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Effects of Fuel Relocation Model of FAMILY Code in Halden IFA-650.4 LOCA Test

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Contents

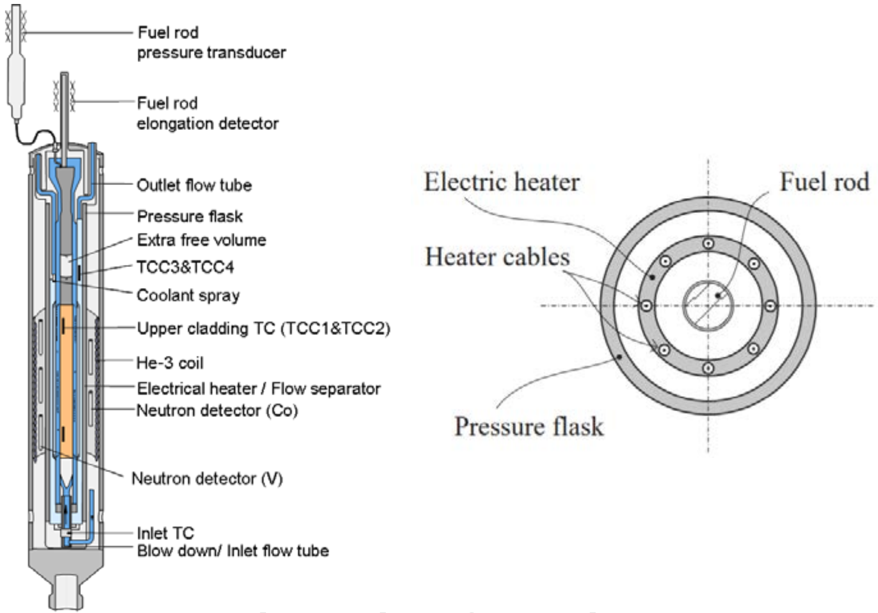
I. Introduction

- **Modeling Requirements of the Proposed ECCS Rule Revision to Reflect High Burn-up Effect of Fuel**
  - Inner surface oxidation
  - Thermal resistance of crud and oxide
  - Fuel relocation, dispersal and flow path blockage due to deformation and burst of fuel
- **FAMILY Code**
  - FAMILY : **F**RAPTRAN **A**nd **M**ARS-KS **I**ntegrated for Safety Ana**LY**sis code
  - Integrated code between fuel performance code, FRAPTRAN and system thermal-hydraulic code, MARS-KS
  - Fuel models including fuel relocation have been developed for audit calculation reflecting modeling requirements
- **Validation of Fuel Relocation Model of FAMILY Code Using Halden IFA-650.4 LOCA test**
  - Fuel relocation : change of heat source distribution in a fuel rod after burst of fuel rod
  - Halden IFA-650.4 LOCA test
    - Large deformation and relocation of fuel with high burnup condition

II. Halden IFA 650.4 LOCA Test

Test Rig

- Single rod experiment using high burnup fuel
- Heating provided within the rod by low level nuclear power simulating decay heat
- Simulation of the thermal boundary conditions with an insulating channel and heated shroud



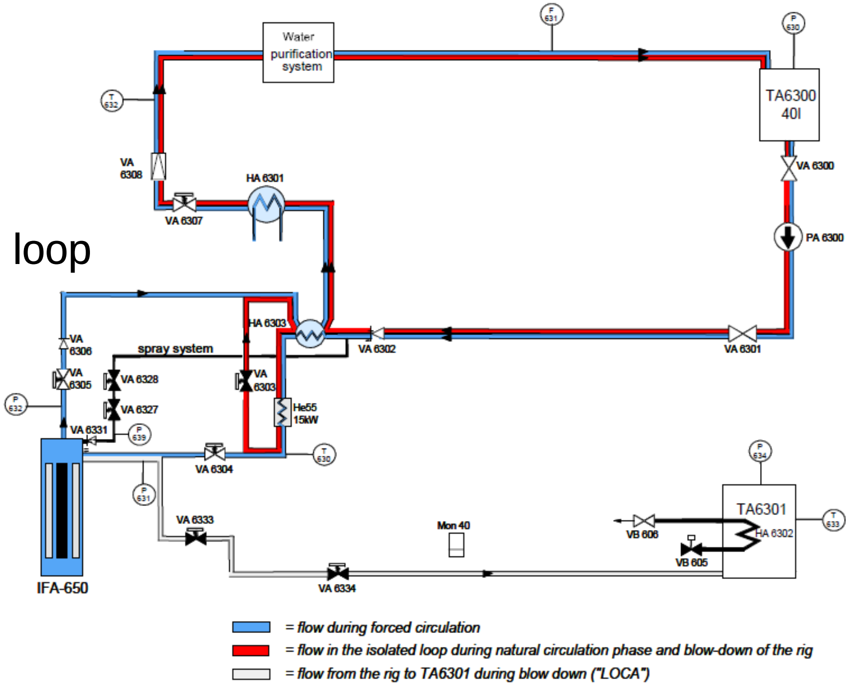
Schematics of test rig

Major parameters

Parameter	Value
Effective fuel length [mm]	480
Fuel weight [kg UO_2]	0.320
Burnup [MWd/kgU]	92.3
Theoretical fuel density [%]	95.2
Pellet length [mm]	11
Clad oxide thickness [μm]	mean 10 / max 11
Clad O.D. [mm]	10.75
Clad thickness [mm]	0.725
Flask I.D./O.D. [mm]	34/40
Electrical heater length [mm]	518
Target PCT [°C]	800

II. Halden IFA 650.4 LOCA Test

- **Sequence of Test**
  - Phase 1 (forced circulation)
    - Test loop pressure : ~ 70 bar
    - LHGR of fuel : ~ 10 W/cm
    - LHGR of electrical heater : ~ 15 W/cm
  - Phase 2 (natural circulation)
    - Disconnection of the rig from the outer loop
  - Phase 3 (blowdown)
    - Opening of valves to the dump tank
  - Phase 4 (heat-up)
    - Peak cladding temperature : 1075 K
    - Cladding burst : 336 s
    - Start of spraying : 566 s
  - Phase 5 (cooling)
    - Reactor scram : 617 s

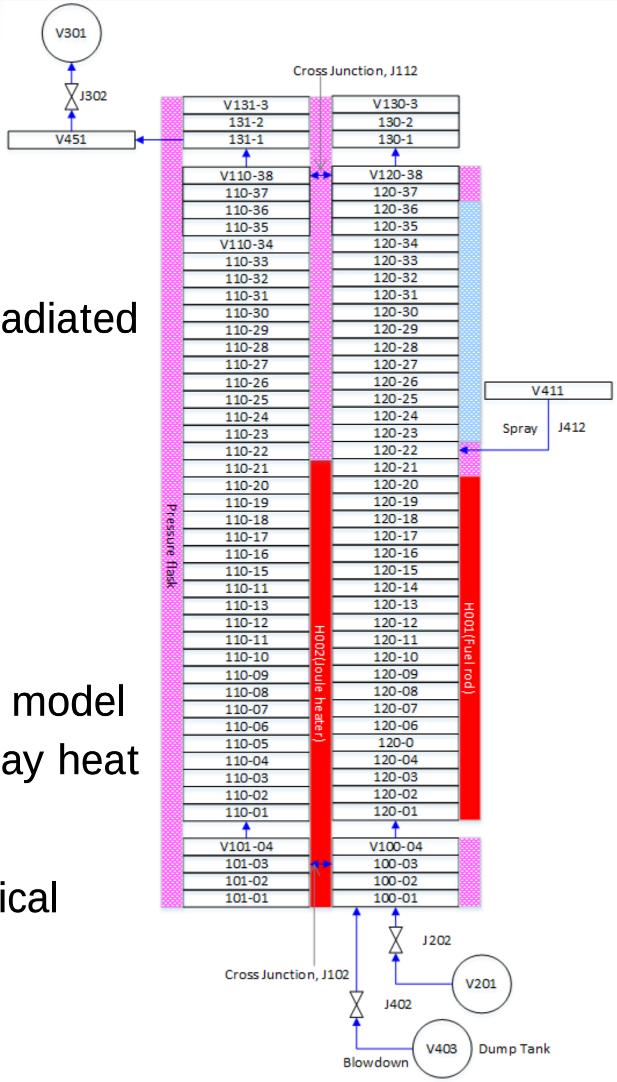


Simplified test loop

III. Modeling of FAMILY Code

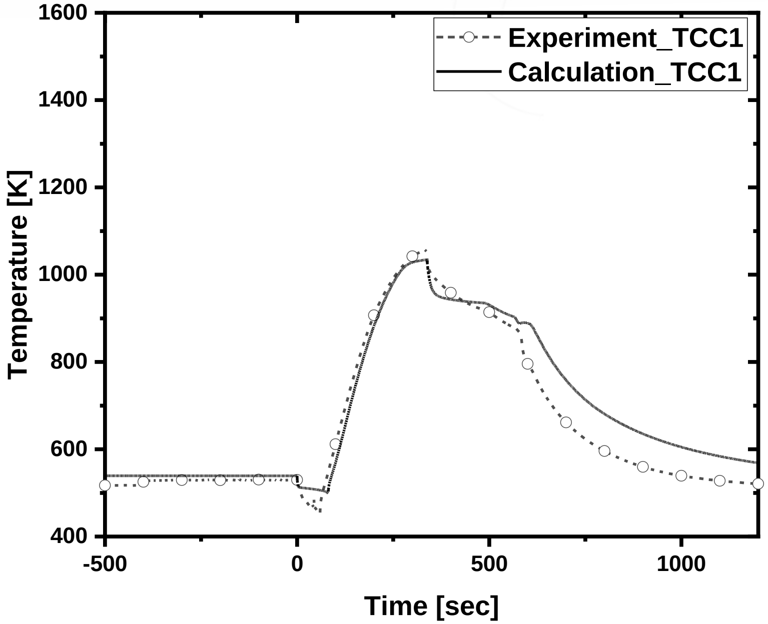
Evaluation Methods

- Computer codes
    - FAMILY code: Transient calculation
    - FRAPCON code: Providing initial conditions of pre-irradiated fuel rod
- Applied models
    - Fuel relocation model developed by Quantum Technology(QT)
    - Models improved in previous studies
      - Linear heat generation model of QT fuel relocation model
      - Axial fuel power model to reflect the history of decay heat
- Heat structure modeling
    - Radiation heat transfers between fuel rod and electrical heater/between electrical heater and outer flask
      - Emissivity of fuel assumed to be 0.8



Nodalization of Halden IFA-650.4 test rig in FAMILY code

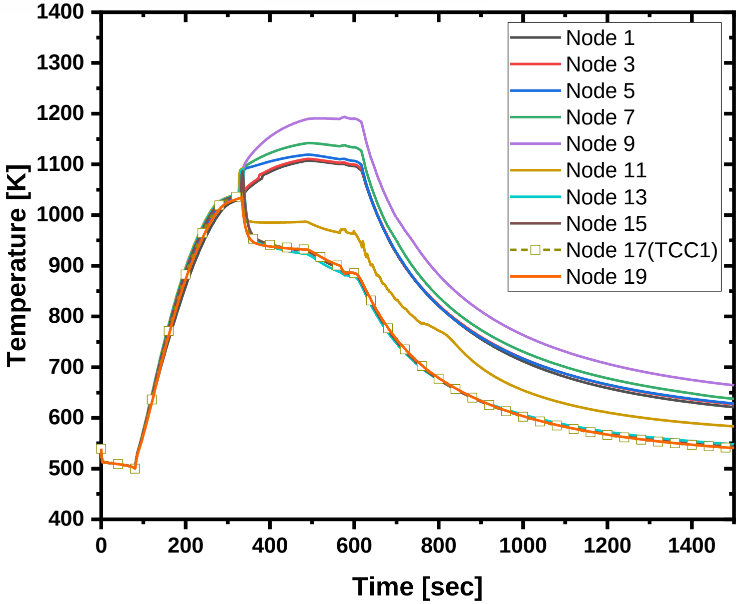
IV. Results and Discussion



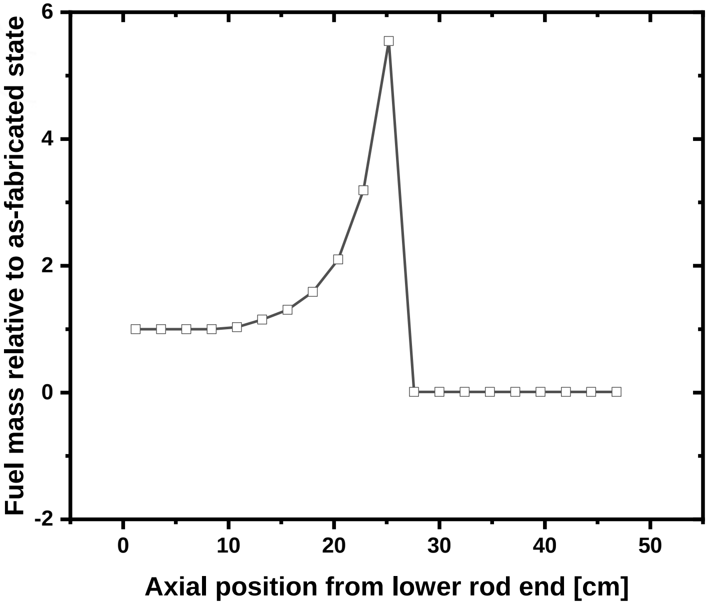
Fuel cladding temperature at TCC1 T/C

- Fuel cladding temperature
  - Increases continuously due to heat-up during blowdown phase
  - Decreases rapidly after the fuel cladding burst
    - At the elevation of TCC1, there is no fuel producing heat
- Burst time of fuel rod was
  - Predicted to be earlier than experiment

IV. Results and Discussion



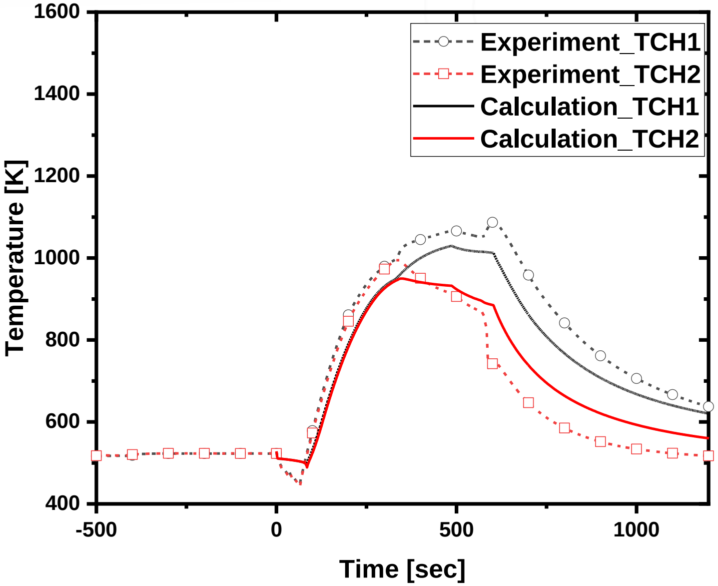
Fuel cladding temperature along axial direction



Relative fuel mass after burst

- Fuel cladding temperatures after burst
  - Decreases rapidly at higher elevation decreases rapidly
    - Fuel mass became 0
  - Increases significantly at lower elevation
    - Fuel mass increase due to dropped fuel into the ballooned region
    - Maximum fuel mass at the burst location: more than 5 times to the initial condition

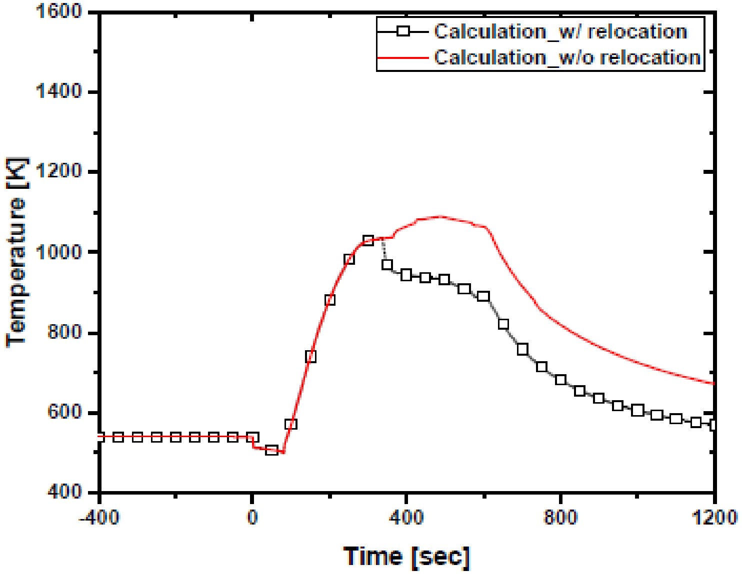
IV. Results and Discussion



Electrical heater temperatures

- Temperatures of TCH1 and TCH2
  - Lower before the occurrence of fuel cladding burst compared to test results
    - Radiation heat transfer and boundary conditions of heat transfer through outer flask not identified well
  - Predicted cooling rates after the burst comparatively well
    - Dominantly depends on the boundary condition of heat transfer between heater and outer flask

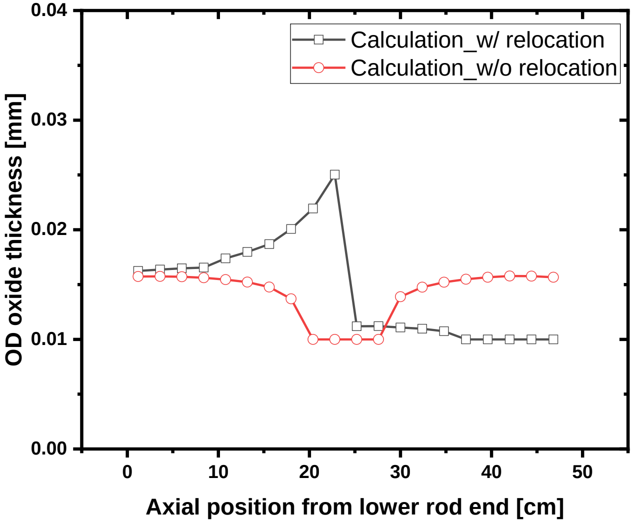
IV. Results and Discussion



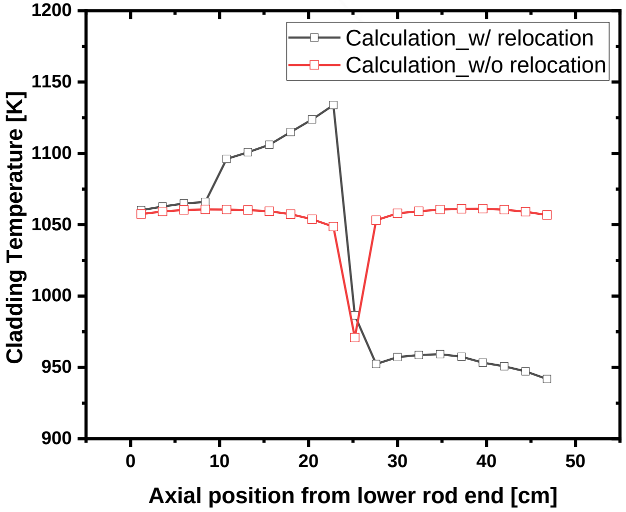
Fuel cladding temperature w or w/o relocation model application

- Effect of Fuel Relocation Model
  - Fuel cladding temperature decreases rapidly
    - No more fuel producing heat exists at higher location than fuel cladding burst

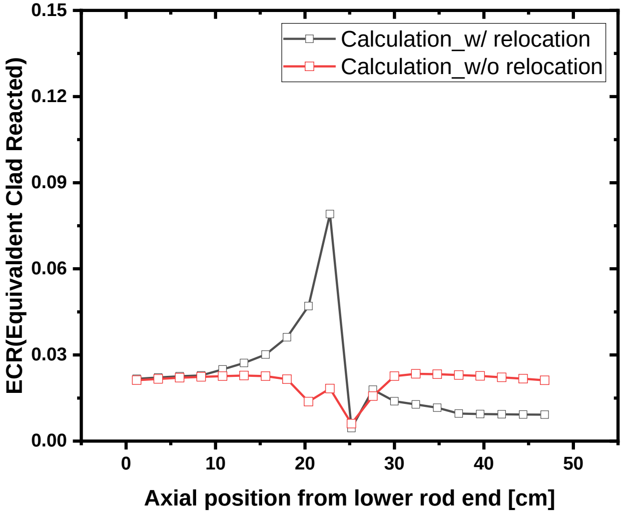
IV. Results and Discussion



Oxide thickness along axial direction



Cladding temperature just after burst along axial direction



Equivalent clad reacted along axial direction

- Effect of Fuel Relocation Model
  - Calculated by Cathcart-Powel cladding oxidation model

    \- Oxidation rate affected by the temperature
  - Oxide thickness and ECR around the burst location

    \- w/ relocation : large due to high power

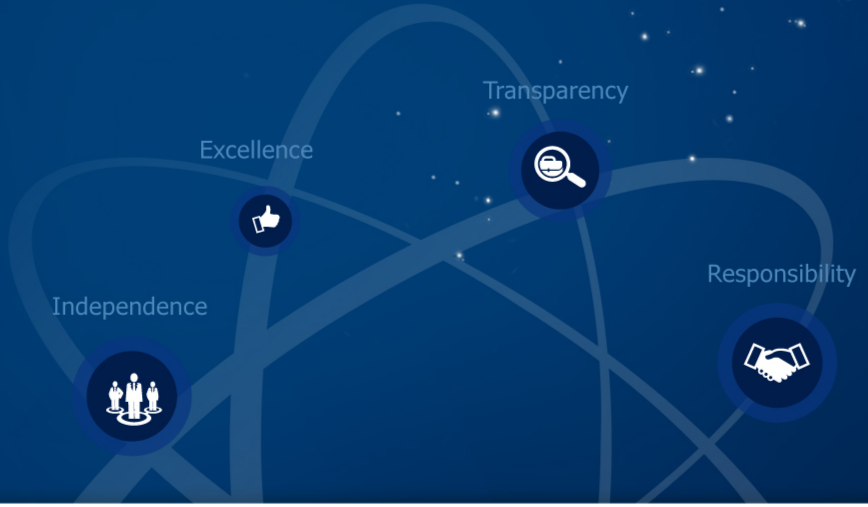
    \- w/o relocation : smaller due to direct convection heat transfer to the coolant

V. Summary and Conclusion

- **Preliminary evaluation of fuel relocation model of FAMILY code by the analysis of Halden IFA-650.4 LOCA test**
  - The fuel cladding temperature until reactor scram is predicted well by the application of fuel relocation model
  - In terms of electrical heater, heat-up rate before the burst and cool-down rate after the reactor scram are predicted comparatively well
  - Fuel relocation directly affects increasing oxide thickness and ECR due to changed power distribution

- **As further studies**
  - Heat transfer characteristics including radiation and boundary conditions of heat structures needs to be investigated
  - Effect of fuel parameters related with fuel deformation needs to be further studied

Thank you for your attention.



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