An Integrated Approach To Fusion Material Research At SCK•CEN

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For the last 20 years, fusion material programs in Europe, Japan and US have been focused on developing Reduced Activation Ferritic/Martensitic (RAFM) steels as prominent structural materials, which would reduce the environmental impact of the irradiated steel after the service lifetime of a fusion reactor.

In the European Union, within the Long Term Programme of EFDA (European Fusion Development Agreement), remarkable efforts are spent by several scientific institutions for the characterization and optimization of the European reference RAFM steel, EUROFER97. This was modelled after the conventional T91 alloy and exhibits a tempered martensitic microstructure which allows operation at relatively high temperatures (up to 500 – 550 °C).

Within the Belgian Nuclear Centre (SCK•CEN), an integrated approach to the characterization of EUROFER97 is being consistently applied; this includes the following investigations, which are conducted in parallel and whenever possible in synergy.

- *Neutron irradiations in the BR2 reactor*. Several irradiation experiments on EUROFER97 have been performed in the period 2000-2003, all at 300 °C and corresponding to accumulated doses in the range 0.3 to 2 dpa. Further irradiations are foreseen in 2004-2005.
- *Characterization of the unirradiated and irradiated mechanical properties.* Tensile, instrumented Charpy and static fracture toughness tests have been performed in the baseline condition and for different dose levels, allowing to assess the evolution of the mechanical properties of the material as a function of accumulated fluence (specifically, hardening and embrittlement). Comparisons with similar data for other RAFM steels are being made, and extensions to EUROFER97 welded joints and ODS materials are in preparation.
- *Investigation of environmentally assisted cracking (EAC).* This is a critical concern for the design of nuclear systems; for fusion reactor applications, there are two potentially corrosive environments: water at high temperature and liquid lead-lithium eutectic alloys, depending on the cooling option for the blanket. Furthermore, an interaction between radiation damage and EAC is likely. For both EAC and liquid metal embrittlement, the yield stress of the material is a known key factor. At SCK•CEN, a research programme is presently being carried out to investigate the influence of irradiation damage on both EAC and embrittlement in Pb-Li alloys; the first results of EAC tests on irradiated EUROFER97 are now available.
- *Multiscale modelling of radiation effects and specific effects on Fe-Cr systems.* The objective here is to model radiation effects in RAFM steels under fusion relevant conditions, in the range T = RT – 550 °C and in the presence of high concentration of irradiation induced impurities (H, He, etc). The applied methods range from atomic level ab initio calculations (MD – Molecular Dynamics and KMC – Kinetic Monte Carlo) up to mesoscopic dislocation dynamics and finite element at the macroscopic level. More specifically, work is in progress for the setting up of libraries of displacement cascades in Fe and Fe-Cr alloys using MD with an adequate interatomic potential. In parallel, multiscale models are developed capable of simulating, by means of suitable computational models, the evolution of radiation-induced damage in fusion-relevant model materials (e.g. Fe-Cr as model alloy for RAFM steel).

This paper will provide a general overview of the above mentioned investigations, as well as highlights of the most significant results obtained in the different fields of activity.