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Status and prospect of international collaboration on PWI research: Behavior of hydrogen isotopes in neutron-irradiated plasma-facing materials

国際共同研究によるＰＷＩ研究の進展と今後の展開：
中性子照射プラズマ対向材料中の水素同位体挙動

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Tritium retention and release by plasma-facing materials is a critical issue in safety assessment of fusion reactors. The influence of neutron irradiation on hydrogen isotope retention and release by tungsten has been examined in Japan-US Joint Project TITAN Task 2-1. The obtained results indicated significant change in both retention and release by trapping effects of radiation damages. The overview of this project is given in this presentation together with lessons learned for future international collaborations.

1. Background

Plasma-facing materials (PFMs) of fusion reactors are subjected to extensive irradiation of 14 MeV neutrons. Various types of defects, such as vacancy, interstitial loops and voids, are created by the irradiation, and physical and chemical properties PFMs are modified with the accumulation of defects. From the viewpoints of safety assessment, increase in tritium retention by trapping effects of defects is a critical issue. It should be noted that PFMs emit significant decay heat after extensive neutron irradiation, and PFMs retaining a large amount of tritium and heated to high temperature could be a major source of tritium release under accidental conditions. The accumulation of data on hydrogen isotope behavior in neutron-irradiated PFMs is therefore indispensable for the development of fusion reactors.

International collaboration is really necessary to understand neutron irradiation effects on PFMs because (1) availability of neutron source is limited in most countries/areas, and (2) facilities for post-irradiation examination (PIE) of nuclear materials are not necessarily equipped with instruments suitable for tests of PFMs. For example, in the author's knowledge, a high flux plasma machine being able to accept radioactive specimens is available only in Idaho National Laboratory (INL), US at the present.

In the Japan-US Joint Project TITAN Task 2-1 (Irradiation-Tritium Synergism), the retention and release of hydrogen isotopes by neutron-irradiated tungsten has been examined because tungsten is currently recognized as a primary candidate of PFM in DEMO reactor [1-3]. The objectives of this presentation are to provide the overview of this activity and to extract the issues important for future international collaboration in this direction.

2. Japan-US Joint Project TITAN Task 2-1

In this subtask of TITAN project, disk-type specimens of pure tungsten prepared in Japan are irradiated in High Flux Isotope Reactor (HFIR), Oak Ridge National Laboratory (ORNL). Then, the specimens are shipped to INL to examine retention and release of hydrogen isotopes including tritium with the liner plasma machine called Tritium Plasma Experiment (TPE). A part of specimens are also transported to University of Wisconsin, Madison, for depth profile measurements with nuclear reaction analysis (NRA) technique, and International Research Center for Nuclear Materials Science, Institute for Materials Research, Tohoku University for microstructure examination.

The specimens were prepared in University of Toyama by slicing the rods of pure tungsten (99.99 %) supplied by A. L. M. T. Co., Japan under stress-relieved (SR) and recrystallized conditions. The grains in the specimens were elongated to the direction perpendicular to the surface like ITER-grade tungsten. The size of specimens for hydrogen isotope retention/release measurements were limited to be $\phi 6 \times t$ 0.2 mm by the volume of irradiation capsule and radioactivity induced by neutron irradiation, and those for microstructure examination were $\phi 3 \times t$ 0.2 mm. The conditions for neutron irradiation in HFIR are summarized in Table I. Irradiation at higher temperature is currently under discussion.

The neutron-irradiated specimens were shipped to INL and tested with TPE. Figure 1 shows the comparison of deuterium retention in neutron-irradiated specimens (SR) [3] and that in ion-damaged specimens [4-7]. It should be noted that the retention in neutron-irradiated specimens was relatively high especially at high temperature in spite of lower dpa value. Significant increase in desorption temperature by neutron irradiation was also observed. These results suggested the formation of strong trapping sites by neutron irradiation. The binding energy between those trapping sites and deuterium was about 2 eV, and this binding energy corresponds to trapping by voids [7,8]. The specimens irradiated to higher dpa values will be examined in the near future.

Table I. Conditions of neutron irradiation in HFIR

Temperature (^{o}C)	Dose (dpa)
50	0.025, 0.3
300	2.5

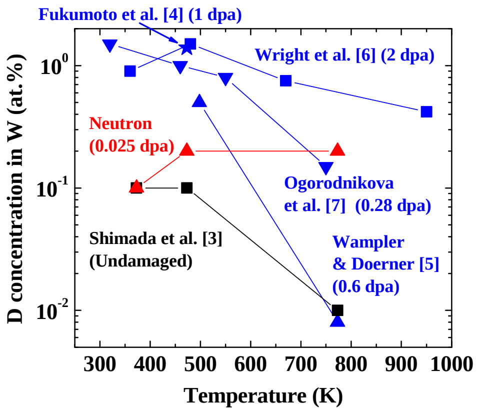

Fig.1. Comparison of deuterium retention between neutron-irradiated tungsten specimens (SR) [3] and ion-damaged specimens [4-7].

3. Lessons Learned

Post-irradiation experiments of PFMs are significantly different from those of common nuclear materials. The special requirements for PFM study we learned from the experiences in TITAN Task 2-1 are listed below.

(1) Because of large mass number and high displacement energy, damage rate (dpa/s) in tungsten under fission neutron environment is relatively small. The irradiation to 2.4 dpa takes roughly 1 year in HFIR. Neutron irradiation should be started well in advance of target date of PIEs.

(2) As described above, most of PIE facilities are not well equipped with instruments necessary for PFM tests such as plasma machines and NRA device. Hence, the radioactive specimens have to be shipped from one facility to another frequently. Good coordination of specimen shipping is indispensable for timely PIEs.

(3) Control of surface states is important for PFM study but it may be difficult during neutron irradiation. Hence, methods for surface treatments of radioactive specimens should be considered in advance.

4. Conclusions

The observations in TITAN project clearly showed significant change in hydrogen isotope retention and release by neutron irradiation. This project will be over at 2012 Japanese fiscal year. On the other hand, importance of neutron irradiation effects on PFMs is recognized not only in Japan and US but also in Europe [9] and other countries. Establishment of new international collaboration framework is really necessary to obtain sufficient understanding of neutron irradiation effects before starting the design of plasma-facing components of DEMO reactor.

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