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Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides: Quarterly Progress Report 8/16/01- 11/15/01

Yitung Chen
University of Nevada, Las Vegas

Randy Clarksean
University of Nevada, Las Vegas

Darrell Pepper
University of Nevada Las Vegas, pepperu@nye.nscee.edu

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Phase I: Design and Analysis for Melt Casting Metallic Fuel Pins
Incorporating Volatile Actinides

Quarterly Progress Report
8/16/01- 11/15/01

UNLV-AAA University Participation Program

Principle Investigator: Yitung Chen
Co-Principle Investigators: Randy Clarksean and Darrell Pepper

Purpose and Problem Statement

An important aspect of the Advanced Accelerator Applications (AAA) program is the development of a casting process by which volatile actinide element (i.e., americium) can be incorporated into metallic alloy fuel pins. The traditional metal fuel casting process uses an inductively heated crucible. The process involves evacuation of the furnace. The evacuation of the furnace also evacuates quartz rods used as fuel pin molds. Once evacuated the open ends of the molds are lowered into the melt; the casting furnace is then rapidly pressurized, forcing the molten metal up into the evacuated molds where solidification occurs.

This process works well for the fabrication of metal fuel pins traditionally composed of alloys of uranium and plutonium, but does not work well when highly volatile actinides are included in the melt. The problem occurs both during the extended time period required to superheat the alloy melt as well as when the chamber must be evacuated. The low vapor-pressure actinides, particularly americium, are susceptible to rapid vaporization and transport throughout the casting furnace, resulting in only a fraction of the charge being incorporated into the fuel pins as desired. This is undesirable both from a materials accountability standpoint as well as from the failure to achieve the objective of including these actinides in the fuel for transmutation.

Candidate design concepts are being evaluated for their potential to successfully cast alloys containing volatile actinides. The selection of design concepts has been conducted in close cooperation with ANL staff. The research centers on the development of advanced numerical models to assess conditions that significantly impact the transport of volatile actinides during the melt casting process. The work will include the collection and documentation of volatile actinide properties, development of several conceptual designs for melt casting furnaces, modeling and analysis of these concepts, development of sophisticated numerical models to assess furnace operations, and analysis of these operations to determine which furnace concept has the greatest potential of success. Research efforts will focus on the development of complex heat transfer, mass transfer, and inductive heating models.
Personnel

Principle Investigator:
• Dr. Yitung Chen (Mechanical Engineering)

Co-Principle Investigators:
• Dr. Randy Clarksean (Mechanical Engineering)
• Dr. Darrell Pepper (Mechanical Engineering)

Student:
• Mr. Xialong (Frank) Wu, M.S. Graduate Student, (Mechanical Engineering)

National Laboratory Collaborators:
• Dr. Mitch Meyer, Leader of Fabrication Development Group, ANL-West
• Dr. Steve Hayes, Manager of Fuels & Reactor Materials Section, Nuclear Technology Division, ANL-West

Management Progress

Budget Issues:
• Purchase of annual user license of commercial computational fluid dynamics code (FIDAP)
• One computer system has been ordered for Mr. Wu and other one will be ordered in December or January for the undergraduate student
• Most of the major equipment budget has been spent
• Salary expenditures need to be adjusted because the secretary of mechanical department has not revised the correct student name based upon the proper account number

Management Problems

The first year budget of the phase I research task is from 05/01/01 to 04/30/02. Since the budget was started when the school was still in the spring semester, it was very difficult to implement the budget immediately. It was because student and faculty all had other research supports from the federal or local government during that time. The contracts for Mr. Wu and Dr. Clarksean were start from June 1, 2001. Therefore, we would like to make a request to extend the first year budget to the end of June or July 2002 without any additional cost. It will also be very helpful for us to carry over the first year budget to the second year without any additional cost if our phase II proposal is funded. It is because of the soft money salary issues. The other problem is the serious delay on the travel reimbursement which it usually takes more than 6 weeks to get travel money back to traveler.

We are still looking for one undergraduate student to work with us on this project. Many undergraduates already had their part-time jobs in or out of UNLV campus. Some of
them will be available from the spring semester 2002. We will keep contacting with qualified student and recruit him/her in the beginning of spring semester 2002.

**Technical Progress**

Progress meetings at Argonne National Laboratory in Idaho were very productive on October 1, 2001. The intent of the meeting was to select the design, which had the greatest chance of success for casting americium. An induction skull melter (ISM) concept was selected and will be analyzed in detail for the rest of the year. The design includes a

- Segmented copper crucible,
- NaK cooling loop for crucible,
- Cover for the crucible region to minimize Americium transport,
- Set of “chill” molds for the fuel rods, and a
- Set of resistance heaters to control the preheat of the chill molds.

This design leads to three basic areas for modeling. These areas are americium transport (impact of increased pressure and confinement), processing times, and fuel casting. A general approach for the americium transport has been identified and attempts are being made to locate materials property data. A general model of the casting crucible region is being developed at present. The fuel casting model has been developed and preliminary analyses have been completed.

The casting model has to take into account heat transfer, fluid flow, phase change, material properties, and preheat conditions for the chill molds. The general-purpose finite element code FIDAP™ is being used for these analyses. The long length-to-diameter ratio of the fuel rod makes the problem more complex and more expensive computationally. The fuel rod casting geometry is shown schematically in Figure 1.

![Figure 1. Schematic of casting model. Axisymmetric model of geometry used to simplify problem.](image-url)
The fluid is considered to be molten as it enters the domain and it is cooled as it flows into the mold. The model considers preheating along the length of the mold. For the simulations to be shown in the figures that follow, the initial temperature profile varied from 1500°C on the left end to 1000°C on the right end of the mold. The molten material initially enters the domain at 1500°C.

Figure 2 shows the velocity field as the fluid enters the mold from the casting crucible region (left side of schematic in Figure 1). Figure 3 shows the temperature distribution within the mold and the molten fuel as a function of time.

Figure 2. Velocity vectors of melt flowing into chill mold (transient conditions). Red represents high velocities; blue represents lower velocities. Entrance velocity assumed to be 0.4 m/sec.

Figure 3. Temperature distribution of melt and mold as melt flows into the chill mold. Red represents a temperature of 1500°C, while blue represents a temperature of 1000°C.
The modeling is progressing well. These models are very computationally expensive, hence they require significant amounts of computing time. Future modeling efforts will consider the impact of mold preheating on the flow and solidification into the mold. A parametric study will be performed to determine what conditions would work best for casting a long slender fuel rod.