# Development of an Innovative High-Thermal Conductivity $UO_2$ Ceramic Composites Fuel Pellets with Carbon Nano-Tubes Using Spark Plasma Sintering

**PI**: Ghatu Subhash – University of Florida

**Collaborators**: Kuang-His Wu – Florida International University

**Program**: FCR&D

**ABSTRACT**

Uranium dioxide (UO2) is the most common fuel material in commercial nuclear power reactors. Despite its numerous advantages such as high melting point, good high-temperature stability, good chemical compatibility with cladding and coolant, and resistance to radiation, it suffers from low thermal conductivity that can result in large temperature gradients within the UO2 fuel pellet, causing it to crack and release fission gases. Thermal swelling of the pellets also limits the lifetime of UO2 fuel in the reactor. To mitigate these problems, we propose to develop novel UO2 fuel with uniformly distributed carbon nanotubes (CNTs) that can provide high-conductivity thermal pathways and can eliminate fuel cracking and fission gas release due to high temperatures.

CNTs have been investigated extensively for the past decade to explore their unique physical properties and many potential applications. CNTs have high thermal conductivity (6600 W/mK for an individual single-walled CNT and >3000 W/mK for an individual multi-walled CNT) and high temperature stability up to 2800°C in vacuum and about 750°C in air. These properties make them attractive candidates in preparing nano-composites with new functional properties.

The objective of the proposed research is to develop high thermal conductivity of UO2–CNT composites without affecting the neutronic property of UO2 significantly. The concept of this goal is to utilize a rapid sintering method (5–15 min) called spark plasma sintering (SPS) in which a mixture of CNTs and UO2 powder are used to make composites with different volume fractions of CNTs. Incorporation of these nanoscale materials plays a fundamentally critical role in controlling the performance and stability of UO2 fuel. We will use a novel in situ growth process to grow CNTs on UO2 particles for rapid sintering and develop UO2-CNT composites. This method is expected to provide a uniform distribution of CNTs at various volume fractions so that a high thermally conductive UO2-CNT composite is obtained with a minimal volume fraction of CNTs. The mixtures are sintered in the SPS facility at a range of temperatures, pressures, and time durations so as to identify the optimal processing conditions to obtain the desired microstructure of sintered UO2-CNT pellets.

The second objective of the proposed work is to identify the optimal volume fraction of CNTs in the microstructure of the composites that provides the desired high thermal conductivity yet retaining the mechanical strength required for efficient function as a reactor fuel. We will systematically study the resulting microstructure (grain size, porosity, distribution of CNTs, etc.) obtained at various SPS processing conditions using optical microscopy, scanning electron microscopy (SEM), and transmission electron microscope (TEM). We will conduct indentation hardness measurements and uniaxial strength measurements as a function of volume fraction of CNTs to determine the mechanical strength and compare them to the properties of UO2. The fracture surfaces will be studied to determine the fracture characteristics that may relate to the observed

cracking during service. Finally, we will perform thermal conductivity measurements on all the composites up to 1000° C. This study will relate the microstructure, mechanical properties, and thermal properties at various volume fractions of CNTs. The overall intent is to identify optimal processing conditions that will provide a well-consolidated compact with optimal microstructure and thermo-mechanical properties.

The deliverables include: (1) fully characterized $UO_2$-CNT composite with optimal CNT volume fraction and high thermal conductivity and (2) processing conditions for production of $UO_2$-CNT composite pellets using SPS method.