Advanced Atomic Energy Research Section

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1. Introduction

Main objective of our research section is to realize advanced energy systems for the sustainable development under global environmental constraints. We have shown a Zero-emission energy scenario based on fusion energy with biomass-based recycling system where biomass waste is converted into liquid fuel or hydrogen. And further we now propose an innovative Negative emission scenario to isolate CO_2 in the atmosphere by a carbonization process. Our research section focuses on development of hydrogen isotopes fuel cycle system, breeding blankets, fusion material R&D, feasibility study for fusion-biomass hybrid power system, conversion of biomass waste, and fusion neutron generation/measurement. Followings are main research achievements in the fiscal year of 2020.

-Experimental evaluation of tritium by DD neutron using a diamond detector

-Calculation of tritium generation and radioactivity of activation foils to be performed by DT neutron source

-Development of liquid lithium lead droplet system for efficient recovery of hydrogen isotope and electrochemical purification system

-Direct quantification of nitrogen in Fe-Ti alloy which trapped nitrogen in liquid lithium

-Development of DD neutron source using 3D printed electrode

2. Blanket mock-up neutronics study

Neutron distribution monitoring in fusion blanket mock up is a key to ensure the self-sufficiency of the tritium fuel. Developing a method of measuring tritium production rate and neutron flux distribution are required. Tritium production rate was experimentally evaluated by using a single-crystal diamond detector and a compact DD fusion neutron source as shown in Fig. 1. By using Monte-Carlo simulation code, MCNP-6, transport of deuterium-tritium (DT) fusion reaction neutrons were simulated by MCNP6 and activation calculations were performed by DCHAIN as shown in Fig. 2. The results of activation calculations indicate each activity of activation foils inside the blanket, which proposes the exposure conditions for measurements using imaging plate.

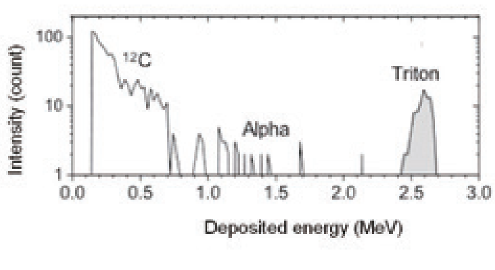

Fig. 1 Energy spectrum measured by single-crystal diamond detector with ^{6}LiF converter.

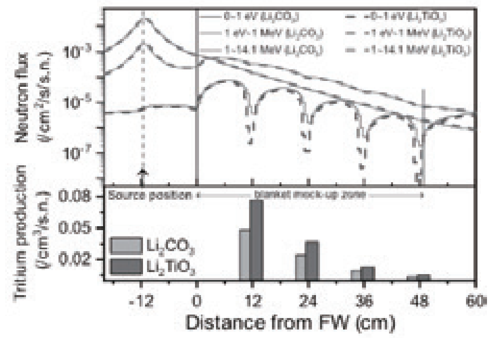

Fig. 2 Neutron fluxes and tritium production rate within a blanket mock-up irradiated with a DT neutron source

3. Development of liquid lithium purification system

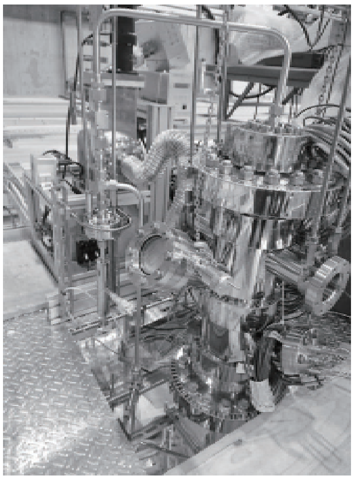

Fig.3: The VST system on Oroshhi-2 Pb-Li loop at NIFS.

Lead lithium eutectic alloy (Pb-17at%Li, Pb-Li) is a candidate liquid breeding material with low chemical reactivity and good tritium breeding ratio. Effective tritium recovery method from the liquid must be developed for the blanket system with minimal tritium loss. The vacuum sieve tray (VST) method, tritium recovery from the liquid droplet surface falling in vacuum, is a candidate developed in this section. This fiscal year, on a collaboration work with National Institute for Fusion Science (NIFS) the operation of VST test device shown in Fig. 3 integrated to Oroshhi-2 (Liquid metal test loop) at NIFS has been started.

Oxygen impurity in Pb-Li is also important from the view point of material compatibility. Oxygen removal by an electrochemical method using LiCl-KCl molten salt developed in this section has also been investigated in this fiscal year, and oxygen in Pb-Li is confirmed to be removed as CO_2 when oxygen impurity transferred into the molten salt reacted with the glass-like carbon electrochemically.

4. Nitrogen hot trapping for liquid lithium

Liquid lithium which is also a hopeful candidate as a liquid breeding material, is to be used as a flowing target in an intense neutron source such as A-FNS or IFMIF those are indispensable for fusion reactor development. Nitrogen impurity in liquid lithium is known to degrade the compatibility of structure material against lithium as well as the surface contamination of yttrium which is used for tritium trapping in lithium. For the removal of nitrogen, hot trapping using Fe-Ti alloy has been investigated though the detail transport behavior of nitrogen in the alloy has not been clarified. In this fiscal year, using SXES (soft X-ray energy spectroscopy), nitrogen distribution and diffusion in the alloy has been investigated. Most of the nitrogen in the alloy is concentrated in the grain boundary where titanium is also concentrated and the effective diffusivity of nitrogen in the alloy at 823 K is shown to be in the order of 10^{-16} m^2/s. The nitrogen distribution in the alloy is shown in the figure 4. The X-axis of the figure is the depth from the surface of the alloy pebble, which was kept in N-containing Li (~1000wppm) at 823 K followed by the embedding into a resin and polish to show its equatorial plane.

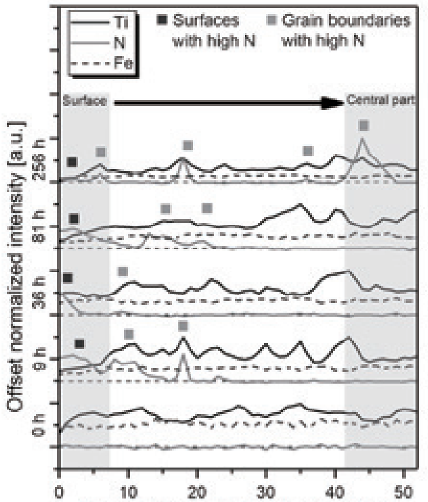

Fig.4: The nitrogen penetration into the Fe-Ti alloy quantified by SXES. Nitrogen is detected in deep region when the heating time is long (256h)

From the practical view point, nitrogen trapping behavior in flowing lithium condition is also important. A small liquid lithium loop has been constructed in this fiscal year and the experiment using the device has also been started.

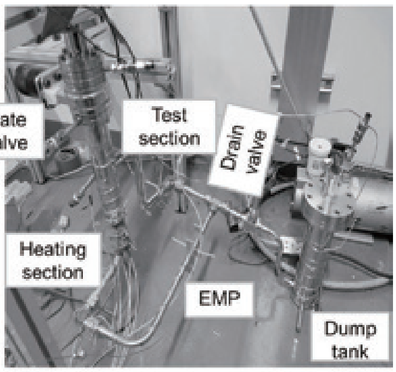

Fig.5: Major components of the lithium loop. The thermal insulator, a glove box connected to the gate valve, a casing with magnets of EMP etc. are not included.

5. Development of compact fusion neutron source with 3D-printed cathode

Development of a compact neutron source with a higher neutron production rate is of great importance for a wide range of its application, including radiography and boron neutron capture therapy (BNCT). Concentric spherical transparent cathodes made of stainless-steel and titanium were fabricated by a metal 3D printer (Figure 6). The measured neutron production rate using the Ti cathode is higher than that of the SS cathode by factors of 1.36–1.64 across the 20–70 kV range. Moreover, fusion on the Ti cathode surface enhances the total neutron yield significantly compared to the SS cathode under the same conditions. The Ti's considerable ability to accumulate D ions and molecules compared with that of SS explains the difference of measured NPR results.

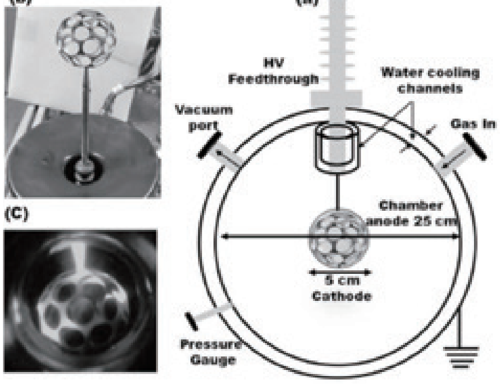

Fig.6 (a) a compact fusion neutron source. (b) buckyball-shaped grid cathode. (c) stainless-steel cathode during discharge

Collaboration Works

八木重郎，University of California San Diego（アメリカ），SiC 材料を用いたプラズマ対向機器の実用性に関する研究

八木重郎，核融合科学研究所・LHD 計画共同研究，液体溶融塩ブランケット第一壁開発のための高磁場下伝熱促進流路の特性評価

向井啓祐，小西哲之，八木重郎，核融合科学研究所・一般共同研究，LHD 本体室における中性子線量の制御による核融合炉ブランケットの高性能化

八木重郎，核融合科学研究所・一般共同研究，溶融塩循環システム凝固バルブの試作と機能実証

八木重郎，小西哲之，向井啓祐，核融合科学研究所・一般共同研究，高融点鉛リチウム金属間化合物を用いた水素移行に関する基礎研究

八木重郎，核融合科学研究所・一般共同研究，DT 中性子源を用いた液体ブランケット増殖材中における核変換トリチウム挙動の研究

八木重郎，核融合科学研究所・一般共同研究，液体ブラケット適用に向けた三面複層コーティング流路の製作性および流動特性評価

八木重郎，核融合科学研究所・一般共同研究，トリチウム透過低減被覆の層構造の制御と液体ブランケット適用性

Financial Support

1. Grant-in-Aid for Scientific Research

八木重郎，基盤研究(B)，核融合炉ブランケットにおける水素・腐食・照射相乗効果の解明と機能性材料設計（分担金）

向井啓祐，若手研究，核融合ブランケットの中性子輸送と燃料生産性の実験評価

向井啓祐，基盤研究(B)，特殊な電圧プロファイル下の電気透析による６リチウム同位体濃縮技術の研究（分担金）

向井啓祐，基盤研究(B)，核融合炉ブランケットにおける水素・腐食・照射相乗効果の解明と機能性材料設計（分担金）

2. Others

小西哲之，核融合科学研究所，高速応答原型炉燃料サイクルとプロトンポンプフロントエンド

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