Multiphase Nanocrystalline Ceramic Concept for Nuclear Fuel

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ABSTRACT:

The goal of this research is to help develop new fuels for higher efficiency, longer lifetimes (higher burn-up) and increased accident tolerance in future nuclear reactors. Multiphase nanocrystalline ceramics will be used in the design of simulated advanced inert matrix nuclear fuel to provide for enhanced plasticity, better radiation tolerance, and improved thermal conductivity. This project explores the use of nanoparticles and nanostructured ceramics to create new materials that can extend the service life for nuclear fuel. Ceramic surrogates will be used for screening and validation studies, and depleted UO2 for the most promising systems. Second phases with relatively high thermal conductivity, high radiation stability, and high chemical stability with respect to nuclear fuel will provide improved thermal conductivity. Multi-cation oxide third phases will be incorporated to accommodate fissile products. The use of multiple phases will create a stable fine grain size resistant to grain growth even at high temperatures. This fine grain size will enhance room-temperature fracture strength, decrease thermal shock, and increase high-temperature plasticity, making the materials more resistant to brittle fracture. The increased grain boundary and interface density in multiphase nanocrystalline materials may also improve the material's radiation stability, with grain boundaries serving as sources and sinks for point defects. Improvements in thermal conductivity as a function of second phase material properties, phase fractions, and microstructural distribution will be not only experimentally characterized but also modeled using object-oriented finite element analysis (OOF2, from NIST).

This project uses the complementary skills from four diverse groups of researchers at three universities and one National Laboratory. Each group brings critical expertise to the project to understand how to design nanocrystalline multiphase fuels that will have enhanced plasticity, radiation tolerance, and thermal conductivity. Martha Mecartney at the University of California, Irvine is responsible for the development of the multiphase ceramics, microstructural analysis by advanced electron microscopy and diffraction techniques, experimental characterization of creep and thermal shock, and computational modeling of thermal properties based on object-oriented finite element analysis using material microstructures. Olivia Graeve at the University of California, San Diego is responsible for the fabrication of multiphase nanocrystalline ceramic materials using spark plasma synthesis and novel nanoparticle synthesis techniques. Andy Nelson at Los Alamos National Laboratory is responsible for the characterization of thermal properties and nuclear fuel design. Maulik Patel at the University of Tennessee, Knoxville is responsible for neutron and X-ray diffraction studies and radiation-induced modification studies using ion beam irradiations.