Project Title: Spark plasma sintering for nuclear fuel and alloy fabrication at Massachusetts Institute of Technology

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Abstract: The objective of this NEUP infrastructure project is to acquire a state-of-the-art spark plasma sintering (SPS) set up to enhance the Massachusetts Institute of Technology (MIT)'s educational and research capabilities in high throughput nuclear fuels, sensor materials, cladding materials, and reactor structural materials fabrication. This would add new capability to our role as a Nuclear Science User Facilities (NSUF) partner. Besides supporting the mission of the DOE-NE and fast-tracking the design of materials for advanced nuclear reactors, the proposed SPS infrastructure will provide hands-on educational training for our students in advanced manufacturing and nuclear materials fabrication. We have strong capabilities in materials irradiation experiments and thermophysical properties measurement. The acquisition and installation of the SPS will complete the whole materials design loop. The SPS can reach a temperature of 2500 ^{o}C and operate in controlled environments such as Ar, He, and N_2. The heat rate can be programmed to 1000 ^{o}C or higher with various sample molds designated for radioactive and non-radioactive materials sintering.

Several techniques have been considered to reduce the sintering temperature of materials, including nuclear fuels. For instance, the production of highly dense ThO_2 by conventional sintering techniques only occurs at high temperatures >2000 ^{o}C, and adding additives lowers the sintering temperature but introduces point defects. We have recently fabricated high-density ThO_2[1] and ThO_2-SiC[2] composite fuels using the SPS technique. The X-ray diffraction analysis of the fabricated composite pellets indicates that SPS could produce pellets without intermetallics or reaction products. While this technique shows promising results, SPS is only accessible in two national laboratories and very few universities where they may be used for only non-radioactive materials sintering. Meanwhile, a further fundamental understanding of the densification process is still lacking for scaling SPS as a commercial manufacturing technique, especially for nuclear fuel pellet fabrication. Acquisition of the SPS system would allow us to develop a database of processing parameters for a series of materials. This can enable us to develop sintering curves and predictable sintering parameters and incorporate them into existing sintering models to improve the fuel fabrication process.

Therefore, the project will benefit from the additional infrastructure proposed here by advancing the state-of-the-art understanding of materials sintering and solid-state fabrication process. Our goal is to provide access to the nuclear materials community with the capacity to handle radioactive samples. Such access will not be limited to researchers at MIT including support irradiation activity at MIT reactor (MITR) and collaborators but to researchers from other institutions through the NSUF program to provide the tools necessary to answer questions regarding actinide fabrication that will undoubtedly arise as we develop advanced reactors.

[1] L. Malakkal, A. Prasad, J. Ranasinghe, E. Jossou, D. Oladimeji, B. Szpunar, L. Bichler, J. Szpunar, Journal of Nuclear Materials 527 (2019) 151811.

[2] L. Malakkal, A. Prasad, J. Ranasinghe, E. Jossou, L. Bichler, J. Szpunar, Nuclear Engineering and Technology (2023).