

Task 1

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

Y. Chen, D.W. Pepper, and R. Clarksean

BACKGROUND

The incorporation of non-fertile actinides into a fuel matrix for a transmuter blanket is of interest to the Advanced Fuel Cycle Initiative. One of three 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.

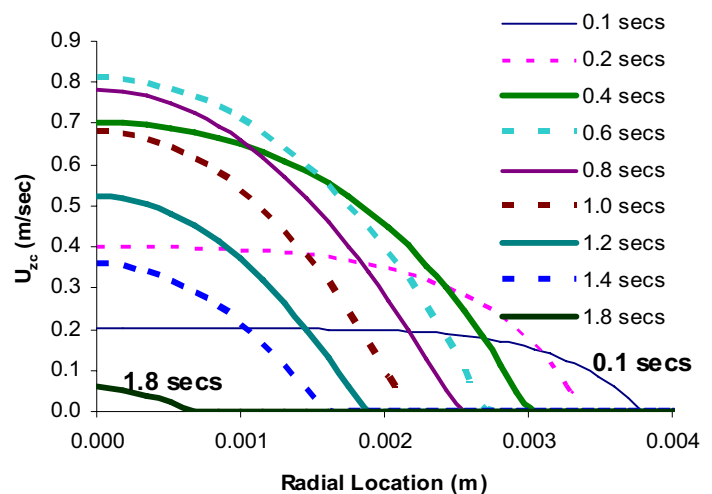
Modeling of casting process: Efforts continued to improve a model for the casting of fuel pins. Work considered the flow of the melt into the mold and heat transfer into the mold during solidification (after flow has stopped). Results from an energy balance model indicate that the thermal mass would 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 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.



Axial velocity profile for constant inlet pressure of 20 kPa (Mold temperature = 400°C, initial melt temperature = 1500°C, interfacial heat transfer coefficient = 2,000 W/m²-K).

TASK 1 PROFILE

Start Date: June 2001

Completion Date: June 2004

Theses Generated:

Xiaolong Wu, M.S., Mechanical Engineering, "Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides," August 2002.

Taide Tan, M.S., Mechanical Engineering, "Design and Simulation of an Induction Skull Melting System," May 2004.

Journal Article:

T. Tan, R. Clarksean, Y. Chen, S. Hsieh, and M. Meyer, 2004, "Simulation of the Casting Process for Melt Casting a Metallic Fuel Pin," submitted to *Nuclear Engineering and Design* – under review.

Conference Proceedings:

T. Tan, R. Clarksean, Y. Chen, S. Hsieh, and M. Meyer, "Analyzing a Process for Casting Volatile Actinides," *6th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Operations and Safety*, Nara, Japan, October 4-8, 2004.

T. Tan, R. Clarksean, Y. Chen, S. Hsieh, S., and M. Meyer, "Numerical Simulation of an Induction Heating Process in an Induction Skull Melting Furnace," *ICHMT International Symposium on Advances in Computational Heat Transfer*, Norway, April 19-24, 2004.

T. Tan, R. Clarksean, Y. Chen, S. Hsieh, and M. Meyer, "Simulating the Casting Process for Melt Casting a Metallic Fuel Pin," *12th International Conference on Nuclear Engineering (ICONE-12)*, Arlington, VA, 25-29, 2004.

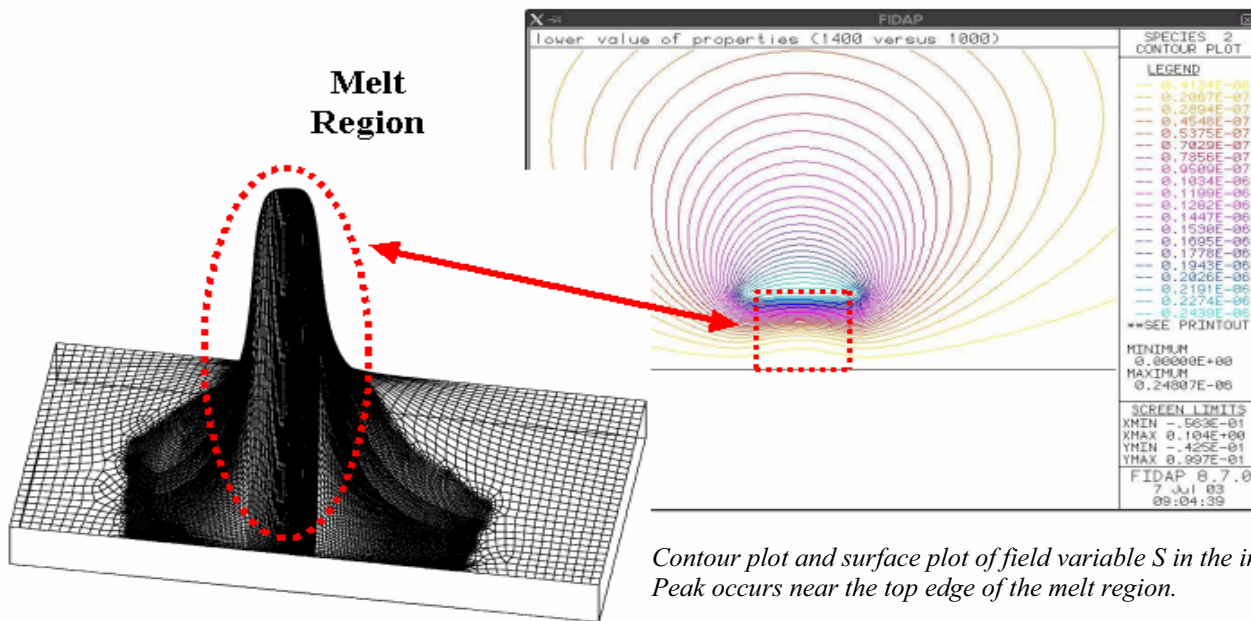
T. Tan, R. Clarksean, Y. Chen, S. Hsieh, and M. Meyer, "Simulating the Induction Heating Process in an Induction Skull Melter for Casting Metallic Fuel," *ICONE-12*, Arlington, VA, April 25-29, 2004.

T. Tan, R. Clarksean, Y. Chen, D. Pepper, and M. Meyer, "Simulation and Analysis for Melt Casting a Metallic Fuel Pin Incorporating Volatile Actinides" *International Mechanical Engineering Congress and Exposition*, Washington, DC, November 16-21, 2003.

X. Wu, R. Clarksean, Y. Chen, D. Pepper, and M.K. Meyer, "An Analysis of the Melt Casting of Metallic Fuel Pins," *International Mechanical Engineering Congress and Exposition*, New Orleans, LA, November 17-22, 2002.

X. Wu, R. Clarksean, Y. Chen, and D. Pepper, "Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides," *International Youth Nuclear Congress*, Daejeon, Korea, April 16-20, 2002.

X. Wu, R. Clarksean, and Y. Chen, "Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides," *International Congress on Advanced Nuclear Power Plants*, Hollywood, FL, June 9-13, 2002.



Research Staff

Yitong Chen, Principal Investigator; Associate Professor, Mechanical Engineering Department; Associate Director, NCACM
Darrell W. Pepper, Professor, Mechanical Engineering Department; Director, Nevada Center for Advanced Computational Methods
Randy Clarksean, Adjunct Professor, Mechanical Engineering Department

Students

Taide Tan and Xiaolong Wu, Graduate Students, Mechanical Engineering Department
Yulien Chen and Paul Lawson, Undergraduate Students

Collaborators

Mitchell K. Meyer, Leader of Fabrication Development Group, Nuclear Technology Division, Argonne National Laboratory
Steven L. Hayes, Manager of Fuels & Reactor Materials Section, Nuclear Technology Division, Argonne National Laboratory