

Materials chosen for constructing structural components in nuclear reactors require careful selection and characterization, as their operational conditions presume the constant influence of harmful neutron irradiation, which undesirably degrades their mechanical properties and eventually may lead to the failure of the component. Therefore, we need to ensure that the margin of safety of the material is enough to sustain a certain amount of neutron damage. However, neutron irradiation for research purposes is a costly, lengthy and complicated process, so the possibility of imitating the damage of neutrons by other types of irradiation is of high interest. In this research, we aim to substitute complicated neutron irradiation with relatively cheap, fast, and safe ion irradiation, analyze its impact on mechanical properties, deeply investigate the microstructural changes it does, and compare it with the existing data done with neutrons. We target to establish an experimentally-computational procedure for effectively characterizing the consequences of ion irradiation as a surrogate for neutron irradiation. This will allow us to accelerate the delivery of new research data on structural materials for nuclear applications.

To execute the project, we will perform ion irradiation of samples of the European structural steel Eurofer97, specially designed for applications in future fusion reactors. The irradiation campaign will be based on the parameters most representative of real operational conditions. Further, the irradiated and non-irradiated samples will be experimentally studied, including complementary investigations done using different microscopy techniques. The obtained results will be compared to distinguish and characterize the influence of the ion-induced damage. Finally, the outcoming knowledge will be used to correctly feed computational models for numerical simulations, allowing us to connect the obtained from ion-irradiated material data with neutrons. The proposed research is to be done at the NOMATEN Centre of Excellence (CoE), led by Tymofii Khvan (principal investigator) under the guidance of Dr. Lukasz Kurpaska (project mentor), including cooperation with Prof. Jacek Jagielski (ion irradiation damage expert) and with the numerical group at CoE: Prof. Mikko Alava and Prof. Stefanos Papanikolaou (experts in multi-scale simulations).

Globally, the execution of the proposed research is driven by the substantial complexities of using neutron irradiation for research purposes. Besides being highly expensive, the lowest damage dose of interest for the demonstrative fusion reactor would take a minimum of 10 years to reach with the modern capabilities of the research reactors (50 dpa with 5 dpa/year). In contrast, ion irradiation can handle this in 1 day. Moreover, metallic materials are very active and dangerous after neutron irradiation, leading to the use of bulky protective equipment, specially trained personnel, and strict safety protocols. The data available in the literature shows the good substitutional potential of ions once imitating the neutron damage in terms of mechanical or structural analysis. However, due to its specifics, the experimental characterization process usually comes with noticeable uncertainties and artifacts, affecting accuracy. Consequently, transferred for computational analysis, inaccurate data affect the effectivity of the approach to apply ion irradiation. Therefore, an establishment of a complete testing cycle with complementary investigations to support the experimental activities and rectify the results is demandable and proposed within the project.

Upon completion of the project, it is expected to obtain a proven research protocol for the effective experimentally-computational steps toward fast and safe characterization of the irradiation impact on the mechanical properties of structural steels with the lowest uncertainty. Moreover, this procedure can be applied to other metallic materials by repeating the validation process established within the proposed project. The outcoming results are expected to pace the delivery of new research data in the nuclear materials field and give rise to similar studies. The project will also positively impact the professional growth of the PI, will provide an additional internationally-collaborative resource for CoE, and globally will contribute to the stability of the European energy sector.