IFMIF: THE NEUTRON SOURCE FOR THE FUSION PROGRAM

Juan Knaster, IFMIF/EVEDA (F4E), Rokkasho, Japan

Fusion materials research started in the early 70s following the observation of unprecedented irradiation induced damage levels in core components of the first commercial fission reactors within their first decade of operation. The substantially more severe conditions in fusion reactors (thus, obvious higher degradation than the observed with fission reactors) was apparent given 1) the harder mono-energetic spectrum of DT fusion neutrons (14.1 MeV compared to <2 MeV average for fission neutrons), 2) the multi-directional cyclic stresses of hundreds MPa in the in-vessel structural elements from Lorentz forces, and 3) the power densities >10 MW/m^2 to be withstood by plasma-facing components. The technological challenges of fusion energy are intimately linked with the availability of suitable materials capable of reliably withstanding the extremely severe operational conditions of fusion reactors. In a future commercial fusion reactor, strict safety standards will be required for the thermomechanical properties of the in-vessel components exposed to irradiation damages reaching >20 dpa/year for a 3 GW thermal power plant. If 14 MeV neutrons are in place, two transmutation reactions release gases in the structural materials driving to an unknown degradation: 1) He at a rate of ~12 appm/dpa, $^{56}Fe(n,He)^{53}Cr$, and 2) H at a rate of ~45 appm/dpa, $^{56}Fe(n,p)^{56}Mn$. These reactions exhibit threshold energies; in particular, He is released only with impacting neutrons >3.7 MeV, that leads to He generation rates under irradiation with fission neutrons of only ~0.3 appm/dpa. The materials swelling and irradiation induced degradation is mainly driven by the accumulation of He, thus fission neutrons are not capable to provide needed answers, neither can spallation sources. Irradiation of materials under fusion relevant conditions is an indispensable step in world fusion roadmaps to characterize the existing materials and pave the way towards new materials through a deeper insight of the complex phenomena involved [1]. The optimal choice for a 14 MeV neutron flux was identified 40 years ago [2]. Neutrons with a broad peak at 14 MeV and required flux could be obtained through Li(d,n) stripping reactions with a D^+ beam at suitable energy and current impacting on a flowing Li target with suitable thickness and speed. The first attempt towards such a facility was undertaken in the US in the early 80s under the Fusion Materials Irradiation Tests (FMIT) project [3]. A prototype accelerator of 100 mA in continuous wave at 2 MeV was constructed, but the accelerators technology was not ready for such a challenging performance. Other ideas appeared, but they are either obviously not sufficiently matured (a fusion reactor for materials testing) or technologically unfeasible (rotatable carbon target at >1 MW beam powers); the urgencies for making available 14 MeV neutrons with needed fluxes welcome all reasonable proposals. Fortunately, the worldwide development efforts towards a Li(d,n) continued since FMIT and have matured under the on-going Engineering Validation and Engineering Design Activity (EVEDA phase) of IFMIF, the International Fusion Materials Irradiation Facility that is succeeding to close all historical technological showstoppers [4]. A design of IFMIF (2 x 125 mA CW D^+ accelerators impacting on a 15 m/s 25 mm thick 250 °C flowing Li screen) has been released [5], obviously additional detail engineering efforts will be required for construction. The present lower thermal power of a demonstration fusion reactor, if compared with the ones considered in the past, suggests a reduction of the required performance of a fusion-relevant neutron source. Thus, possibly only one accelerator at 125 mA in CW mode will suffice; the design available can be adapted in a straightforward manner. The ongoing success of the IFMIF/EVEDA phase, the known cost of the facility (reliable because of the construction of prototypes of the most challenging hardware), which is marginal compared with the cost of a fusion power plant, together with its paramount relevance for the continuation of the fusion programme have recently triggered interest in the construction of a simplified version of IFMIF [6].

REFERENCES

[1] J. Knaster, A. Moeslang and T. Muroga, Materials research for fusion, Nature Physics Vol. 12, May 2016

[2] P. Grand et al., An intense Li(d,n) neutron radiation test facility for controlled thermonuclear reactor materials testing. Nucl. Technol. 29, 327-336 (1976)

[3] E. W. Jr Pottmeyer, The fusion material irradiation facility at Handford. J. Nucl. Mater. 85, 86, 463465 (1979)

[4] J. Knaster et al., IFMIF, the European-Japanese eorts under the Broader Approach Agreement towards a Li(d,xn) neutron source: current status and future options. Nucl. Mater. Energy (in the press)

[5] J. Knaster et al., The accomplishment of the Engineering Design Activities of IFMIF/EVEDA: the European-Japanese project towards a Li(d,xn) fusion relevant neutron source. Nucl. Fusion 55, 086003 (2015).

[6] A. Ibarra et al., A stepped Approach from IFMIF/EVEDA toward IFMIF. Fusion Sci. Tech. 66, 252259 (2014).