UO_2-ZrO_2 melting in a cold crucible induction furnace : simulation and experiments

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$UO_2 – ZRO_2$ MELTING IN A COLD CRUCIBLE INDUCTION FURNACE: SIMULATION AND EXPERIMENTS

XVIII International UIE-Congress
ELECTROTECHNOLOGIES FOR MATERIAL PROCESSING
Hannover (Germany), June 6 - 9, 2017

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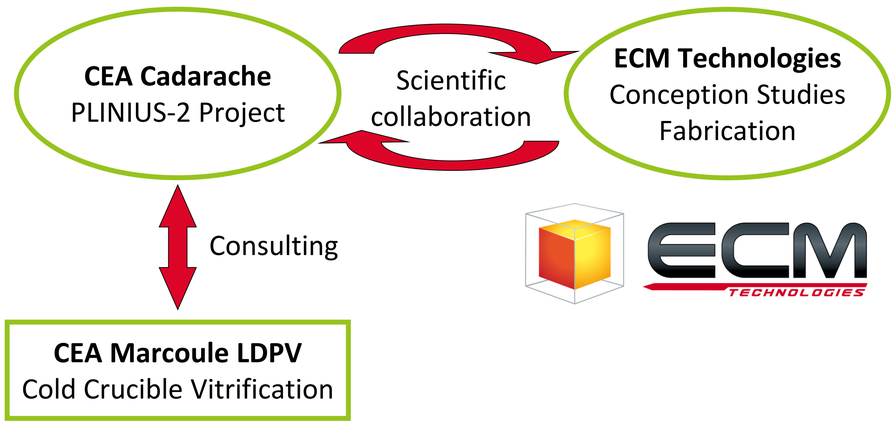
Plinius-2 project

In the field of severe accident studies for generation 2, 3 & 4 nuclear reactors, the Plinius-2 project aims to build a new facility to perform experiments of corium interactions tests at a large scale until 2020. In this context, the project, in collaboration with ECM Technologies, has to define and build a furnace able to melt up to 500 kg of different compositions of corium surrogates.

This poster presents the work achieved in the CEA Marcoule.

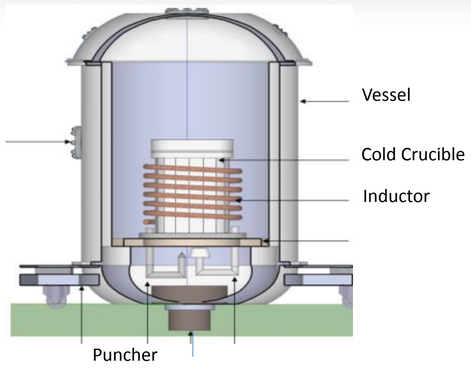


Corium interactions studies

- Corium composition
  - oxides mix (UO_2, ZrO_2, SiO_2)
  - with or without a metallic fraction (U, Zr, Fe, Ni etc.) from 0 to 30%wt
- Melting temperature > 2500°C
- Cold crucible technology has been chosen

Building project (CEA Cadarache)

Concept of the future furnace

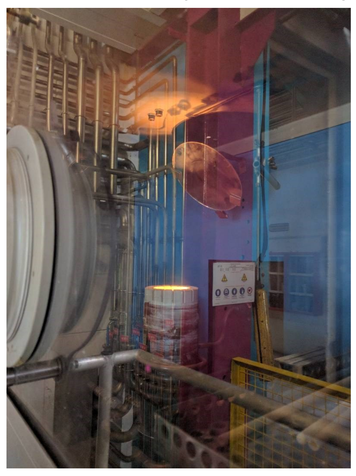


CEA Marcoule

Experimental setup

- Small scale experiments with ZrO_2 to check :
  - Wall heat fluxes
  - Loading feasibility
  - Pouring feasibility
  - Crust properties
- Lamp HF generator
  - 80 kW
  - 2.8 MHz
- Cold Crucible
  - Inner diameter 8 cm
  - Coated stainless steel

Fusion cell (Marcoule)



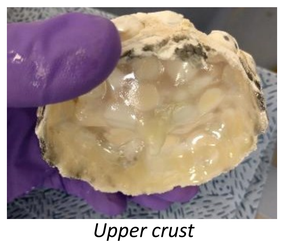
Initial load

Mix of solid balls and powder to enhance apparent density (ZrO_2+Y_2O_3 5%)

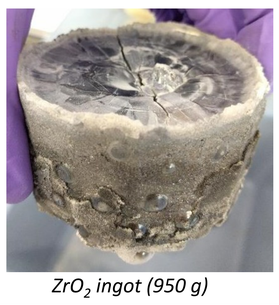
Melting process

Melting at T > 2800 °C
Reloading during melting

After melting



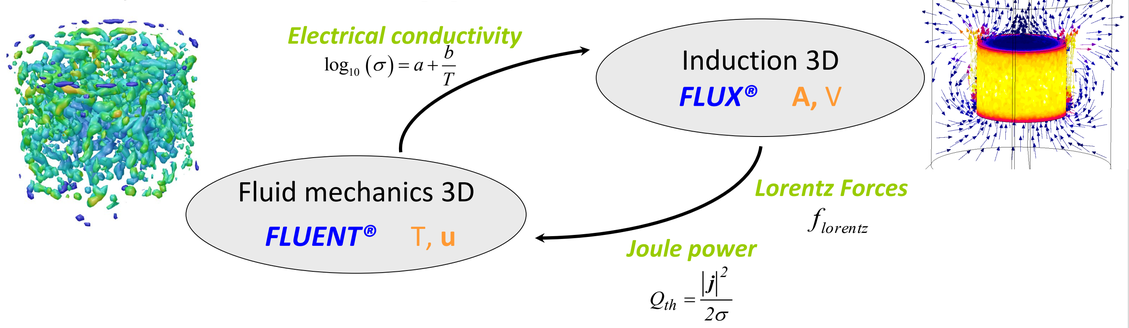
Upper crust



ZrO_2 ingot (950 g)

Numerical Simulation

- Simulations are performed to bridge the gap between the « small scale experiments with ZrO_2 » and the « large scale with complex corium ». See [3] for more details.

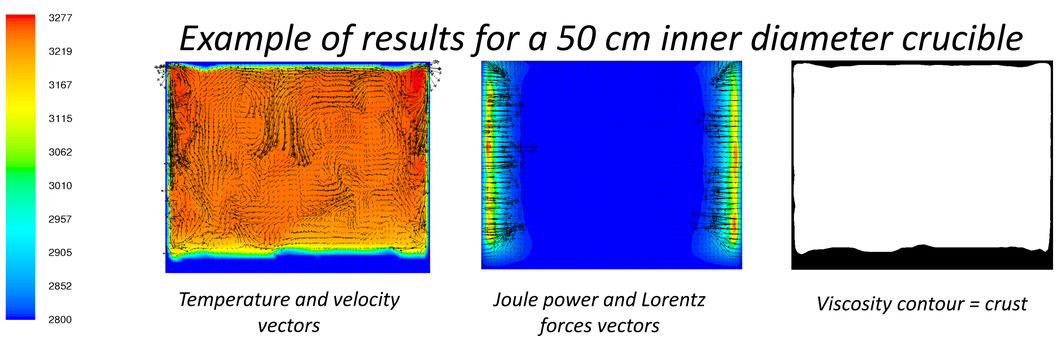


- Incompressible Navier-Stokes equation with turbulence modelling : LES
- Files transfer between Fluent and Flux with interpolation

UO_2 data set from [2]

Properties	Unit	Value / Law
Density	kg m^{-3}	10900 – 0.7*T
Heat capacity	J kg^{-1} K^{-1}	480
Thermal conductivity	W m^{-1} K^{-1}	9
Viscosity	kg m^{-1} s^{-1}	T>3120K : 0.004 else 10^4
Electrical conductivity	Ω^{-1} m^{-1}	3.569*10^5*exp(-13345/T)

Example of results for a 50 cm inner diameter crucible



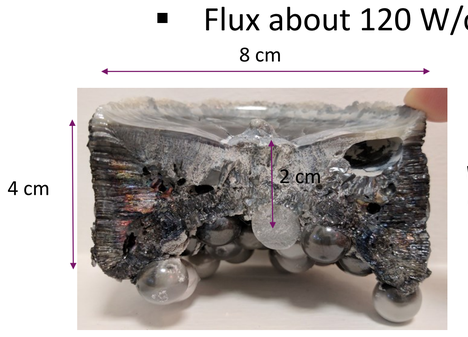
Temperature and velocity vectors

Joule power and Lorentz forces vectors

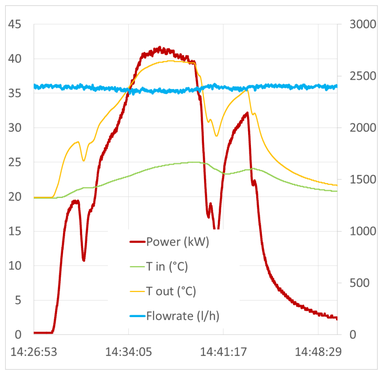
Viscosity contour = crust

Contributions to the project

- Estimation of the wall heat flux between the melt and the crucible
  - Power received by the crucible
  - Flux about 120 W/cm²



View of the ingot after slicing



Thermal power of the crucible during a melting

- Repartition of crust thickness is a function of injected Joule power
- Thermal condition at the wall is of great importance to catch the appropriate heat flux. A mixed convection-radiation is used.

Total Joule Power	MW	0.7	0.9	1.1	1.3
Melt fraction	%	78	83	90	94
Mean temperature	K	3021	3103	3207	3382
Bottom crust thickness	cm	7	5.5	3	2

Parametric study for a 500kg furnace with UO_2

- Design and sizing of a 120kg furnace are now completed, construction is under progress. First melting scheduled during 2018 in ECM (Grenoble)

Reference

1. **E. Sauvage, A. Gagnoud, Y. Fautrelle, P. Brun and J. Lacombe.** Thermoconvective flow of molten glass heated by direct induction in a cold crucible. **Magnetohydrodynamics**, vol. 45 (2009), no. 4, pp. 535-542.
2. **IAEA.** Thermophysical properties database of materials for light water reactors and heavy water reactors, vol. **IAEA-TECDOC**-1496 (IAEA, 2006).
3. **E. Sauvage, P. Brun, J. Lacombe and L. Aufore.** 3D simulation of a 500kg UO2 melt in a cold crucible induction furnace. **Magnetohydrodynamics**, vol. 53 (2017), to be published.