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Fusion tritium research facilities in KAERI

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ABSTRACT

Korea Domestic Agency (KODA) is developing a nuclear fusion fuel storage and delivery system (SDS) as one of the Korean procurement packages. Korea Atomic Energy Research Institute (KAERI) is operating the following basic scientific research laboratories for an SDS and tritium supply study: a metal hydride bed preparation laboratory, hydrogen isotope recovery and delivery performance test rig, in-bed calorimetry performance test rig, and tritium shipping container integrity test facility. Furthermore, the development of a test blanket module (TBM) is required to test and validate the design concept of tritium breeding blankets relevant to fusion power plants. KAERI is also operating the following laboratories for the TBM research, such as a tritium extraction performance test rig, High-flux Advanced Neutron Application Reactor (HANARO), and Experimental Loop for Liquid Breeder (ELLI).

1. Introduction

Korea Domestic Agency (KODA) is responsible for the supply of a nuclear fusion fuel storage and delivery system (SDS) as one of the Korean procurement packages to ITER. We present the basic scientific research laboratories and R&D work that will be used to support the design of the ITER SDS. Some facilities are newly developed. The facilities are being applied to the development of ITER fuel cycle systems as summarized under the concluding remarks. HANARO has not been used for the fusion energy research. We newly present the possibility of HANARO utilization. Furthermore we report our new experimental rig for tritium extraction. In this paper, we present in particular not only R&D activities performed at a newly licensed Metal hydride bed preparation laboratory in which depleted uranium can be safely treated, but also the capability of the laboratories for nuclear fusion research at KAERI.

2. SDS and tritium container test facilities

2.1. Metal hydride bed preparation laboratory

Fig. 1 shows a glovebox for the metal hydride bed preparation. The argon in the glovebox is pumped through a series of treatment devices, which remove water and oxygen from the gas. Finely divided heated copper metal is used to remove oxygen, and this oxygen removing column is regenerated by passing 4% hydrogen in an argon mixture through it while it is heated, and the water formed is passed out of the box with the excess hydrogen and argon. A 13× molecular sieve is used to remove water by adsorbing it in the pores of the molecular sieves. The hermetically sealed glovebox maintains an argon atmosphere with an H_2O concentration at 0.0 ppm, and O_2 concentration at about 0.0–0.4 ppm. The glovebox is kept at a higher pressure of about 1.25-in. H_2O than the surrounding air, so that any microscopic leaks are mostly leaking inert gas out of the box instead of letting air in.

Fig. 2 shows a metal hydride bed in the glovebox. The metal hydride bed is introduced into the main chamber through a sealed antechamber on the right side of the glovebox. In the glovebox we open the Swagelok nut on the primary vessel to introduce the depleted uranium into the primary vessel of the metal hydride bed. The quantity of the depleted uranium has already been exactly measured by using a precision balance in the glovebox. The primary vessel that contains depleted uranium sealed by the Swagelok nut is withdrawn from the glovebox through the antechamber. Finally the primary vessel is assembled with the secondary vessel of the metal hydride bed.

Fig. 3 shows the metal hydride bed preparation laboratory. Metal hydride beds are installed onto the bed performance test rig. The bed performance test rig can equip two different beds at the same time to compare their performance. The rig is used for a

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Fig. 1. Glovebox for the metal hydride bed preparation.

Fig. 2. Metal hydride bed in the glovebox.

measurement of the hydrogen recovery and delivery rates. A hydrogen delivery scroll pump is connected to the manifold piping. The ISP scroll pump has a desirable pumping characteristic. Its leakage rate is negligibly small. But we measure the leakage rate every time before each hydrogen delivery experiment. Because of its leakage characteristics we use this pump only for an experimental purpose. Metal powder in the two bed models is activated through several repetitions of hydriding and dehydriding. The amount of hydrogen used for the initial activation and hydriding and dehydriding runs is measured by the hydrogen pressure filled in the loading vessel and the manifold. The control and data acquisition system is provided.

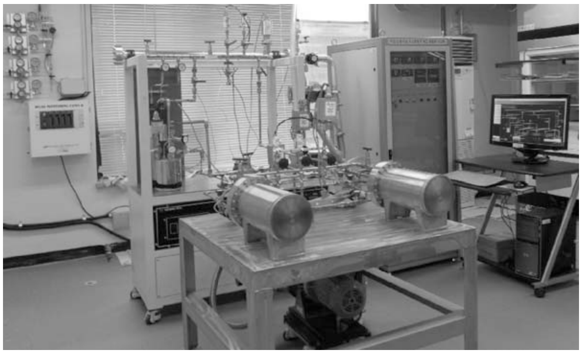


Fig. 3. Metal hydride bed preparation laboratory.

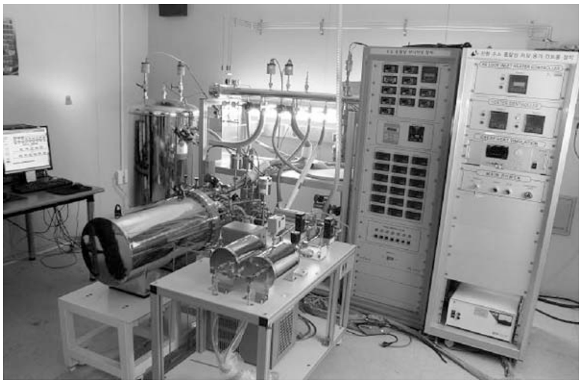


Fig. 4. SDS bed performance test rig.

2.2. SDS bed performance test rig

Fig. 4 shows a test rig used for the performance tests of an SDS bed. The rig comprises two loops. One loop is used to test the performance of hydrogen recovery and delivery (Fig. 5). The other is

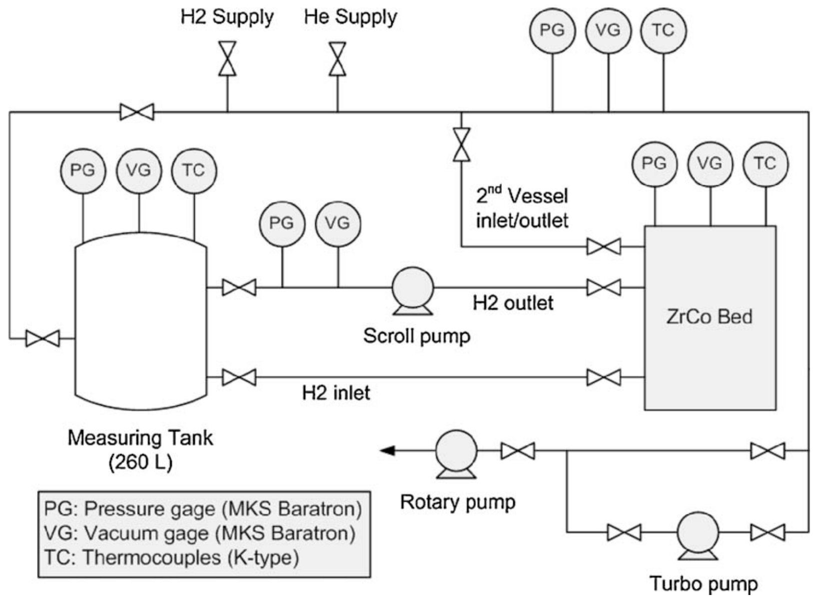


Fig. 5. Hydrogen recovery and delivery test.

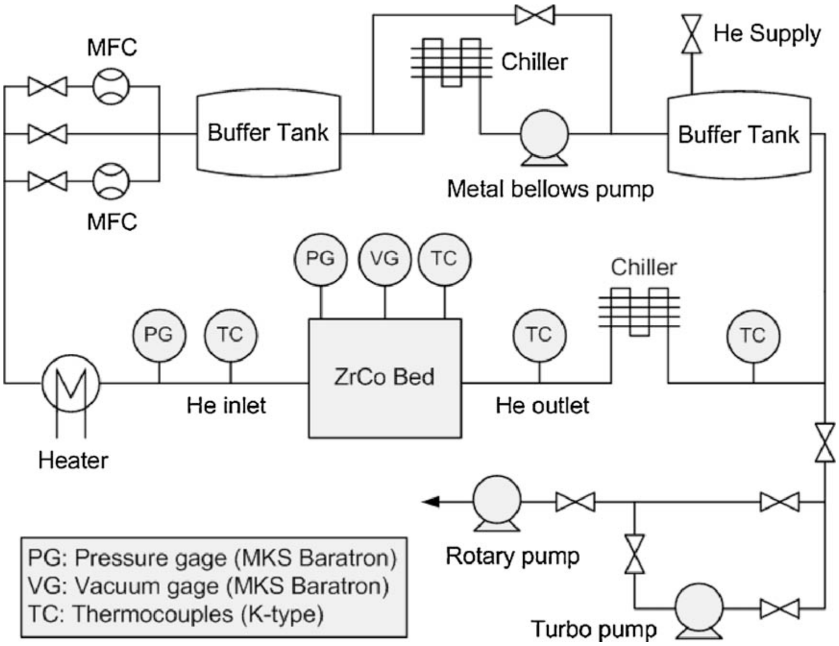


Fig. 6. In-bed calorimetry measurement.

used to measure an in-bed calorimetry for the tritium accountancy in the bed (Fig. 6).

2.3. *Tritium shipping container integrity test facility*

As a potential supplier of ITER tritium, Korea needs to develop and test B(U) type tritium shipping containers. IAEA has established standards of safety that provide an acceptable level of control of the radiation, criticality, and thermal hazards to persons, property, and the environment that are associated with the transport of radioactive material [1]. The following are examples of the test requirements for tritium shipping containers (Figs. 7–9).

Free drop test: the specimen shall drop onto the target so as to suffer the maximum damage with respect to the containment. The

Fig. 7. Free drop test rig.

Fig. 8. Fire test preparation.

Fig. 9. Water immersion test.

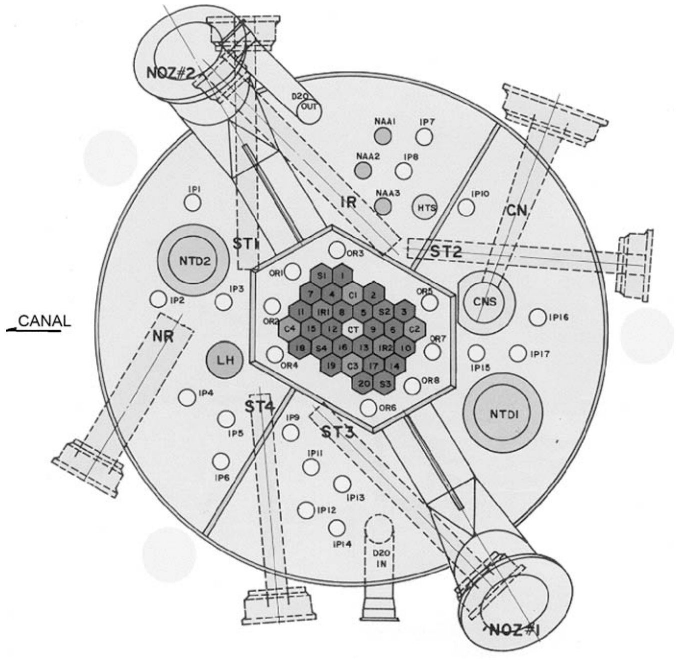


Fig. 10. Plan view of HANARO.

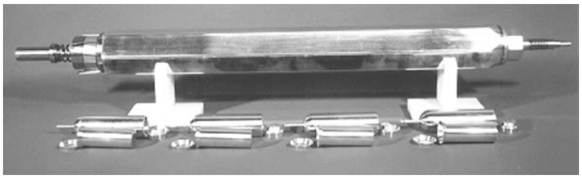


Fig. 11. Irradiation rig.

height of the drop measured from the lowest part of the specimen to the upper surface of the target shall be 9 m.

Thermal test: the exposure of a specimen for a period of 30 min to a thermal environment that provides a heat flux at least equivalent to that of a hydrocarbon fuel/air fire under sufficiently quiescent ambient conditions to give a minimum average flame emissivity coefficient of 0.9 and average temperature of at least 800 °C, fully engulfing the specimen, with a surface absorptivity coefficient of 0.8 or the value that the package may be demonstrated to possess if exposed to the specified fire.

Water immersion test: The specimen shall be immersed under a head of water of at least 15 m for a period of not less than eight hours at the attitude that will lead to maximum damage. For demonstration purposes, an external gauge pressure of at least 150 kPa shall be considered to meet these conditions.

3. TBM R&D facilities

KAERI is carrying out basic research on liquid tritium breeding materials. KAERI is equipped with HANARO, an experimental loop for a liquid PbLi breeder, and an experimental rig for tritium extraction.

Table 1
Irradiation holes in HANARO.

Region	Symbol	Number of holes	Thermal neutron flux (n/cm^2 sec)
Inner-core	CT	1	4.39×10^{14}
	IR	2	3.93×10^{14}
Outer-core	OR	4	$(2.2–3) \times 10^{14}$
Reflector	IP	17	2.4×10^{13} to 1.9×10^{14}

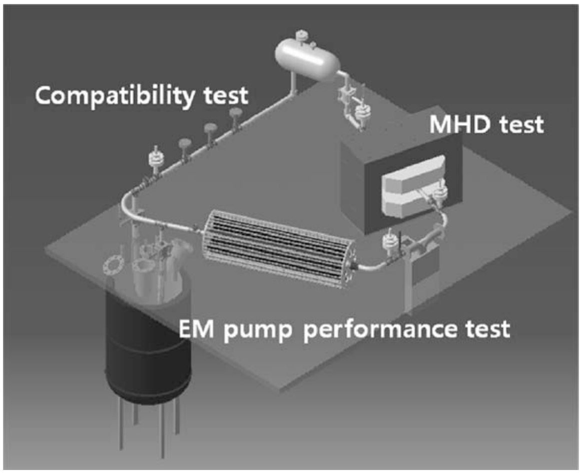


Fig. 12. Schematic drawing of the ELLI loop.

3.1. Neutron irradiation test on TBM material at the High-flux Advanced Neutron Application Reactor (HANARO)

The High-flux Advanced Neutron Application Reactor (HANARO) is a 30 MWth multi-purpose research reactor at KAERI that generates a high neutron flux (fast flux of 2.1×10^{14} n/cm^2/s and thermal flux of 4×10^{14} n/cm^2/s). HANARO is considered to be a useful neutron source for not only irradiation tests on TBM material but also various nuclear fusion materials.

There are 3 hexagonal and 4 circular flow channels in the core used for radio isotope (RI) production and irradiation of fuel and material. These holes are good for targets that need a high flux and cooling by a convective flow. Because three hexagonal irradiation holes have high thermal and fast neutrons, the first purpose of these holes is a material test and the second purpose is a fuel depletion test and RI production of high specific activity. Four circular irradiation holes have high thermal and epi-thermal flux. These holes are used for RI production of high specific activity and fuel depletion test. In the D_2O reflector region, there are 17 irradiation holes called IP for RI production. The targets loaded in the IP holes are cooled through natural convection (Figs. 10 and 11, Table 1). Holes such as CT or OR3 are considered to be adequate for a basic study on TBM or nuclear fusion material irradiation. Irradiations will be able to be carried out only after an appropriate permission procedure.

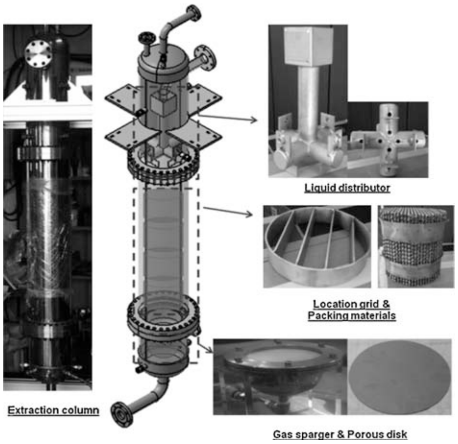
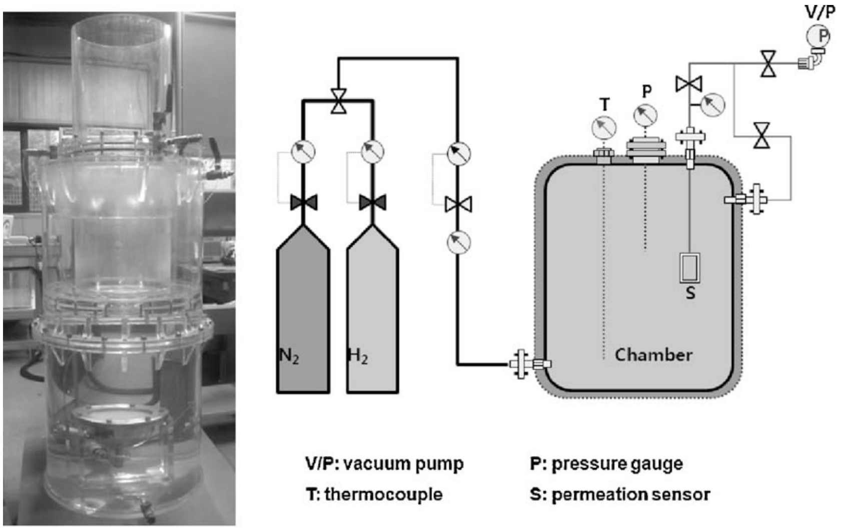


Fig. 13. Photos of the experimental extraction column.



(a) Bubble observation tank

(b) Permeation sensor test tank

Fig. 14. Photo of the bubble observation tank (a) and schematic drawing of the permeation sensor test tank (b).

3.2. *Experimental Loop for Liquid Breeder (ELLI)*

To develop a liquid breeder system of the Korean TBM, an Experimental Loop for Liquid breeder (ELLI) was constructed (Fig. 12). ELLI is not only used to validate the Electro-Magnetic (EM) pump design and its performance and study the Magneto-Hydro-Dynamic (MHD) phenomena, but also to examine structural materials in the liquid metal of liquid breeder operation environments [2]. In this facility, the liquid lead lithium (Pb15.7Li) is used as a liquid breeder and the EM pump was designed and fabricated to circulate the lead lithium up to 60 lpm. And the lead lithium can be heated up to 550 °C by a jacket type heater around the loop, and a maximum magnetic field of 2.2 Tesla can be generated by the Magnet, installed in ELLI, with 30-mm pole gap size.

3.3. *Experimental rig for tritium extraction*

To extract tritium from a liquid breeder, there are various tritium extraction methods such as permeation method, gettering method, trapping method, and liquid–gas contacting method. We have selected a countercurrent liquid–gas contacting method [3]. We are carrying out a basic experimental study for an extraction column as shown in Fig. 13 [4]. To increase the residence time and interfacial area of stripping, argon gas bubbles in a packed countercurrent extraction column with a porous metal sparger are going to be used. To correlate interfacial area between the liquid metal and gas, we are going to use a bubble observation tank as shown in Fig. 14a. We are developing a permeation sensor and its test chamber to measure the concentration of hydrogen isotopes in the liquid metal (Fig. 14b). The membrane of the permeation sensor is made of pure iron (Fe). The membrane is supported on a metal sintered plate in order to reduce remarkably the ratio ‘volume/surface of sensor’ and to endure high pressure operational condition with a thin membrane. Therefore, the suggested permeation sensor can determine the concentration of hydrogen isotopes more rapidly by a factor of several times compared to conventional cylindrical type sensors. We determine the permeation performance by measuring the partial pressure of hydrogen in the various test conditions.

4. Concluding remarks

We have been developing ZrCo beds for nuclear fusion fuel cycle plants [5–14]. However due to the incomplete reproportionation characteristic of zirconium–cobalt, uranium was recommended to be employed as a way to store hydrogen isotopes as metal hydride [15]. This recommendation is due to its chemical, and not its nuclear, properties. Thus, we presented in this paper the status of the depleted uranium hydride bed laboratory, the hydrogen isotope recovery and delivery performance test rig where 260 l of hydrogen can be measured, and our in-bed calorimetry performance test rig where rapid bed cooling can be tested. With our previous efforts on the development of ZrCo beds, we think that we will be able to develop a high performance depleted uranium hydride bed. We also presented tritium transport package integrity test rigs where nine meter free drop test can be performed, an experimental rig for tritium extraction where new Fe permeator sensor is installed, HANARO where various irradiation tests can be performed, and tilt able ELLI where a speed controllable EM pump is installed at KAERI. Although producing energy from nuclear fusion still remains a complex and demanding task, we hope that our research facilities will contribute to the development of a new energy source that is intrinsically safe and does not produce greenhouse gas emissions.

Acknowledgements

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