# Simulation of fusion neutron damage in tungsten,

# molybdenum and iron using high energy protons, high energy ions, high energy neutrons and fission neutrons

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Currently, tungsten and tungsten coatings are the reference materials of the ITER divertor and DEMO reactors and the possibility of using low-activated ferrite-martensitic, RAFM, steels not only as structural materials, but also as the material of the first wall of the fusion reactor is considered. Also, these steels, together with a new generation of RAFM steels with oxide dispersion strengthened by adding Y2O3 nanoparticles, the so-called ODS steels, are considered as promising materials for fast neutron fuel cladding. One of the key ITER and, especially, DEMO issues is radiation-induced damage caused by 14 MeV (in peak) neutron irradiation and its effect on the fuel and helium retention. As a fusion neutron source does not exist yet, to simulate fusion neutron-induced damage in materials, fission neutrons and charged particles are widely used. However, it is not always clear if the mechanisms under the ion irradiation are relevant to lower dose rate and the primary knock-on atom (PKA) spectrum under neutron irradiation [1,2]. On the other hand, the fusion neutron spectrum is different from that in available fission reactors. In order to simulate the fusion experimental conditions for reliable predictions of radiation damage in fusion reactors, it is necessary to establish the adequacy of the radiation damage produced by different types of irradiation. For this reason, comparison of radiation-induced defects in metals based on W, Mo and Fe produced by high-energy self-ions, protons and neutrons with different spectrum has been performed. Radiation-induced defects have been studied by well-established method of positron-annihilation lifetime-spectroscopy (PALS), transmission electron microscopy (TEM) and nuclear reaction analysis. The study of different distributions of radiation-induced vacancies and vacancy clusters of different sizes created by different types of irradiation using PALS and TEM methods allows us an experimental validation of the value of “displacement per atom” (dpa) when comparing different types of irradiation. We found a formation of the larger size of the defects with lower density in the case of irradiation with high-energy neutrons from the p(35 MeV)-Be source compared to fission neutron- and proton- irradiations. It is shown that fission neutrons do not appear to be a good surrogate for simulating radiation damage caused by thermonuclear neutrons. Fast neutrons from p-Be source or other accelerator source can be a good surrogate to simulate radiation damage caused by fusion neutrons. Energetic protons can be a surrogate to simulate fusion neutron damage in certain materials over a certain temperature range. The new experimental data together with data available from the literature are compared with the dpa theory, including molecular dynamic simulations. Second, He/dpa ratios in different neutron facilities have been compared. We show that He/dpa ratios in the facilities with the hard energy spectra (fusion like) p(35 MeV)-Be source and DEMO are one-two orders larger than in the fission ones LVR-15, HFIR and BOR60.

Since significant amounts of helium and hydrogen will accumulate in the structural materials and in the first wall and other nodes of the reactor chamber, along with a high level of radiation damage, it is necessary to simulate the retention of helium and hydrogen in radiation-induced defects. Hydrogen embrittlement and helium swelling in a fusion reactor are important issues determining the applicability of the material, and may be the reason of shortening the lifetime of reactor components. It is shown that the hydrogen retention significantly increases in the presence of radiation damage and strongly depends on the target temperature. To predict radiation damage in DEMO, the temperature distribution along the material and the temperature gradient in the normal operation regime and during ELMs should be taken into account. Methods to obtain the best approach to modelling fusion neutron damage and to bridging the gap between theory prediction of primary defect formation and long-term damage, including gaseous and solid transmutation products, as well as thermal effects (including the temperature gradient in the normal operation regime and during ELMs) are discussed taking into account the uncertainties.

References

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