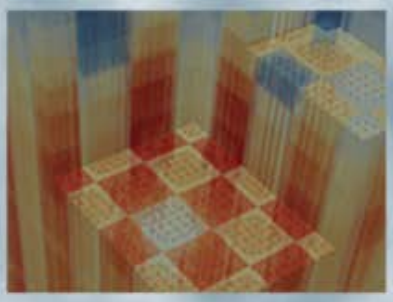
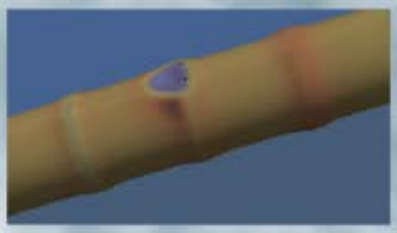
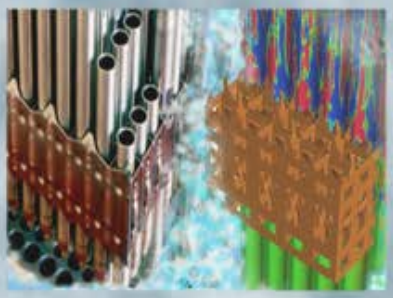
CASL-U-2015-0251-000

Study on Two-Phase Fluid and Heat Transfer Regimes in CRUD







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July 7, 2015

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

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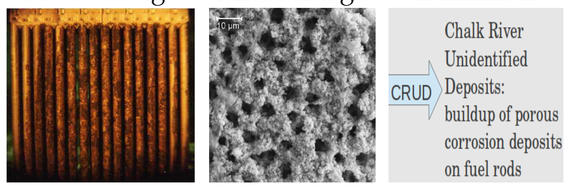
Study on Two-Phase Fluid and heat transfer regimes in CRUD

{ Miaomiao Jin, Michael P. Short }@Massachusetts Institute of Technology

Background

Macro Image | Micro Image | Definition



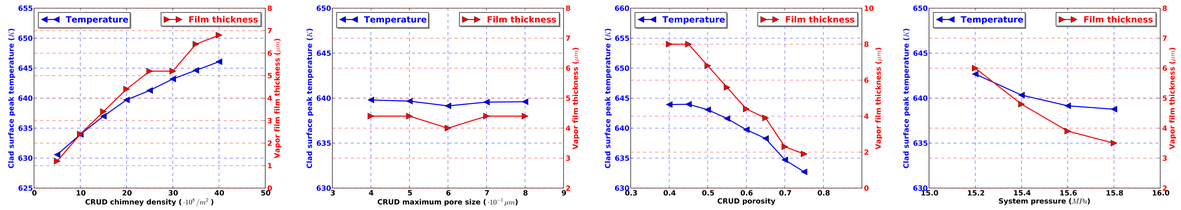
- Consequences:
  - Boron pickup⇑ ⇒ axial offset anomaly
  - Heat transfer⇓ ⇒ corrosion⇑
  - Post-process radioactivity
- Details need understanding:
  - Heat transfer
  - Chemistry

Method

- Overview
  - Based on the parallel computing framework, MOOSE (Multiphysics Object Oriented Simulation Environment).
  - MAMBA-2Phase
    - 3-D symmetric (2-D)
    - Heat & flow & chemistry coupled
  - PWR operating parameters
- Features
  - Explicitly assume film boiling
  - Abandon wick boiling assumption

Results for typical PWR

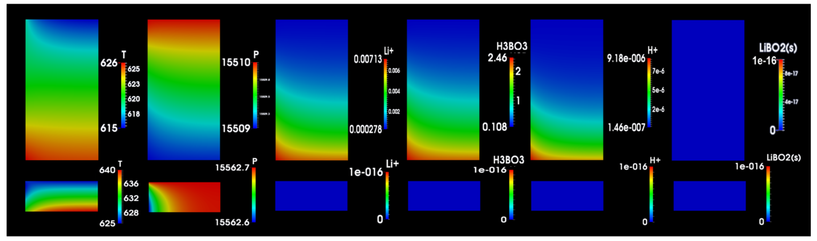
A. Parametric Analysis:



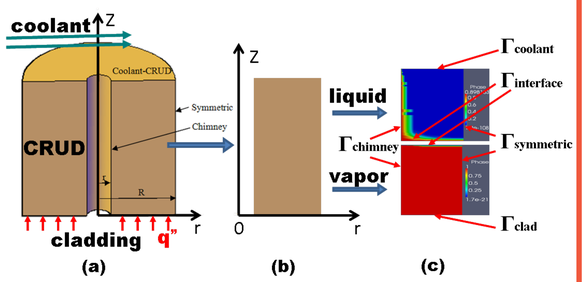
B. Case study (left fig):

Variables across domain ⇨

h_{conv}: 4.5209×10^4 W/m^2
Heat flux: 1.0 MW/m^2
System pressure: 15.5 MPa
Coolant temperature: 600 K



Model Construction

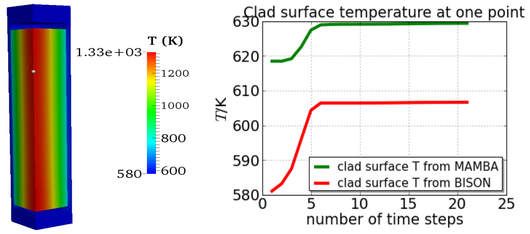


Typical CRUD parameters

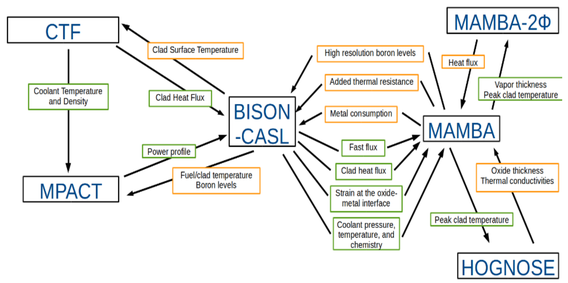
CRUD porosity	0.6
CRUD tortuosity	1.5
CRUD chimney diameter	4 μm
CRUD pore diameter (min)	0.25 μm
CRUD pore diameter (max)	0.50 μm
CRUD thickness	25 μm
Chimney density	$2 \times 10^9/m^2$

- Separated two domains
- A phase flag on each domain
- Tune relative thickness of the two domains until the solving gets mutually converged.

CRUD added to BISON



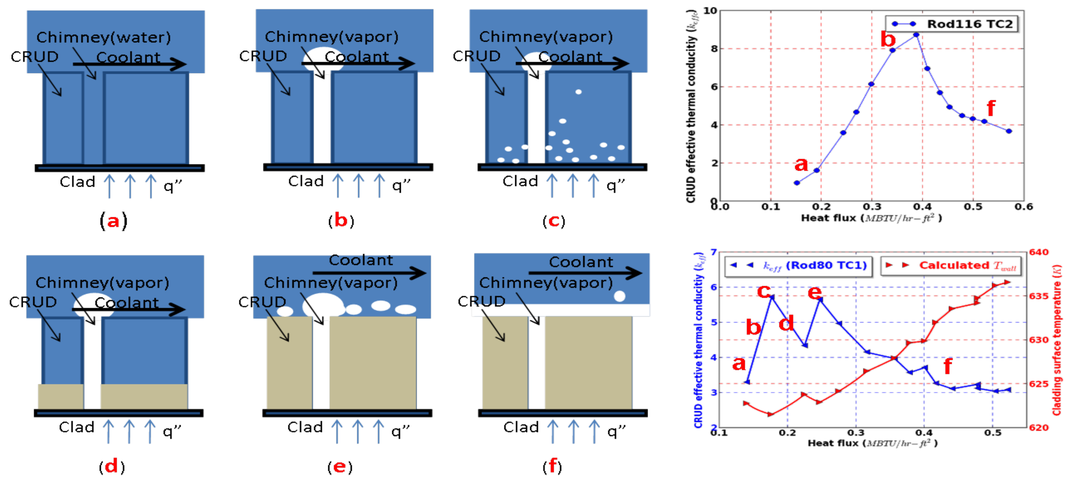
(a) Quarter fuel rod (b) Compare results from BISON and MAMBA[a]



(c) Schematic big picture of coupling

Single phase MAMBA calculation under low heat flux implies the necessity of coupling BOTH (b).

Discussion-heat transfer regimes



From the profile of experimental results [1], we propose a concept of **double critical heat flux** for porous media with boiling chimney, heated and cooled at each end. (1) thin CRUD: the heat transfer may go through $(a)-(b)-(f)$ with increasing heat flux(left fig, upper right). These pores can act as nucleation sites, facilitating heat transfer; (2) thick CRUD: (a) to (f) may be expected(left fig, lower right). Under high heat flux, film boiling hinders heat transfer.

References and Footnote

[1] Deshon, J et al. Simulated Fuel CRUD Thermal Conductivity Measurements Under Pressurized Water Reactor Conditions. Technical Report 1022896, 2011

[a] Single phase wick boiling model, under low heat flux

Acknowledgements

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Future Work

1. Simulate CRUD growth.
2. One way coupling: add an external layer in BISON with pre-calculated CRUD thermal conductivity depending on local heat flux.
3. Two-way coupling: neutron depression by boron deposition could be calculated by code, e.g. MPACT and fed back to BISON.
4. Add water radiolysis.

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