Karlsruhe Institute of Technology

SIMULATION OF ULOF INITIATION PHASE IN ESFR-SMART WITH SIMMER-III

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International Conference on Fast Reactors and Related Fuel Cycles

FR22: Sustainable Clean Energy for the Future (CN-291)

Vienna, Austria

19-22 April 2022

❑ Introduction

Karlsruhe Institute of Technology

- Euratom Project: ESFR-SMART since 2017
- Core Performance Improvement:

From positive void worth in CP-ESFR Working Horse Core to low/negative void worth in ESFR-SMART

- Major question here: if power excursion can be initiated by sodium boiling in ULOF transients

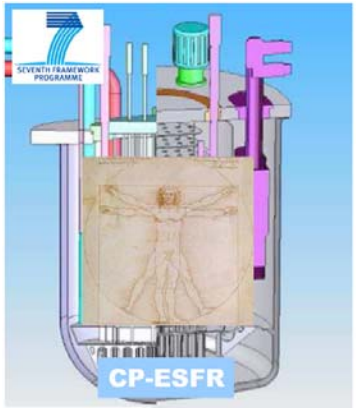
ESFR-SMART
sodium fast reactor safety

Our Studies:

Direct numerical simulations with SIMMER-III

Thermal hydraulic and neutronic space-time coupled calculation of ULOF

Major neutronic feedback effects are included



Hope to find something new and useful

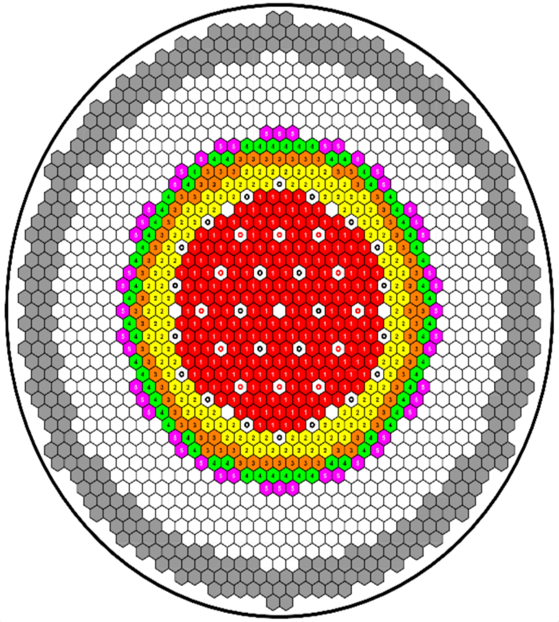
❑ Introduction

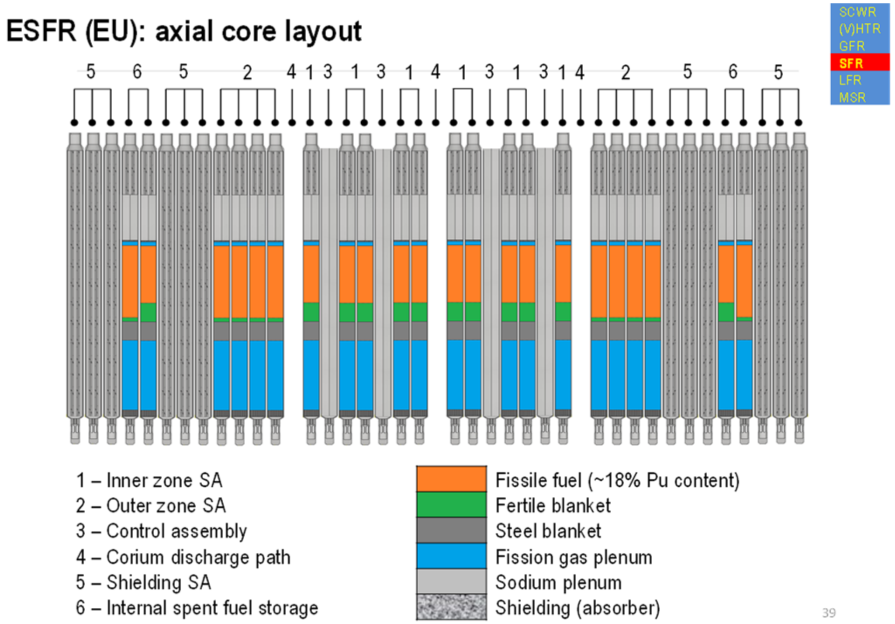
➢ ESFR-SMART Concept Design: P= 3600 MWth and Sodium Tin = 395 C and Tout = 545 C

➢ Fissile part is higher in the outer zone and the lower fertile part is shorter

➢ Hottest FAs are in innermost ring of the outer zone

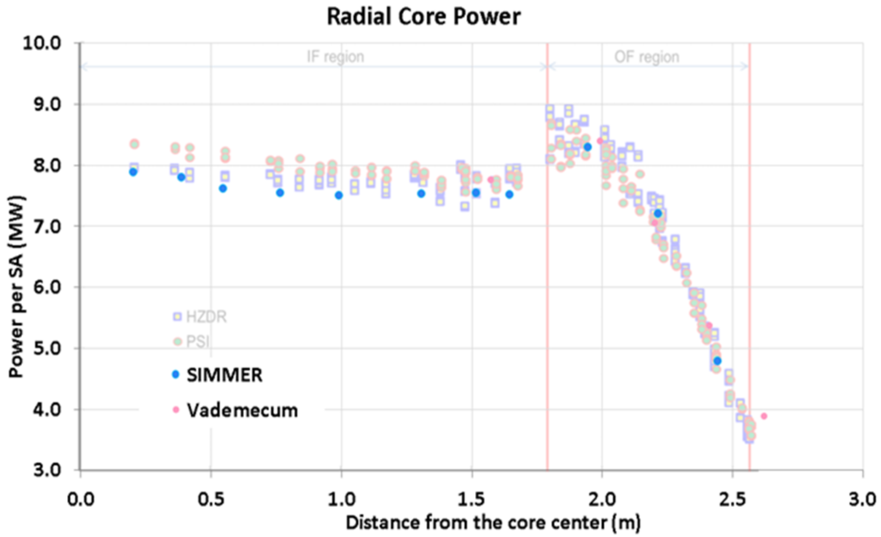
➢ Boiling onset takes place there. The effective boiling void worth is negative.

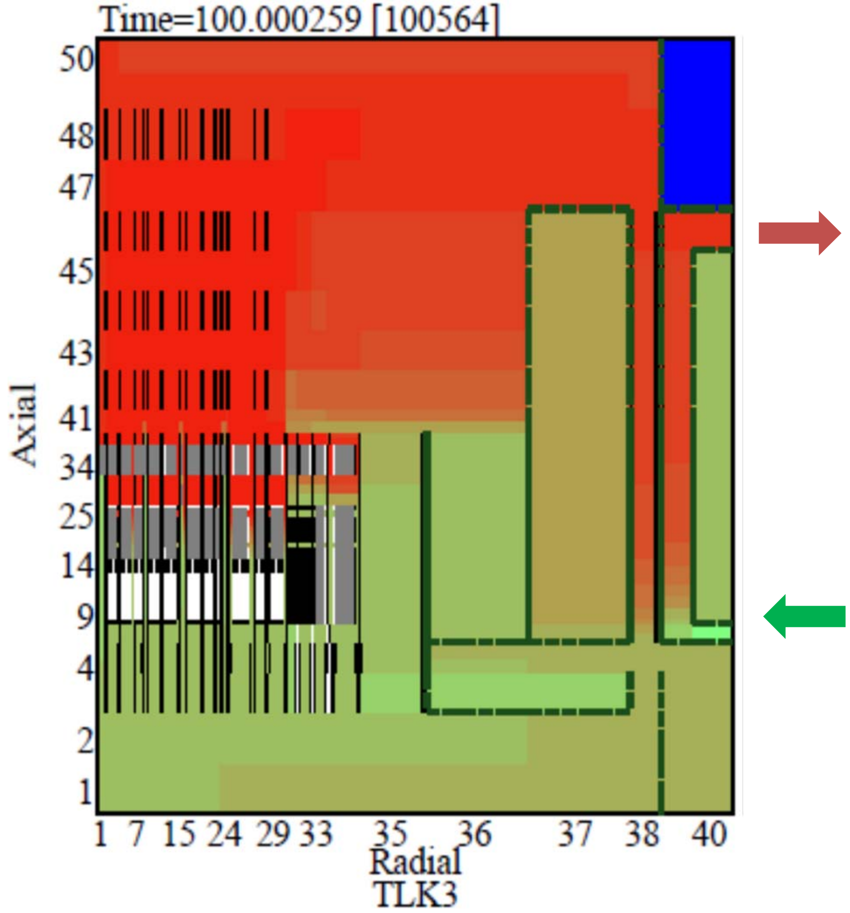




❑ SIMMER ESFR-SMART Model

- Geometric and thermal hydraulic model, where cover gas is modelled
- Neutronic feedback: Doppler and coolant feedback are automatically taken into account.
- Thermal expansion models for the core, axial and radial, and CRDL are included.





Neutronic Feedback Coefficients

Parameter	Unit	SIMMER	Reference (Serpent calculations)
K_{eff}		1.00937	1.00471
Prompt Neutron Lifetime	[s]	4.25E-07	4.74E-07
Beta Effective	[pcm]	347	362
Doppler Constant Fissile 1500 K -> 1800 K Fertile 900 K -> 900 K	[pcm]	-808	-685
Core Void Worth without Voided Gaps at T_{cool} 763.2 K	[pcm]	1755	
Core Void Worth with Voided Gaps	[pcm]	1727	1542
Upper Gas Plenum + Plug Void Worth	[pcm]	**-41.3**	**-62**
Coolant Density Reactivity Coefficient	[pcm/K]	49/110.8= 0.442	48/110.8 = 0.433
Axial Thermal Expansion Coefficient	[pcm/K]	-0.0715	-0.083
Radial Thermal Expansion Coefficient	[pcm/K]	-0.711	-0.646
Control Rod Drivelines Expansion Coefficient	[pcm/cm]	-423/14.5	-423/14.5

SIMMER ESFR-SMART ULOF Results

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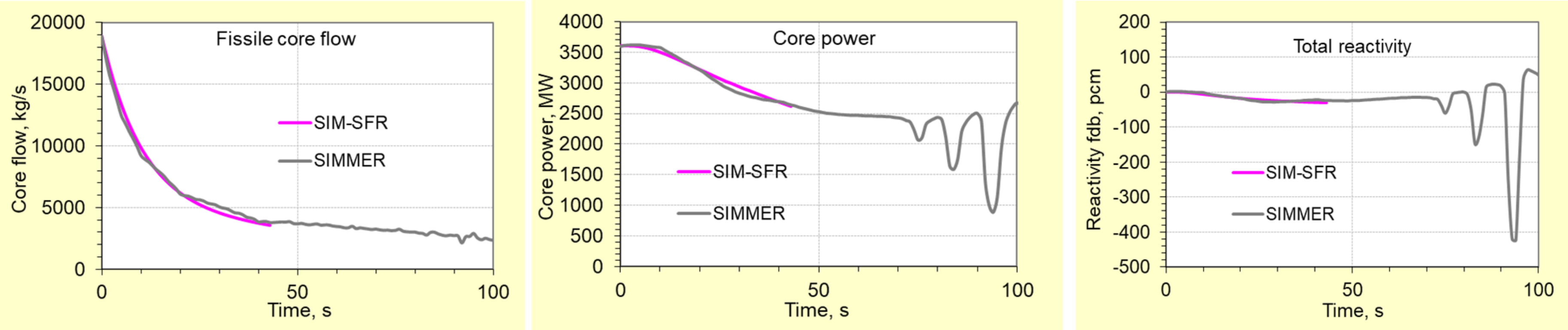
ESFR-SMART CORE THERMAL HYDRALIC CONDITIONS

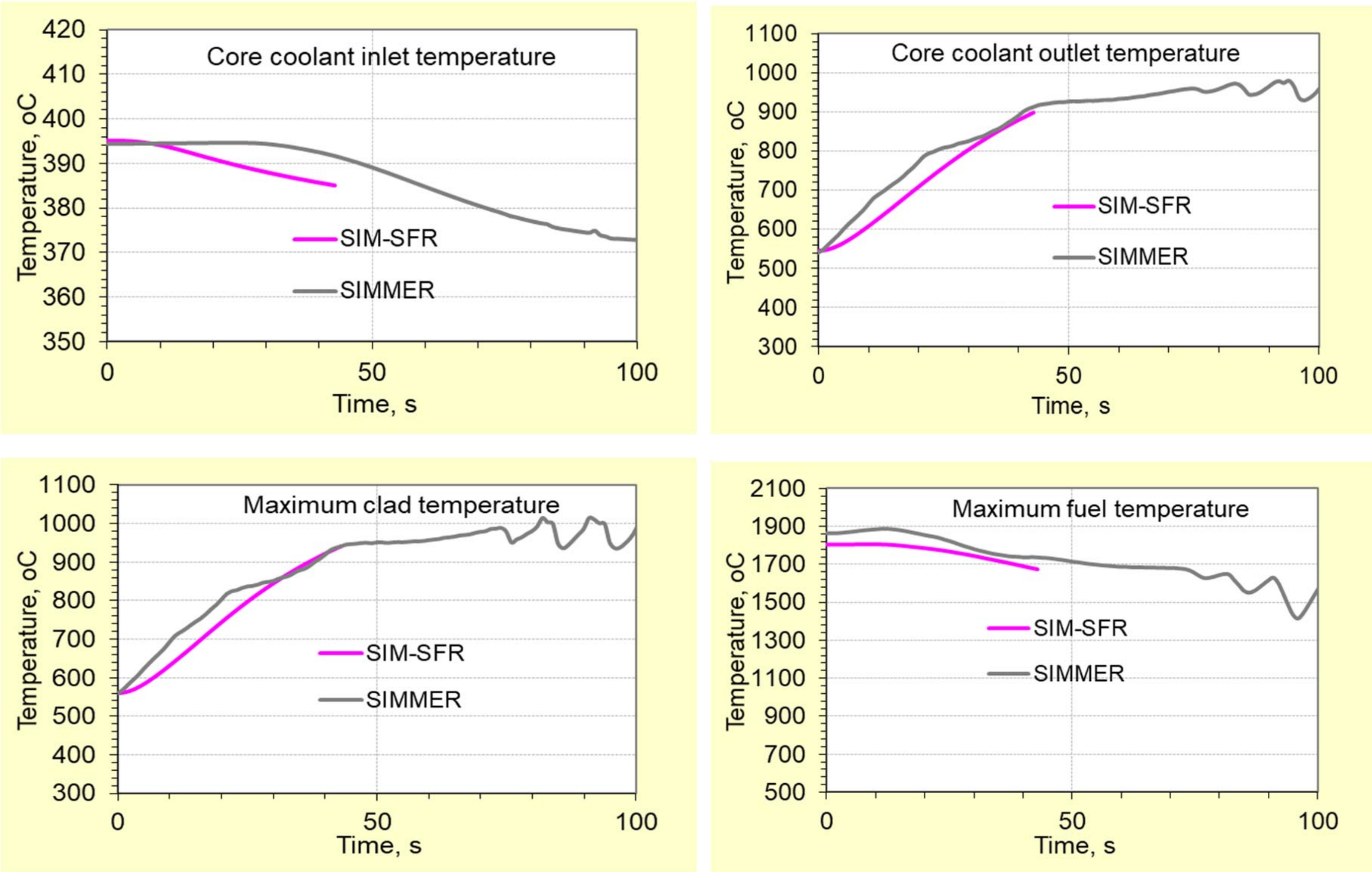
Case No.	Case Description	Boiling Onset	Power Excursion
1	Axial Fuel-Driven and 1.53E-5 CRDL	42 s	Yes at 102 s
2	Axial Clad-Driven and 1.53E-5 CRDL	69 s	Yes at 129 s
3	Axial Fuel-Driven and 1.82E-5 CRDL	45 s	Yes at 117 s
4	**Axial Clad-Driven and 1.82E-5 CRDL**	**73 s**	**No**

Case 4 Results



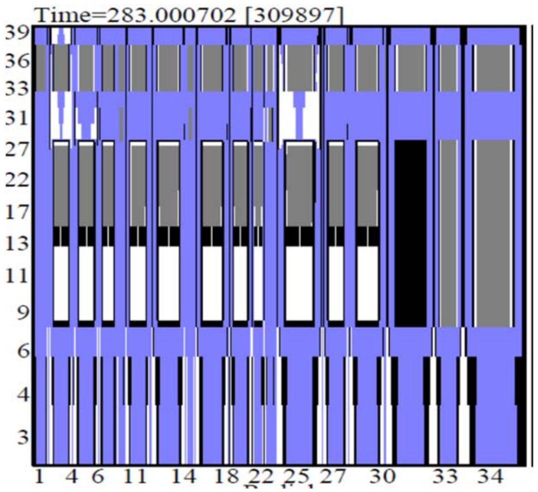
SIMMER ESFR-SMART ULOF Results

Case 4 Results

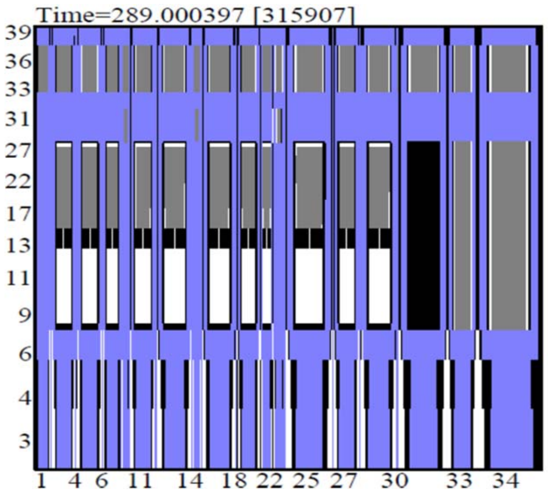


❑ SIMMER ESFR-SMART ULOF Results

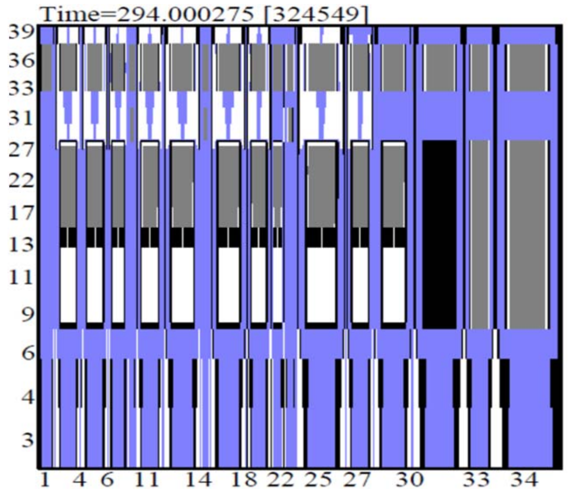
Case 4 Results: boiling void and reactivity



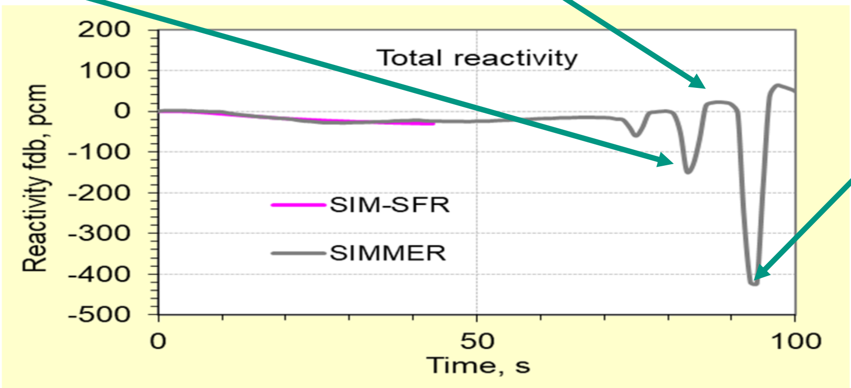
t = 83 s



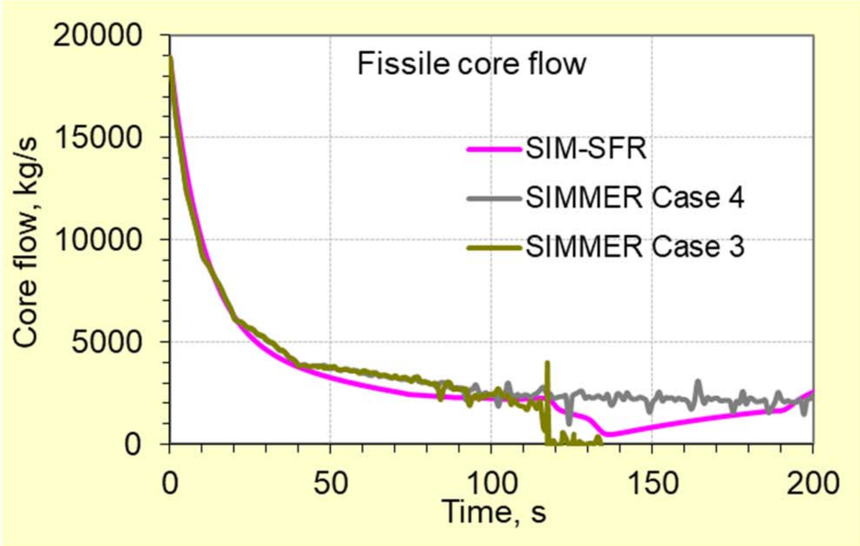
t = 89 s

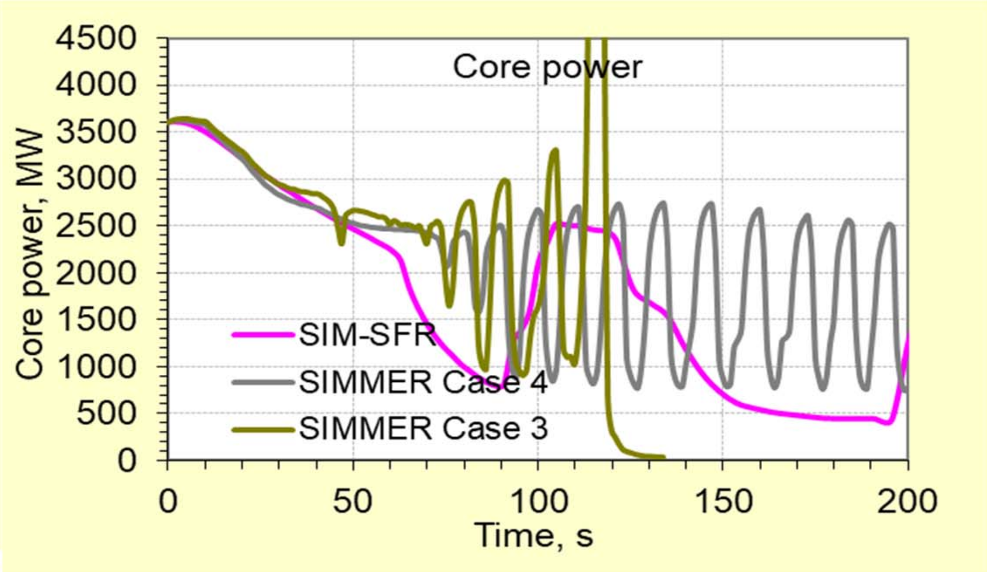


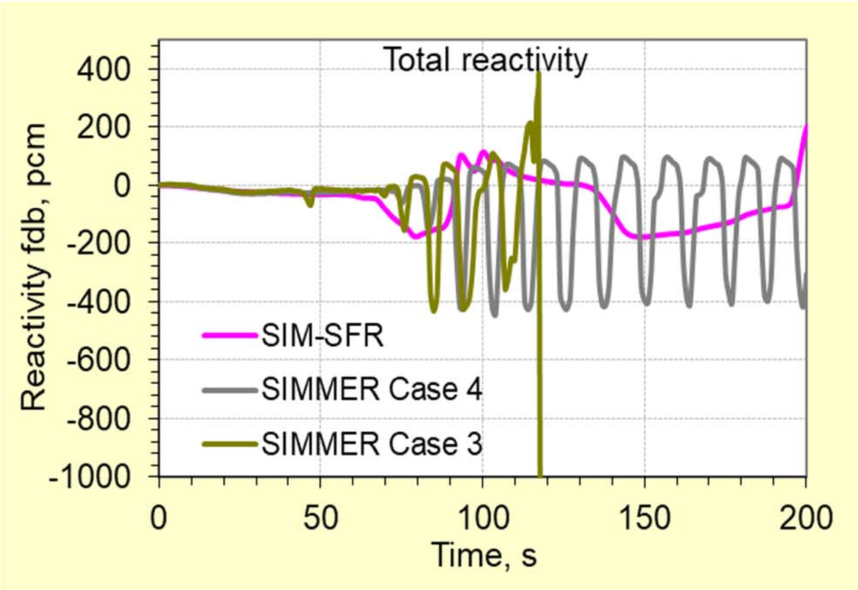
t = 94 s



❑ ULOF Results with Power Excursion







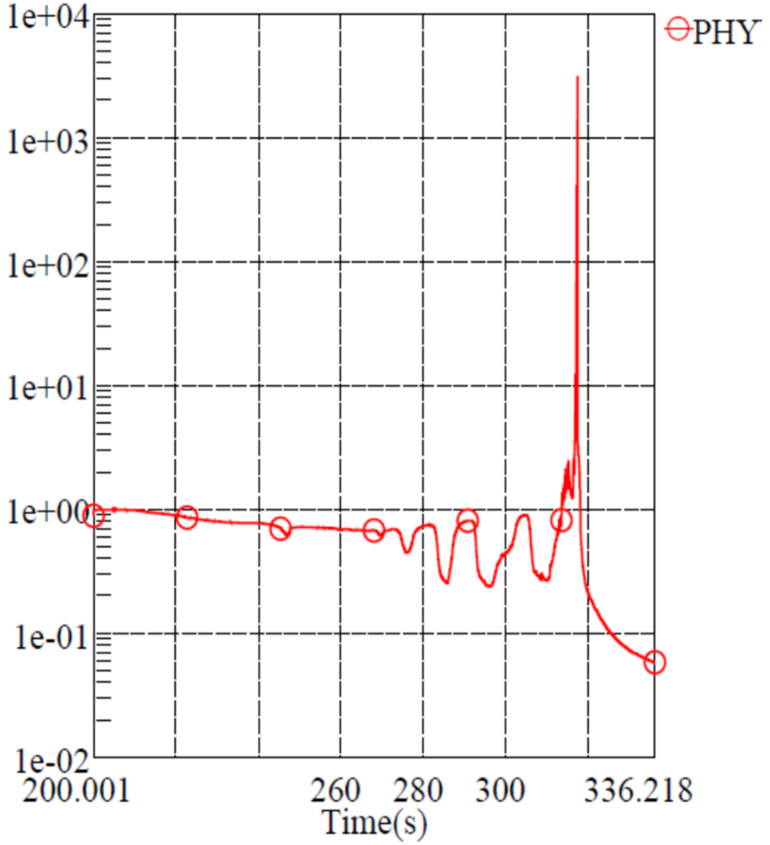
Case 3: Fuel driven ThmExp, boiling onset at 43 s

Power excursion at 117 s

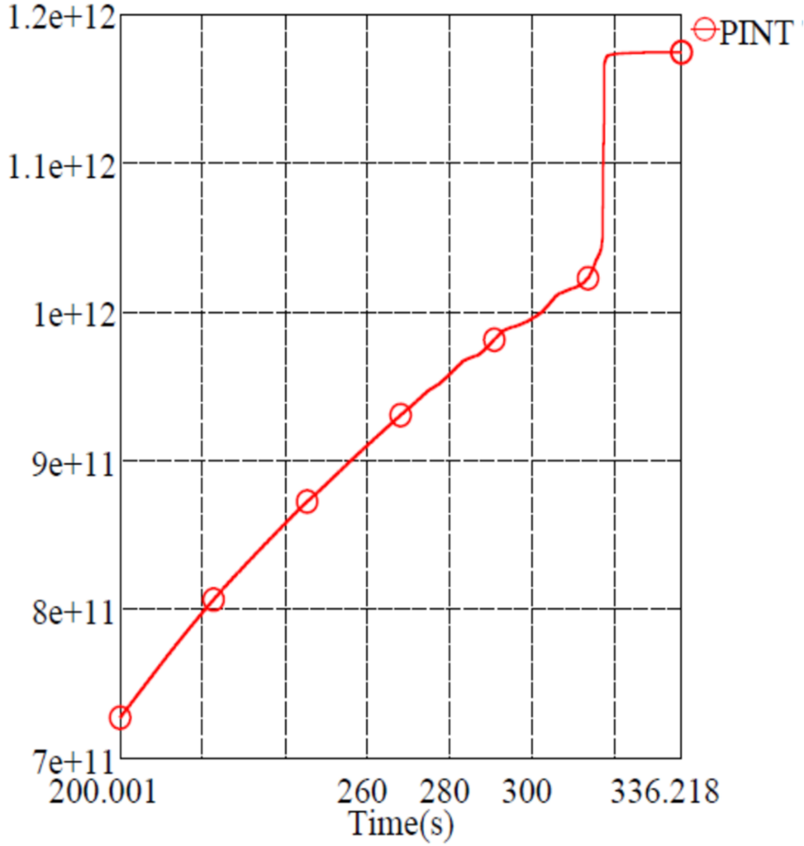
Case 4: Clad driven ThmExp, boiling onset at 69 s

No power excursion

ULOF Results with Power Excursion



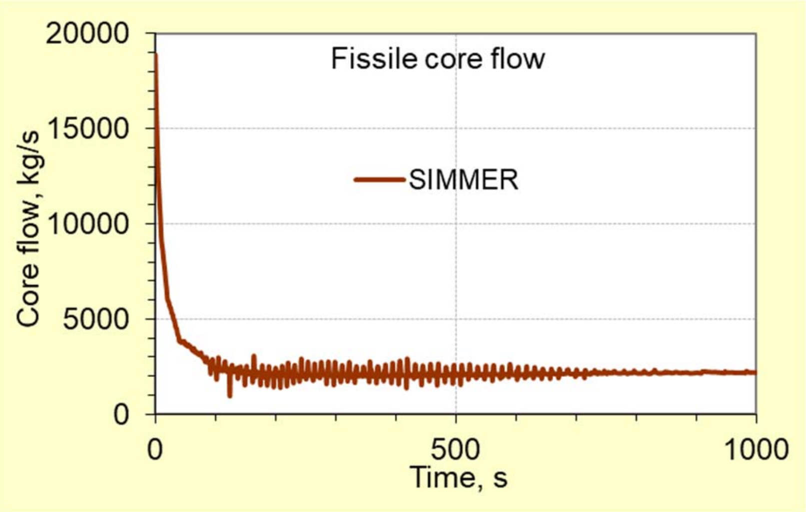
Normalized Power in Case 3

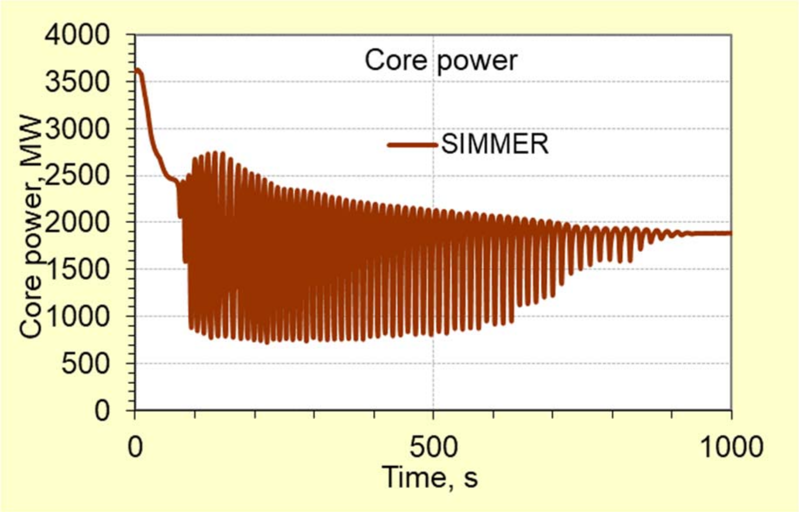


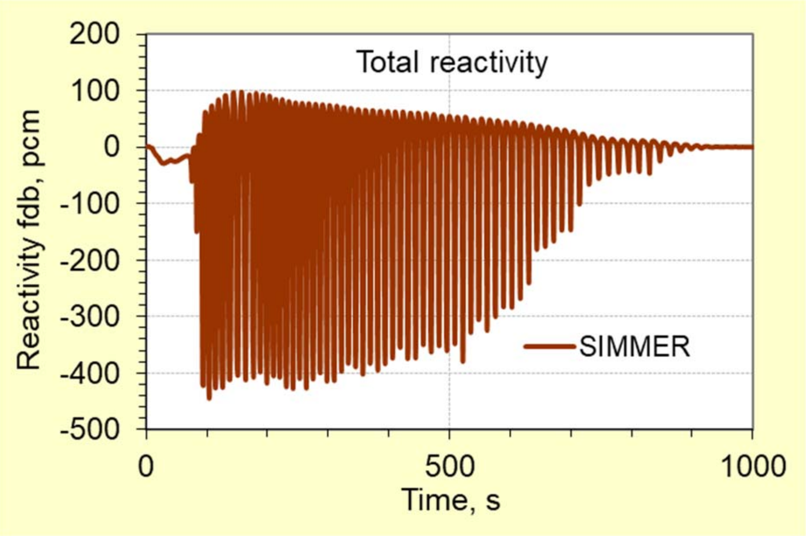
Thermal Energy Release, J

The power excursion generates about 100 GJ

❑ ULOF Long Time Results (Case 4)







- The boiling oscillation decays and finally disappears
- Due to sodium boiling the pressure at the cover gas increases from 1 bar to 2.7 bar.
- 1 bar => boiling temperature 883°C (1156 K)
- 3.2 bar=> boiling temperature 1027°C (1300 K)

❑ Conclusions

- The thermal expansion model is included and the new CRDL model is developed and used.
- 4 ULOF cases with fuel/clad driven axial thermal expansion and two different steel thermal expansion coefficients for CRDL are calculated.
- Sodium boiling oscillations with a period of 10s are observed and explained, which is decisive for, whether the prompt criticality can be reached.
- Power excursions are obtained in the first 3 cases, with about 100 GJ thermal energy release.
- No power excursion in the last case with strongest negative feedback.
- Long time calculation shows that the boiling oscillation can even disappear finally, which suggests a higher initial cover gas pressure can prevent the sodium boiling here.

Acknowledgement:

ESFR-SMART: This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 754501.