The Studsvik Cladding Integrity Project (SCIP) III – Overview

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SCIP III – Overview

WWER FUEL

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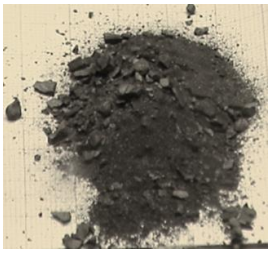
Background

- NRC LOCA test program 2008 – 2013
  - Objective - LOCA PQD of balloon in modern high burnup fuel rod cladding
  - Design and commissioning of a LOCA test apparatus and a bend test machine
  - Six LOCA tests performed
  - Findings on fuel fragmentation
- Results were presented in conjunction with the SCIP II meetings



Dispersed fuel fragments from one of the NRC tests

References:

1. Flanagan, M., NUREG-2119, 2012
2. Raynaud, P. A.C., NUREG-2121, 2012
3. Flanagan, M., NUREG-2160, 2013
4. Askeljung, P., WRFPM 2011
5. Flanagan, M., TopFuel 2013
6. Askeljung, P., TopFuel 2012
7. Puranen, A., TopFuel 2013

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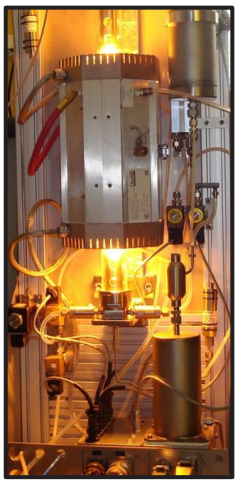
Test method: Semi-integral LOCA tests

- Experiment features:
  - Conducted in a hot cell facility
  - External heating provided by a clam-shell, radiant furnace
  - Pressurized single test fuel rod
  - Controlled temperature transient up to 1200 ºC
  - Variable environment (steam, argon, air)
  - Quenching



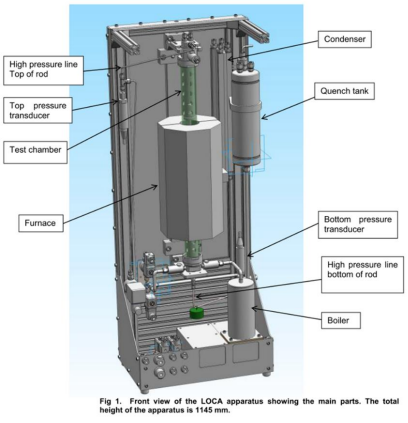
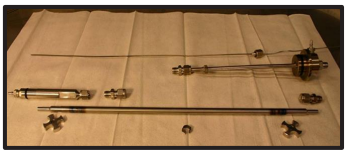


Fig 1. Front view of the LOCA apparatus showing the main parts. The total height of the apparatus is 1145 mm.



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LOCA test #193
Rod Id AM2-F10-2-1
2011-03-11
Part 1

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Bend test #193
Rod Id AM2-F10-2-1
2011-03-16

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Shake test #193
Rod Id AM2-F10-2-1
2011-03-17
Top and bottom part

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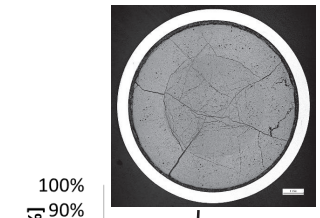
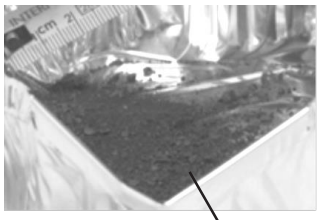
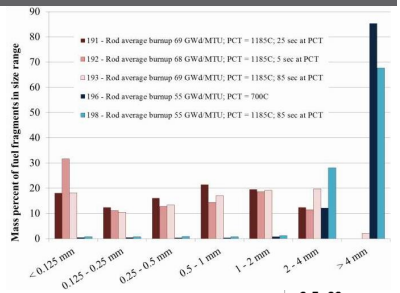
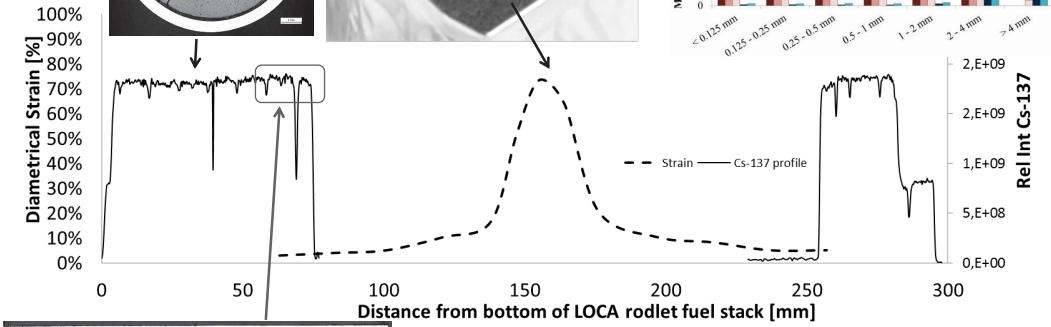
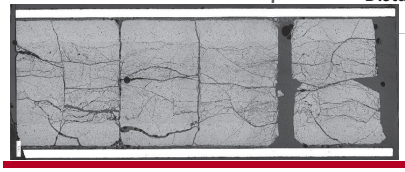
Test 192 (Rod av. BU ~70 MWd/KgU)











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SCIP

Studsvik Cladding Integrity Programme

- An OECD-NEA project with Studsvik as the principal investigator
- Running 5-year programs funded by project members
- SCIP 2004-2009. Cladding failure mechanisms at high burnup
- SCIP II 2009-2014. PCI mitigation and behaviour of additive fuels
- SCIP III 2014-2019. LOCA and overheating transients. PCI mitigation at low ramp rates and the effect of oxygen

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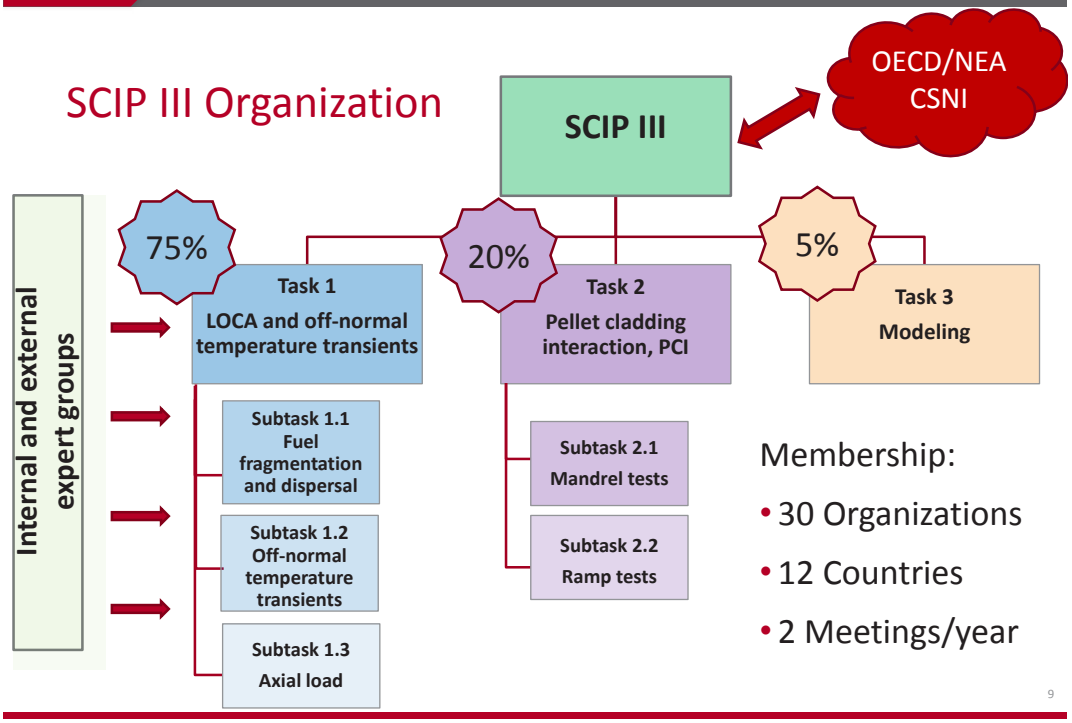
SCIP III Organization



Membership:

- 30 Organizations
- 12 Countries
- 2 Meetings/year

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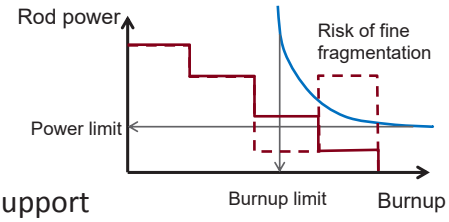
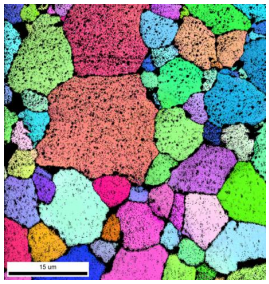
Task 1.1 - Fuel fragmentation and dispersal in LOCA

- Experimental program for determining thresholds:
  - Burnup – power history dependence
  - Temperature dependence
  - Strain dependence
  - Gas pressure/volume and depressurization on fragmentation and dispersal



- Detailed fuel structure characterization to support understanding of FFRD mechanisms
- Fuel performance modeling
  – Focus on FG behaviour & mechanical stress
- Benchmark integral tests Halden – Studsvik (Integral tests on sibling material)



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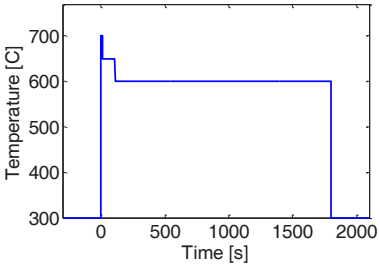
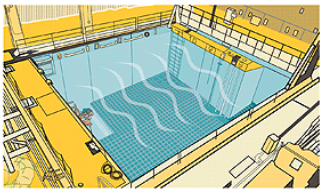
Task 1.2 and Task 1.3

- Task 1.2 – Off normal temperature transients
  - Focused on rod survivability in less severe overheating scenarios (transient dry-out, SB-LOCA) and special transient sequences
  - Includes BWR dry-out overheating, a study of cladding oxygen and hydrogen uptake in a LOCA without burst, a TFGR test and SFP LOCA tests in steam+air



- Task 1.3 – Axial load
  - For strength based LOCA criteria, axial load effects need to be considered. Limited data and no tests on irradiated rod sections with fuel
  - Study impact of pre-test oxidation, hydrogen and fuel cladding bonding
  - Verify ECR limits under axial load
  - Fuel dispersal after an axial failure
  - Post-test loading to verify earthquake resistance



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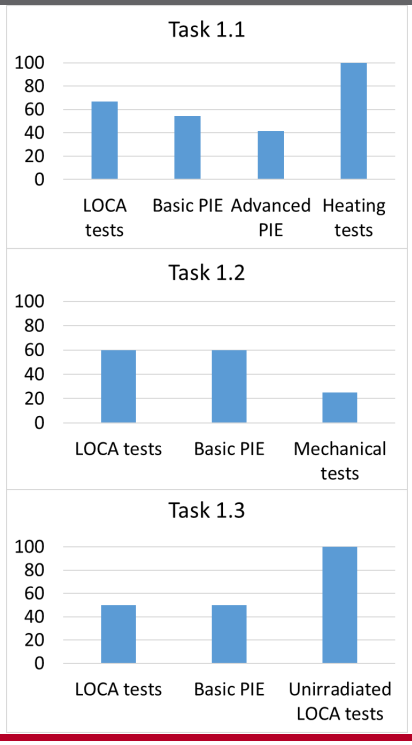
Task 1 – Test plan and status

- Integral LOCA tests
  - 21 irradiated tests
  - 10 unirradiated axial load tests
- Pre- and post-test PIE packages
  - 20 Basic,
  - 6 Advanced
- Furnace heating tests
  - 21 tests
- Mechanical testing
  - 28 tests (RTT & RCT, creep)



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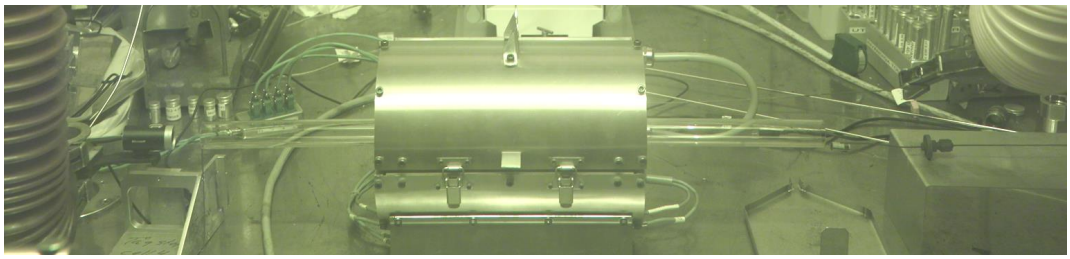
Test method: Furnace heating tests

- Furnace heating tests first initiated by EPRI as an effective method to determine sensitivity to fuel fragmentation
- Uses ~2 cm fuel sample with reduced radial restraint (clad slit)
- Sample is inserted in a pre-heated furnace and heated to the target temperature in air or inert atmosphere
- Temperature is monitored by a thermocouple clamped on the sample



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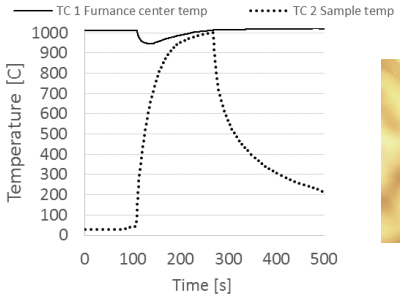
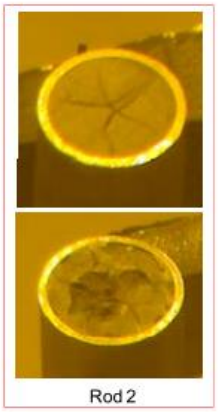
Furnace heating tests cont.

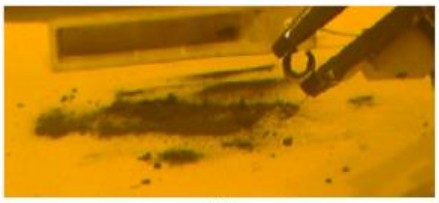


Before Heating

No slit

After Heating





Before heating

After heating

K. Yueh et al, Fuel Fragmentation Data Review and Separate Effects Testing, Proceedings of WRFPM 2014 Sendai, Japan, Sep. 14-17, 2014 Paper No. 100117

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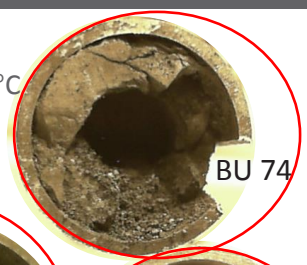
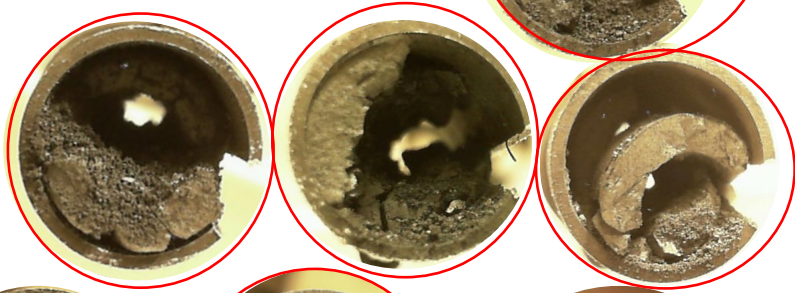
SCIP III heating tests

- Fuel images ”straight from the furnace” after heating to 1000 °C
- Local BU from gamma scanning, from 56 -> 74 MWd/kgU
- Encircled samples comes from the same rod
- Note FF in pellet center
- Limited FF outside center zone
- Degree of FF not only dependent on local BU

Ref. A. Puranen, HRP/WGFS LOCA Workshop, 2015



BU 74



BU 56

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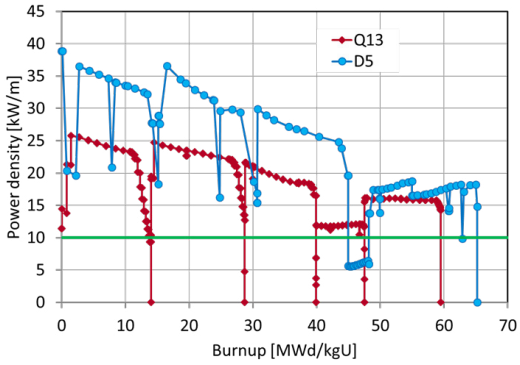
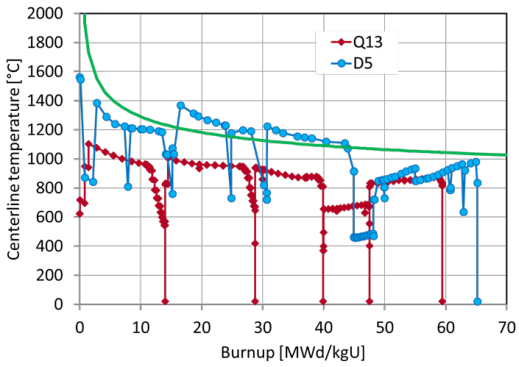
Modeling of rods above and below the FF threshold

- Modeling is an integrated part of the SCIP program supporting interpretation and evaluation of the experiments
- HT of a sample from rod D5 showed intense fragmentation and practically all fuel was ejected, while a sample from rod Q13 stayed intact
- Modeling was performed by Gerardo Grandi, SSP, using ENIGMA





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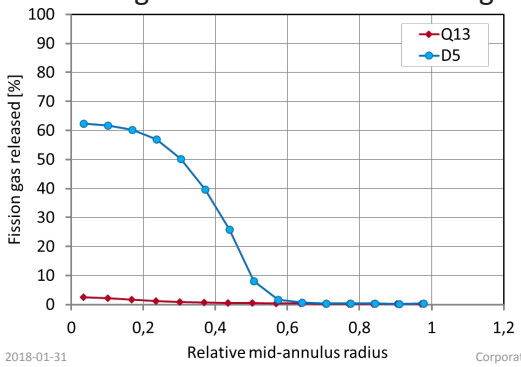
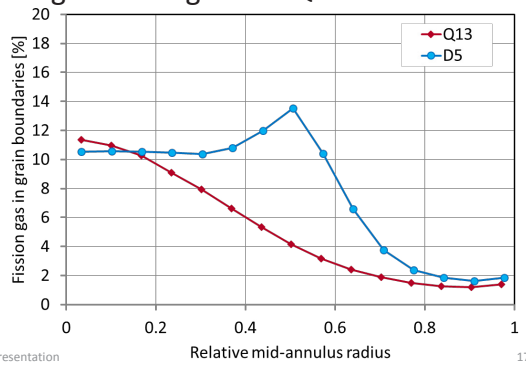
Modeling results

- Modeling results generally agree with PIE data, e.g. burnup profile, diameter change, FGR
- Both rods have similar cladding strains and stresses and fuel pellet strains and stresses
- FGR for D5 is 7.6%, and 0.39% for Q13. Large difference in gas partition. A larger fraction of D5 has intergranular gas coverage than Q13





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Summary

- Extensive fuel fragmentation of high burnup fuel may occur in a LOCA transient
- SCIP III studies fuel fragmentation and successfully delivers new experimental data on the thresholds and new understanding of the mechanism
- SCIP III also delivers data on cladding behaviour in overheating transients and axial strength during quench
- The program includes an integrated modeling effort