Modelling of fuel pellet fragmentation and axial relocation under LOCA and RIA

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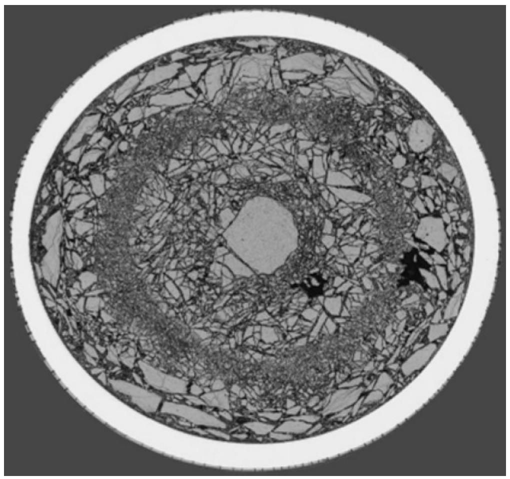
Outline of presentation

- Fuel pellet fragmentation in accident conditions
  - Examples
  - Underlying mechanisms
- Potential consequences
- Related research supported by SSM
  - Experimental programs
  - Computational modelling
- Computational modelling and analyses
- Conclusions and outlook

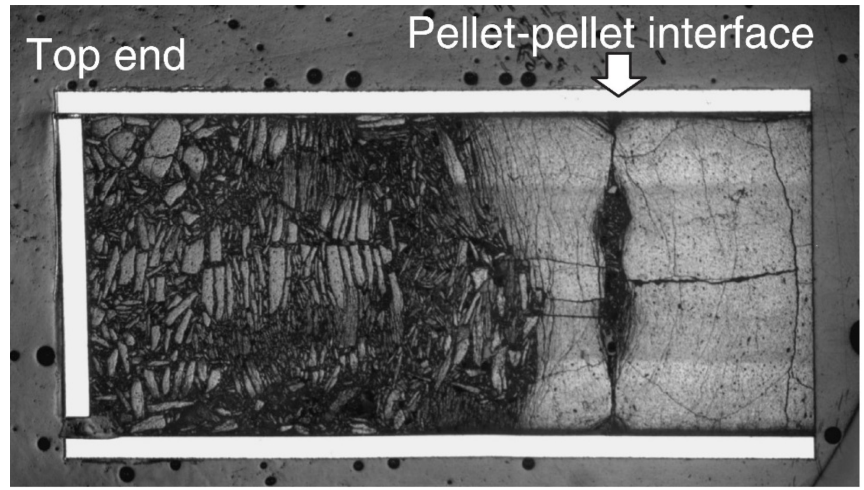
Fuel pellet fragmentation in accident conditions

Examples: Post-test appearance of high-burnup LWR UO_2 fuel pellets:



Loss-of-coolant accident (LOCA)
test Halden IFA-650.5 [1].

Fuel pellet burnup: 83 MWd/kgU



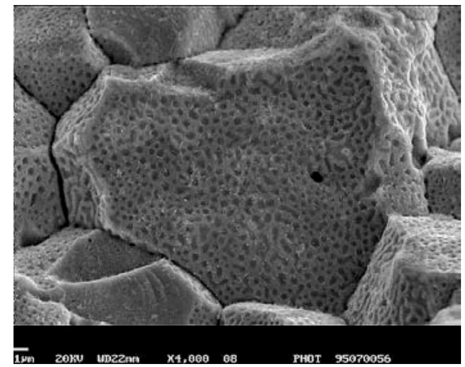
Reactivity-initiated accident (RIA)
test NSRR RH-2 [2].

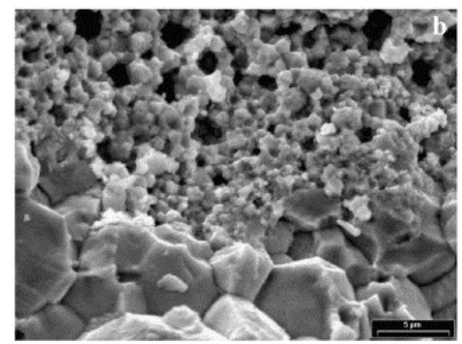
Fuel pellet burnup: 67 MWd/kgU

Fuel pellet fragmentation in accident conditions

Mechanisms:

- Fine fragmentation is caused mainly by rupture of overpressurized fission gas cavities [3,4]
  - Intergranular fission gas bubbles
  - Pores in the high-burnup structure ("rim zone")
- Possible only under certain conditions [5]
  - Sufficient fuel burnup
  - Sufficient overheating
  - Sufficient heating rate
  - No mechanical constraint from the cladding tube
- Results in <u>small</u> fragments (<0.5 mm) and extensive fission gas release



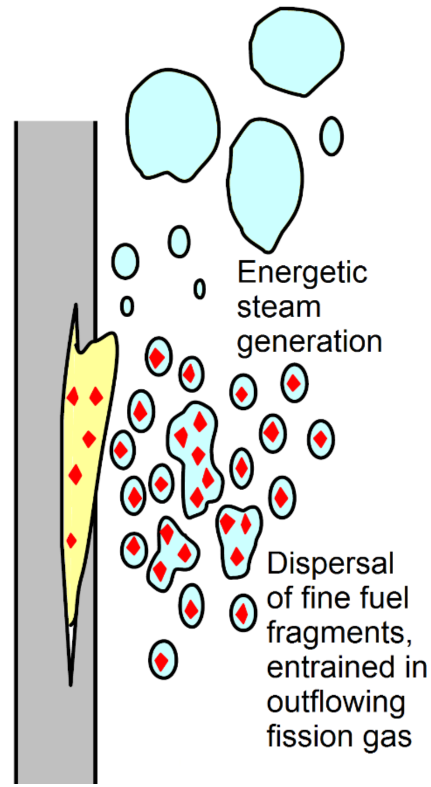


Micrographs from [6,7].

Potential consequences

Fission-gas induced fuel fragmentation may lead to:

- Extensive release of fission gas from ruptured cavities
  - Increased pressure load on cladding
  - Worsened radiological consequences
- Dispersion of fine fuel fragments from failed rods
  - Worsened radiological consequences
  - Fuel-coolant interaction (pressure pulses)
- Aggravated axial relocation of fuel fragments in unfailed but distended fuel rods



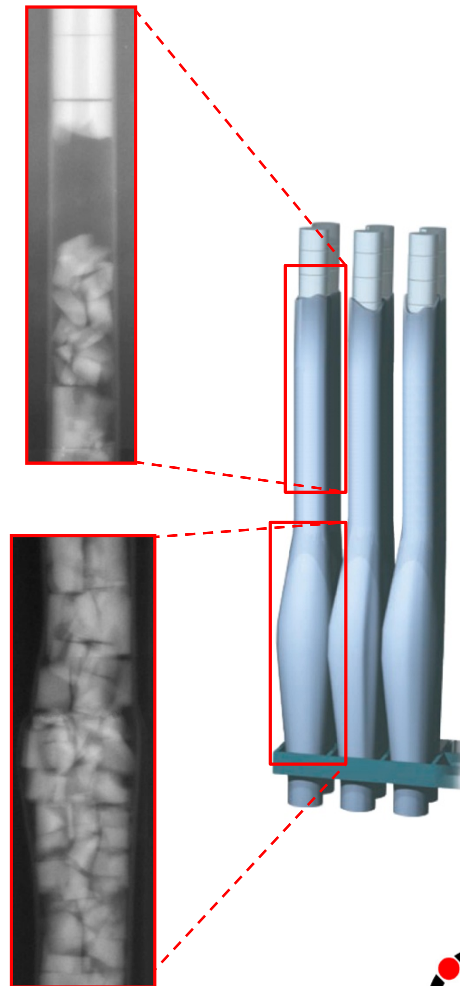
Axial relocation of fuel fragments

Observations from LOCA simulation tests [5]:

- Fuel pellet fragments may detach and move downward when the cladding tube distends
- Finely fragmented fuel has a higher tendency to relocate than coarsely fragmented fuel

Leads to a local increase of fuel mass, stored heat and power in the ballooned region:

- May increase cladding temperature locally
- May increase fuel dispersal upon cladding rupture



Related research supported by SSM

LOCA simulation tests (OECD/NEA):

- Halden Reactor Project IFA-650 test series
- Studsvik Cladding Integrity Project (SCIP-III)

RIA simulation tests (OECD/NEA):

- CABRI International Project (CIP)

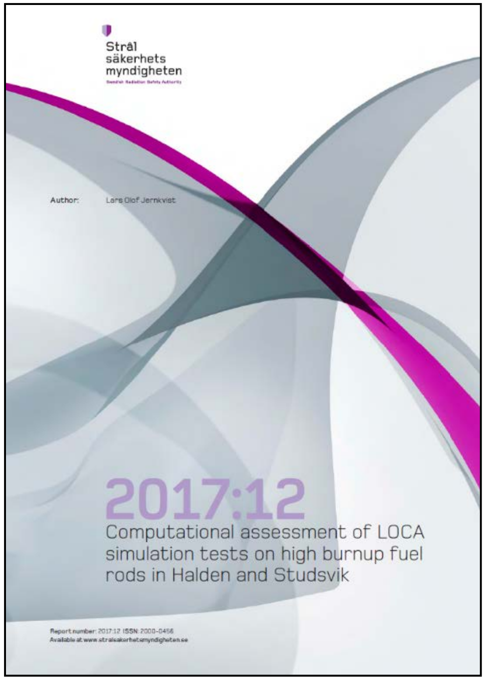
Computational modelling and analyses (Quantum Technologies):

- Partly conducted within SCIP-III [8]
- Partly within the IAEA Coordinated Research Project FUMAC:
  Fuel Modelling in Accident Conditions [9]

Computational modelling and analyses

Objectives:

- Interpret and assess experimental results [10-12]
- Confirm understanding of fundamental mechanisms and/or identify knowledge gaps
- Extrapolate experimental results to expected LWR accident conditions


Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Author: Lars Olof Jernkvist

2017:12
Computational assessment of LOCA simulation tests on high burnup fuel rods in Halden and Studsvik

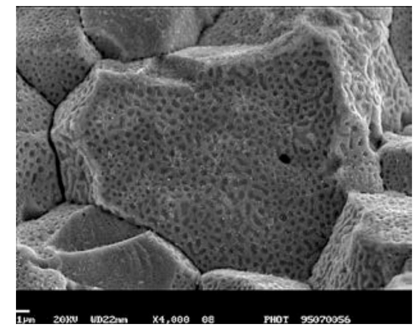
Report number: 2017:12 ISSN: 2000-0456
Available at www.stralsakerhetsmyndigheten.se

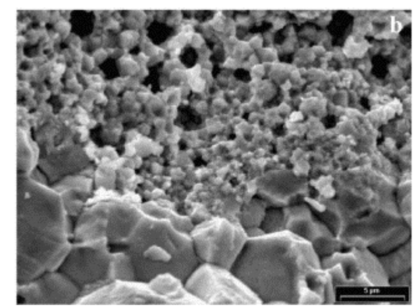
Computational modelling and analyses

Specific models developed by Quantum Technologies:

- Unified model for fission gas behaviour in UO_2 fuel [12]
  - Fission gas transport/distribution/release
  - Evolution of fuel microstructure, e.g. gas-filled cavities
  - Rupture criteria for overpressurized cavities

- Unified model for axial relocation of fuel fragments [3,13,14]
  - Detachment and axial flow of fuel fragments
  - Effective medium models for fragmented material
  - Thermal feedback effects of relocated fuel

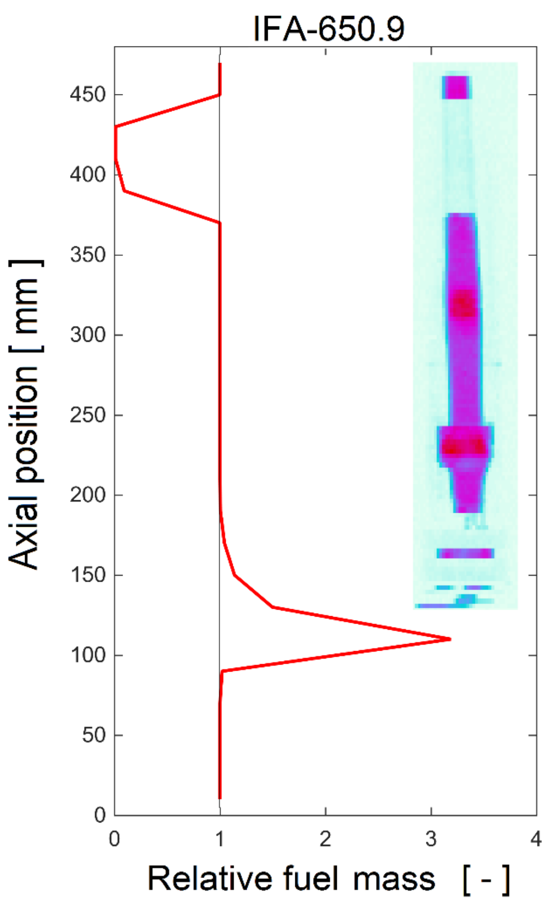


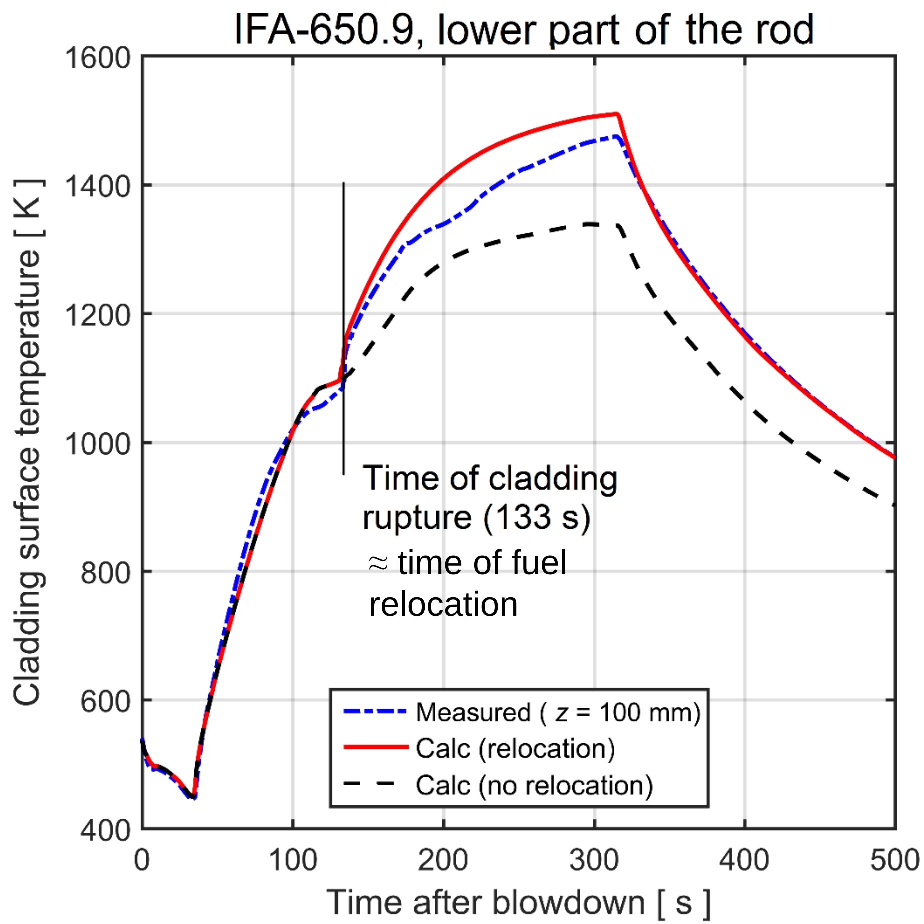


All models have been implemented in extended versions of the US NRC FRAPCON/FRAPTRAN fuel rod analysis programs and validated against aforementioned LOCA/RIA simulation tests

Example: Halden IFA-650.9 LOCA test

Calculated vs observed fuel relocation and its thermal effects [9-11]:





Conclusions and outlook

- Our computational models reproduce fuel fine fragmentation and axial relocation observed in LOCA/RIA experiments on high-burnup UO_2 fuel
- The models have been used for identifying key parameters for the phenomena observed in tests (feedback to experimentalists)
- Modelling of fuel fine fragmentation and axial relocation under expected LWR LOCA/RIA conditions remains to be done

References and acknowledgement

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Works marked in blue were produced in SSM research projects SSM 2014-2355, 2015-4050 and 2016-3944.