Final Report on Investigations of the influence of Helium concentration and implantation rate on Cavity Nucleation and Growth during neutron irradiation of Fe and EUROFER 97 - DTU Orbit (23/08/2019)

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This report presents results of investigations of damage accumulation during neutron irradiation of pure iron and EUROFER 97 steel with or without prior helium implantation. The defect microstructure, in particular the cavities, was characterized using Positron Annihilation Spectroscopy (PAS) and Transmission Electron Microscopy (TEM). The PAS investigations revealed a clear difference between the He implantation effects in Fe and EUROFER 97 at 623 K. For both materials the mean positron lifetimes increased with He dose in the range 1 – 100 appm, although the increase was stronger for Fe than for EUROFER 97 and for both materials smaller for implantation at 623 K than at 323 K. This lifetime increase is due primarily to the formation of He bubbles. For He doses of 10 – 100 appm cavity sizes and densities in Fe were estimated to be 1.7 – 2.8 nm and 4 - 14×1021 m-3, respectively. Neutron irradiation after He implantation in general leads to an increase of both cavity sizes and densities. Estimates of cavity sizes and densities in EUROFER 97 after neutron irradiation with or without prior helium implantation are rather uncertain, but lead to values of the same order as for iron. TEM cannot resolve any cavities in Fe or EUROFER 97 after implantation of 100 appm He neither at 323 K nor at 623 K. However, neutron irradiation at 623 K to a dose level of 0.23 dpa in Fe is observed to lead to cavities with sizes of about 4 nm and densities of about 1.5×1021 m-3. He implantation (100 appm) prior to neutron irradiation results in a cavity density increase to ~1×1022 m-3. In EUROFER 97 a very inhomogeneous cavity distribution, formed at dislocations and interfaces, is observed after He implantation with subsequent neutron irradiation. In addition, a very low density of very large voids have been observed in Fe (without He) neutron irradiated at 323 K, already at a dose level of 0.036 dpa. Detailed numerical calculations within the framework of the Production Bias Model have been carried out for neutron irradiation with and without prior He implantation and for different implantation rates for comparison with the experimental results. Further, the purpose was to evaluate the role of helium in cavity nucleation and growth during 14 MeV neutron irradiation in a fusion reactor. Calculations were carried out for the experimental temperatures of 323 K and 623 K, i.e. below and above the recovery stage V. In general, the calculations agree qualitatively with the experimental observations and in some cases quantitatively. In this way the calculations give an experimentally supported detailed insight into the evolution of the cavity microstructure under different conditions.

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