Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Karlsruher Institut für Technologie

TRANSIENT 3D SIMULATIONS FOR THE ASTRID REACTOR: PRELIMINARY RESULTS FOR THE ULOF INITIATION PHASE

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S. Gianfelici, M. Massone, A. Rineiski, M. Marchetti, L. Andriolo, D. Lemasson, S. Poumerouly

The ASTRID reactor

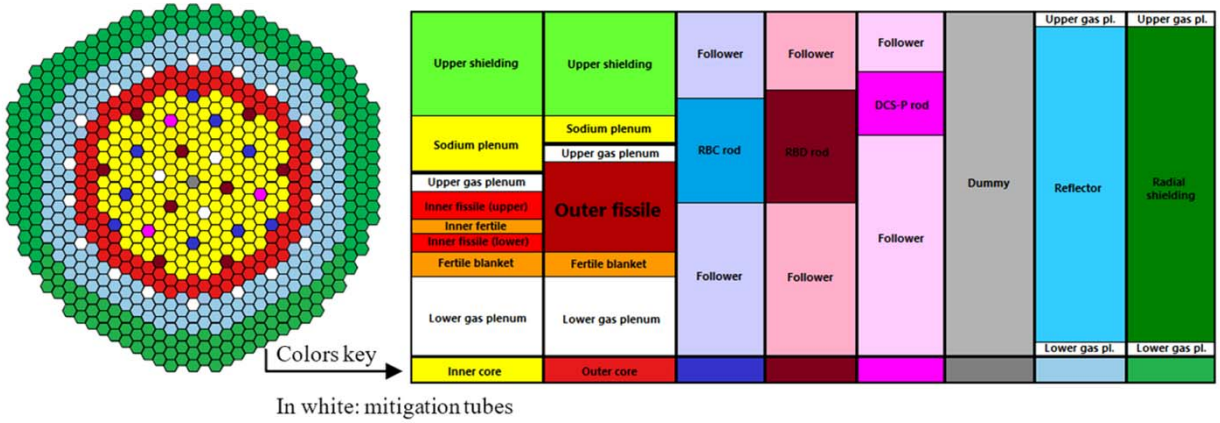
- ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration)
- Gen-IV SFR pool-type reactor of 1500 MWth designed for industrial scale demonstration
- CFV (Low Void worth Core) core design
  - negative full void coefficient
  - good fuel burnup performances
  - intrinsic safety features improve behavior during transients

Parameter	Value
Nominal thermal power	1500 MW
Core inlet/outlet temperature	400/550 °C
Mass flow rate through the fuel SAs	7206 kg/s
Inner/outer fissile height	60/90 cm
Inner/lower fertile height	20/30 cm
Inner/outer sodium plenum	40/30 cm
Void reactivity effect, core at equilibrium	-0.5 $ (-184 pcm)

CFV core parameters

The ASTRID reactor

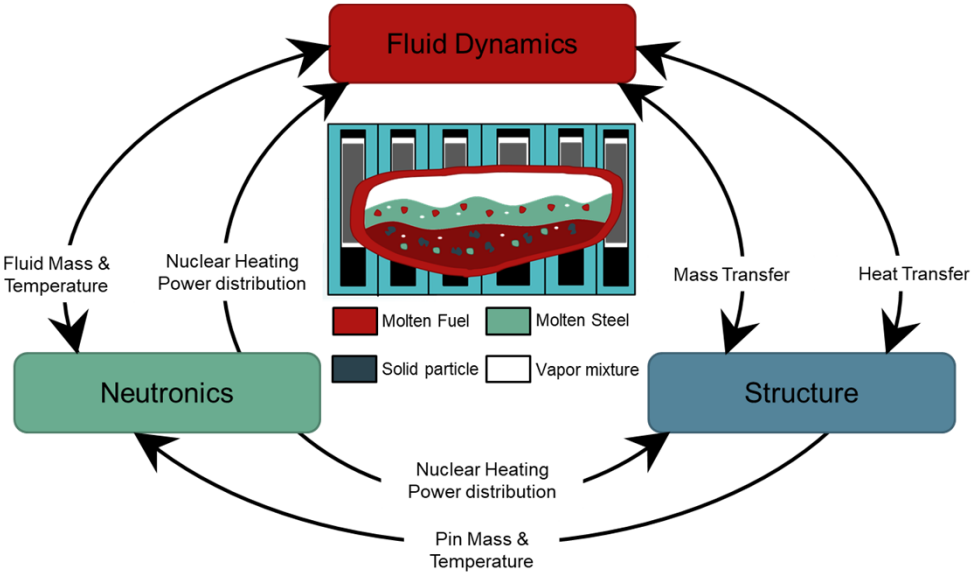
- Two zones, inner and outer, with different active region heights and fuel enrichments.
- Sodium plenum zone above the active region, aiming at the reduction of the sodium voiding feedback coefficient.
- Inner core subassemblies with an intermediate fertile zone, which limits the power peaking factor and improves the breeding ratio.
- Three different types of absorber rods: control and shutdown rods (RBC), diverse control and shutdown rods (RBD) and floating safety rods (DCS-P).
- Core material relocation tubes.



CFV core, horizontal and vertical

SIMMER-III and SIMMER-IV codes

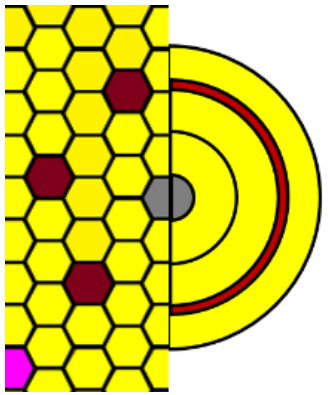
- SIMMER-III and SIMMER-IV codes, 2D and 3D tools with multi-phase, multi-velocity-field and multi-component fluid-dynamic framework coupled with a structure and a neutronic model.
- Capable to simulate reactivity excursions and possible recriticalities due to fuel relocation.
- Originally developed for severe accidents analyses in SFRs.
- With the increasing availability of computational power, a transition from 2D to full 3D simulations is to be expected, with a more realistic representation of the reactor core and components.
- A 3D SIMMER-IV steady state, followed by an ULOF transient, has been modelled for ASTRID. The results were compared with the data obtained with previous 2D models.



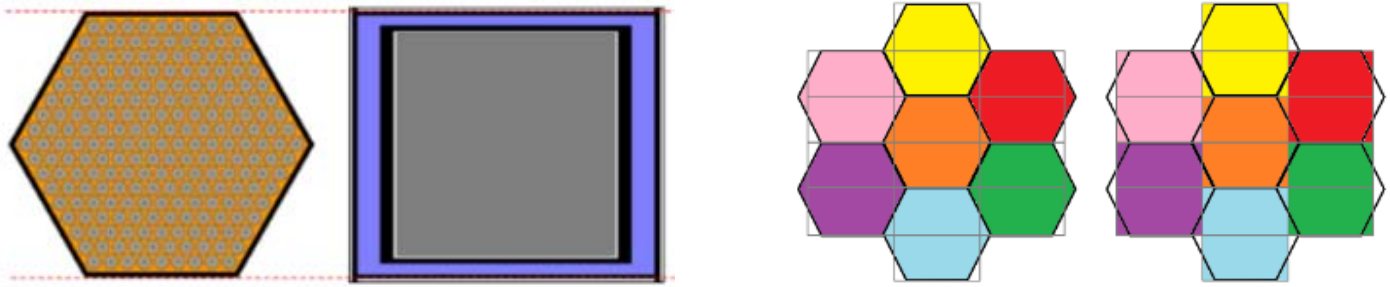
SIMMER code structure

SIMMER nodalizations

- Cartesian (XYZ) and axial symmetric (RZΘ) options available to model the 2D and 3D meshes
- In our 2D simulation, axially symmetric (RZ) setup was used. Different subassembly groups are approximated using different 2D rings.
- 3D setup with cartesian (XYZ) geometry. Each subassembly is modelled individually with 2 dedicated meshes.



2D SIMMER-III rings

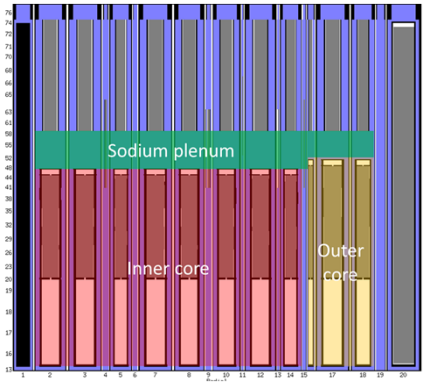


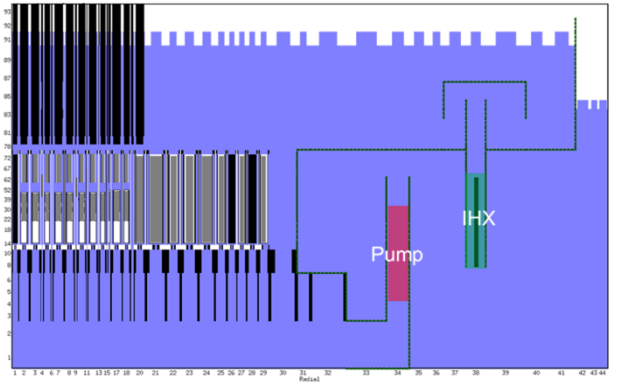
3D SIMMER-IV model: hexagonal subassemblies are approximated with 2 cartesian meshes

SIMMER models

SIMMER-III 2D:

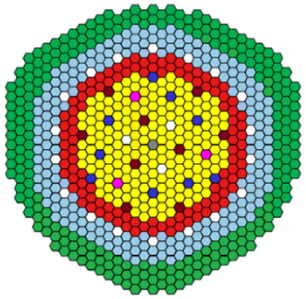
- Axial-symmetric 2D model, 44 radial and 93 axial meshes.
- The core of 18 SA rings, 11 fuel rods and 7 control and safety rods.

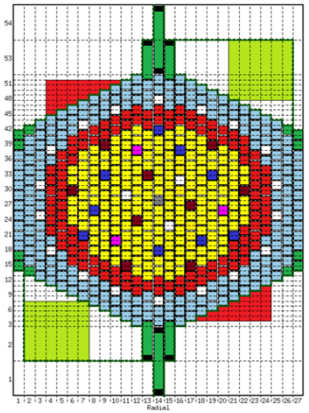


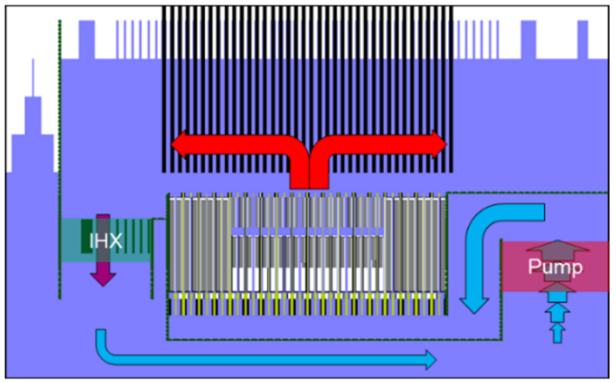


SIMMER-IV 3D:

- Fluid-dynamics mesh is composed by 27×54×76 cells in XYZ geometry
- Cells in the corners are employed to model the two pumps and the two IHXs





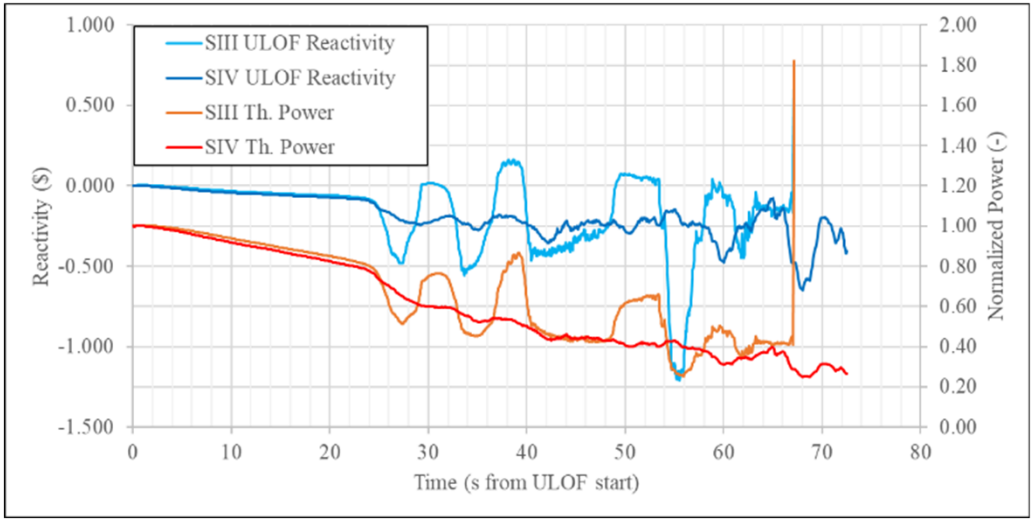


SIMMER modifications

- A 3D model with neutronics and thermohydraulic models enabled is still a very challenging task from a computational standpoint, even in a parallel environment.
- KIT has developed a correction set that replaces the original SIMMER transport solver, based on DANTSYS, with the PARTISN code, which features parallelization capabilities.
- Parallelization has been introduced also in the cross-section generation and self-shielding procedure.
- Multi-group cross-section collapsing technique is implemented to condense, at every time step, an 11-groups cross-sections library, usually used at KIT for SFR calculations, into 4-groups one.
- The neutron flux convergence criteria have been eased in cells with very low flux values, e.g. at neutronics domain corners.

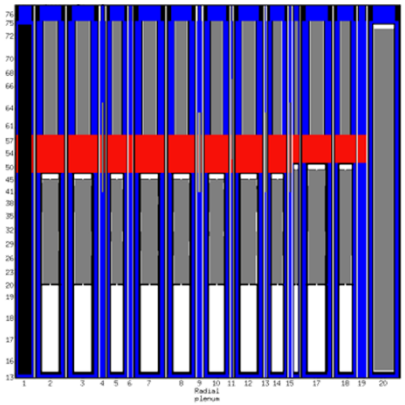
ULOF core power and reactivity

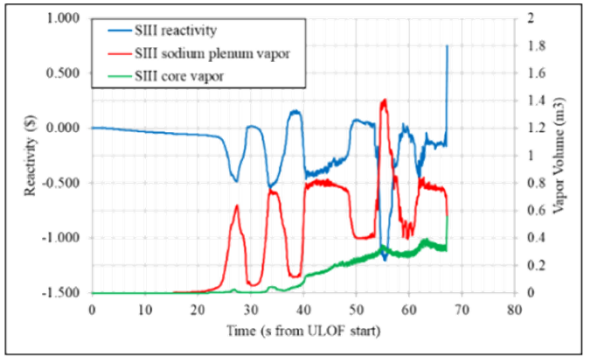
- Initial decrease to around 80% of the nominal value in the first 20 s of the ULOF transient for both 2D and 3D cases.
- After this point, sodium boiling starts to influence the transient and the evolution of the two calculations diverge significantly.
- The sodium boiling and rewetting behavior in the inner core sodium plenum leads to reactivity oscillations.
- In 2D geometry the reactivity swings are much wider, reaching values above zero and so leading to wider power swings.

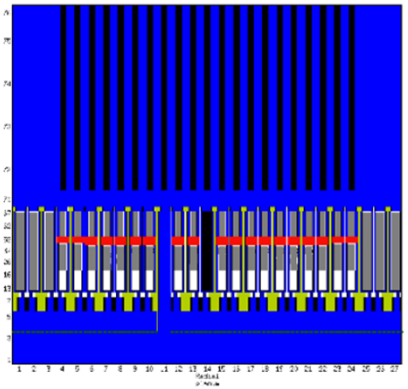


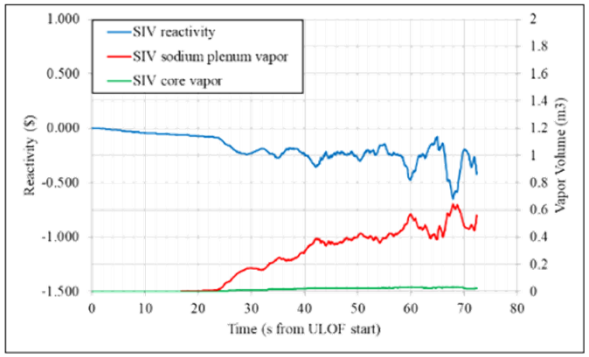
ULOF core power and reactivity

- Reactivity and power trends heavily influenced by the sodium boiling and rewetting
- Sodium vapor volume evaluated in the sodium plenum area and in the core
- Steep increase in vapor formation at 24 s leads to a first reactivity swing.
- Voiding/condensation evolution in 3D is more gradual and the reactivity swings are less pronounced compared to 2D during the initiation phase.







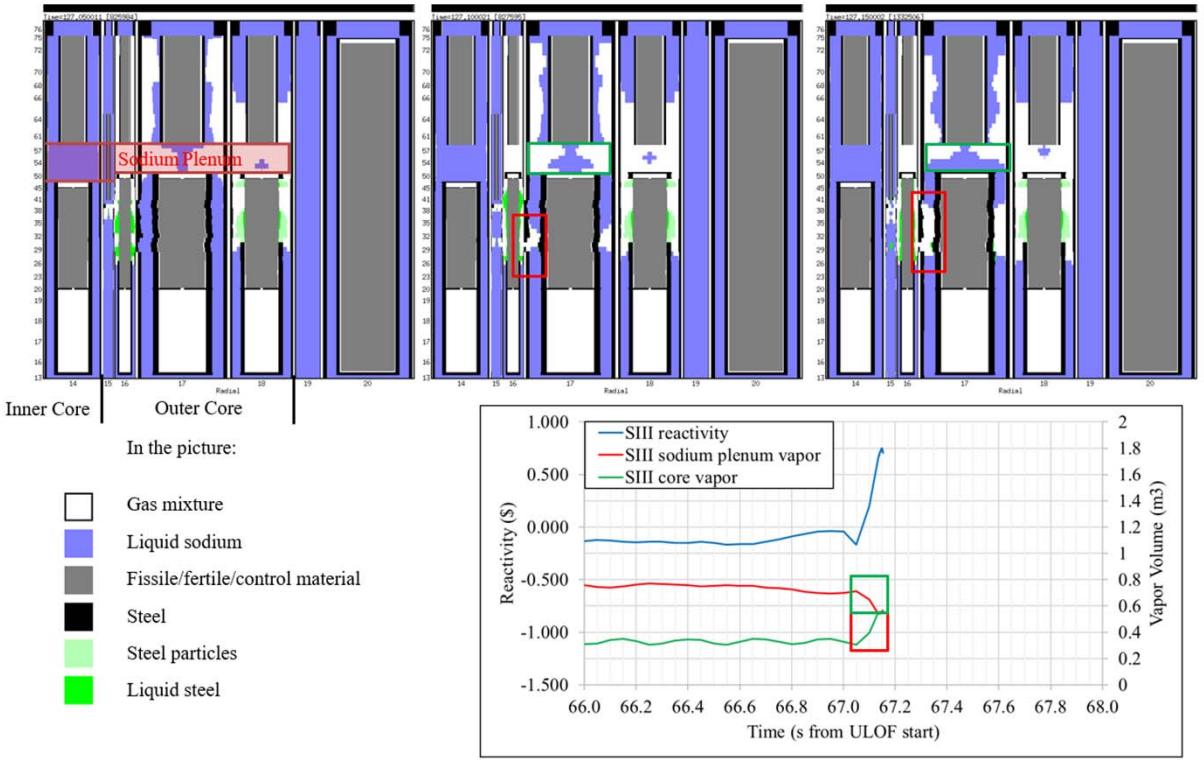


ULOF Pin and SA failure

- 3D SIMMER calculation
  - First pin failure: 39.3 s after ULOF start
  - First can wall failure: 64.3 s after ULOF start
  - After 72.5 s, the last considered time in the 3D calculation, 8 subassemblies in the outer core zone show pin failures, of which 2 with can wall failures. These failures are located in the SAs of the outer core, where the power is higher due to Beginning Of Life (BOL) core configuration.
  - No fuel melting is observed.
- 2D SIMMER calculation
  - First pin failure: 44.15 s after ULOF start
  - First can wall failure: 62.1 s after ULOF start
- Comparing the 2D and 3D discretizations, an event such as a can wall failure involves all of the SAs discretized in one ring of the bidimensional model, instead of a limited number of SAs in the 3D model.

ULOF Pin and SA failure

- At 67.1 s from ULOF start (60 s) the can-wall fails on the right side.
- The sodium vapor enters the second outer core ring, increasing the sodium vapor volume in the active zone and pushing the liquid sodium in the sodium plenum.
- Subsequent reactivity insertion and a final power peak is calculated.
- Compared to the 3D, in 2D rings geometry the insertion of sodium vapor in the active core zone from one mesh to the other has a much stronger impact on the reactivity feedbacks and on the global reactivity.



Conclusions

- With the availability of new computers and techniques, a 3D model calculation has been set up and used as basis for steady state and ULOF transient analyses for the ASTRID reactor. The results obtained have been compared to previous 2D calculations to assess effects of 2D and 3D modelling on the evolution of the transient.
- Due to the computational power required, modifications to the code have been applied with the aim of speeding up the calculation. Nonetheless, the computation of such a case is still very challenging: the simulation of about 72.5 s of ULOF transient, steady state included, has taken almost one year of computation using 32 processors.
- However, the preliminary results show interesting differences between 2D and 3D results, especially regarding the sodium boiling and rewetting behavior, which greatly affects the reactivity swing and thus the power evolution during the ULOF transient.
- The results demonstrate the applicability of SIMMER-IV to full vessel SFRs for the simulation of ULOF initiation phase. This applicability was up to now restricted by the very high computation costs and very long simulation times, and full vessel SFR models for transient analyses at KIT were mainly performed with the 2D SIMMER-III code. These limitations have been eased recently with modification and optimization of the code.
- The established model and code versions offer a basis for further SIMMER-IV code and 3D ASTRID model optimizations. They may help to accelerate 3D calculations further, thus opening ways for routine application of 3D models for the initiation phase and for investigation of SIMMER-IV applicability to 3D simulations of later phases of ULOF, such as transition to full core melting and mechanical energy release under hypothetical accident conditions.

Thank you for your kind attention!