



“Examination of the VVER fuel behavior under the severe accident conditions. Quench stage”

ISTC 1648.2 Project Progress Report

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**11th CEG-SAM Meeting
Dresden, March 6-9, 2007**



Project structure

STAGE A. Spent ROD-QUENCH: Study of the spent fuel rod segments behavior under reflood conditions.

STAGE B. Fresh FA-QUENCH: Integral experiment of QUENCH type using model bundle with 31 fuel rod simulators under QUENCH conditions.

STAGE C. FA Quench Model: Development of models and codes to describe VVER core behavior under severe accident conditions (“quench” stage) on the base of results of stages A and B

Stage A : Study of the irradiated fuel rod segments behavior under reflood conditions

- **Pre-oxidized cladding failure behaviour**
- **Hydrogen generation**
- **Fission products release**

Objective:

Extension of the experimental database for the irradiated fuel behaviour during reflooding

Stage A

- **Test rig designing and manufacturing**
- **Working out the experimental technique**
- **Tests with unirradiated fuel rod simulators**
- **18 tests with the irradiated fuel rod simulators at quench temperatures of 1400, 1600 and 1700 °C.**

Tests with unirradiated simulators

Objectives:

- Checking the test rig
- Test regimes determining
- Revealing the possible simulators post-test state and sources of additional H₂ generation at quench
- Obtaining the data base for comparison with the irradiated simulators and previous results (FZKA)

Results

Two series of tests with unirradiated simulators at temperatures of 1400 and 1700 °C are done.

Tested simulators appearance



Simulator 21



Simulator 22

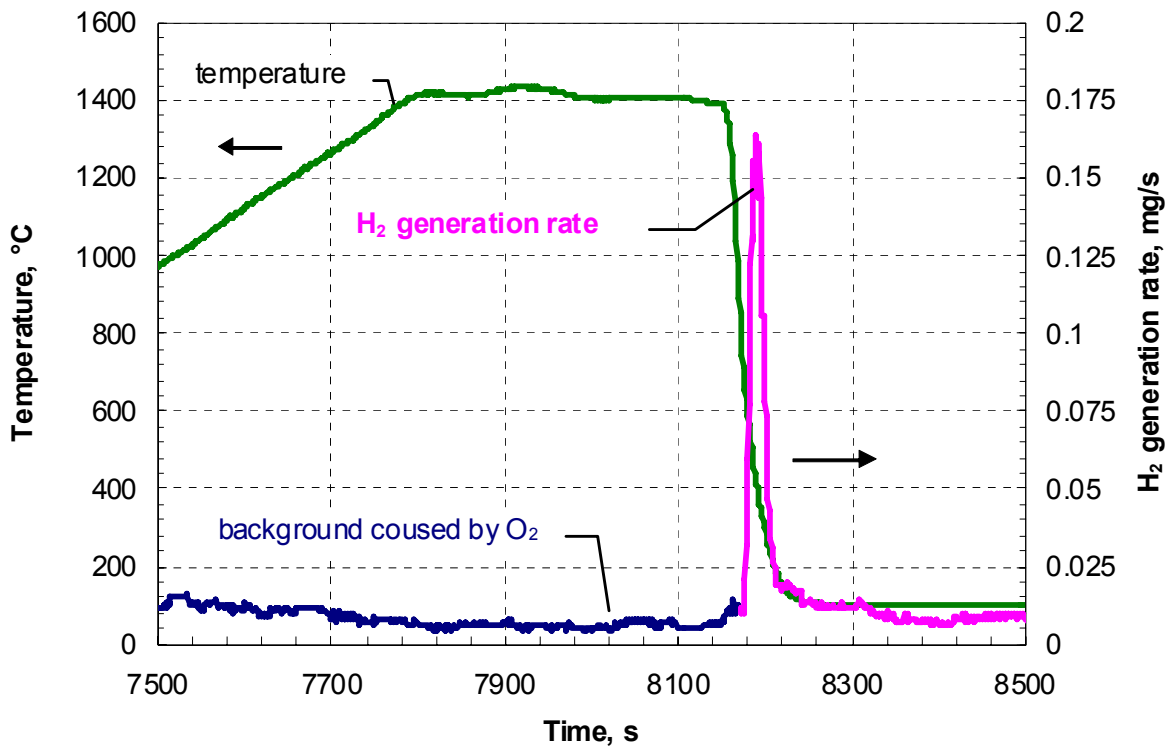


Simulator 23



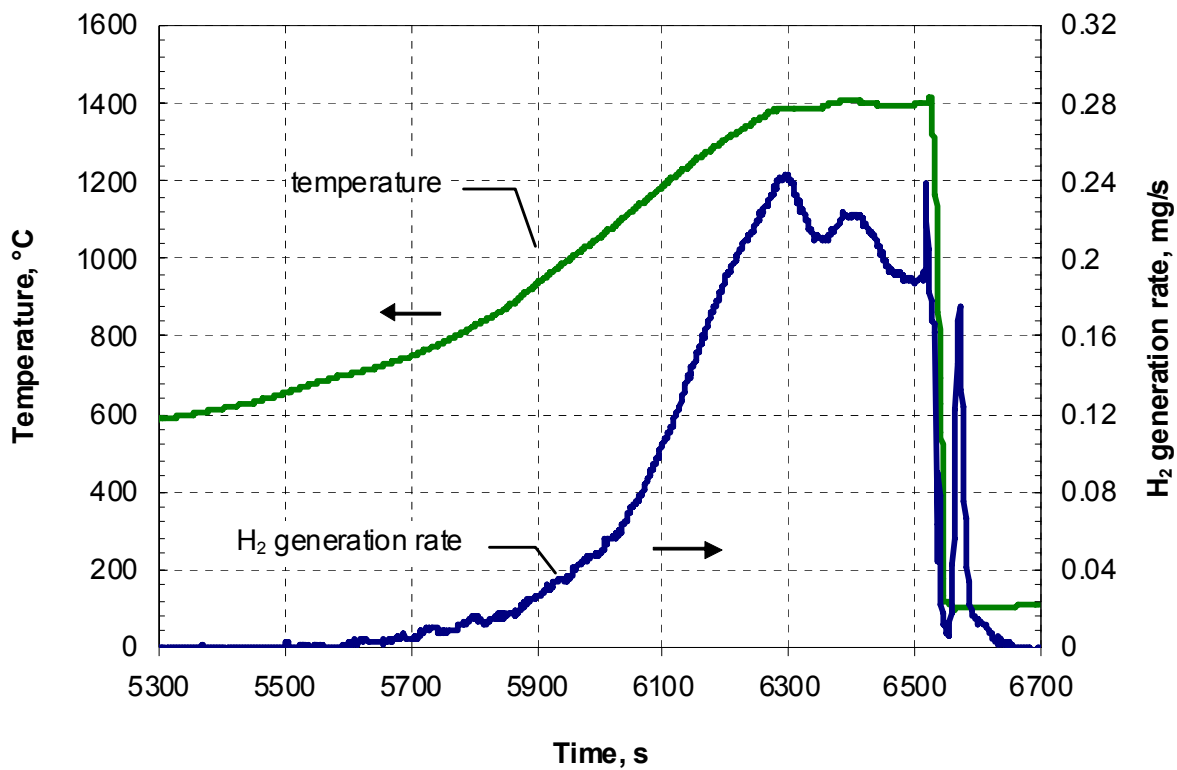
Simulator 24

Test regime and H₂ generation rate

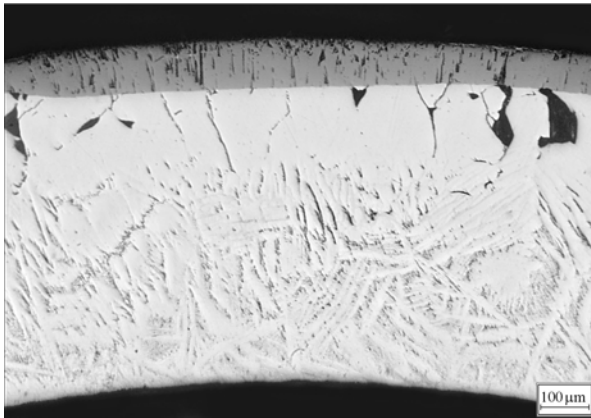


Unirradiated simulator (in-hot-cell test, steam oxidation)

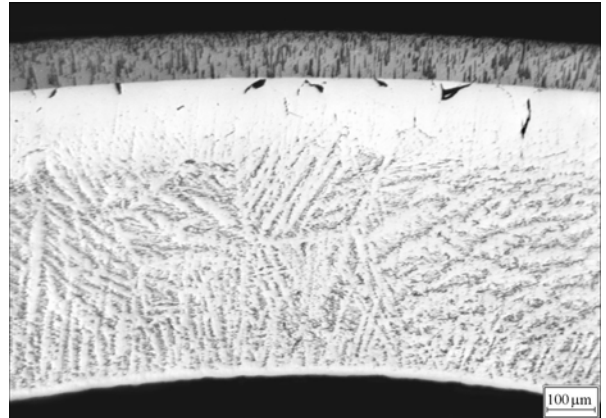
Simulator 35



Structure of oxide films formed during oxidation in Ar-O₂ mixture and steam



Simulator 24 (Ar-O)



Simulator 35 (steam)

Results of unirradiated simulator tests at quench temperature of 1400 °C

Simulator	Pre-oxidation	Simulator weight gain, mg	Oxide film thickness, μm	H ₂ generation at quench, mg
21	Ar - O	353	41	7.2 ± 0.6
22	Ar - O	596	65	3.5 ± 0.3
23	Ar - O	912	99	3.4 ± 0.3
24	Ar - O	973	105	2.7 ± 0.2
35	Steam	-	99	3.2 ± 0.3

Unirradiated simulator tests at 1700 °C



Simulator 25



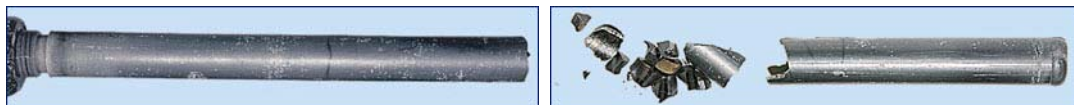
Simulator 26



Simulator 27



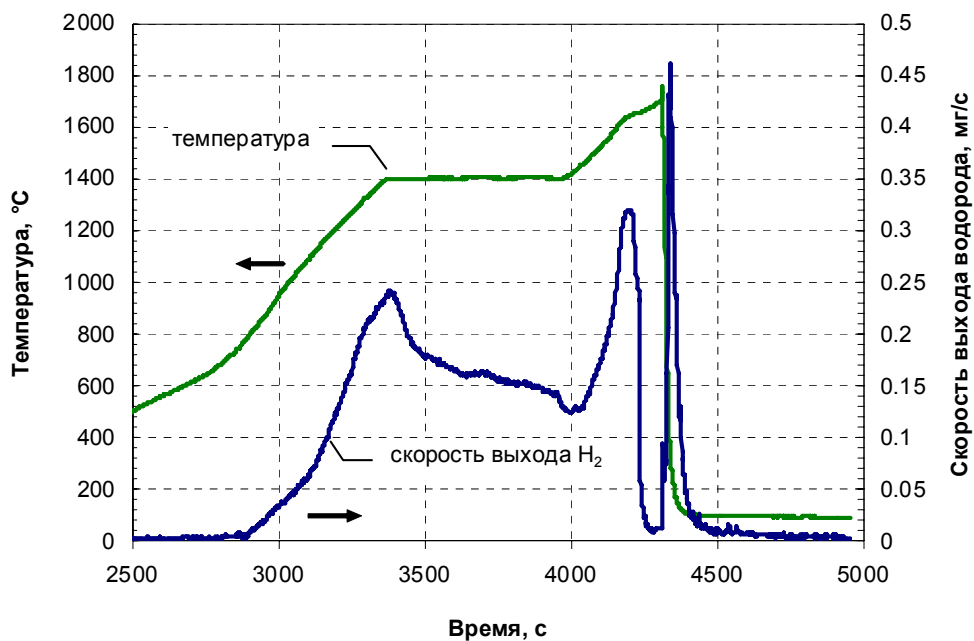
Simulator 28



Simulator 31



Simulator 32





Results of unirradiated simulator tests at quench temperature of 1700°C

Simulator	25	26	27	28	31	32
Preliminary oxidation time at 1400 °C, s	240	240	240	240	0	600
Quench environment	H ₂ O	H ₂ O	steam	steam	H ₂ O	H ₂ O
Pellets	UO ₂	UO ₂	-	-	UO ₂	UO ₂
Quench temperature, °C	1717	1722	1704	1703	1770	1755
Post-test simulator state	Failed	Intact	Intact	Intact	Failed	Failed
Oxide film thickness, μm	270	140	120	150	150	270
Total H ₂ generation, mg	238 ± 19	187 ± 15	140 ± 11	166 ± 14	153 ± 12	226 ± 18
H ₂ generation at quench,mg	14.1 ± 1.1	8.6 ± 0.7	11.6 ± 0.9	6.6 ± 0.5	27.4 ± 2.2	17.5 ± 1.4

Irradiated Simulators Test

Simulators 36, 39:

- Irradiated simulators, refabricated from VVER fuel rod with burnup of 54 MW·d/kg U and 65 MW·d/kg U;
- Quench tests at 1400 °C in the regime similar to simulator 35 (comparison of the unirradiated and irradiated simulator tests).

Simulator 37:

- Irradiated simulator, refabricated from VVER fuel rod with burnup of 54 MW·d/kg U ;
- Quench tests at 1700 °C without preliminary oxidation (maximal hydrogen peak at quench is expected).

Simulator 40

- Irradiated simulator, refabricated from VVER fuel rod with burnup of 65 MW·d/kg U ;
- Quench tests at 1400 °C without preliminary oxidation



Simulator 39

54 MW·d/kg U;
 Quench test at 1400 °C
 (preliminary oxidation
 240 s at 1400 °C)



Simulator 37

65 MW·d/kg U;
 Quench test at 1400 °C
 (preliminary oxidation
 240 s at 1400 °C)



Simulator 40

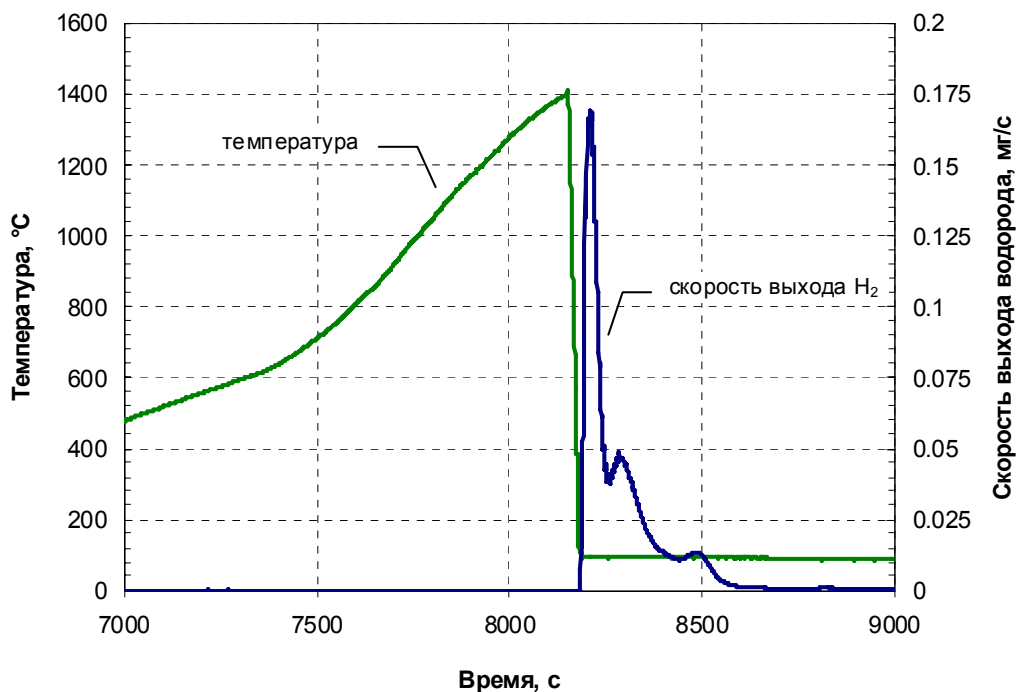
54 MW·d/kg U;
 Quench test at 1700 °C
 (no preliminary
 oxidation)



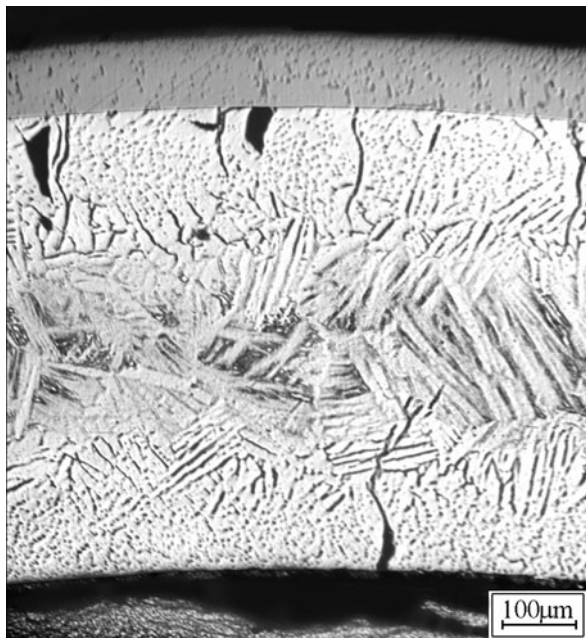
65 MW·d/kg U;
 Quench test at 1400 °C
 (no preliminary xidation)

Simulator 40.

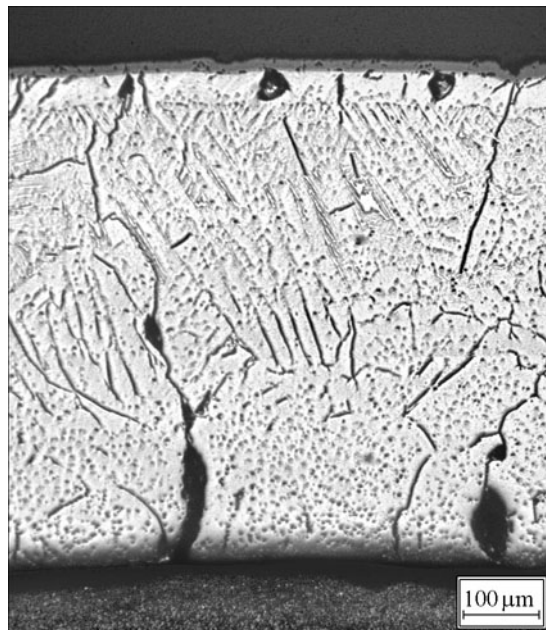
Test regime and hydrogen generation rate



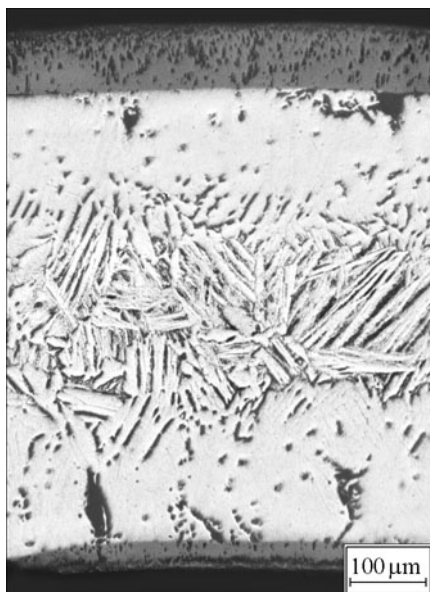
Oxide film thickness and cladding structure of the irradiated simulators



Simulator 36



Simulator 37



Simulator 39



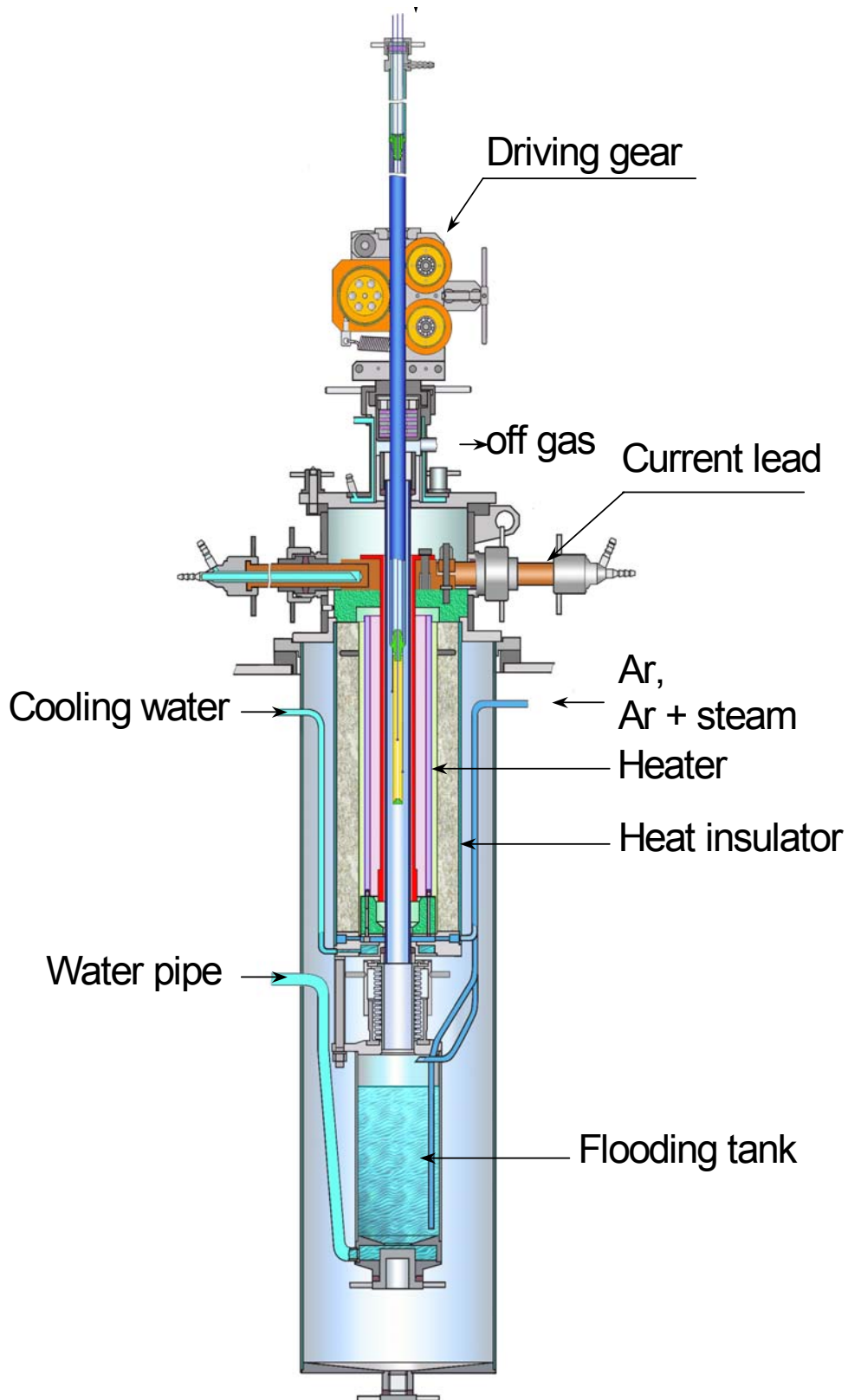
Simulator 40



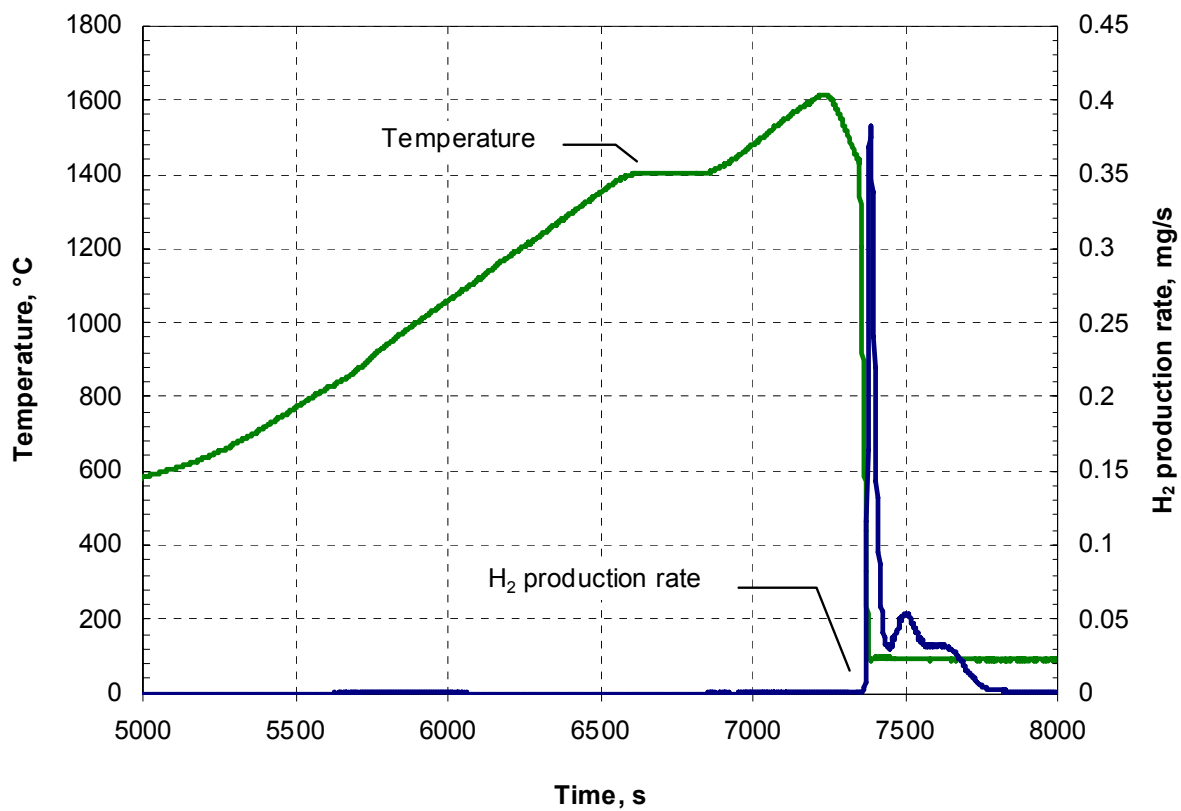
Results of irradiated simulator tests

Simulator	36	37	39	40
Burnap, MWt-d/kg U	54	54	65	65
Preliminary oxidation time at 1400 °C, s	240	0	240	0
Quench temperature, °C	1407	1703	1428	1411
Oxide film thickness, μm	111	15	98	9
Outer $\alpha\text{Zr(O)}$, μm	186	55	158	21
Inner $\alpha\text{Zr(O)}$, μm	170	261	182	120
Total H ₂ generation, mg	164 \pm 13	16.3 \pm 1.3	173 \pm 14	13.6 \pm 1.1
H ₂ generation at quench, mg	6.7 \pm 0.5	14.7 \pm 1.2	7.0 \pm 0.6	13.6 \pm 1.1
Total ⁸⁵ Kr release, ml	0.037 \pm 0.004	0.065 \pm 0.008	0.033 \pm 0.004	0.016 \pm 0.002
Total Xe, release ml	12.9 \pm 1.3	34 \pm 3.4	9.9 \pm 1.0	4.9 \pm 0.5
Relative ⁸⁵ Kr release, %	18.2	33.1	9.2	4.5
Relative Xe release, %	15.9	42.2	10.2	5.0
⁸⁵ Kr, release at quench, %	4.4	21.3	11.2	29.9
Xe, release at quench, %	2.9	17.6	10.5	32.6
Total 137 Cs release, %	4.3	11.3	8.9	2.6
137 Cs release at quench, %	0.7	1.3	1.2	0.6

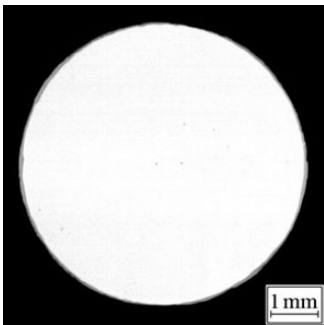
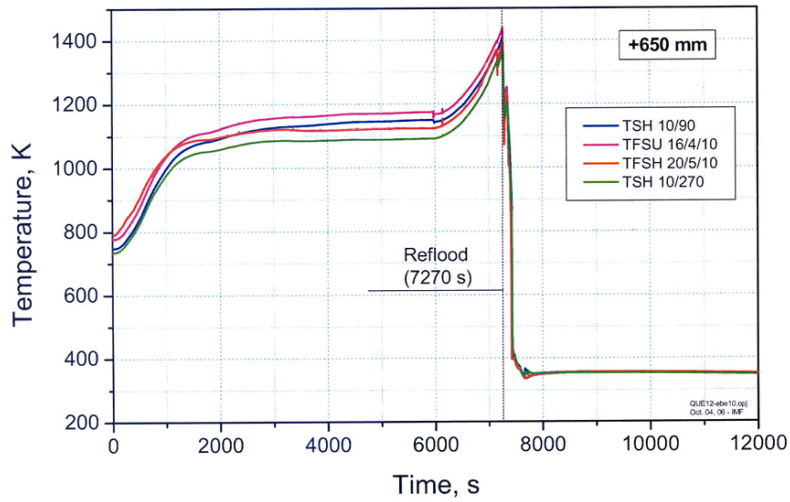
Test rig furnace



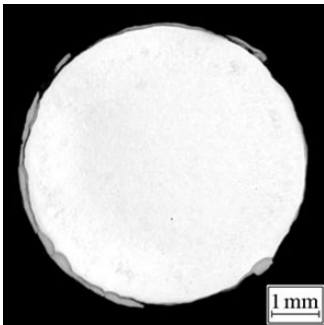
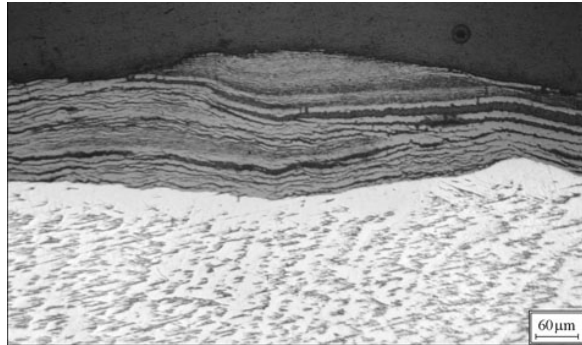
Simulator 42



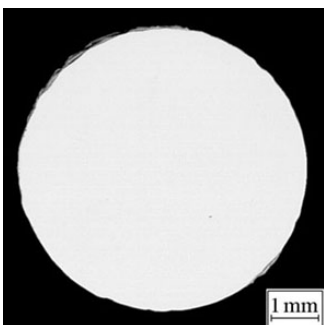
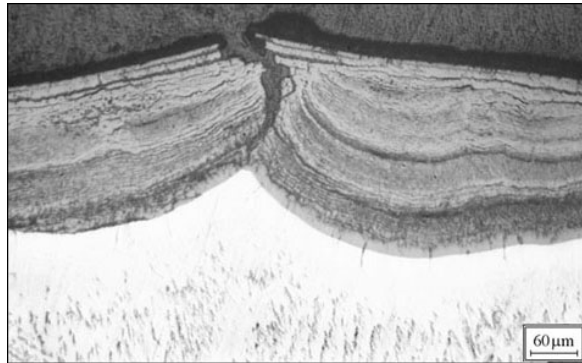
Elevation 700 mm



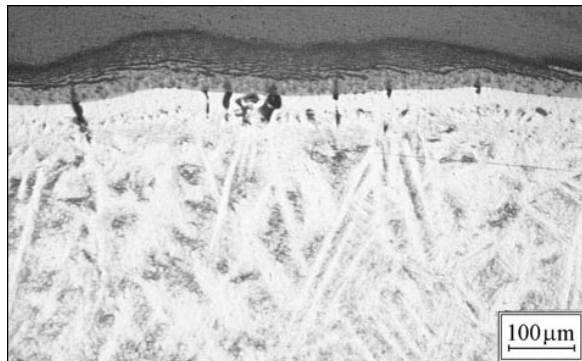
ROD D: 700 mm



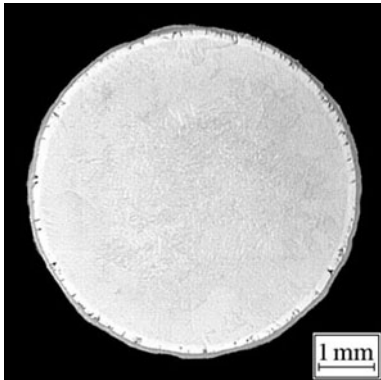
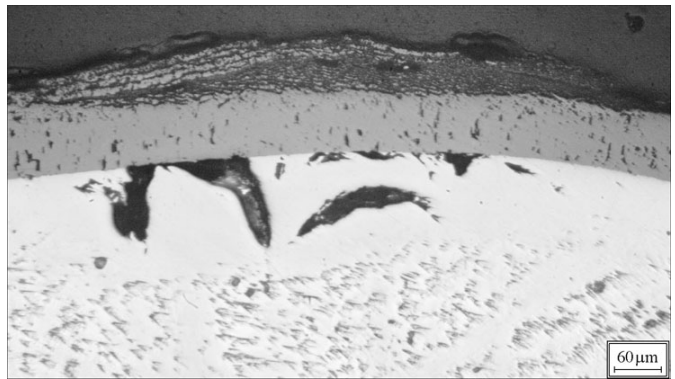
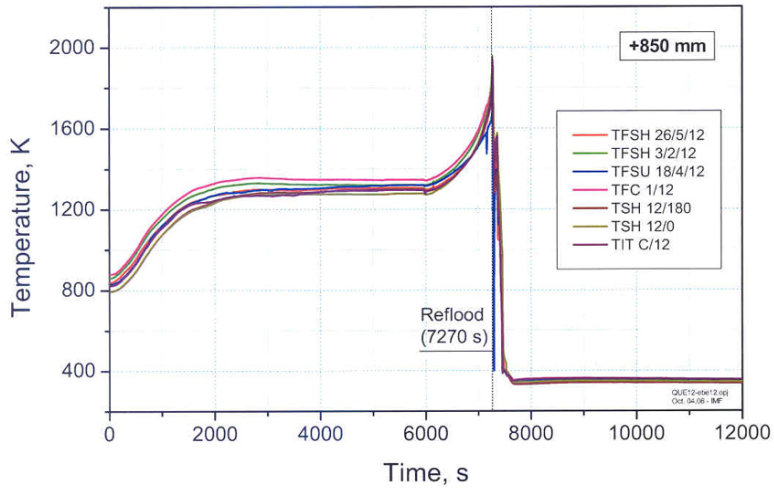
ROD F: 700 mm



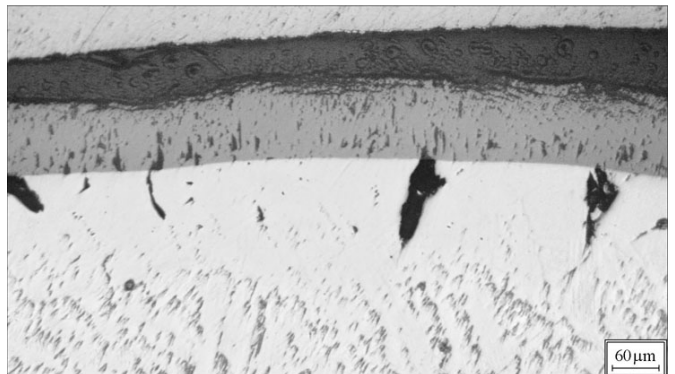
ROD B: 700 mm



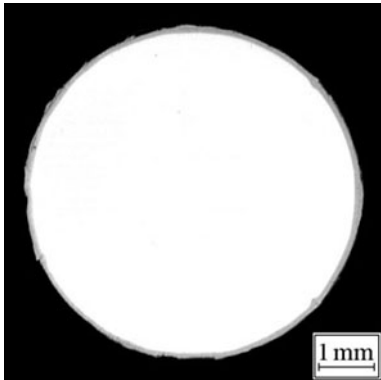
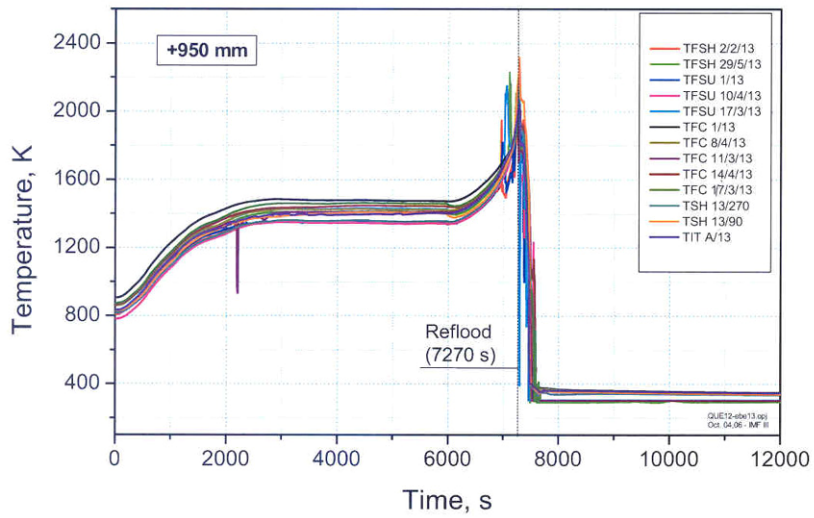
Elevation 820 mm



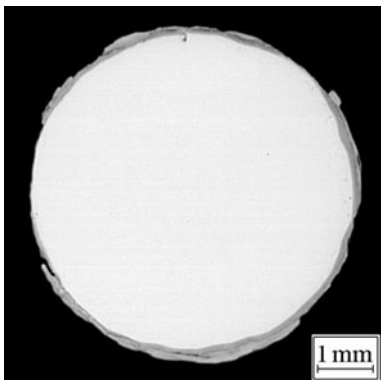
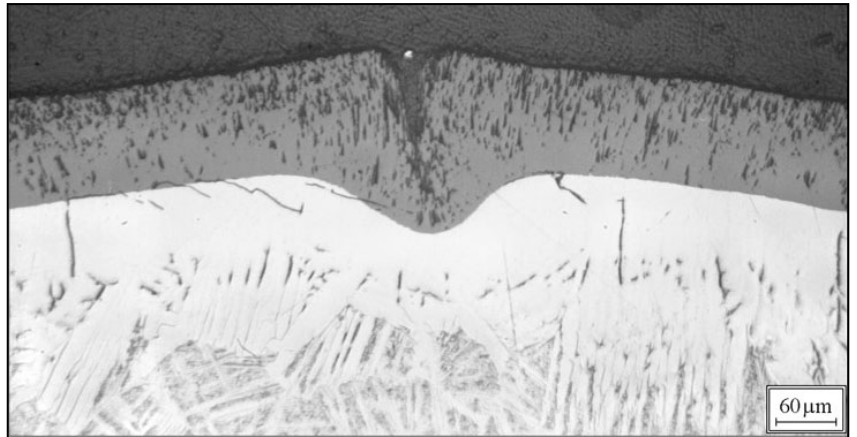
ROD B: 820 mm



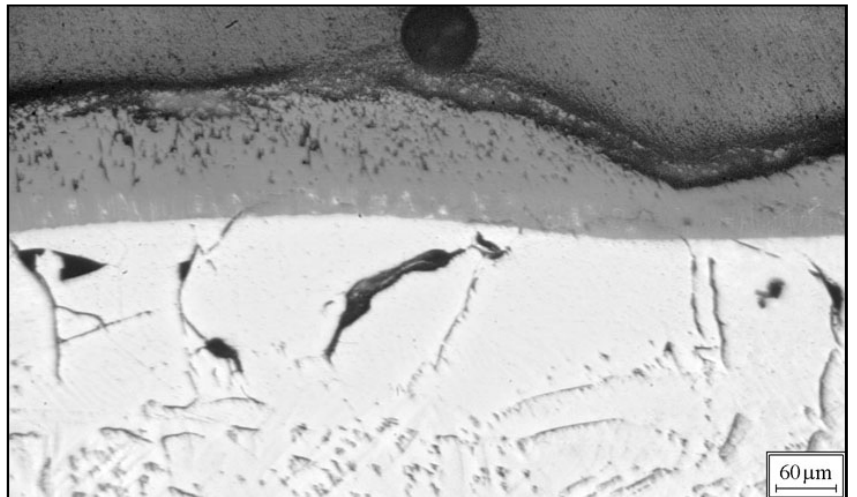
Elevation 940 mm



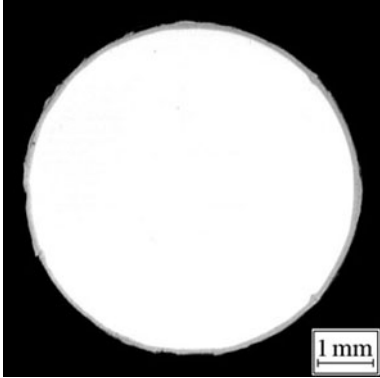
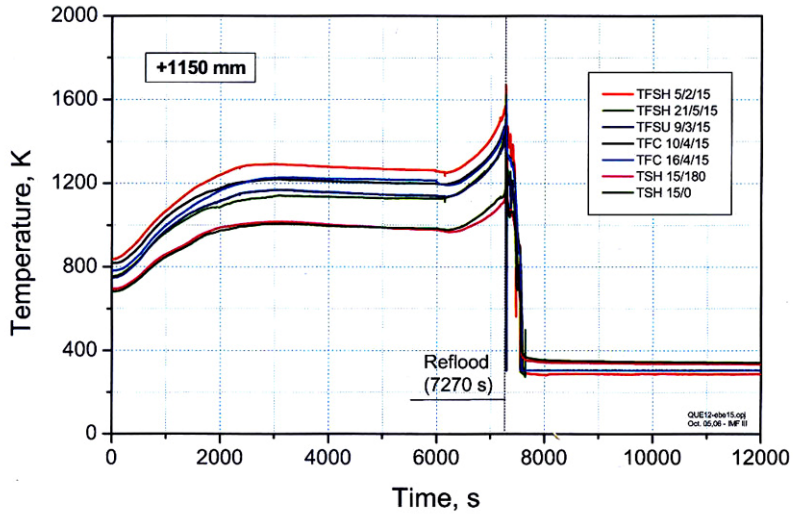
ROD D: 940 mm



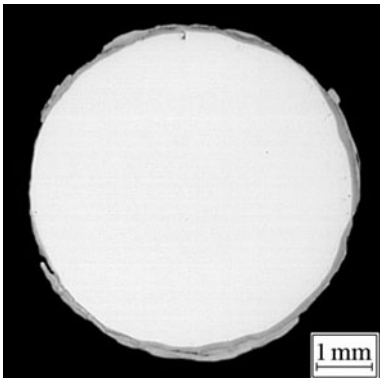
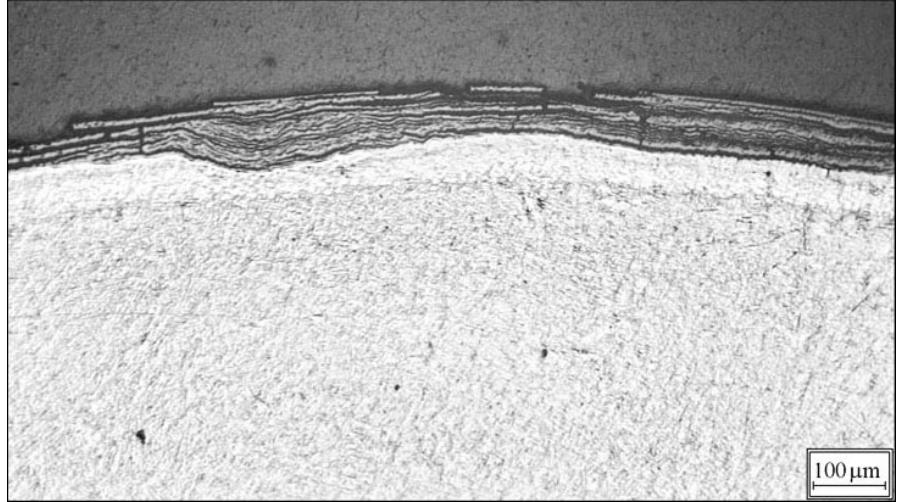
ROD F: 940 mm



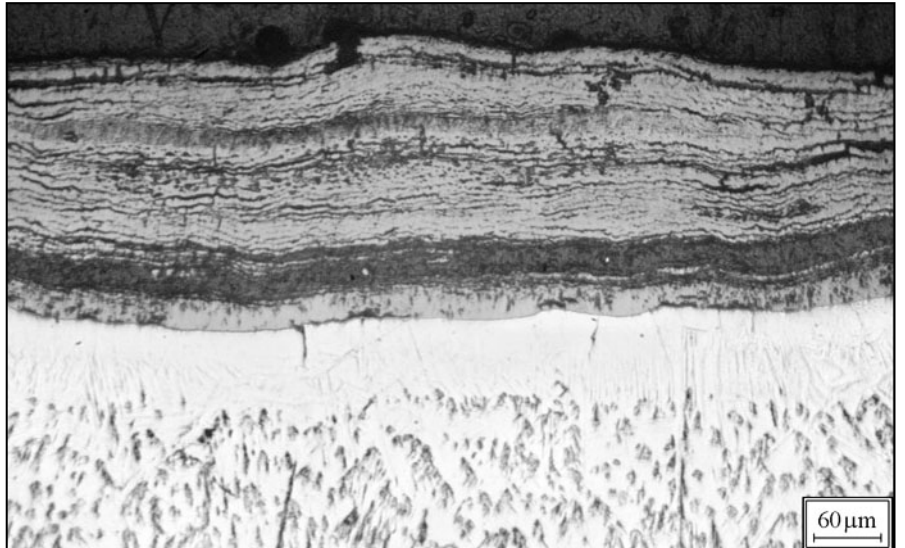
Elevation 1120 mm



ROD D: 1120 mm



ROD F: 1120 mm





1648.2 Project Time Schedule

	1 st year		2 nd year		3 rd year	
STAGE A. Spent ROD- QUENCH						
STAGE B. FA-QUENCH						
STAGE C. FA-QUENCH Model						



Current 1648.2 Project state

STAGE A. Spent ROD-QUENCH

- The tests with unirradiated VVER fuel rod simulators are performed under the reflooding conditions
- 5 of 18 planned tests with irradiated simulators are done
- Test rig is restored, but additional time (about two quarters) is needed to accomplish the planned tests.

STAGE B. Fresh FA-QUENCH

Work may be accomplished within the time schedule

STAGE C. FA Quench Model