NUCLEAR ENERGY RESEARCH INITIATIVE

The Application of Self-Propagating High-Temperature Synthesis (SHS) to the Fabrication of Actinide Bearing Nitride and Other Ceramic Nuclear Fuels

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Collaborators: Idaho National Laboratory

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Related Program: AFCI

Project Description

This project will use an exothermic combustion synthesis method, termed self-propagating high-temperature synthesis (SHS), to produce high quality, reproducible nitride fuels and possibly other ceramic type nuclear fuels (cercers and cermets, etc.) in conjunction with the fabrication of transmutation fuels. This method of fuel fabrication has potential application in the production of other nuclear energy (advanced reactors and space reactors) as well as space nuclear propulsion reactor designs. The method, which is based on the concept of high reaction and cooling rates, is applicable to a wide variety of ceramic and intermetallic materials including nitrides, zirconides, oxides, carbides, oxycarbides, carbonitrides, and chalcogenides, which have been synthesized using SHS techniques for a range of applications. SHS offers a number of advantages that are suitable for remote processing of radioactive materials, such as one-step synthesis and consolidation, simplicity, and ease of containment, equating to reduced cost and high product throughput. Careful control of operational parameters offers the possibility of tailoring material properties to specific requirements.

The major research objective of this project is to determine the fundamental SHS processing parameters by first using manganese as a surrogate for americium to produce dense Zr-Mn-N ceramic compounds. These fundamental principles will then be transferred to the production of dense Zr-Am-N ceramic materials. Because of the high vapor pressures of Am and americium nitride (AmN), there is concern about producing nitride ceramic nuclear fuels containing Am. Sintering results in major retention problems of Am with current processing methods and it adversely affects the synthesis of a consistent product with desirable homogeneity, density, and porosity. Similar difficulties experienced during laboratory-scale process development for producing metal alloys containing Am have led researchers to abandon compact powder sintering methods and investigate other synthesis methods, such as SHS.

A further research objective in this research program will be to generate fundamental SHS processing data to the synthesis of (i) Pu-Am-Zr-N and (ii) U-Pu-Am-N ceramic fuels. In this case, Ce will be used as the surrogate for Pu, Mn as the surrogate for Am, and depleted uranium. The sequence for SHS synthesis of these ceramic fuels will be as follows:

(i) Pu-Am-Zr-N: using Ce as the surrogate for Pu, and Mn as the surrogate for Am
   a. $(Ce_{0.5}Mn_{0.5})N$
   b. $64wt\%[(Ce_{0.5}Mn_{0.5})N]-36wt\%ZrN$

(ii) U-Pu-Am-N: using depleted uranium (DU), Ce as the surrogate for Pu, and Mn as the surrogate for Am:

a. $(DU_{0.5}Mn_{0.5})N$
b. $(DU_{0.5}Ce_{0..25}Mn_{0..25})N$

Once sufficient fundamental data has been determined for these surrogate systems, this will be transferred to Idaho National Laboratory (INL) for synthesis of Zr-Am-N, Pu-Am-Zr-N and U-Pu-Am-N ceramic fuels. At this point in the research program, one of the two Ph.D. students will transfer to INL to work with Dr. Rory Kennedy on this technology transfer, while the second Ph.D. student will continue the work at CSM in generating more fundamental SHS data on the surrogate SHS systems.

Work Scope

- Synthesize porous zirconium-nitride and manganese-nitride compounds using high pressure N_2 gas. The porous nitrides are readily ground into powder for subsequent processing. Fundamental thermochemical property data will be collected throughout and the processes optimized.
- Synthesize dense Zr-Mn-N (ZrAmN) compounds using a one-step SHS consolidation process. Determine fundamental thermochemistry and kinetic data, and optimize the process.
- Synthesize porous $(Ce_{0.5}Mn_{0.5})N$
- Synthesize dense 64wt%[$(Ce_{0.5}Mn_{0.5})N$]-36wt%ZrN
- Synthesize $(DU_{0.5}Mn_{0.5})N$
- Synthesize dense $(DU_{0.5}Ce_{0.25}Mn_{0.25})N$
- Transfer the technology to synthesize dense Zr-Am-N, Zr-Am-N, Pu-Am-Zr-N and U-Pu-Am-N ceramic compounds containing uranium and plutonium, and optimize the processes.