U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Fuel Cycle Research and Development

Metallic Fuel Casting Development and Parameter Optimization Simulations

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International Conference on Fast reators and Related Fuel Cycles (FR13)

4-7 March 2013, Paris France

Outline

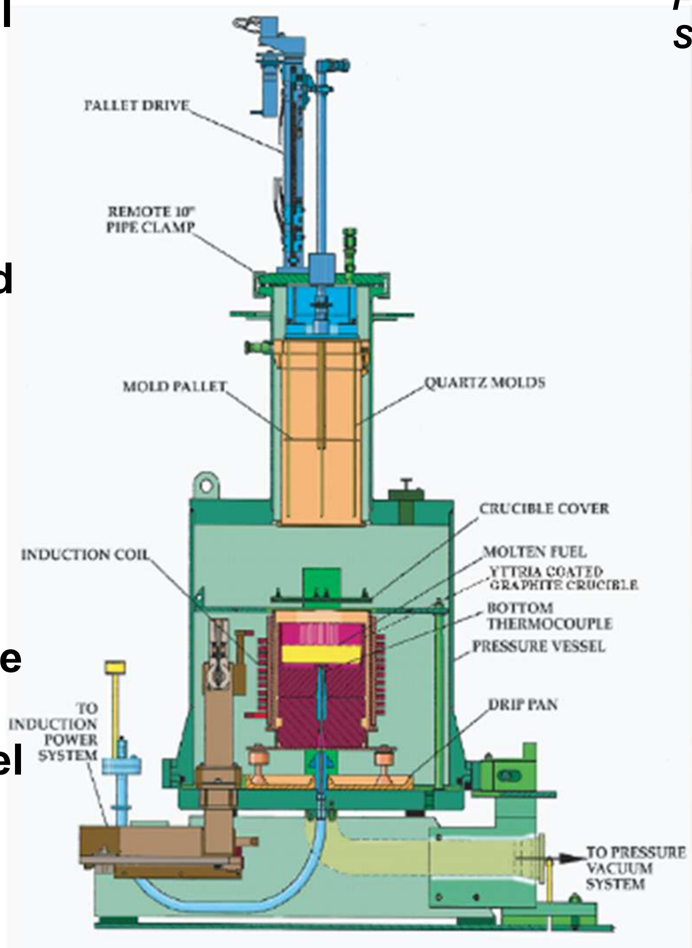
- **Introduction to metallic fuel casting**
  - History
  - Counter-gravity injection casting (CGIC)
- **Current Development Activities**
- **Experimental Results**
- **Parameter Optimization and Simulations**
  - Gas compressibility/venting
  - Surface tension
- **Conclusions**

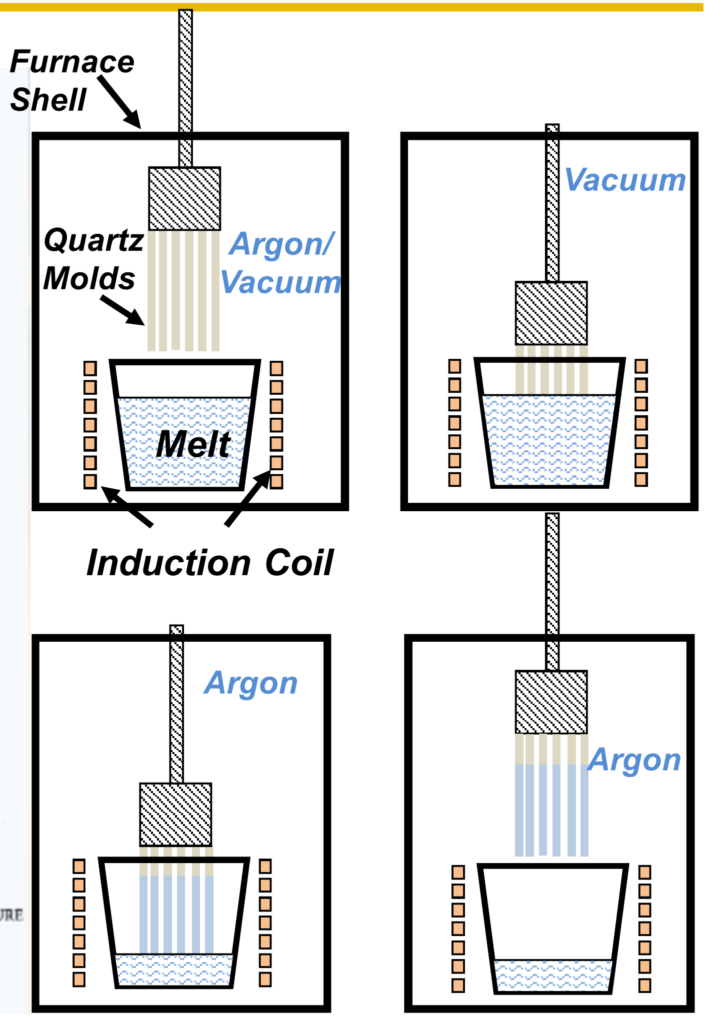
Introduction

- **Metallic fuel has been used for several decade in fast reactors**
  - Variety of sized and technologies led to a variety of fabrication methods
  - Fabrication method influence by fuel design and fabrication environment
    - *Large vs. small diameter*
    - *Hands-on/glovebox fabrication vs. remote/hotcell fabrication*
  - Several fabrication methods also used
    - *Deformation processes (extrusion, swaging, etc.)*
    - *Casting*
    - *Combination*
- **EBR-II provided the most recent U.S. experience on larger than laboratory scale**
  - Fuel for the EBR-II was fabricated using the counter gravity injection casting (CGIC) process
    - *Fuel fabrication was done both remotely and hands-on*
    - *Over 130,000 pins were cast and irradiated using this methods*

Introduction-CGIC

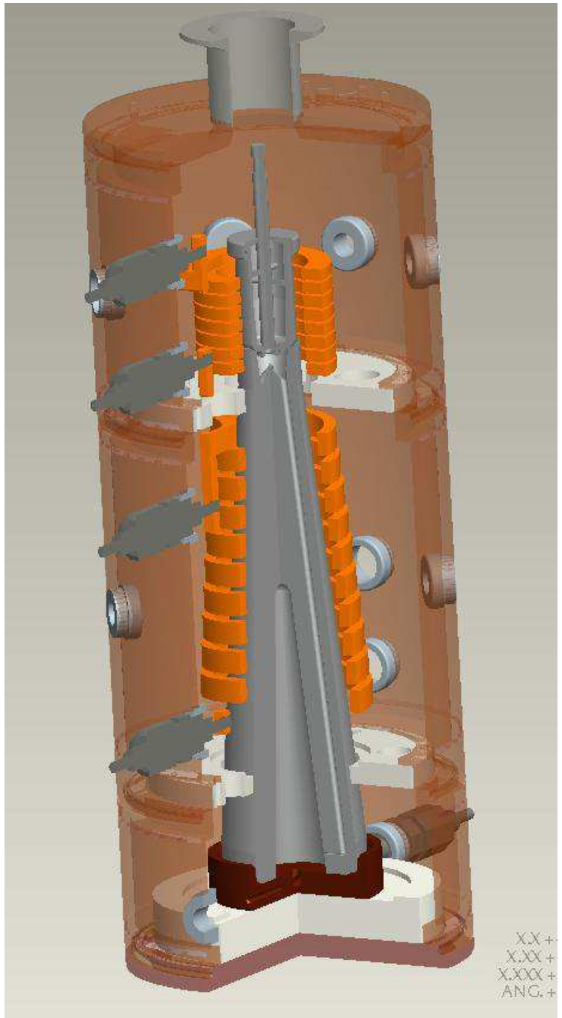
- CGIC worked well but had some efficiency disadvantages
- Large recycle stream- heels and end crops (~40% of melt)
- One time use molds create a large amount of waste
- Reduced pressure may affect transmutation fuel i.e. Am





Casting Development

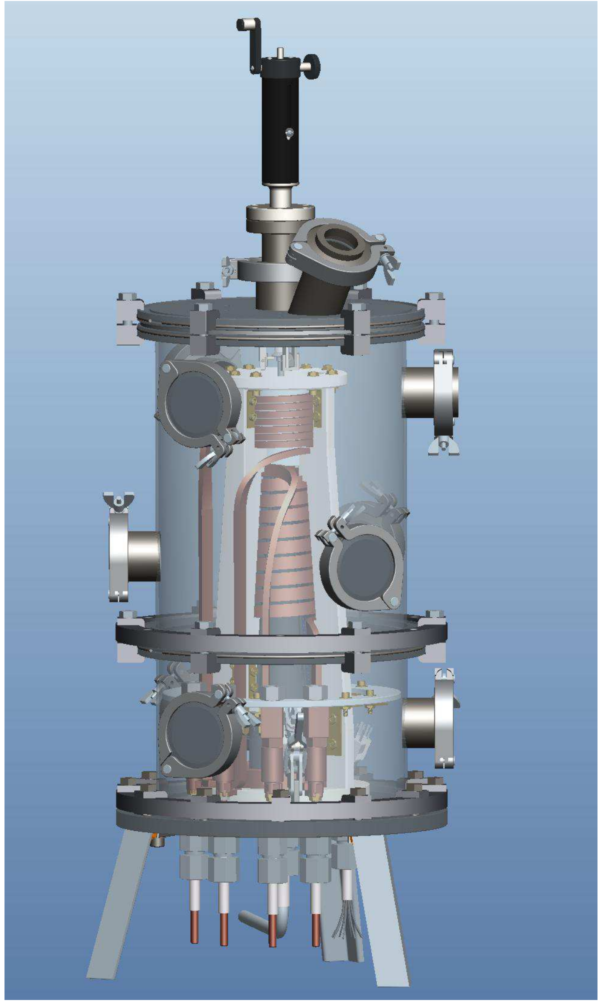
- **Bottom or gravity pour casting was seen as the lowest risk casting development path**
  - Wide spread industrial use
  - Scale-able from lab to engineering and production use
  - Does not require a reduced pressure (better for Am bearing fuels)
  - Increases melt utilization (large heel is not required and smaller end croppings)
  - Can be used for permanent mold development
- **First system was designed and used for uranium alloys (BCS)**
- **Second system has been designed and is currently being installed for use with Pu and minor actinide bearing casting (GACS)**



Casting Development

- **Initially using Y_2O_3 coated graphite molds and crucibles**
- **Current fuel slug size: 4.3 mm diameter x 250 mm long**
  - Based on EBR-II fuel diameter and was considered to be conservative
- **Mold and crucible are independently induction heated**
- **Designed to allow pressure differential assisted casting i.e. mold can be at a reduced pressure**

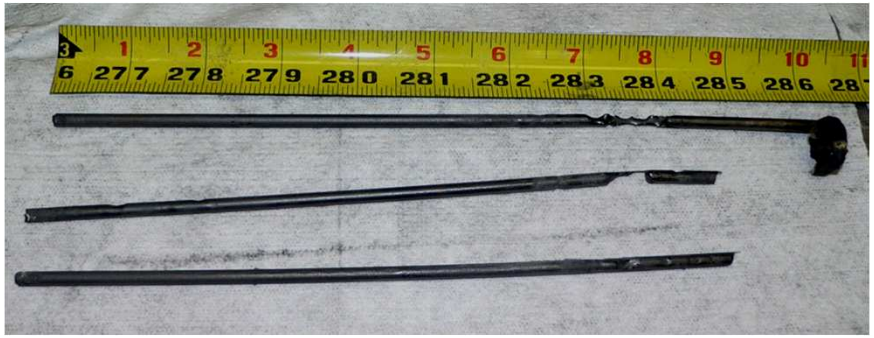
BCS



GACS

Casting Development-Results

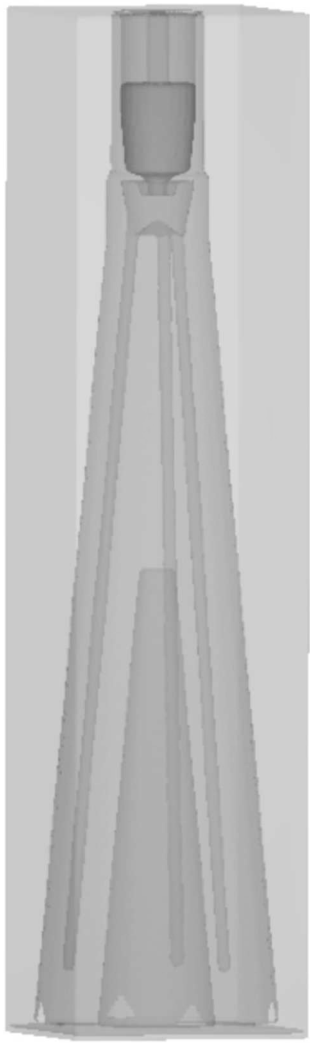
- **A number of parameters were examined with using uranium alloys- amount and time of pressure assist, mold coating vs. no mold coating, mold pre-heating, and super heat amount**
  - Pressure assist caused multiple pin segments
  - No mold coating performed well but resulted in pre-mature freezing (short pins)
  - Level of pre-heating did not have significant effect (800-1000°)
  - Too much super heat lead to pins made of many small segment
  - Mold vent size greatly affects the flow of the material
- **Results high light the need to couple experiments with computations and for better defined molten material properties**



Simulations

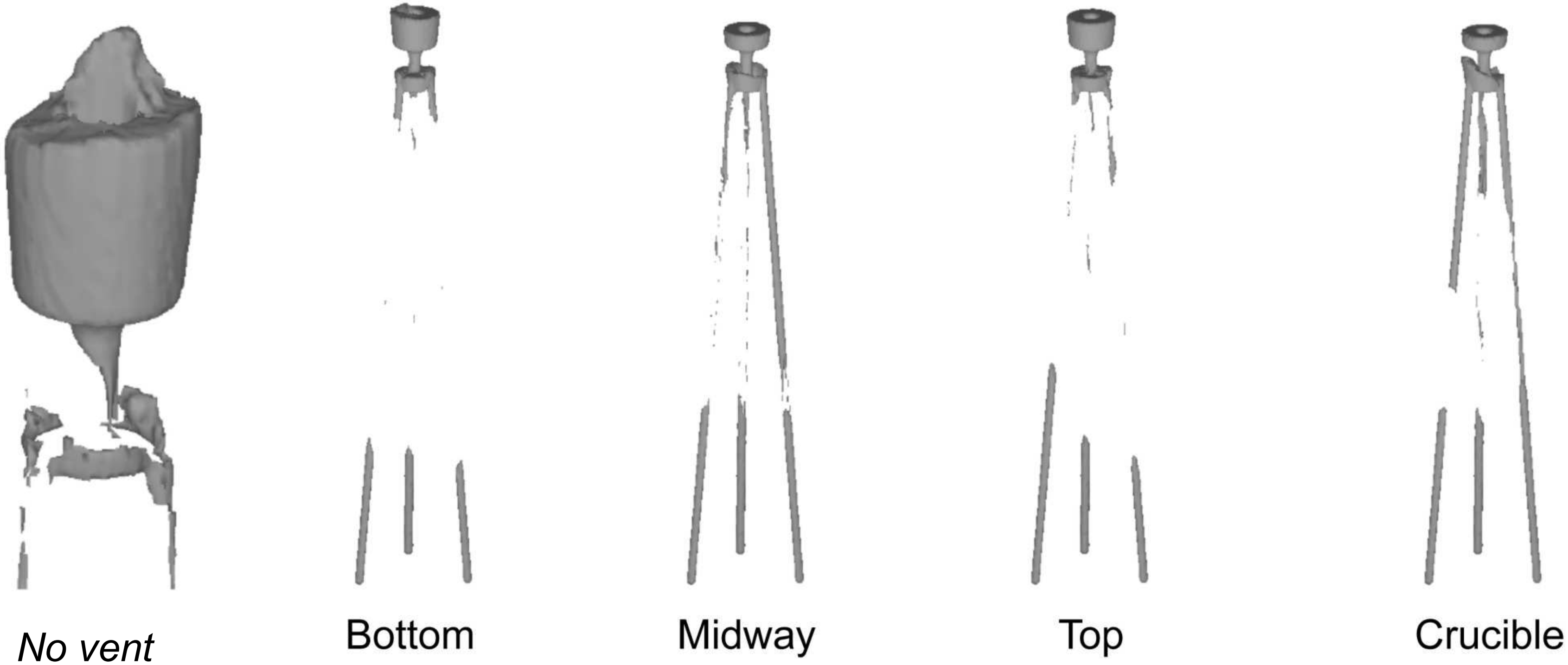
- **Two codes were used for simulations of the casting process**
  - Initially used TRUCHAS when experimental results showed the need for gas compressibility then a switch was made to FLOW-3D
- **Models based on actual BCS/GACS dimensions were developed while casting pressures and temperatures were based on actual casting runs**
- **Basic simulations accounted gravity, heat transfer, and solidification**
  - Surface tension and gas compressibility effects were examined in separate simulations
- **Separate effects testing was done to determine relative importance of thermal and physical properties on casting results**

Density	Specific Heat	Thermal Conductivity	Liquidus	Solidus	Latent Heat of Fusion
17.4 g/cm^3	201.3 J/kg· K	26 W/m· K	1340°C	1240°C	38,720 J/kg



Simulations- Venting

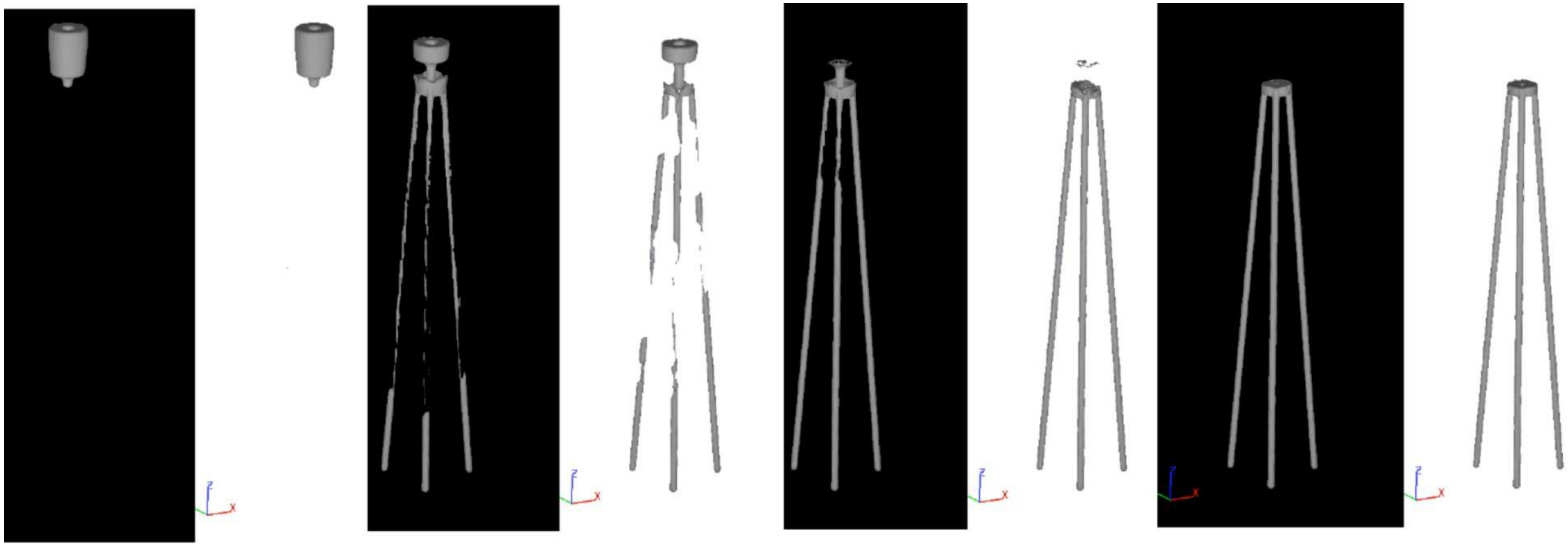
- Initial simulation was run assuming the mold was filled with argon at atmospheric pressure with no vents in the mold
- Following simulations placed vents at one of four locations



Filling time = 1.7 sec. (Bottom)
Filling time = 1.7 sec. (Midway)
Filling time = 2.1 sec. (Top)
Filling time = 1.5 sec. (Crucible)

Simulations- Surface Tension

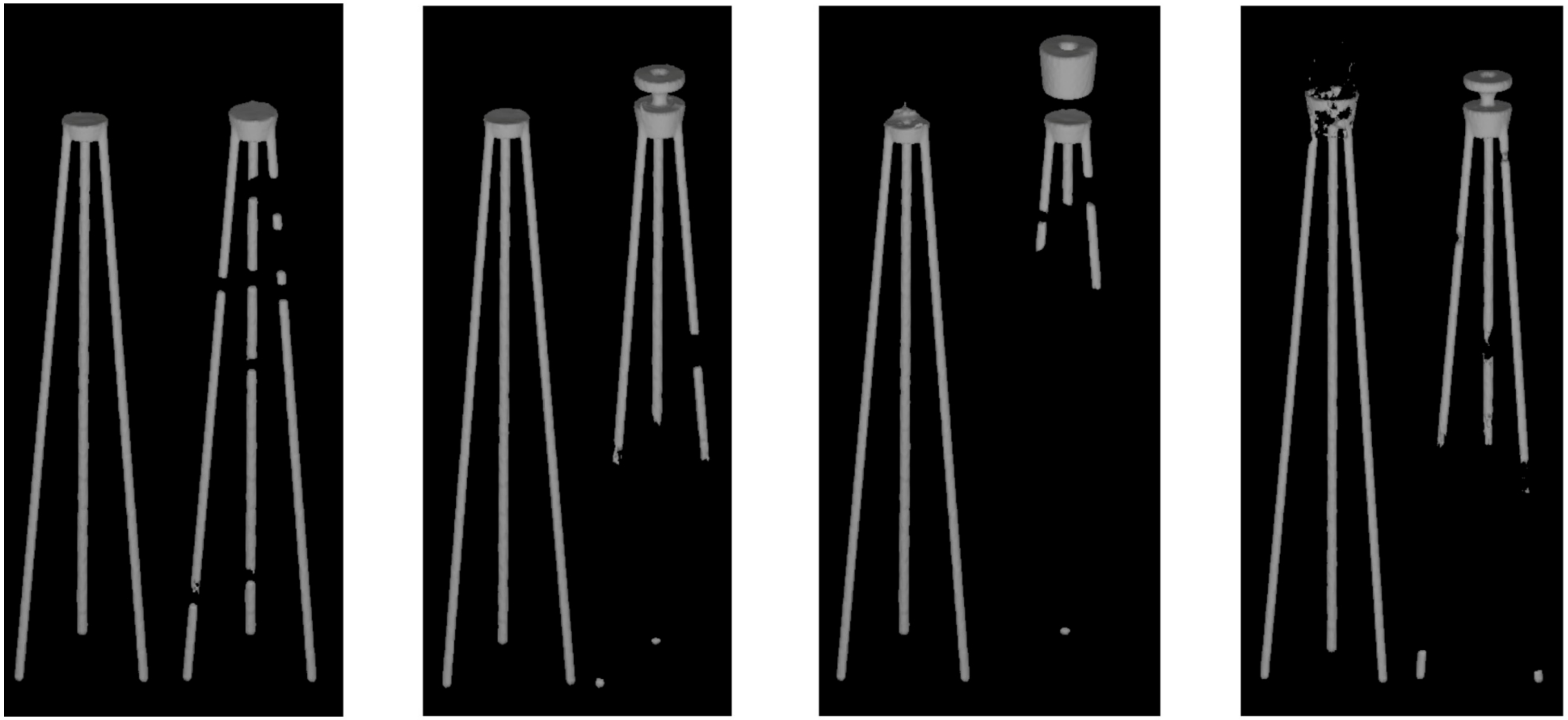
- **A value of 1.55 N/m was estimated for U-10Zr**
- **Simulations were first done using an evacuated mold then a mold initially filled with argon and vented**



0s 0.4s 0.7s 1.5s

Assumes evacuated mold- left images (black background) does not take surface tension into account

Simulation- Surface Tension



Bottom Midway Top Crucible

Argon filled molds- left images does not take surface tension into account

Simulations- Parameter Optimization

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- **Several simulations were run to determine the importance of melt/mold wetting angle, surface tension, melt viscosity, and viscosity surface tension relation**
- **In addition to physical parameters the importance of liquid thermal properties and the effects on casting results was also examined**

	Primary	**Secondary**	**Tertiary**
Fluid Flow Parameters			
Void Fraction	Wetting angle	Surface tension/viscosity	Surface tension
Solidification	Wetting angle	Surface tension	Surface tension/viscosity
Liquid thermal Properties			
Initial solidification	Heat x-fer coefficient	Latent heat	Specifc heat of liquid
Final Solidification	Heat x-fer coefficient	Heat x-fer coefficient	Latent heat

Parameter effect on casting results ranked based on importance

Conclusions

- **Gravity casting is a feasible process for casting of metallic fuels**
  - May not be as robust as CGIC, more parameter dependent to find right "sweet spot" for high quality castings
  - Fluid flow is very important and is affected by mold design, vent size, super heat, etc.
  - Pressure differential assist was found to be detrimental

- **Simulation found that vent location was important to allow adequate filling of mold**
- **Surface tension plays an important role in determining casting quality**
- **Casting and simulations high light the need for better characterized fluid physical and thermal properties**
- **Results from simulations will be incorporated in GACS design such as vent location and physical property characterization**