Nuclear power plants are one of the largest, most reliable, and at the same time, low-carbon sources of electricity. For this reason, the Polish Nuclear Power Programme has been formulated, and its aim is to enhance energy security, reduce greenhouse gases emissions, and lower energy costs. Therefore, it is planned to build nuclear power plants in Poland, which will enable the country to meet climate neutrality goals, diversify energy sources, and increase independency from imported energy and fossil fuels. The actions aimed at building nuclear power plants in Poland have already begun, and the AP1000 reactor technology from Westinghouse has been chosen due to its safety and cost efficiency. It is a pressurised water reactor of Generation III+, which is recognised for its advanced features and passive safety systems, offering superior safety and competitive energy generation costs. Nonetheless, an important aspect of the proper functioning of the reactor is the reliability of materials, which degrade over time, necessitating periodic replacement of certain components due to their deterioration. Central to the success of nuclear energy is ensuring the reliability and safety of reactor components, particularly fuel claddings. They are made from materials such as zirconium, that are transparent to neutrons and do not influence the nuclear reaction. Their primary role is to isolate the created radioactive materials from the coolant and therefore prevent undesired chemical reactions, that the fuel could undergo. During reactor operation, fuel claddings are exposed to several damaging factors, including neutron radiation, high temperature, pressure and oxidative environment. Prolonged exposure to these factors leads to oxidation. Developing strategies to mitigate and prevent this effect may prolong the lifespan of fuel cladding and ensuring overall reactor safety.

Oxidation of zirconium fuel claddings result in oxide creation on their surface. This oxide occurs in two polymorphs, namely tetragonal and monoclinic phase. The tetragonal phase is protective but metastable, and the monoclinic phase tends to form as oxidation progresses, leading to porosity and increasing the oxidation rate. Therefore it is necessary to stabilise the tetragonal phase and prevent transformation as long as it is possible to ensure maximum material reliability. There are several factors that stabilise tetragonal phase, namely compressive stress, nanometric grain size and stoichiometry. Modifying these parameters is expected to enhance the stability of the tetragonal phase in zirconium oxide and prevent its transformation to monoclinic phase. Taking into account, that these factors occur together, it is difficult to determine their individual impact on oxidation process. Nevertheless multiple research methods can be used to investigate the specific effects of each of the stabilisation factors.

The presented issue is a part of the proposed research project, that aims to provide a detailed knowledge and understanding of degradation processes that occur in nuclear reactor environments, with a specific emphasis on the cladding material made from zirconium alloy. It will focuses on the oxidation behaviour of zirconium-based materials (high purity zirconium and zirconium-niobium alloy) under external stress. This will enable to distinguish impact of stress from the other stabilisation factors (namely grain size and stoichiometry). Moreover, it will explores the potential benefits of stabilising the tetragonal phase in zirconium alloys. Finally, influence of other stabilisation factors will be addressed. Special attention will be put on zirconia dependence on oxygen stoichiometry. The oxygen contents were never traced back in the literature, but actual methods offers this possibility. It is planned to employ a combination of innovative in-situ and ex-situ analytical techniques. Behaviour of samples oxidised with and without external stress will be compared. In-situ observation of behaviour of samples during oxidation will be performed using Raman spectroscopy. Furthermore, X-ray diffraction, Scanning Electron Microscope analysis and Raman imaging on the cross section of the oxide will be employed. Next, other stabilisation factors will be analysed, namely grain size will be determined using Transmission Electron Microscope, and stoichiometry will be investigated using Laser Induced Breakdown Spectroscopy. This equipment is already installed in National Centre of Nuclear Research, where the project will be realised.

The presented measurements and analysis are expected to unravel the complex relationship between stress, grain size and stoichiometry, and their individual impact on phase stability and oxidation kinetics. Advancing the understanding of these fundamental processes influencing material evolution, will enable further development of improved zirconium alloys that could significantly extend the operational lifespan of nuclear reactors. The findings from this research will substantially contribute to the principal investigator's doctoral dissertation and are anticipated to advance global energy research goals, developing nuclear reactor technology and supporting Poland's transition to a more sustainable energy future.