Results of the Validation Activities of the IFMIF/EVEDA Phase for the IFMIF Test- and Lithium Facilities

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The International Fusion Materials Irradiation Facility IFMIF is developed with the mission to generate materials irradiation test data for design, licensing, construction and safe operation of a fusion DEMO reactor. A facility with such capabilities is element of the EU and Japanese roadmaps for the development of fusion power. This paper deals with the outcomes of validation activities for systems of the so called Lithium Facilities and Test Facilities, as part of the Engineering Validation and Engineering Design Activities (EVEDA), performed 2007 - 2015 by Japanese and European laboratories.

In the IFMIF plant [1], the systems of the Accelerator Facility (with two 40MeV 125mA deuteron beams) act together with the systems of the Lithium Facility (with a free-surface lithium target) to establish a neutron source with the demanded fusion-relevant energy spectrum and enough neutron flux to achieve accelerated testing. The so called Test Facilities provide the irradiation experiments (housing Small Specimen Test Technique (SSTT) material specimens), radiation protection environment and infrastructure to implement the mission of material testing.

At the lithium target, a lithium flow guided on one side by a concave back plate at speeds of 15 - 25m/s is generated. From the free surface side, the two deuteron beams impinge, releasing a power of 10MW within the beam footprint area of 20 x 5 cm² in the lithium. Due to the heat release depth profile, the thickness of the lithium flow should be maintained at 25mm +/- 1mm. It was a major goal of the validation activities to demonstrate the technical feasibility of such a lithium flow over a long term and to limit the wave amplitudes in the free surface as specified. The EVEDA Lithium Test Loop designed and operated by JAEA in Oarai, has successfully demonstrated the long term stability over 25 days of continuous operation, where 12 measurements spanned in the experimental time matched perfectly. In turn, the beam-target interaction has been carefully re-assessed demonstrating that beam momentum transfer or thermal gradients are not strong enough to induce destructive resonances. In addition, studies related with remote handling, diagnostics, purification and corrosion/erosion on RAFM steels were performed. Their results will be summarized in this overview.

In the high neutron flux region directly behind the back plate, a calculated volume of about $500cm^3$ is available to irradiate steel specimens to structural damages of 20-50dpa per full power year of IFMIF. Exchangeable irradiation rigs (High Flux Test Module, HFTM) were developed to achieve a high specimen packing density in the limited irradiation volume, and to maintain controlled temperature environments. A high temperature variant (up to 1100°C) was developed in Japan, and a variant addressing the temperature window (250 - 550°C) of Reduced Activating Ferritic Martensitic (RAFM) steels was developed in Europe. For both HFTM variants prototypes were built, and successful thermal-hydraulic tests were performed in helium loops. Excellent temperature stability and low temperature spread within the specimen stack were demonstrated. The EU HFTM was tested in the HELOKA-LP helium loop at KIT, which has prototypical features for the helium loops of the IFIMF Test Facility ancillary systems. Heater systems and specimen-filled 1:1 scale capsules were further more tested in the BR2 reactor in Mol, yielding important lessons learned about the heater systems and the capsule design.

In the same irradiation campaign, Cerenkov Fibre Optical Sensors (C_FOS) were studied. These sensors were developed for on-line monitoring the neutron irradiation conditions prevailing in the IFMIF irradiation volume. An arrangement of C_FOS in U-shaped bundles was giving satisfactory results when irradiated to a dose around 10 GGy. Based on these results, it is expected that they will work in the IFMIF environment. Also fission chambers were tested in the BR2 reactor. The key objective was to test their robustness under a combined neutron/gamma field. Over the testing period available in BR2 which corresponds to about 3-4 weeks in IFMIF at full power it was found that the results achieved have been satisfactory.

As central element to the IFMIF material science approach, the Small Specimen Test Technique, was further developed in Japan. Here, the sensitivity of the results on the shape of fatigue and crack growth specimens was experimentally investigated. In the EU, the workflow of loading (and un-loading) the small specimens to the irradiation capsules under hot cell conditions was practiced, providing input to the logistics and maintenance planning of the IFMIF facility.

In conclusion, the validation activities for the IFMIF Lithium- and Test Facilities were able to demonstrate major achievements for the design of critical components, and furthermore, give valuable impulses for the further development of IFMIF systems, which are currently ongoing in EU and Japanese R&D activities, aiming at the realization of an early neuron source for DEMO.

[1] 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, Nuclear Fusion, Volume 55, Number 8, 2015