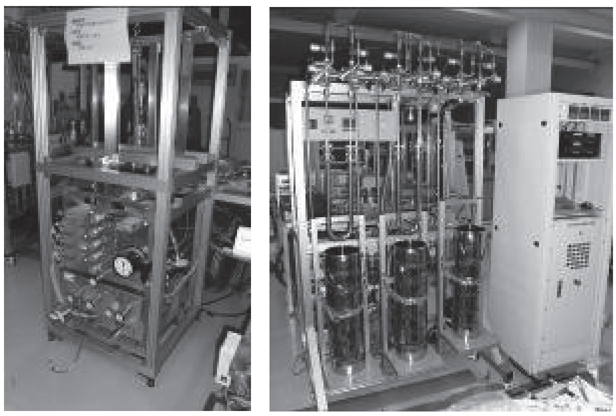

Fig. 2. Photos of the cryocondensation system [left] and the cryogenic PSA system [right].