NTEC Module: Water Reactor Performance and Safety

Lecture 12: The reflood process

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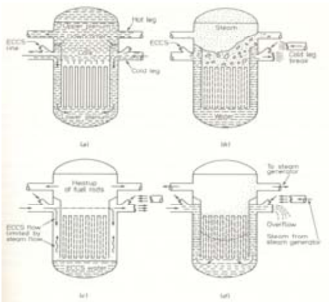
Summary

Events following a large break LOCA



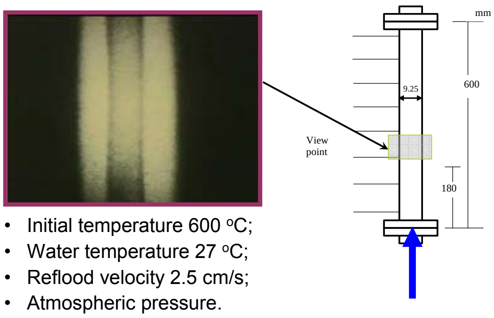
(a) Normal operation

(b) Blowdown phase

(c) Refill phase

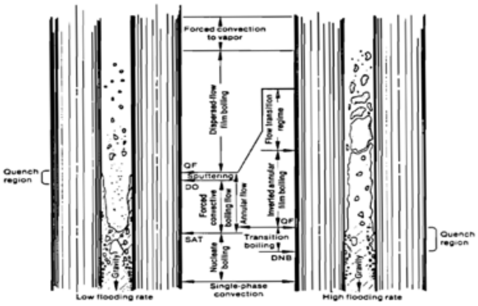
(d) Reflood phase

Visualisation of reflood process: Neutron radiography of reflood of hot tube

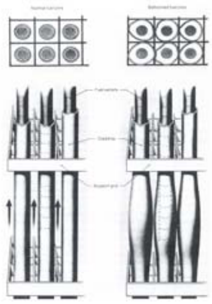


- Initial temperature 600 ^{o}C;
- Water temperature 27 ^{o}C;
- Reflood velocity 2.5 cm/s;
- Atmospheric pressure.

Regions of reflooding



A complicating feature: Clad ballooning

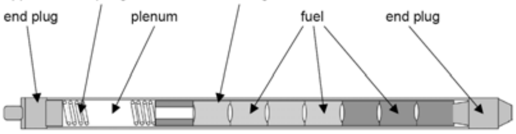


Following LOCA, fuel pin surface temperature increases and cladding may become ductile. Clad expands under internal pressure.

Consequences of clad ballooning:
•Restriction of passage reducing heat transfer.
•Diversion of flow to adjacent sub-channels

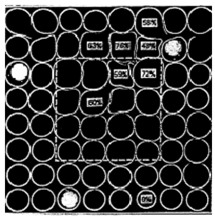
Physics of the Clad Ballooning Problem: Background

- Fuel Pin



Fuel pins are pressurised with helium to maximise heat transfer and prevent creep buckling

Physics of the Problem/ Background



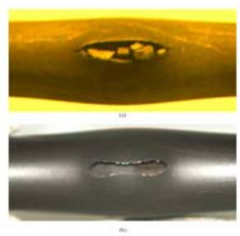
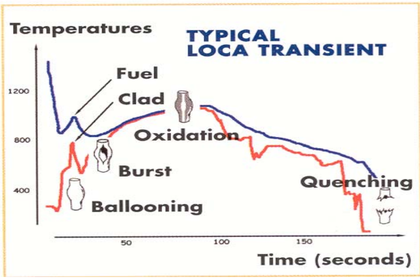
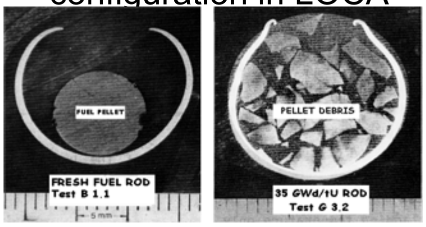


FIG.4 : Clad ballooning and burst (Dr. JONES, British Energy)

Fuel performance in LOCA : Clad temperature and configuration in LOCA



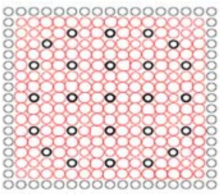
Fuel performance in LOCA : Clad temperature and configuration in LOCA



Modern fuel has high burnup (typically 60GWd/tonne).
Fuel fragments and may slump into ballooned region.

KNOO

Predictions of effects of clad ballooning by Dr. Amirabile at Imperial College using linkage between RELAP thermal hydraulics code and MABEL materials code

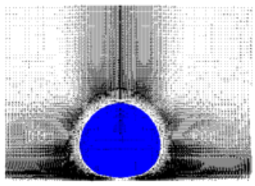


Ballooning computed for a PWR subassembly undergoing a loss of coolant accident. Systematic and stochastic differences between pins have been incorporated. Distinct differences in the ballooning behaviour of pins is clear, as is the absence of large regions of coherent ballooning.

Imperial College London

Fundamental processes in reflood: Drop-hot surface interaction I

- Sessile water droplet in saturated steam
- Density ratio=1662 and viscosity ratio=280
- Wall temperature at 400°C
- Vapour generation- Formation of vapour layer

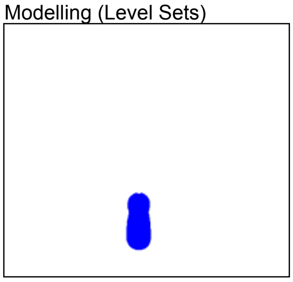


Fundamental processes in reflood: Drop-hot surface interaction II

Experiment

Work at the University of Stuttgart

Modelling (Level Sets)



2D axisymmetric simulation of droplet impacting on a hot surface. Work at Imperial College London

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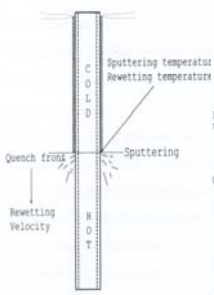
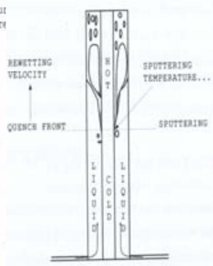
Fundamental processes in reflood: Surface rewetting I



Top reflooding



Bottom reflooding

Photograph of top reflooding showing violent fluid ejection

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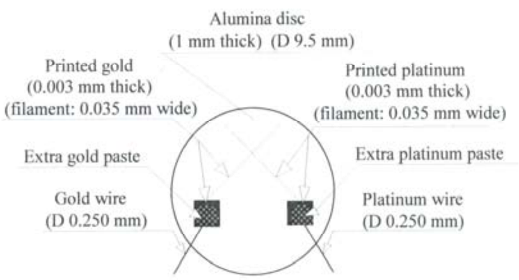
Fundamental processes in reflood: Surface rewetting II: Pereira (1998)



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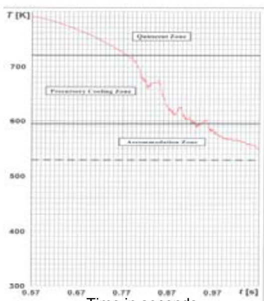
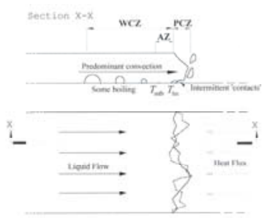
Fundamental processes in reflood: Surface rewetting III: Pereira (1998)



Time in seconds



Intermittent contacts ahead of quench front give precursory cooling. Quench front temperature is homogeneous nucleation temperature.

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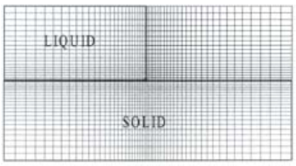
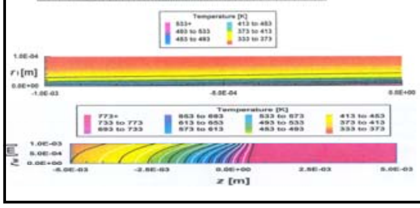
Fundamental processes in reflood: Surface rewetting IV: Pereira (1998)



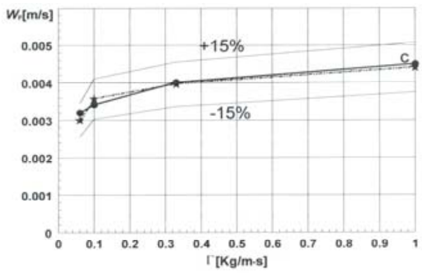
Moving mesh progressing with rewetting velocity.
Mesh refinement around triple interface.
Triple interface at homogeneous nucleation temperature.
Process governed by conduction in solid and conduction and convection in liquid.



Temperature field in the liquid

Temperature field in the solid

Fundamental processes in reflood: Surface rewetting V: Pereira (1998). Comparison of predicted and experimental rewetting velocities



● Simulation

* Experiment

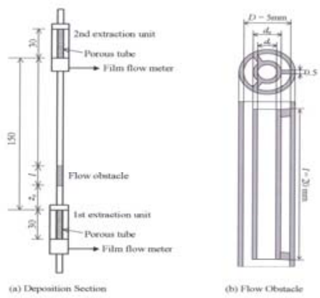
Fundamental processes in reflood: **Effect of Spacer Grids I**

Spacer grids provide a degree of lateral support (vibrations) for the fuel rods.

When the clad balloons:

- Spacers restrain the axial expansion.
- Promote turbulence ⇨ improves heat transfer.
- When wet, the liquid film on their surface cools the superheated steam flowing past.
- Depends on the drop size, the droplets can be captured on the water film (if the grid is wet) or become re-entrained from the trailing edge with a smaller size or a lower speed.

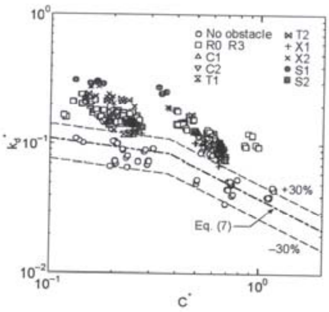
Fundamental processes in reflood: **Effect of Spacer Grids II**



Rate of droplet deposition measured with and without obstacle simulating spacer grid.

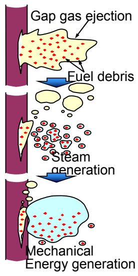
(Okawa et al. 2005

Fundamental processes in reflood: **Effect of Spacer Grids II**



Effect of grid-simulating obstacle
on droplet deposition coefficient
(Okawa et al (2005)

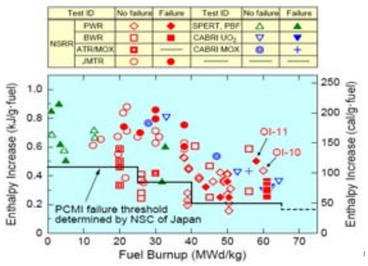
Fuel performance in LOCA: PCMI I



In a Reactivity Insertion Accident (RIA), large amounts of energy are deposited into the fuel. Main concern is Pellet-Cladding Mechanical Interaction (PCMI).

With high burnup, fuel is already fragmented. PCMI occurs at lower energy input.

Fuel performance in LOCA: PCMI II



Fuketa. T. Joint CSNI/CNRA Mtg. , Paris, December , 2004