Nuclear power plants are one of the largest, most stable, and at the same time, low-carbon sources of electricity. They significantly impact environmental protection, especially in the context of climate change. The Paris Agreement and the European Union's long-term strategy are to achieve climate neutrality by 2050 (e.g., through the adopted Fit for 55 package) and provide for nuclear power investments. Nuclear power plants currently in operation represent the concept of second-and third-generation reactors. Advanced fourth-generation systems and fusion reactors under development offer even greater benefits from this energy source. However, one of the main challenges limiting the deployment of these systems for commercial operation is the resilience issues of structural materials.

Nuclear reactor structural components are exposed to operating under adverse conditions. High temperature, high pressure, ionizing radiation, interaction with aggressive cooling media that cause corrosion, and complex stress fields have a negative impact on these materials, causing them to wear out quickly. Therefore, to guarantee the safe operation of the new generation of nuclear reactors, it is imperative to understand the processes occurring in structural materials. The austenitic steels currently in use cannot meet the new requirements due to poor radiation resistance and limited high-temperature mechanical properties, among other factors. Therefore, it is crucial to develop and select new materials and carry out comprehensive studies on changes in their properties under the influence of the above-mentioned operating conditions to bring Gen. IV nuclear reactor technologies to life.

Ferritic-martensitic steels are among many the most promising structural materials for nuclear and fusion reactors. The concept of these materials was developed due to the combined efforts of scientists from the European Union. The developed material - Eurofer97 - is ferritic-martensitic steel with reduced activation, containing 9% chromium, in which high activation alloying elements (Mo, Nb, Co) have been replaced by low-activation elements (Ta, W, V). This material will be used to construct the DEMO reactor (DEMOnstration Power Plant), which is scheduled for completion in 2050. These steels are also being considered for constructing the ITER reactor (Internet Thermonuclear Experimental Reactor) in southern France. This reactor is a precursor to DEMO.

Implementing new material solutions requires a series of systematic tests to ensure the material retains its structural integrity throughout its service life. Despite years of research, many unknowns are still associated with the Eurofer97 alloy. Therefore, the project aims to study and understand the critical properties of ferritic-martensitic steels from the point of view of nuclear applications, such as resistance to temperature or radiation damage. To better understand the effects of individual factors such as alloying additives and temperature on material properties, in this project, we will conduct tests on three model materials (Fe, Fe-9%Cr, Fe-9%Cr-NiSiP) and a commercial Eurofer97 steel, gradually increasing the microstructural complexity of the system. This procedure will help us isolate the phenomena occurring in the material during the accumulation of radiation defects and temperature, allowing a better understanding of the relationship between microstructure and mechanical properties. All materials will be ion-irradiated at high temperature (300 C), simulating the generation of radiation defects that form in a nuclear reactor. The research will be carried out using experimental techniques such as nanoindentation (at room and elevated temperatures), Scanning Electron Microscopy (SEM), and Transmission Electron Microscopy (TEM). In addition, the project involves the use of numerical tools that will be used to simulate the deformation occurring in the material under the influence of an applied external load and the interaction of radiation defects. The expected outcome of the project's research will be a better understanding of the behavior of F/M steels subjected to a nuclear reactor environment, including clarification of the effect of segregation into and out of grain boundaries and localization of Cr in the vicinity of dislocations, which leads to hardening of the material.

The competencies developed, and the research path will be able to be applied to the study of other materials designed for demanding operating conditions. It will also allow closer cooperation between the experimental and theoretical groups of NCBJ. The data obtained as a result of the completed project will form the basis of the planned Ph.D. thesis, which will be submitted for evaluation at the end of 2024.