SIMULATION OF INITIATION AND TRANSITION PHASES OF UNPROTECTED TRANSIENTS IN ESFR-SIMPLE SMR

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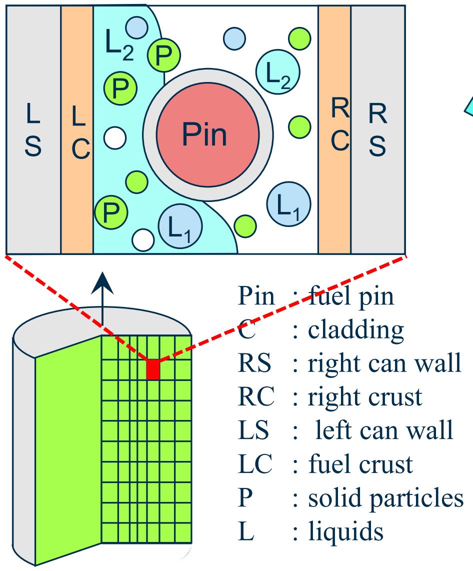
Introduction

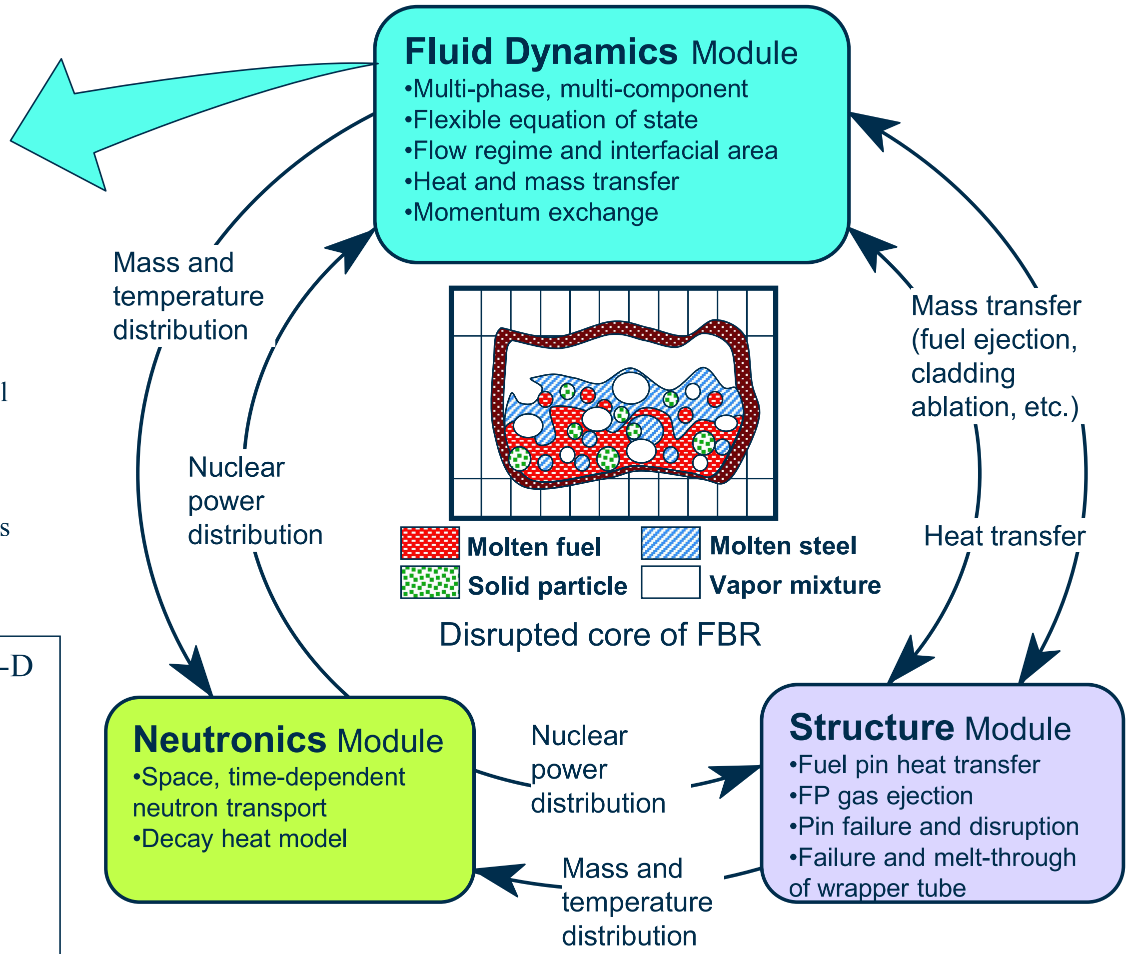
- ESFR-SIMPLE (2022-2026) is an EU-funded project aiming to improve the safety of the European Sodium Fast Reactor through innovative monitoring, power level flexibility and experimental research.
- A 360 MW(th) Small Modular Reactor based on the European Sodium Fast Reactor (ESFR) design is studied within the project.
- Benchmark results obtained by SIMMER show good agreement with those of other partners and indicate no fuel pin failure for ULOF or UTOP cases with reactivity insertions up to 1.14 $.
- A higher reactivity insertion (1.5 $) may induce sodium boiling, leading to power oscillations, core melting, and re-criticality due to fuel relocation.

The SIMMER-III, -IV code

- A Computer code for analyzing the behavior of disrupted core of fast reactors
- Developed by JAEA under the international cooperation with KIT and CEA.
- Fluid dynamics: Advanced Fluid Dynamics Model (AFDM)
- Neutronics: Neutron transport Sn-method
- Structure: Fuel pin is modelled using cylindrical r-z coordinate inside fuel pellet.

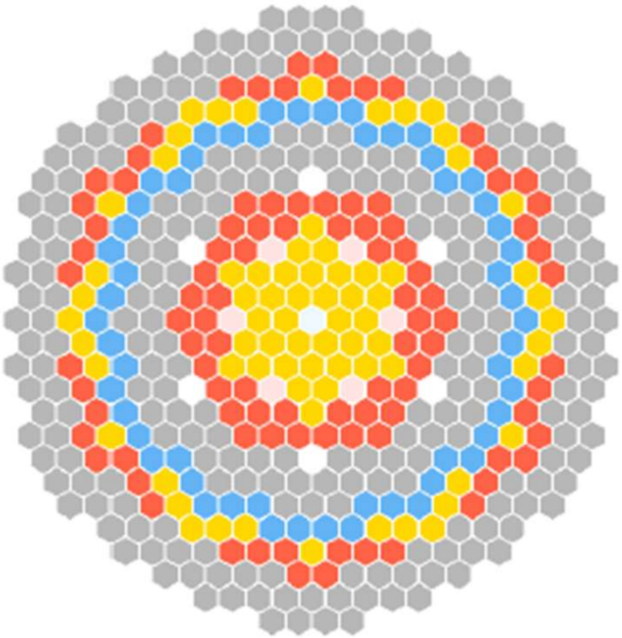


- 2-D r-z or x-z coordinate or 3-D x-y-z coordinate
- 8-velocity fields
- Multi-phase
  solid, liquid, vapor
- Multi-components
  5 material components,
  27 density components,
  16 energy components

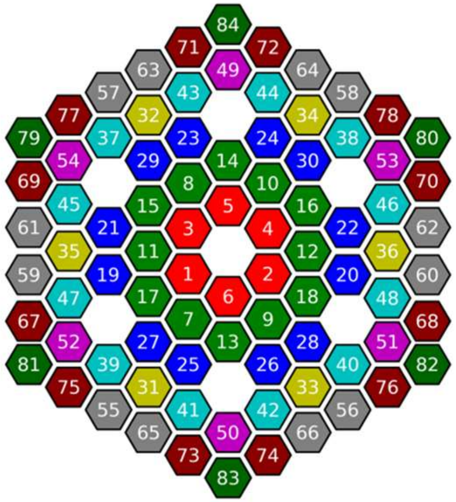


Core configuration of ESFR-SIMPLE, SMR

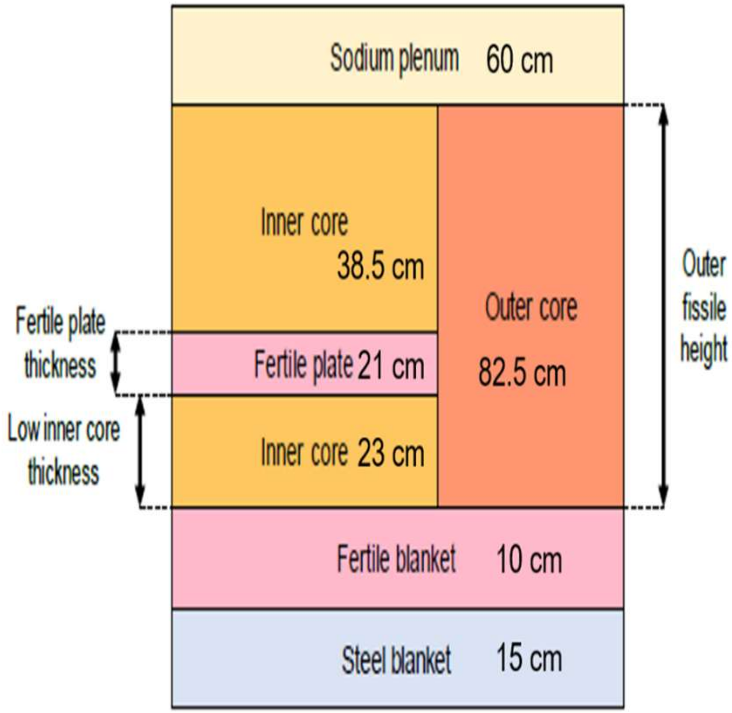
- 360 MW(th)
- Core Inlet/Outlet: 395/545 C
- Fuel: MOX
- SA Pitch: 18.66 cm



Core map



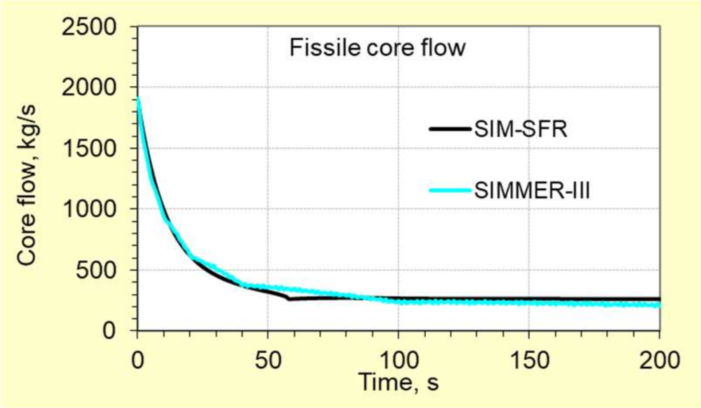
Cooling groups

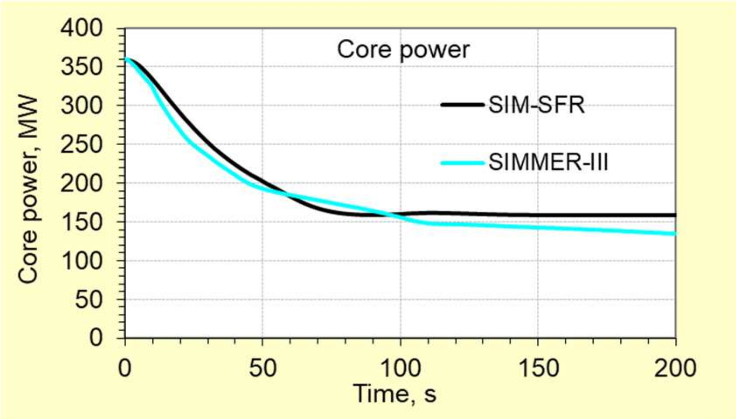


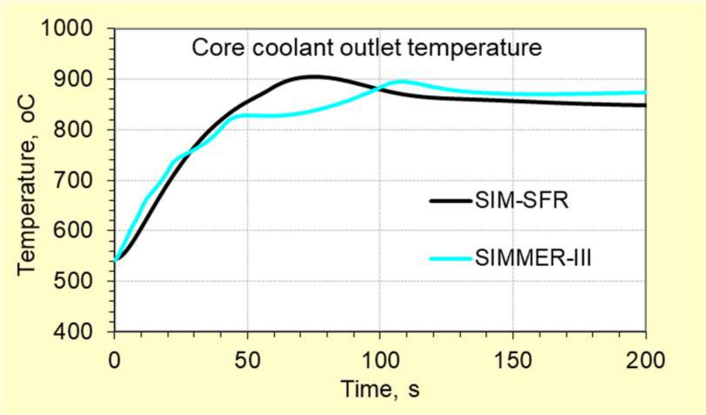
Axial core layout

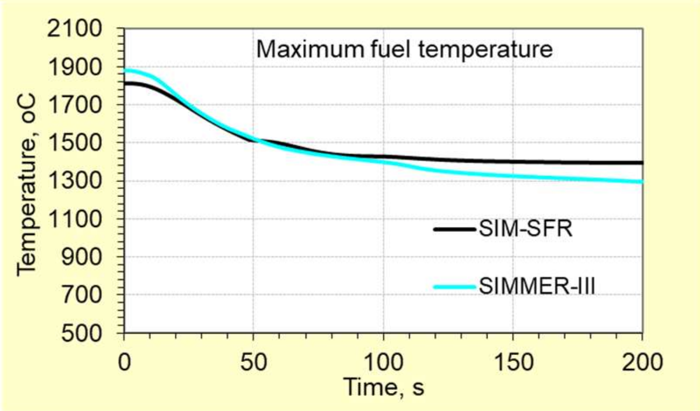
ULOF Benchmark Results

- Flow coast down with halving time ~ 10s, asymptotic flow rate ~ 12 %
- ULOF simulated at KIT with SIMMER, also with a system code, SIM-SFR







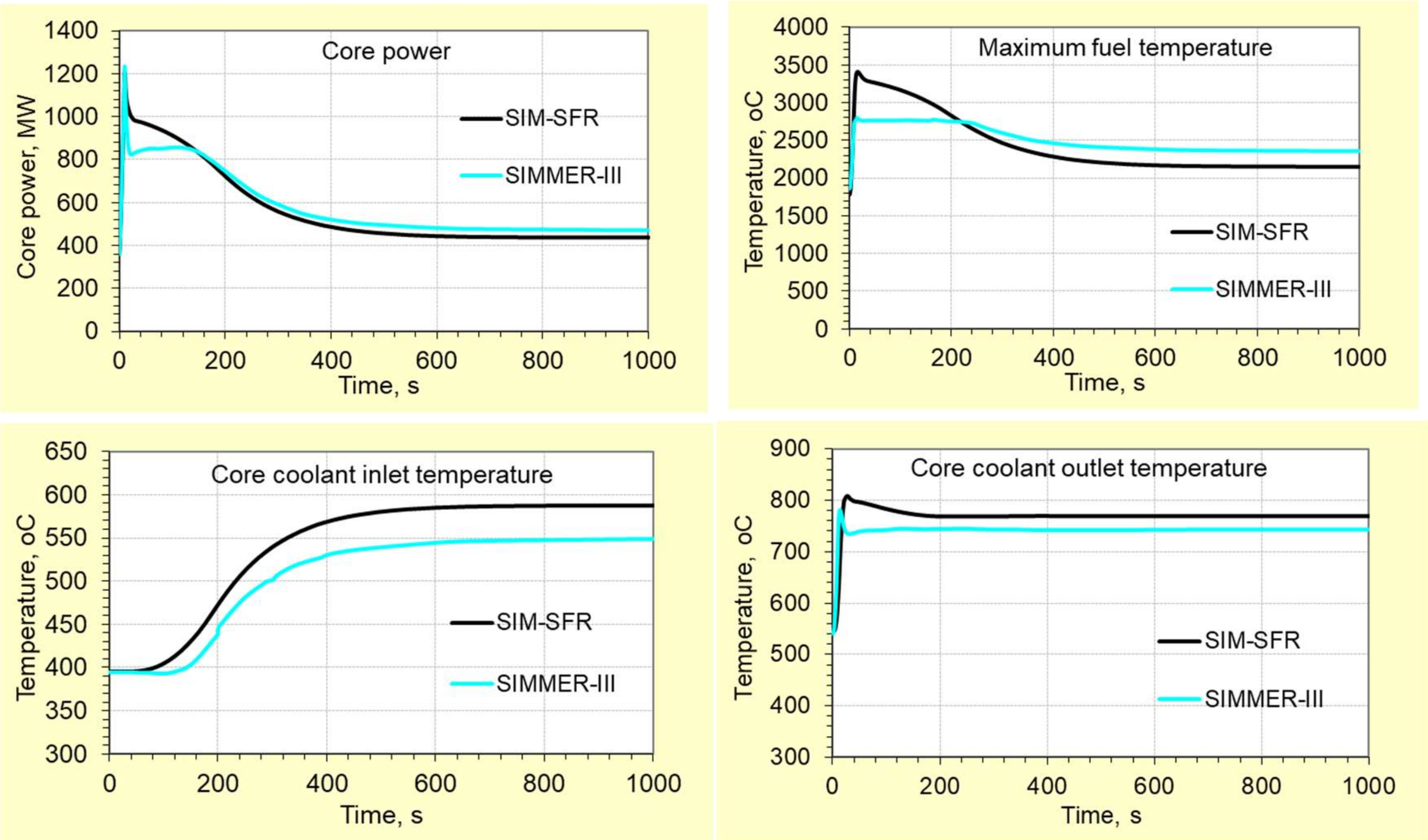


Major reactivity feedbacks, such as Doppler, coolant density, thermal core and CRDL expansion, are taken into account in both codes

For example:
Doppler constant computed with SIMMER (1500-1800 K): -582 pcm
Sodium void worth in the upper plenum: -1386 pcm

UTOP-1.14$ Benchmark Results

- Reactivity insertion of 400 pcm (1.14 $), linearly over 10 s.



Local fuel melting is observed In SIMMER results.

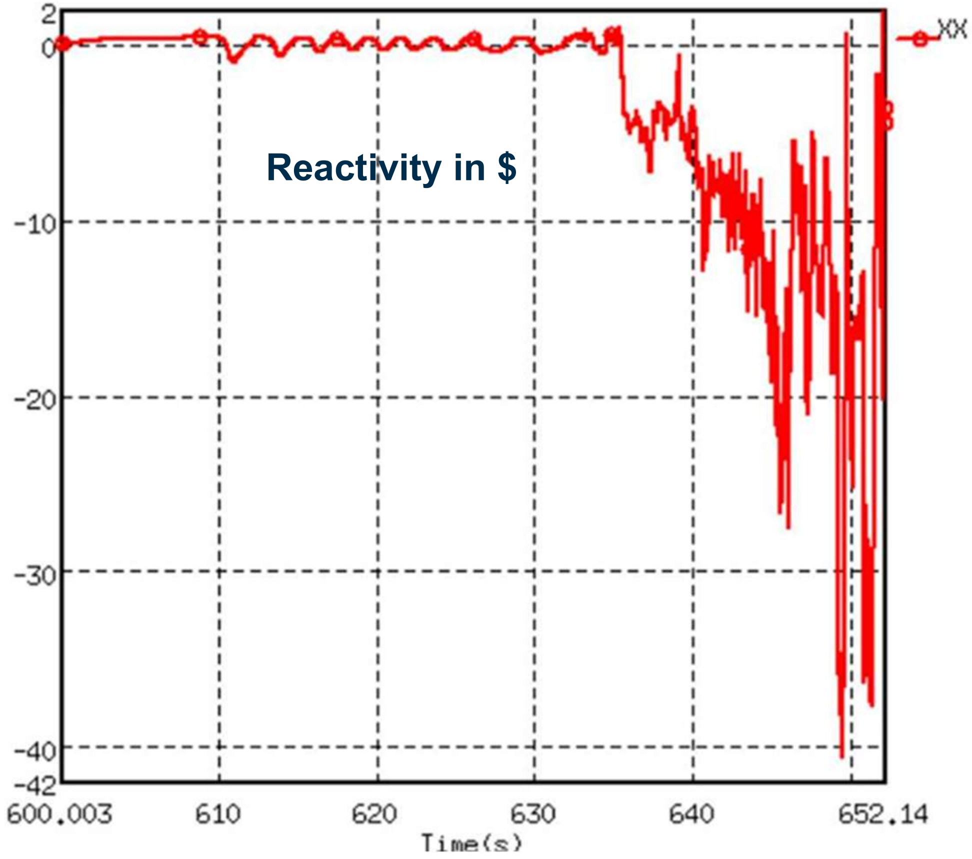
SIM-SFR does not simulate fuel melting

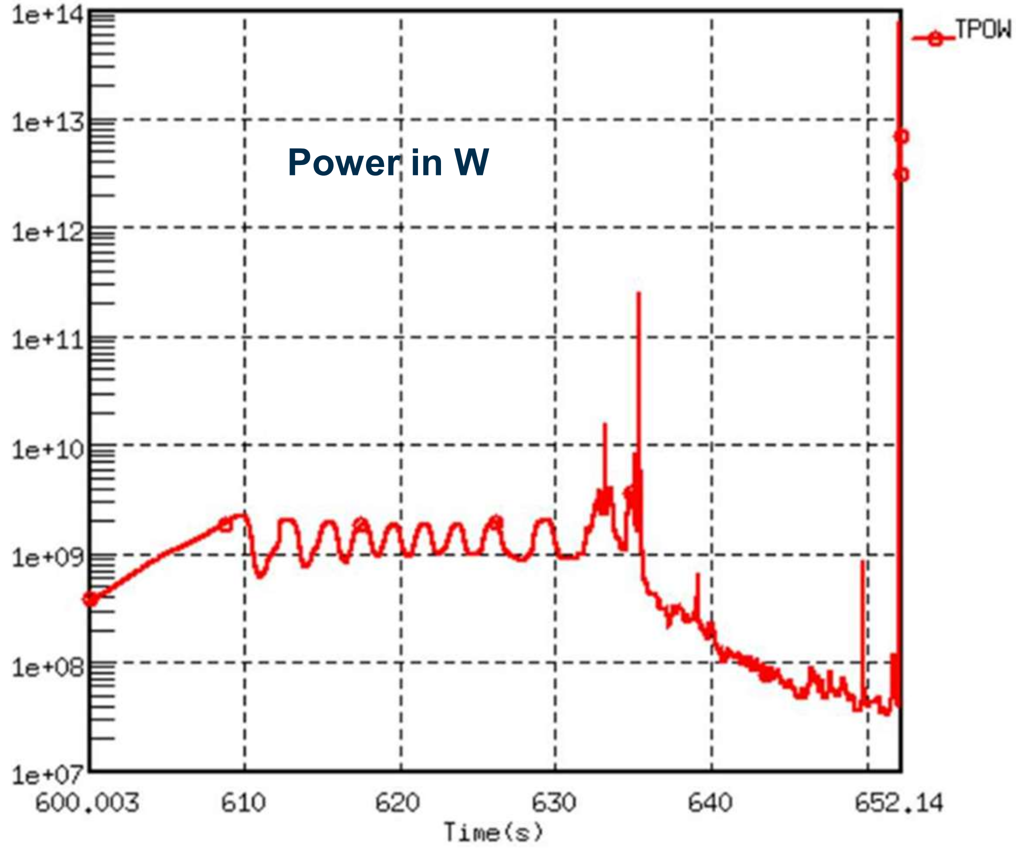
This is the reason for the fuel temperature discrepancy.

ULOF, UTOP-1.14 also simulated by other ESFR-SIMPLE partners, the results are consistent to those of KIT

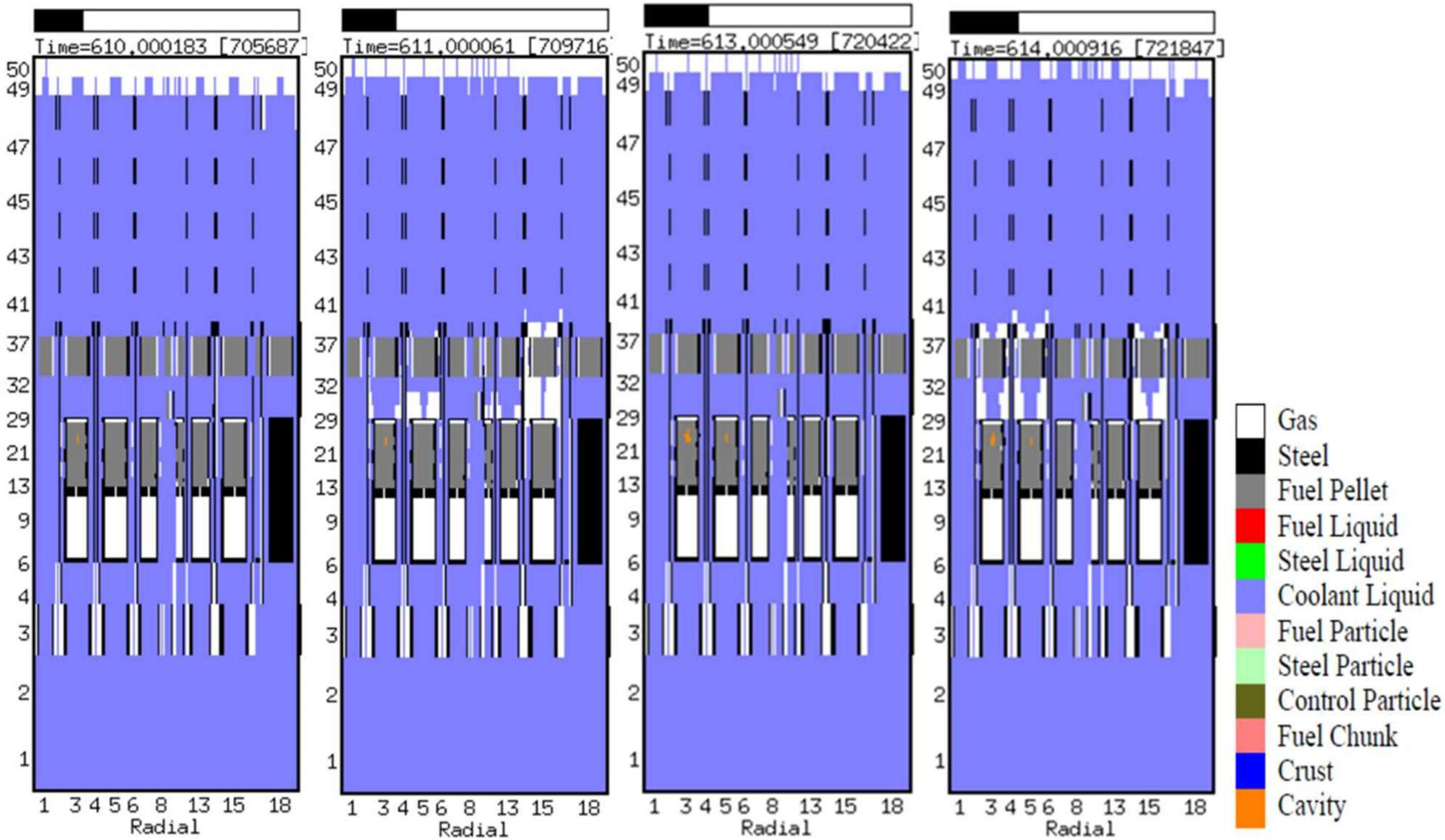
UTOP-1.5$ Simulation with SIMMER: Results

- Reactivity insertion of 1.50 $, linearly within 10 s.



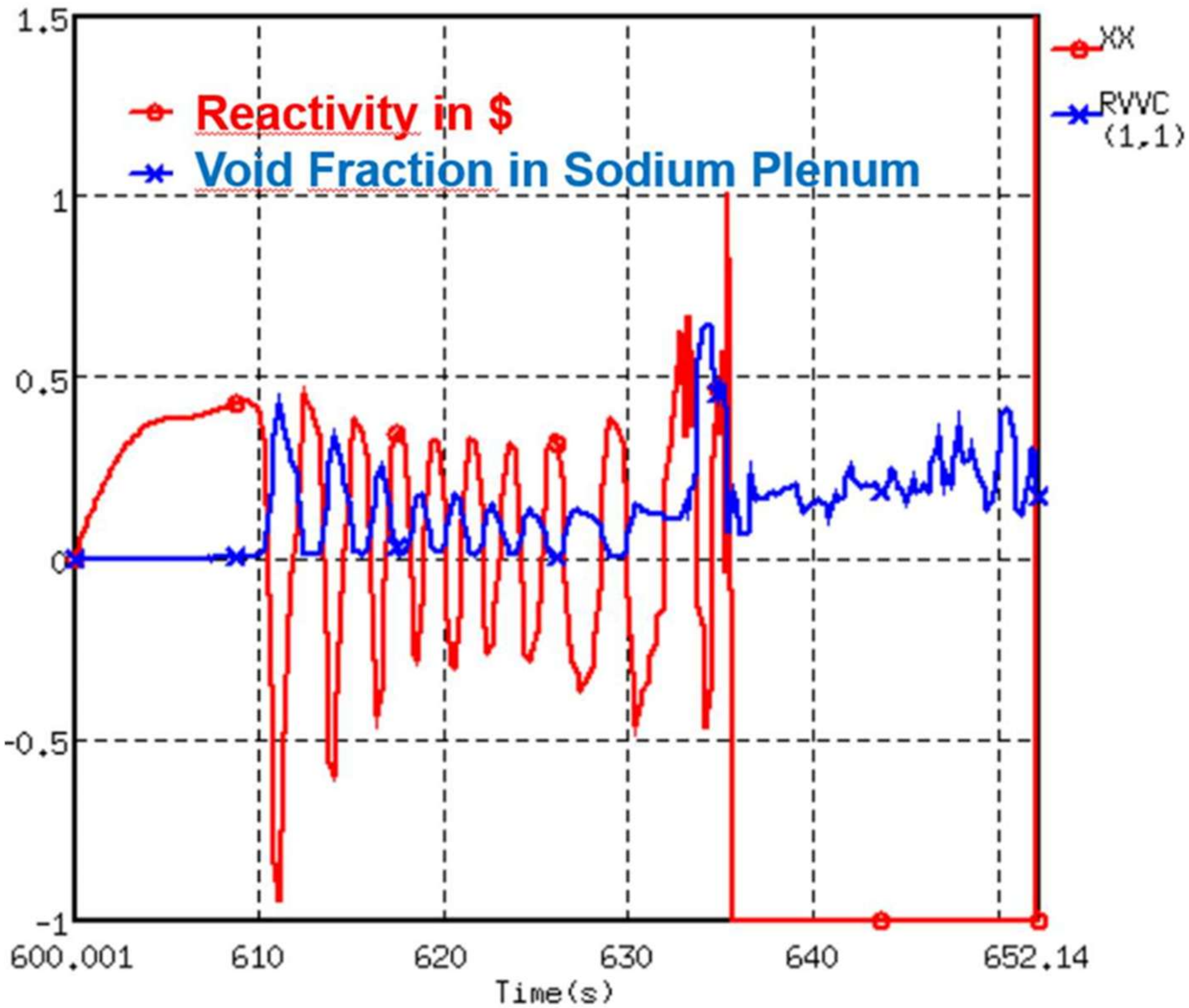


UTOP-1.5$ Simulation Results



10 s 11 s 13 s 14 s

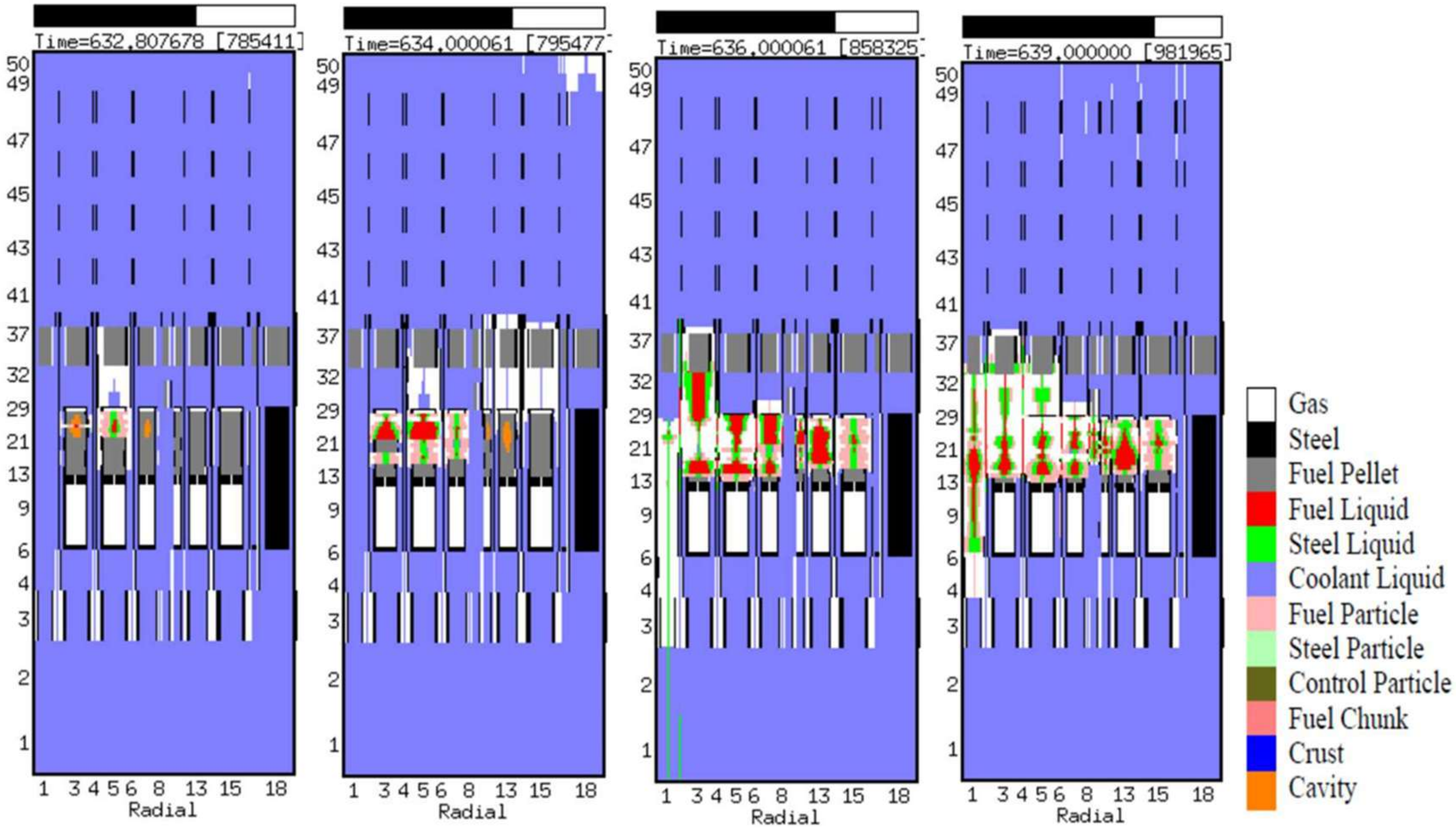
UTOP-1.5$ Simulation Results



- Power oscillations caused by successive boiling and flooding
- Power and boiling are anti-phased
- Mechanism: delay in heat transport from fuel to boiling regions
- Oscillation period: 2 sec
- Such oscillations were observed in ULOF of a larger SFR, where the period is about 10 s:

CHEN, X.-N. et al., Numerical studies of power oscillation induced by sodium boiling in ESFR after ULOF transient, Ann. Nucl. Energy 183 (2023)

UTOP-1.5$ Simulation Results



The power oscillations evolve into a power excursion, ultimately leading to core melting and degradation. The figures above illustrate the sequence of events from cladding failure to core degradation and fuel discharge.

Conclusions

- ULOF and UTOP-1.14$: KIT results consistent to those obtained by other partners
- ULOF: does not leading to fuel pin failure or core degradation.
- UTOP after introduction of 1.14$: no severe accident is observed, showing the robustness of the system after a limited reactivity increase
- UTOP after introduction of 1.5$ may lead to sodium boiling and power oscillations, eventual core melting and degradation.
  - Sodium boiling and flooding oscillations in the upper core part and above, with a period of about 2 s, in antiphase with power and reactivity variations
  - The mechanism is similar to that in the large ESFR design after ULOF

Thank you for your attention