8-30-2001

Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides: Quarterly Report 5/15/01-8/15/01

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Quarterly Report

5/15/01-8/15/01

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

Submitted to

Advanced Accelerator Applications Program
Technical Focus Area
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August 30, 2001

Management Issues:

Mr. Xialong (Frank) Wu, who is a master program student of the Mechanical Engineering Department, has been working on this project since June 1, 2001. He has been paid $1,500 per month from 6/1/01 to 8/31/01. Dr. Randy Clarksean, who is an adjunct professor of the Mechanical Engineering Department, has also been working on this project since June 1, 2001. He will receive his paycheck in the end of August since his contract document wasn't able to go through the campus administration system in time. Dr. Darrell W. Pepper, who is a professor and chairman of the Mechanical Engineering Department, has also provide many technical suggestions in this project. A regular group research meeting is held very Monday afternoon to discuss the technical issues.

The project kick-off meeting was held at HRC in the UNLV campus from June 21 to 22, 2001. Dr. Mitchell K. Meyer, who is the project leader of fabrication development group in the ANL-West, has attended the kick-off meeting at UNLV. Many technical issues and information have been discussed and exchanged during the meeting. Mr. Xialong Wu, Dr. Clarksean, and I will go to Idaho Fall from September 30 to October 1, 2001 to discuss our six conceptual of casting furnace designs with Dr. Meyer and his staff at ANL-West. Mr. Wu has also presented his research project to Dr. Magwood and his staff from DOE on June 29, 2001. He will also be encouraged to participate and present a paper in the American Nuclear Society Winter Meeting, November 10-12, 2001, in Reno, Nevada. Dr. Clarksean and I will also attend the Argonne Workshop on Fuel Development for Actinide Transmutation Systems at Idaho Fall, November 19-21, 2001.

The proposed timeline for research tasks has been followed. A few actinide chemists from ANL or LANL are needed to help us to track down and document the volatile actinide transport properties. Dr. Denis Bellow has been consulted to provide a list of contact people in LANL. The academic annual license of using commercial software FIDAP at UNLV will be purchased in September. One Pentium IV Gateway personal computer will also be purchased in the end of August.

Technical Issues:

Six candidate casting furnace concepts have been identified. These concepts were developed in conjunction with ANL-West researchers at a kick-off meeting. The six concepts include:

- Inductively heated pressurized chamber vacuum cast
- Inductively heated pressurized chamber
- Inductively heated – continuous casting.
- DC Arc melting and casting.
- Induction skull melting and casting.
- Semi-levitation melting and casting.

Each of the different concepts is being evaluated for their advantages and disadvantages. The items under consideration include how pressure or other approaches can impact the transport of volatile actinides from the melt. An extensive literature review is in process to assist in the evaluation of each of the proposed concepts.

(1) DC Furnace:

A: DC Graphite ARC furnace and diagnostic system for soils

- Members: MIT plasma fusion center, Electro-Pyrolysis Inc, Pacific northwest lab
- Advantages: (a) single electrode eliminating the consumption of electrodes due to surface oxidation (50%); (b) ease of power control; (c) high energy transfer efficiency; (d) lower carbon consumption; (e) melts easily processed

B: DOE-1999

- Advantages: (a) a single, high temperature thermal process for melting and fuel fabrication (melting temperature is 1500^{o}C); (b) can deal with a wide range of materials (debris, trash, metals, soil, etc)
- Disadvantages: high temperatures may lead to volatilization of Americium

C: ABB DC arc furnace: past, present, future

- Advantages: (a) reduction of graphite electrode consumption; saves on electric power (5%); (b) long arc operating with foaming slag to shield the arc and to improve heat transfer to the charge; (c) easier to control of the melting process (electromagnetic force);
- Disadvantages: the graphite-containing bottom materials are more expensive

D: Analysis of velocity and temperature fields of molten metal in DC electric arc furnace

- Summary: (a) the circulating patterns and the patterns of increasing the temperature of the melt is significantly affected by the change in bottom electrode diameter; (b) the effect of natural convection on the circulation is negligible.
- Advantages: (a) comparing to AC furnace, DC can deliver heat directly to the melt; (b) reduction of the electrode-tip erosion rate (about 40%);
- Introduction: electrically induced flow (EIF) plays an important role, the actual flow within the molten metal is caused by following driving forces: (a) electromagnetic force generated by arc; (b) natural convection due to temperature gradient; (c) the interaction between the arc plasma and the bath.
- This model consider simultaneously the magnetohydrodynamic and thermodynamic effects

E: DC furnace at Florida Steel Corp. in Tampa/USA

- Advantages: (a) one single electrode (700mm) minimizes the consumption of electrodes, low wear rate and the use of standard MgO ramming materials save refractory costs; (b) comparing to AC furnace, DC will result in a saving of 5.10\$/t_{liquid};
- Notes: The design always focuses on the design and the economy of the anode. Now they have a 60 t DC arc furnace.

F: Improving efficiency of DC arc furnace using oxyfuel cum lances and auxiliary electrodes

- Use of auxiliary and/or oxyfuel burners

(2) Induction Skull Melting:

A: Duriron Co. Dayton, OH and USBM (the United States Patent: 4738713 describe the same model)

- Advantages: alloy uniformity due to the intense stirring action of induction field; Greater melting efficiencies by splitting the crucible into more segments; Also the increased number of crucible segments may render the crucible discontinuous enough to levitate the melt sufficiently to prevent excessive arcing and resulting crucible damage; copper crucible avoiding reaction and contamination; flexibility in charge stock; the induction field and constant stirring of metal maintain a high level of superheat throughout the melt.
- Disadvantages: the process is limited to about 85 lb of molten metal per heat; Electrical efficiency is only about 30% (much of power is attenuated by the crucible).
- One promising area for ISM is the casting of clean (very low inclusion content) metals, particularly nickel-bass superalloys used for aerospace applications.
- Notes: the original and former design of ISM use calcium fluoride or any other slag materials preventing crucible damage

B: Analysis of Induction Skull Melting Furnace by Edge Finite Method Excited from Voltage Source

- Using the 3D edge-based finite element method (short computation time and low memory requirement) to analyze the magnetic flux density an eddy current and electromagnetic force distribution, we can optimize the production of the high-efficiency induction skull-melting furnace.
- The efficiency of the furnace depends to a great degree on the number of and the position of the copper rods and the size of the air gaps between them.

(3) Vacuum Casting:

A: Casting technology for manufacturing metal rods from simulated metallic spent fuels (Uranium metal rod)

- Advantages: (a) vacuum-induction furnace (10^{-3} Torr: prevent reaction to oxygen); (b) induction heating to provide self-stirring and homogeneity and fluidity; (c) directional-solidification equipment to prevent the formation of pores and shrinkage defects (we need to control the axial temperature gradient); (d) from the temperature gradient, we can predict solidification rate and lead the pores to the top of the rod.
- Notes: most nuclear power plants want to decrease the unit cost of electric power generation. Water-cooled.

All of the techniques, except the continuous casting approach, require the use of "molds" to form a fuel rod. The rods will have large length to diameter aspect ratios. A general finite element model is being developed to analyze the flow, heat transfer, and solidification of molten metal as it flows into the mold. The model will eventually consider

- Flow into the mold,
- Heat transfer to the mold,
- Phase change within the metal,
- Heat transfer from the mold to its surroundings,
- Heat transfer within the mold,
- Potential external heater control schemes to cast full length rods, and
- Transport of volatile actinides within the rod – if applicable.

The model presently considers the flow of a fluid into a long rod. The other physics will be added as the modeling work progresses. Preliminary modeling results are shown in Figure 1. A "volume of fluid" (VOF) method is used with the general-purpose code FIDAP to model the system. A mesh is developed for the complete domain and the molten material (fluid) flows into the geometry. A symmetry section is assumed for this problem, with the bottom of each section being the centerline of the "rod."

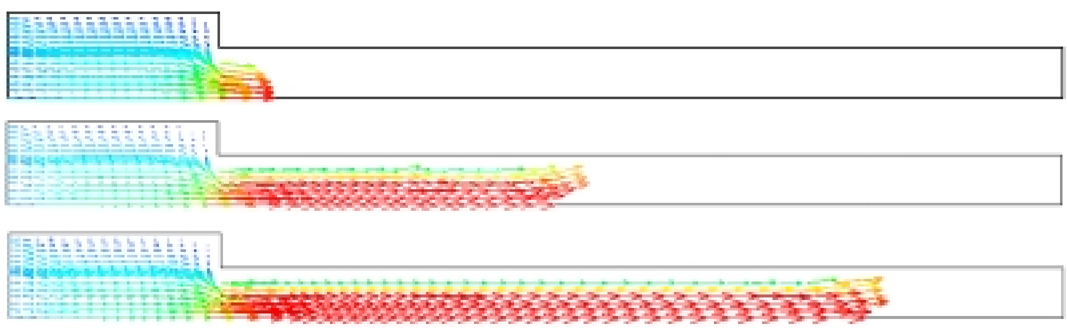

Figure 1 - Preliminary modeling results for the flow of a fluid into a cylindrical rod. Results obtained with the general purpose finite element code FIDAP. Bottom of each section represents the centerline (r=0).