This project explores the structural behavior, stability, and environmental performance of iodine-bearing apatite-type materials, with the goal of developing safe and durable host phases for the immobilization of radioactive iodine-129. As Poland advances its nuclear energy program ATOM, and global energy systems shift toward low-carbon solutions, the safe management of long-lived radionuclides becomes increasingly important. Iodine-129 poses a particular challenge due to its high mobility, long half-life, and potential risks to ecosystems and public health. Effective containment strategies require the development of materials that can incorporate iodine into their structure and remain stable under repository conditions for thousands of years.

Apatite minerals, commonly found in nature and known for their robust crystal structures, are capable of accommodating a wide range of chemical elements, over half of the periodic table. Their structural flexibility, radiation resistance, and chemical durability make them promising candidates for immobilizing not only iodine-129 but also other problematic radionuclides such as strontium-90 and chlorine-36. Recent advances have demonstrated that selected iodine-containing analogs of apatite can be synthesized under low-temperature conditions from water-based solutions. However, the subgroup of iodine-bearing apatites remains poorly understood, and little is known about their long-term stability or mechanisms of iodine incorporation.

This project aims to deepen our understanding of how iodine is incorporated into apatite structure, how stable these materials are under conditions simulating long-term storage, and how they respond to chemical alteration and radiation. Unlike most previous studies, this research combines low-temperature aqueous synthesis, advanced structural characterization, and calorimetric measurements to explore the fundamental behavior of iodine in apatites. Key objectives include the synthesis of selected iodine-substituted apatites and their selected solid solutions, investigation of iodine's position and bonding in the crystal lattice, and evaluation of their thermodynamic properties and chemical durability.

Three scientific hypotheses will be tested:

1. Iodine-bearing apatites can form stable endmember phases and solid solutions with other apatites containing fluorine, hydroxyl, or chlorine.
2. Structural and thermodynamic studies will reveal new insights into the factors controlling phase stability and the behavior of volatile iodine in solid hosts.
3. These materials exhibit strong resistance to chemical alteration and low leaching rates in conditions expected in nuclear waste repositories, making them superior to many existing immobilization materials.

The research will be conducted in collaboration with international partners from Austria, Germany, and the United States, whose expertise in the thermodynamic properties of minerals and nuclear materials will provide essential support and access to advanced analytical techniques. By generating new data on the structural and thermodynamic properties of iodine-apatites, the project will contribute to improved predictive models for radionuclide behavior in waste forms and geological barriers. The findings will not only enhance scientific understanding of anion retention in minerals but also support safer and more sustainable nuclear waste disposal strategies. As Poland enters the nuclear energy era, the national scientific community must become actively involved in the development of safe and sustainable nuclear waste management strategies. This project steps in to face these challenges by building local expertise and contributing to long-term solutions that serve society and protect the environment.