The R&D Status of ITER SDS

Sei-Hun YUN[1)*], Chang Shuk KIM[1)], Min Ho CHANG[1)], Hyun-Goo KANG[1)], Seungyon CHO[1)], Hyun Gon LEE[1)], Ki Jung JUNG[1)], Hongsuk CHUNG[2)], Dae Seo KOO[2)], Kyu-Min SONG[3)], Soon-Hwan SHON[3)] and Duk Jin KIM[4)]

[1)] *ITER KO, National Fusion Research Institute, Gwahangno 113, Daejeon, 205-806, Korea*

[2)] *Korea Atomic Energy Research Institute, Daedeokdaero 1045, Daejeon, 305-353, Korea*

[3)] *Korea Hydro & Nuclear Power Co., Central Research Institute, 70-1312-gil, Yeseong-daero, Daejeon, 305-343, Korea*

[4)] *TUV SUD KOCEN, 13F Kranztechno, Sangdaewon-dong, Jungwon-gu, Seongnam, 462-729, Korea*

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The ITER tritium storage and delivery system (SDS) is still in pre-conceptual phase. The major functions of ITER SDS are composed of tritium storage in a safe way, rapid fueling based on the plasma scenario and tritium inventory accountancy in a day schedule. The ITER SDS will be delivered to the ITER site as a set of glovebox modules which have every tritium compatible components in its space for tritium confinement and are to be assembled together at the ITER tritium building. Meanwhile there have been some reports for the ITER SDS' R&D activities and progress, the current R&D status is still on-going at the pre-conceptual design (CD) phase. The scope of current R&D has been rearranged with the depleted uranium (DU) oriented experiments for the future ITER application. This report deals with the current status and activities, especially setup of handling procedure, test devices and facility design based on DU getter material, for CD completion of the ITER SDS next year.

Keywords: ITER SDS, R&D status, getter material, ZrCo, DU, process verification, 1:1 scale test.

1. Introduction

ITER tritium storage and delivery system is one of key technologies, which are to be utilized for the fusion tritium plant construction, to provide the fusion fueling system by means of tritium storage, supply and inventory, in a safe way, in accordance with the plasma scenario and accountancy availability in a day basis, respectively. While the SDS is composed of major equipment needed further R&D for detailed design, it will be followed by the systematic R&D program. The main objective of the ITER SDS R&D—even though still on-going—is to verify not only each component's requirements in accordance with the system function, but also performance availabilities as the whole of the SDS' requirements physically and technically combined with each other components that have individual characteristics and performance in most aspects of tritium safety and compatibility. The overall project schedule of the ITER SDS is divided into three distinguishable phases: (1) pre-conceptual R&D phase, (ii) systematically programmed R&D phase (conceptual design phase, preliminary design phase), (iii) and the final design & procurement phase. This report is focused on the current R&D status in pre-conceptual phase, in addition to the further consideration on the interface relatives to the SDS in tritium plant fuel cycle as well. The R&Ds on this ITER SDS lies in the starting point of newly programmed systematic R&D phase. In this period the reference material for ITER SDS has been changed from zirconium cobalt (ZrCo) to depleted uranium (DU), because of different shortfalls in material properties and limits in technical applications [4].

There have been some reports for the SDS R&D activities and progress [1-3]. The content in the first phase, pre-conceptual R&D was focused on ZrCo as the tritium storage material; R&Ds for type and design concept of the tritium storage bed and characteristics of storage material were reported in Ref. [1]; R&D's for bed performance in terms of delivery rate, thermo hydraulic analysis of in-bed calorimetry, studies on hydride reaction using visual cell reactor, unit process verification test having 1:1 scaled ZrCo bed, transfer pump performance and its combination, and calorimeter design for the tritium accountancy at the tritium loading station (TLS) were reported in Ref. [2]; and R&D's for highly concentrated and enhanced results on every ITER SDS' component and interrelationship were also reported in Ref. [3].

From the turning point of the tritium storage material, DU, this report deals with the current status and activities mainly issued topics, especially DU handling procedures, experimental devices and facility design, in R&D of ITER SDS.

2. Small Scale Bed Experiments and Basic Study

2.1 DU bed preparation & experiment

Various SDS beds including beds using DU has been developing [5]. Fig. 1 shows a metal hydride bed in the glovebox. 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 13X 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. The metal hydride bed is introduced into the main chamber through a sealed antechamber on the right side of the glovebox. In the glovebox the Swagelok nut on the primary vessel is open 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.1 Hydride bed in the glovebox [5].

Fig. 2(a), 2(b) show the equipped system picture and flow diagram of the metal hydride bed performance test rig, respectively [5]. The bed performance test rig can equip two different beds at the same time to compare their performance. The rig is used for a measurement of the hydrogen recovery and delivery rates. A hydrogen delivery scroll pump is connected to the manifold piping. The scroll pump has a desirable pumping characteristic. Its leakage rate is negligibly small. But the leakage rate is measured every time before each hydrogen delivery experiment. Because of its leakage characteristics this pump is used only for an experimental purpose. Metal powders in two bed models are activated through several repetitions of hydriding and dehydriding. The amount of hydrogen used for the initial activation and hydriding & 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 shows a temperature transient and heating pattern of the primary vessel during the heating test. The measured and setting values of the primary vessel temperature are almost the same. Overshooting of the heater exists but is negligible. Fig. 4 shows the temperature transient of the primary vessel during the cooling test [6]. Secondary vessel was either under vacuum (case A in Fig. 4) or filled with helium (case B in Fig. 4). A series of hydriding and dehydriding tests for the ZrCo and DU beds is going to be performed further.

2.2 Visual DU hydriding reaction

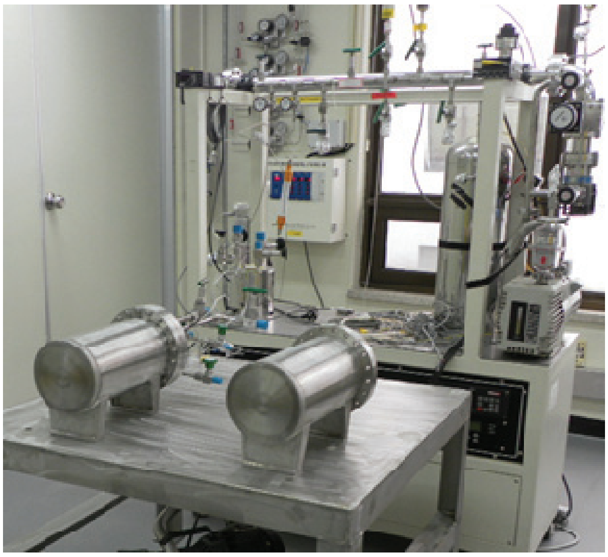
The DU hydride is going to be analyzed by using a visual cell reactor as shown in Fig. 5 and thermo physical property analyzers. This kind of experimental apparatus was utilized in ZrCo hydriding system before [7-8].

The visual cell apparatus in the right-hand side of Fig. 5 was used to look at the hydride material's behavior at hydriding/dehydriding reaction and the compressibility of the expanded hydride micro-powder [7-8]. Table 1 shows the summary of experimental thermo physical properties—packing density, heat capacity, thermal diffusivity and thermal conductivity—of ZrCo hydride material [8]. This result was also applied to the theoretical analysis and simulation of heat & mass transfer phenomena in the complicated getter bed systems, and engineering design as well.

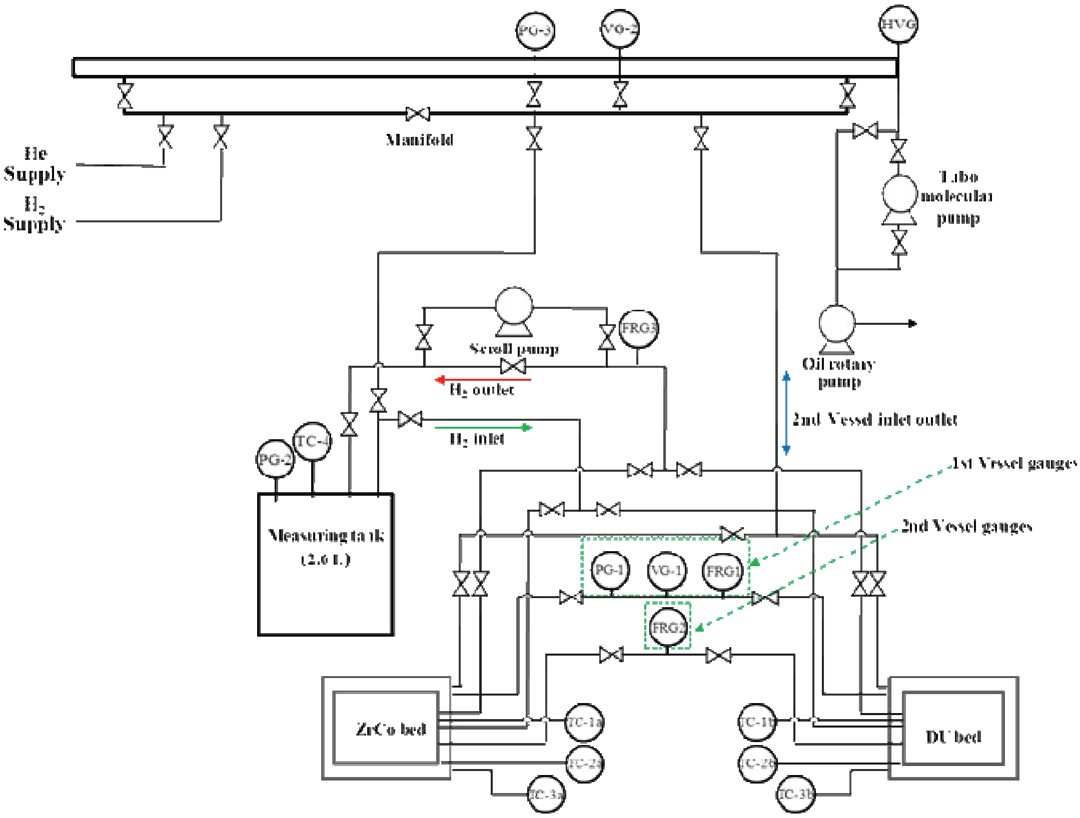
The DU hydride material is to be tested using similar apparatus (left-hand side of Fig. 5). However, the main difference of DU hydriding reaction system including a visual cell reactor comparing to ZrCo hydriding case is to apply an inert gas atmosphere using a glovebox that covers all equipment for the containment of air and moisture.

2.3 Related engineering studies

Fig. 6 shows the detailed mathematical approach to analyze and simulate the getter bed system that is composed of thin double-layered, annulus-type, ZrCo bed to be anticipated getting a rapid absorption/desorption behavior than any other geometric type of getter bed. In comparison of thin annulus bed with the typical cylindrical bed that has same lengthy in Fig. 6 the absorption and desorption rate of the thin annulus bed shows remarkable speed in more than two times. On the other hand, the thermal mass of the getter bed was too gross to cool down. The cooling time, therefore, of the heated getter bed after desorption requires much more hours to get ready for the next cycle at absorption process. The next getter bed model should be limited to minimize the thermal mass and to maximize the heat and mass transfer rate for the ITER SDS optimization, theoretically.



(a) Equipped test rig of (b)



(b) Flow diagram of ZrCo and DU bed system

Fig.2 Hydride bed performance test rig [5].

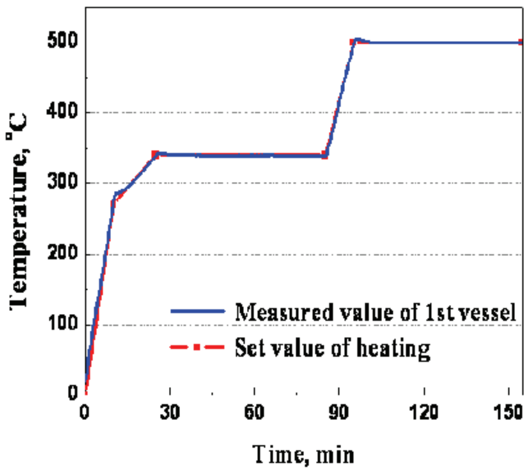


Fig.3 Heating test of the primary vessel [6].

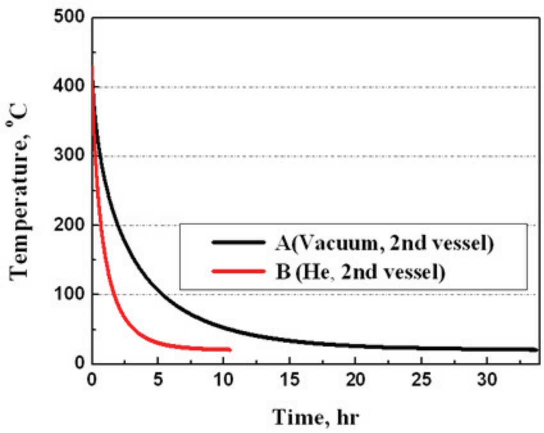


Fig. 4 Cooling test of the bed [6].

Table 1 Thermo physical properties of ZrCoHx [8].

Property	ZrCo	**ZrCo Hydride
Packing Density [g/cm^3]	Baotou : 4.990 SAES G. : 3.500	Baotou : 2.389 SAES G. : 1.645
*Heat Capacity [J/g.K]	(25°C) 0.328 (100°C) 0.339 (200°C) 0.308 (300°C) 0.299 (400°C) 0.314 (500°C) 0.330	(25°C) 0.421 (100°C) 0.485 (200°C) 0.443
*Thermal Diffusivity [mm^2/s]	(25°C) 0.085 (100°C) 0.074 (200°C) 0.070 (300°C) 0.071 (400°C) 0.078 (500°C) 0.081	(25°C) 0.082 (100°C) 0.077 (200°C) 0.066
*Thermal Conductivity [W/m.K]	(25°C) 0.139 (100°C) 0.125 (200°C) 0.108 (300°C) 0.081 (400°C) 0.122 (500°C) 0.133	(25°C) 0.082 (100°C) 0.089 (200°C) 0.070
*TG Mass Change [%]	Range 20~550°C Initial +0.07 Sharp Increase At 350 °C Final +1.04 DSC : No peak	Range 20~550°C 1st +0.17 (250°C) 2nd +0.37 (375°C) 3rd -0.08 (400°C) 4th +1.29 (550°C) Total +1.74 DSC : 382.6°C Exothermic
*Off-Gas (after TG)	[H_2] very small	[H_2] high amount [H_2O] a little bit

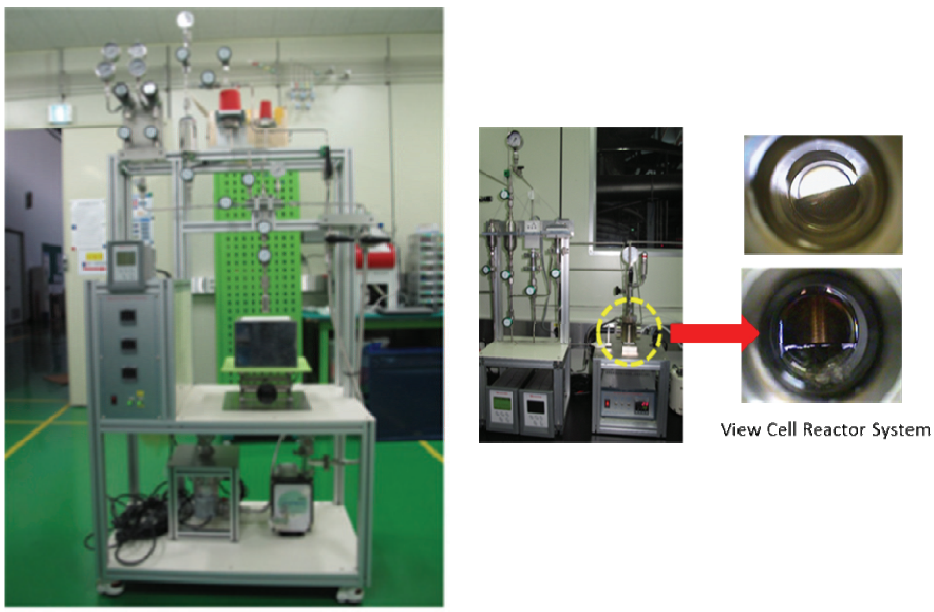
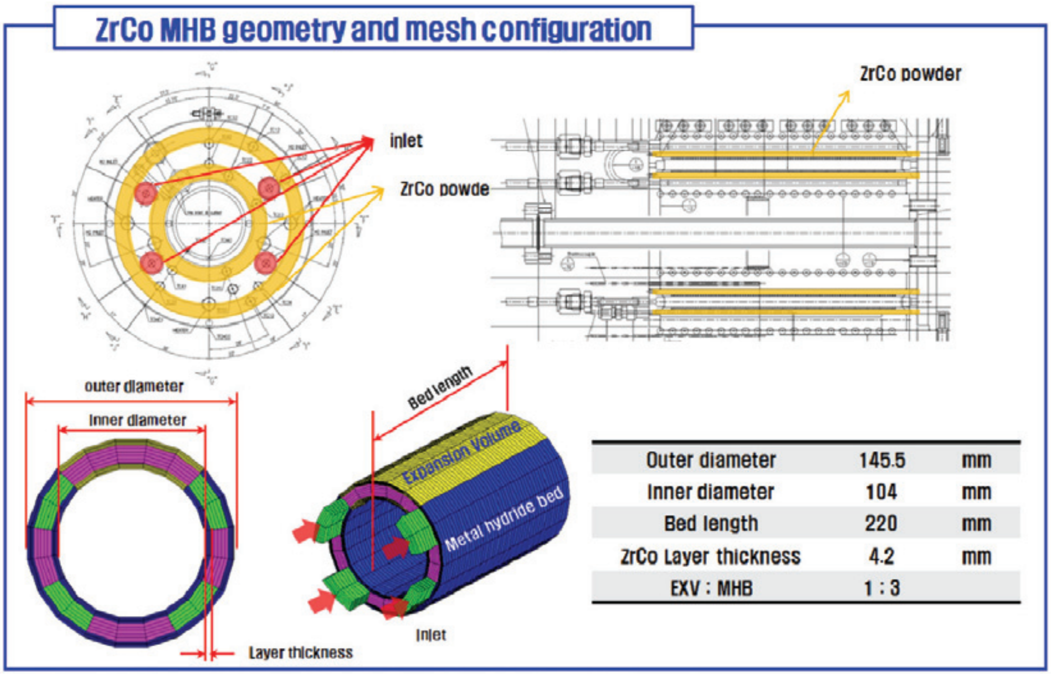
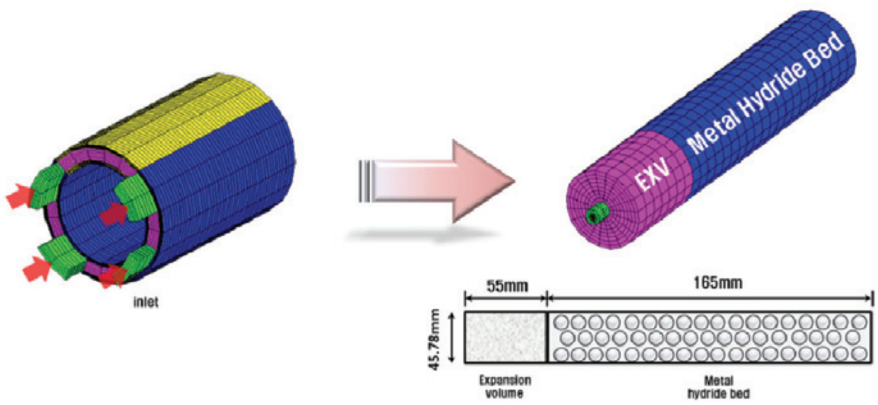


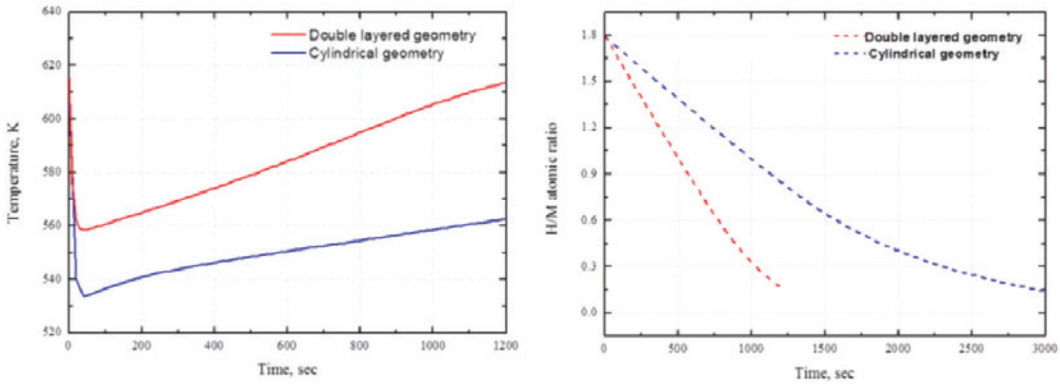
Fig. 5 Metal hydriding apparatus and a visual cell reactor.



(1) Mesh Configuration



(2) Geometric details and mesh reconfiguration



(3) Illustration of temperature and H/M ratio evolution profiles.

Fig. 6 Theoretical approach and simulation result of the annulus-type ZrCo bed (upper), and comparing absorption & desorption rate with cylindrical bed (down).

Fig. 7 shows an illustration of ITER SDS module for the tritium building installation. In general, SDS module and every component in the module glovebox keep the fire-sector rule (The maximum tritium content in every component is limited under 70 gram, and in every container under 700 gram of tritium). ITER SDS module is composed of multiple getter beds, buffer vessels, transfer pumps and many instruments as shown in Fig. 7. Tens of gloveboxes are to be assembled to compose the whole ITER SDS′s functions and requirements.

At one fuel supplying scenario a group of getter beds has to be operated simultaneously to satisfy the ITER fueling requirement. Here, another complicated problem might be occurred, such as control logic development for the optimization of getter bed system operation. Fig. 8 shows a similarity test apparatus using multiple batch-wise efflux system that seems to behave the multiple getter bed system: Efflux/desorption, recharging/ absorption, and successive cyclic operations.

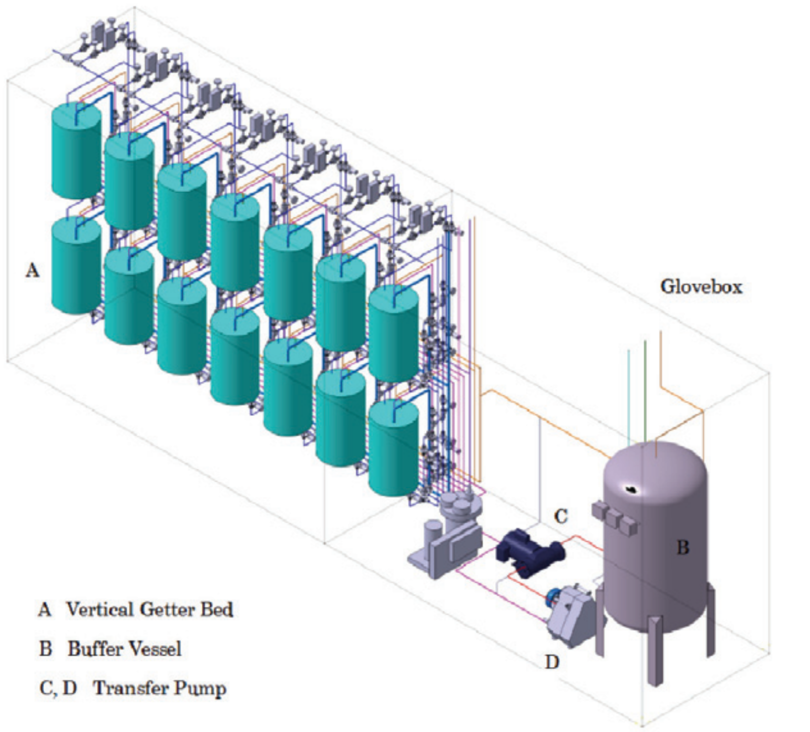


Fig. 7 Illustration of glovebox inside in SDS module (4~6 modules).

1 Series of Tanks
2 Buffer Tank
3 Reservoir Tank
4 Frame
5 Transfer Pump
6 Water Tank (Bed)
7 Level Indicator

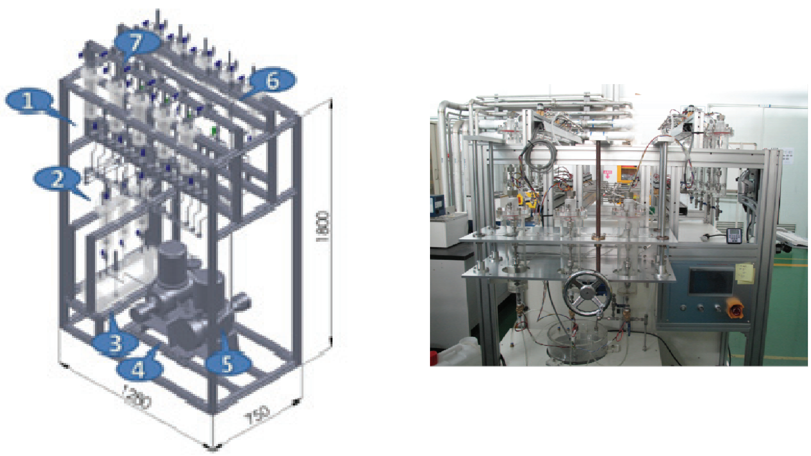


Fig. 8 Similarity test apparatus using multiple batch-wise efflux flow system instead of getter bed system. (Number means a detailed component in this system.)

2.4 He-3 recovery process

Recovery or separation of He-3 from the tritium storage system is one of major function in ITER SDS. Fig. 9 shows the schematic drawing of He-3 recovery system from the tritium storage getter bed as a basis of ITER SDS. Since the release of He-3 from the tritium absorbed in uranium is known to start at about 300 days age, the actual recovery of He-3 in ITER SDS' tritium storage does not seem to be realized. Moreover, the blanket effect is also well known phenomena in recovery of He-3 by concentration of tritium. However, the cyclic circulation of the He-3 mixture is recommended to increase the tritium concentration at the metal getter in Fig. 9. Thereafter, the initial He-3 blanket effect is expected to be diminished in gradual operation. There has been no quantitative result for the cyclic operation of this ITER concept (this concept will be studied also).

3. Verification of SDS Process

3.1 Cooling rate enhancement test

Metal hydride bed is one of the key components in ITER SDS and fusion fuel cycle. As mentioned in section 2.3 (experimental plan for the control logic development), SDS beds are heated for desorption of deuterium and tritium gases. At the same time, SDS beds must be ready for the absorption of DT gases recycled from the fuel cycle. In addition to some flocks of beds have to be ready for the emergency uptake of DT gases. For the better performance of absorption and emergency uptake of DT gases, therefore, the beds must be cooled down in a fast way. If the heating and cooling time of bed is too long, the turnover is delayed and results in enormous increase of SDS beds.

As a part of preparatory, systematic R&D work for the development of SDS bed, experimental study on various cooling of metal hydride bed is to be performed. A revised mock-up of metal hydride bed having the capacity of 70 g tritium storage is developed. ZrCo is used as a dummy material for the getter. The thermal mass is reduced and several active cooling methods are applied to the revised bed. Experimental apparatus for the independent circulation of several cooling circuit is installed as shown in Fig. 10 and Fig. 11. Fig. 10 shows three active cooling circulations. The first is circulation of helium loop which is inserted in the metal hydride layer for the in-bed calorimetry. The second is gas circulation inside outer jacket of the bed. And the last is water cooling jacket which is attached on the surface of outer jacket. Even though the direct water cooling of the getter bed for the purpose of safe tritium storage in priority is to be evaded in feelings, otherwise an indirect cooling should be necessary to maintain the constant glovebox temperature by removing the heat accumulation of heated getter beds. Preliminary test results shows that the outer jacket helium circulation reduces 25 % of cooling time comparing to the natural cooling by helium filled outer jacket. Various combination of active cooling method is under experiments and its results will be presented.

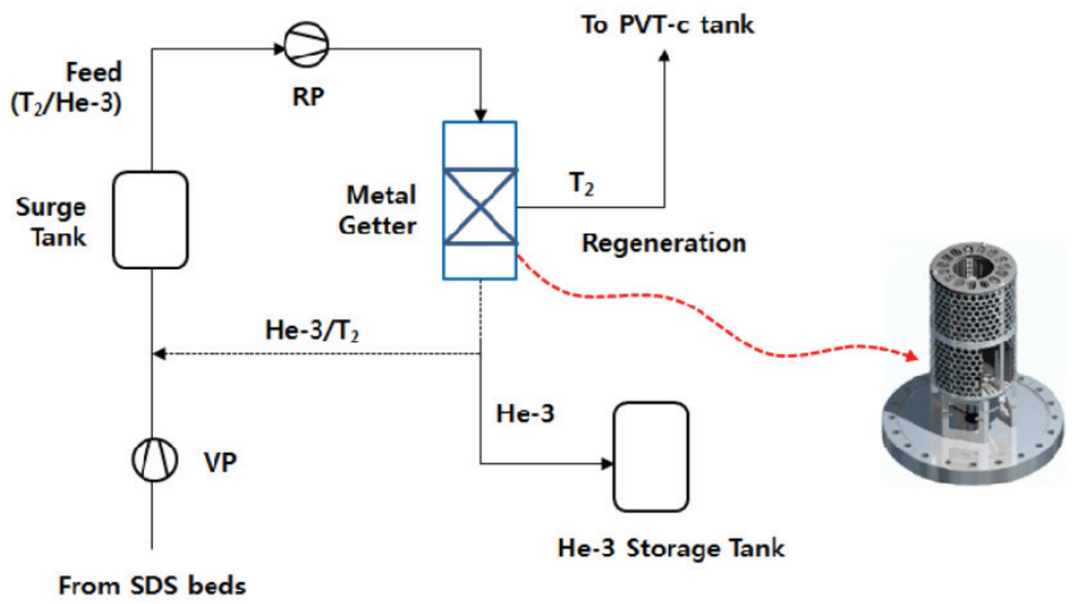


Fig. 9 Schematic He-3 recovery system in ITER SDS.

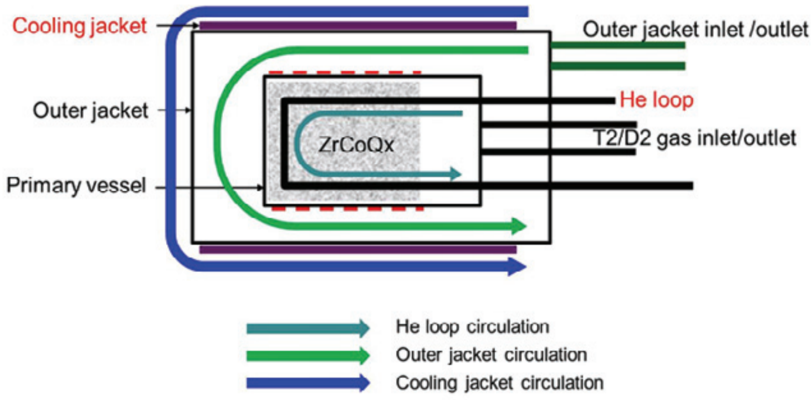


Fig. 10 Schematics of active cooling for hydride bed.

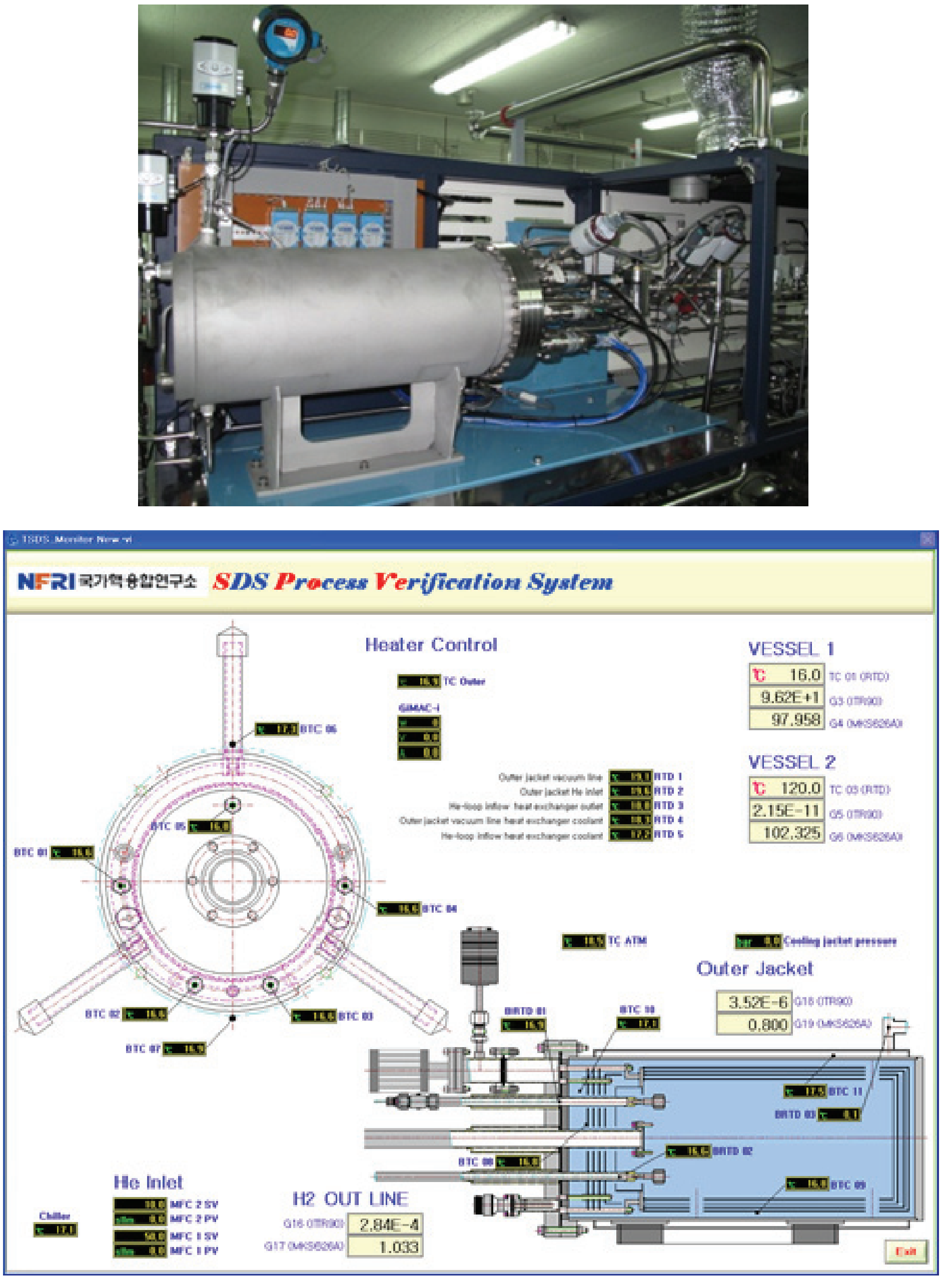
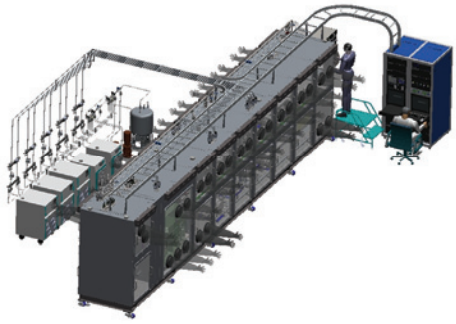


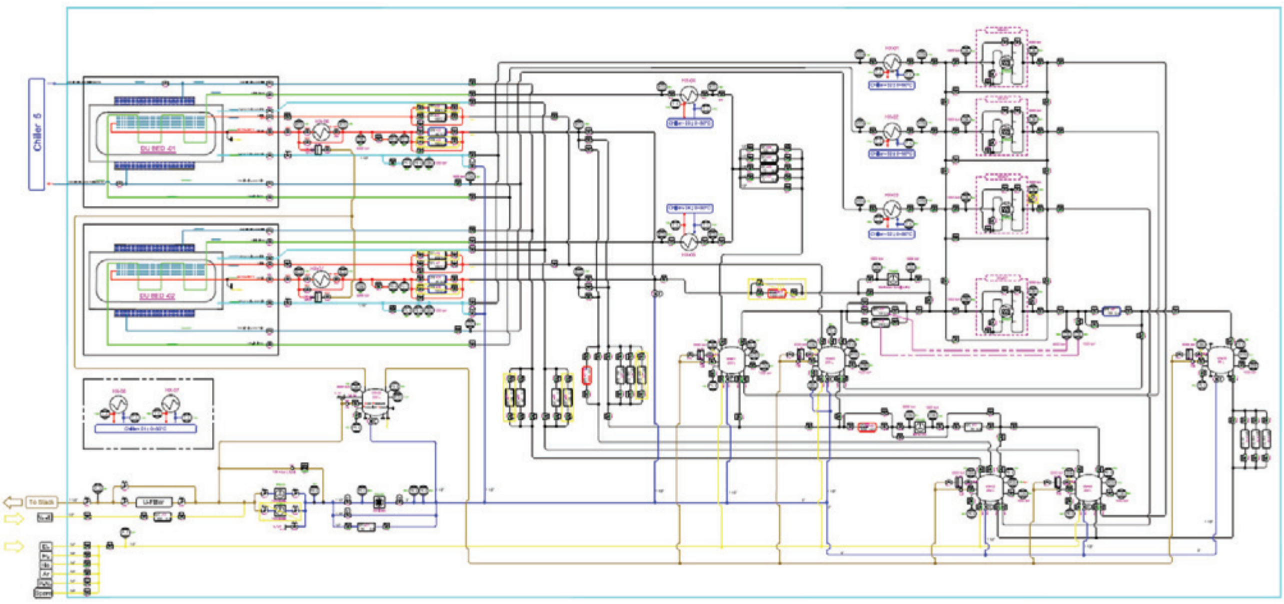
Fig. 11 Installation of improved design 1:1 mock-up bed with active cooling system.

3.2 1:1 scaled DU hydride bed system

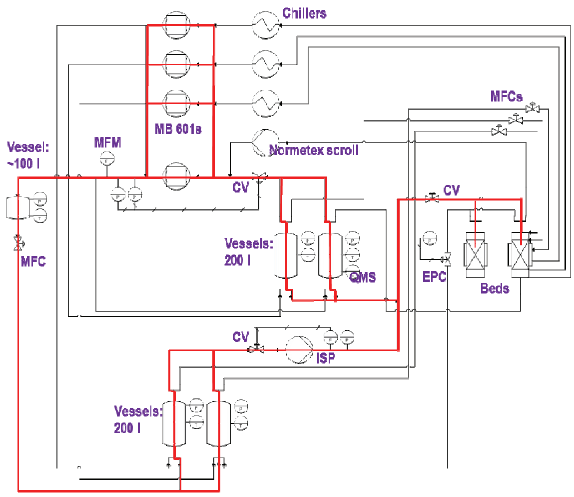
SDS beds and major components including DU system has to be experimented to verify the current SDS technology. Fig. 12(a), 12(b), 12(c) show a schematic 3D installation drawing, an overall flow diagram, and one of the typical operation schemes for absorption/desorption performance test, respectively.



(a) Schematic 3D installation drawing



(b) Overall flow diagram for the SDS verification



(c) Typical operation for absorption/desorption test

Fig. 12 DU hydride system (1:1 scaled system installation).

The SDS verification test apparatus (see Fig. 12(b)) has various kinds of SDS operation processes that should be verified for the technical completion of SDS. Moreover, through this verification test a clear distinction has to be shown the operability of this facility in two safety aspects: one for tritium and the other for DU.

Fig. 12(c) is one typical operation mode in this test apparatus. The other operation modes are to be tested as follows:

DU bed experiments with;

. Fuel receiving rate in absorption phase
. Fuel delivery rate in desorption phase (one bed)
. Fuel delivery rate with multiple beds
. Tritium accountancy using in-bed calorimetry
. Bed cooling with in-bed calorimetry circulation
. Bed cooling with outer jacket circulation
. Bed cooling with external cooling & circulation
. Bed cooling with overall combination
. He-3 recovery and collection
. Transfer pump performance and combinations
. PVT-c measuring and mass flow meter test
. Other instruments test.

4. Conclusion

The ITER SDS is on-going at pre-conceptual R&D phase. The SDS R&D is currently focused on DU getter bed system which requires careful approach to master and verify every component's performance and application skills. Basic approaches and 1:1 scaled process verification apparatus in SDS R&D are to be prepared on this basis.

The current status and activities, especially setup of handling procedure, test devices and facility design based on DU getter material was described in this report. Every R&Ds will be proceeding for the CD completion of the ITER SDS next year.

Acknowledgment

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5. References

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