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Requirements for divertor (ITPA Reports)
ダイバータ要件（ITPA報告など）

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The leading candidate of the material for the divertor plates in a fusion reactor is tungsten because it is a refractory metal, and its erosion rate and the hydrogen isotopes retention in bulk material are much less than those of carbon. It was decided in the last year, 2013, that full tungsten divertor is installed from the initial experiment phases in the ITER. However there are some issues to be solved to use tungsten as a plasma facing material in the ITER and a fusion reactor.

The roles of a divertor in a fusion reactor are (i) impurities removal including helium ash, and (ii) pumping of the residual fuel particles. For these roles, the separatrix and the neighbor magnetic field lines connect on the divertor plates, and the plasma heat load is very high on the plates. Therefore carbon and/or refractory metals are used for the divertor plates material.

Carbon was used in various fusion devices as the plasma facing material in 1990's to 2000's. The reason why the refractory metals had not been used in fusion devices was the degradation of the plasma performance with large radiation from the high-Z impurities, which were generated by the erosion of the refractory metals. The plasma performances were improved in carbon devices, and carbon was planned to be used as a divertor plates material in the ITER [1]. On the other hand, carbon was considered not to be used as the divertor plates material in a fusion reactor because of the large erosion rate of carbon. In addition to physical sputtering and evaporation/sublimation, which are common processes for carbon and the refractory metals, there is another erosion process for the carbon in hydrogen isotope plasma environment, that is, chemical sputtering. If carbon is used as the divertor plates material in a fusion reactor, the lifetime of the plates become so short. The other problem of using carbon in fusion reactor is the retention of hydrogen isotopes. It is well know that hydrogen isotopes can be retained in a bulk carbon up to around 0.4 in H/C ratio at relatively low temperature [2]. In addition to that, the re-deposition layer of carbon can retain hydrogen isotope continuously with the co-deposition process with H/C ratio exceeding 1 [3]. The tritium inventory in vacuum vessel should be small in a fusion reactor, and there is the in-vessel tritium inventory limit for operation in the ITER [3].

In 2000's, the experiments with the metallic plasma facing component were conducted in the TEXTOR [4] and the ASDEX-Upgrade [5], respectively. In particular, in the ASDEX-Upgrade, the experiments with the full tungsten plasma facing components were started from 2007 [6]. As the results of the experiments with metallic plasma facing components, it has been revealed that the effects of the high-Z impurities can be avoided with operational scenarios, such as the central heating and ELM pacing [7]. As a result, the material of the ITER divertor plates for the initial experiment phases was changed to be all tungsten in 2013, though the main reason of the change was budget restrictions [8]. In designs of fusion reactors, tungsten is also the leading candidate of the plasma-facing material.

The tungsten issues for ITER have been discussed in the International Tokamak Physics Activity (ITPA) Scrape-Off-Layer (SOL) and Divertor topical group for years. The ITPA provides a framework for internationally coordinated fusion research activities. The ITPA continues the tokamak physics R&D activities that have been conducted on an international level for many years. This has resulted in the achievement of a broad physics basis essential for the ITER design and useful for all fusion programs and for progress toward fusion energy generally [9]. In the ITPA SOL & Divertor group, the discussion has been focused on the plasma-surface interactions and the phenomena at near the surface region of the material. The topics related to tungsten in the group meetings in the recent two years were as below:

(1) **Migration**, including measurement of the tungsten source mainly with spectroscopy, calculation of tungsten transport, and comparison to surface analysis

(2) **Fuel retention**, including fuel retention machine database, isotope exchange, wall conditioning and effects of neutron damage.

(3) **Dust**, including characterization of ejection velocities, sizes of molten droplets and size distributions of collected dust, dust monitors and measurements.

(4) **Melting**, including melt tungsten in tokamak, measurement of the melt layer dynamics and penetration to core plasma, modelling validation (melt layer behavior and plasma transport), predictions for ITER.

(5) **Morphology**, including the impacts of the melting and solidification (cracking), roughening, helium induced morphology and recrystallization on erosion and plasma operation.

(6) **Tungsten technology**, including high heat flux testing and developments of the plasma facing components with tungsten

In the presentation, some topics from the discussions in the ITPA SOL and Divertor group meetings will be reported.

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