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Design and Analysis of a Process for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides

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Task 1

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BACKGROUND

The incorporation of non-fertile actinides into a fuel matrix for a transmuter blanket is of interest to the Advanced Fuel Cycle Initiative (AFCI). One of three currently proposed candidate matrices for the transmuter is a metallic alloy fuel matrix. Metallic fuels are an outstanding candidate for a transmutation fuel due to excellent irradiation performance and ease of fabrication. However, incorporating a volatile constituent during fabrication of these or other fuel pins presents a challenge.

Volatile actinides, particularly americium, are susceptible to rapid vaporization during the traditional metal fuel casting processes. The actinide vapors boil off, and flow out of the system into the off-gas recovery system, resulting in only a fraction of the volatile actinide charge being incorporated into the fuel pins. The loss of these actinides from the fuel greatly complicates the task of preparing them for transmutation, requiring additional recovery and fuel fabrication steps to try to incorporate the volatile actinides into the transmuter fuel.

RESEARCH OBJECTIVES AND METHODS

The goal of this project is to investigate the casting processes for metallic fuels to help design a process that minimizes the loss of the volatile actinide elements from the fuel. The research effort centers on the development of advanced numerical models to assess conditions that significantly impact the transport of volatile actinides during the melt casting process and represents a joint effort between researchers at UNLV and Argonne National Laboratory (ANL). Assessing critical equipment and process variables is required to build a successful system that will operate efficiently.

RESEARCH ACCOMPLISHMENTS

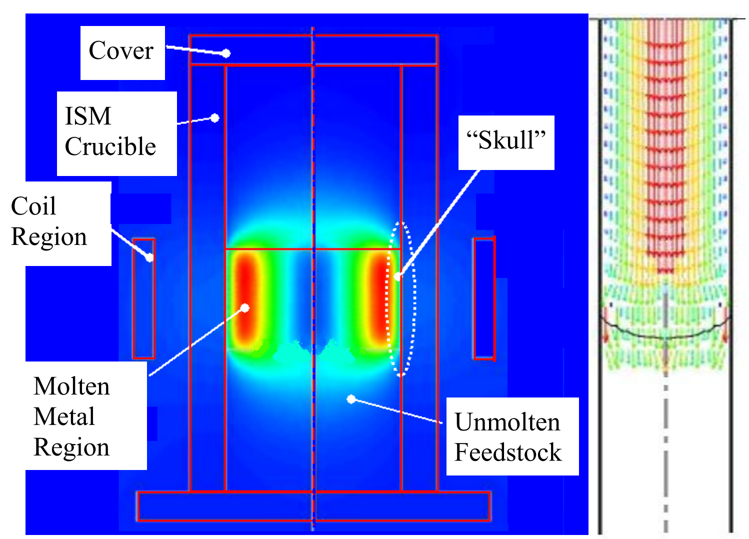
Development of the induction-heating model: Modeling efforts centered on the development of the governing equations, incorporating these equations into computer codes, setting up a test problem, and making preliminary calculations for the geometry of interest. Detailed analyses were conducted for an Induction Skull Melter (ISM) previously built and tested by ANL.

Modeling of casting process: Efforts continued to improve a model for the casting of fuel pins. Work considered the flow of the melt into the mold and heat transfer into the mold during solidification (after flow has stopped). Results from an energy balance model indicate that the thermal mass would typically be greater than needed to solidify the melt within the mold. The results of this simple model have aided in designing a mold to hold and solidify the fuel pins. Detailed flow and heat transfer models show how the melt flows into the mold and ultimately solidifies.

In order to test the impact of process parameters (temperature, pressure, alloying elements, etc.) on the casting process, parametric studies were carried on different processing parameters. These studies centered around model development and analysis of the impact of mold preheating on heat transfer into the model. Results will assist with determining which process parameters are critical in manufacturing a suitable metallic fuel pin.

Americium Transport Models: A model that analyzes the transport of americium from the melt to the vapor phases above the crucible has also been developed. The model considers mass transport in the melt, vaporization at the surface, and transport through the vapor phase. Parametric studies are underway to evaluate the impact of different properties or situations on the transport of americium from the melt.

Develop Prototype Furnace Design: A preliminary furnace design that can be built and tested with surrogate materials is critical in order to assess the viability of metal fuels. A preliminary analysis of potential surrogate materials has been



Induction skull melting process in the crucible and the casting process in a metallic fuel pin mold. Rapid heating occurs near the surface of the melt region (small localized region of high heat generation). Flow into mold occurs rapidly with the flow solidifying near the walls initially, fluid near centerline then flows out past the solidified material to touch the walls of the mold.

completed. Manganese appears to be an acceptable surrogate material. Discussions will be held with Argonne National Laboratory staff members to insure that no health and safety issues prevent manganese from being used in future tests.

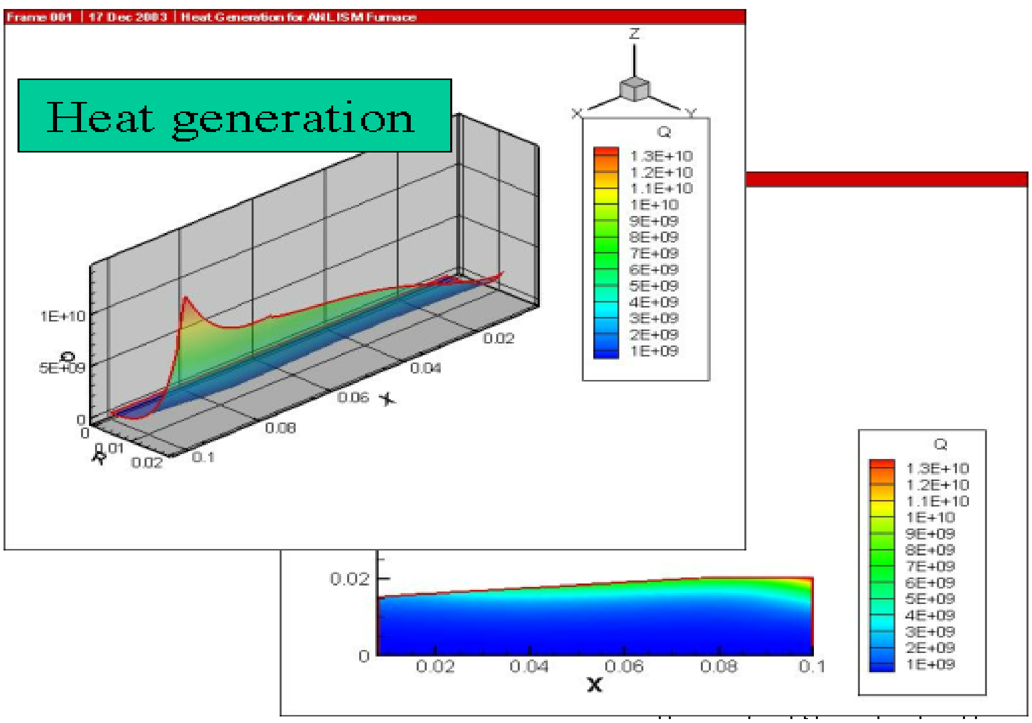
FUTURE WORK

The following are research objectives for future research:

- Continue analysis of americium transport and loss from the melt process using the combined heat and mass transfer models developed at UNLV.
- Continue to revise and refine the combined heat and mass transfer model of representative furnace geometry.
- Benchmark and validate the model through comparisons to experimental tests.
- Develop a complete model that incorporates all of the complex physics and test its ability to model the complete system.

HIGHLIGHTS

- "Simulation and Analysis for Melt Casting a Metallic Fuel Pin Incorporating Volatile Actinides," ASME International Mechanical Engineering Congress and R&D Expo, Washington, DC, November 16-21, 2003.
- "Design and Numerical Simulation of an Induction Skull Melting Process," ANS Student Conference, Madison, WI, April 1-3, 2004.
- "Numerical Simulation of an Induction Heating Process in an Induction Skull Melting Furnace," International Symposium on Advances in Computational Heat Transfer, April 19-24, 2004, Norway.
- "Simulating the Casting Process for Melt Casting a Metallic Fuel Pin" and "Simulating the Induction Heating Process in an Induction Skull Melter for Casting Metallic Fuel," 12th International Conference on Nuclear Engineering (ICONE), Arlington, VA, April 25-29, 2004.



2-D (lower right) and 3-D (upper left) view of the time average power deposition (x (m), Q (w/m3) inside of induction skull melting furnace. 3D view (upper left) shows rapid rise in power deposition near the outer edge of the melt. x is the distance from bottom of crucible – other dimension shows the radial variation of the heat deposition. Q is the heat generation or power deposition rate within the melt material. Model is able to capture the skin heating effect and the sharp gradients near the surface of the melt.

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