Status and perspectives of the Molten Salt Fast Reactor analyses with the SIMMER code

M. Massone, L. Guo, A. Rineiski

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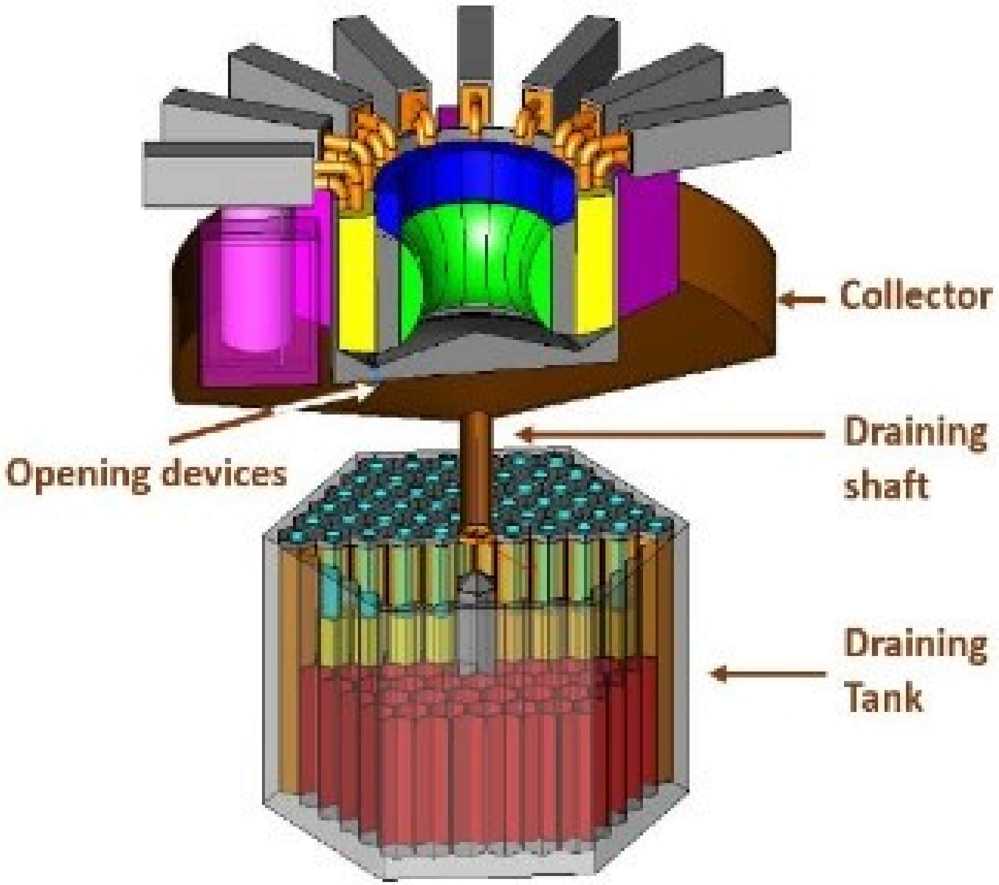
Introduction

- Molten Salt Fast Reactor
  - Fast spectrum
  - No internal structures
  - Fluoride salt
  - ^{233}U or Th cycle

- KIT has participated with SIMMER in:
  - SAMOSAFER
  - SAMOFAR
  - EVOL
  - …

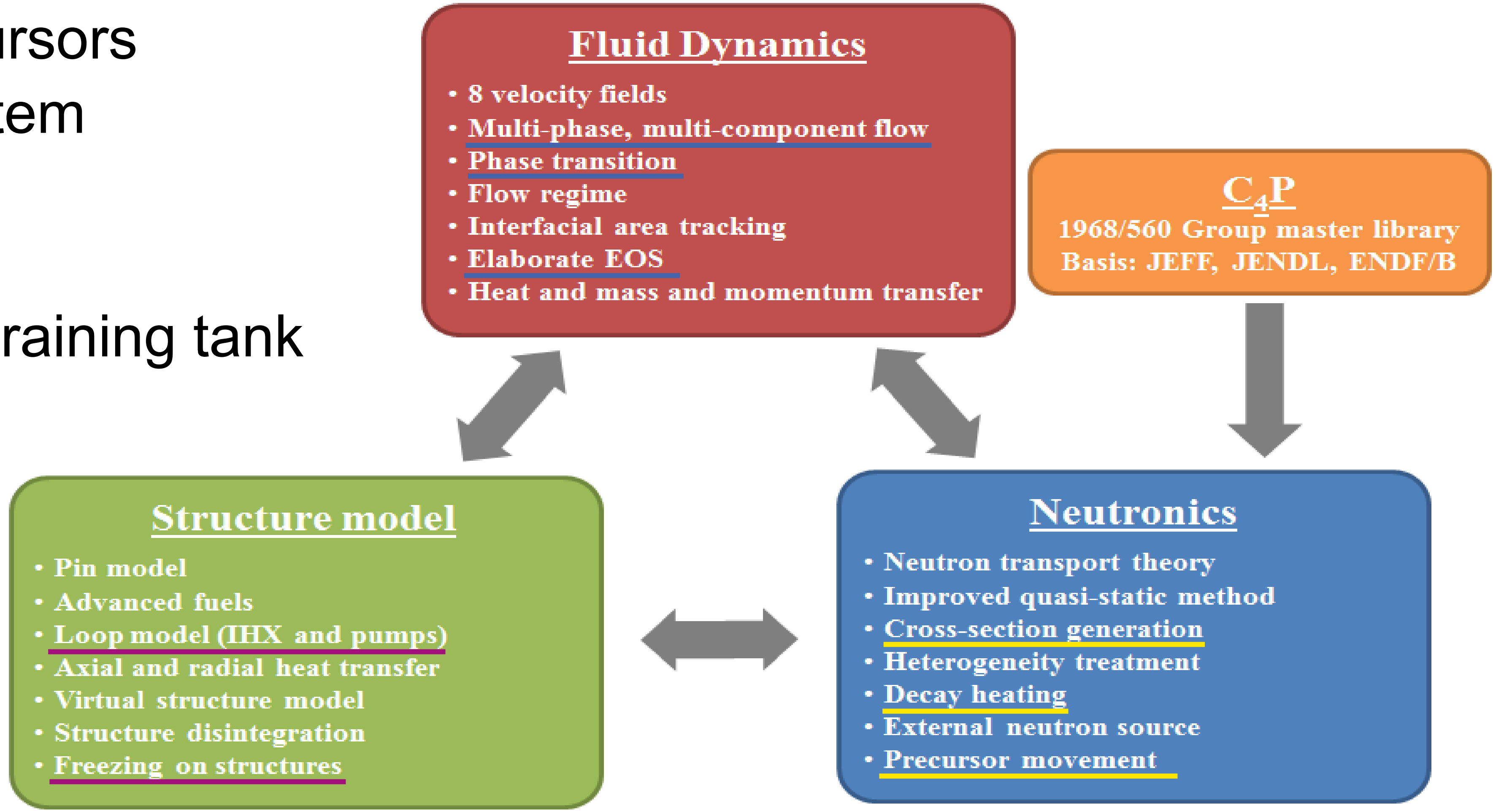


The SIMMER code

- SIMMER is a mechanistic, multi-velocity-field, multiphase, multicomponent, Eulerian fluid-dynamics code coupled with a space-dependent neutron kinetics model and a structure model
- Developed for safety studies of liquid-metal-cooled fast reactors
  - Further developed and improved, it has been applied successfully to LWRs, general multiphase problems, steam explosions…
- Liquid fuel motion is a condition that has to be dealt with when modeling core disruptive accidents
  - Validated for a number of phenomena relevant also for MSRs

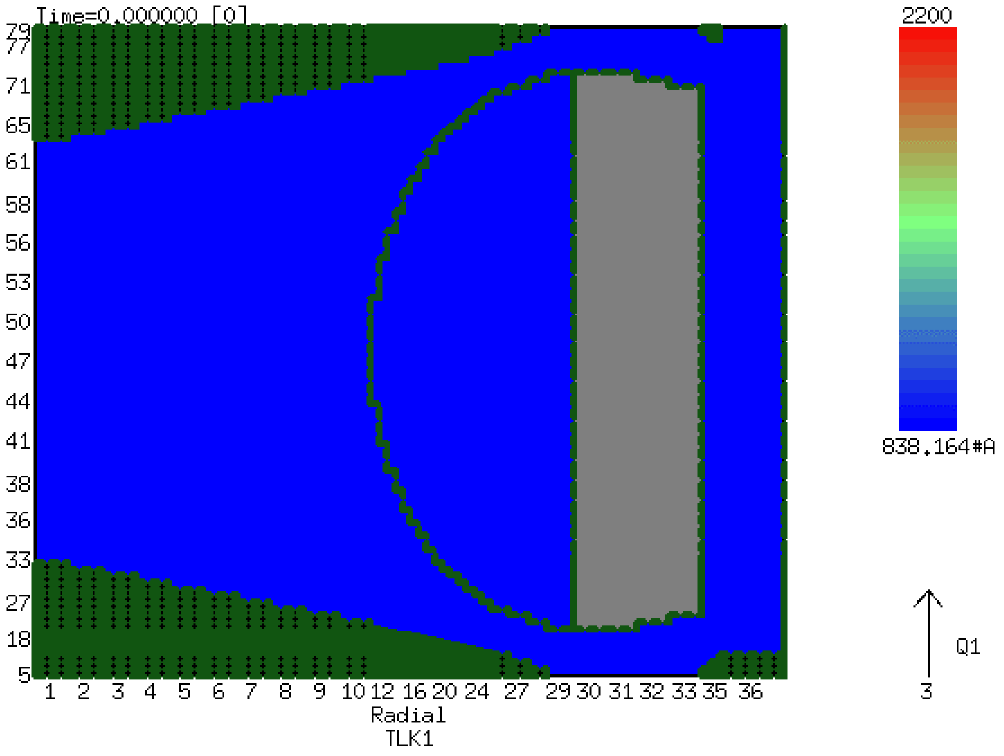
The SIMMER code

- Moving precursors
- Bubbling system
- Freeze plugs
- Draining
- Emergency draining tank



MSFR model

- A preliminary model of the MSFR has been established
- Tuning still ongoing
  - Temperature
  - Wall friction
  - Turbulent flow
- Flexible EOS
  - KIT developed specific EOS for the molten salt
  - Can be reassessed based on available new data



Moving precursors

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- Multigroup transport equation

$$\frac{1}{v_g}\frac{\partial\varphi_g(\boldsymbol{r},\widehat{\boldsymbol{\Omega}},t)}{\partial t}+\widehat{\boldsymbol{\Omega}}\cdot\nabla\varphi_g(\boldsymbol{r},\widehat{\boldsymbol{\Omega}},t)+\Sigma_{\mathrm{t}}^{g}(\boldsymbol{r})\varphi_g(\boldsymbol{r},\widehat{\boldsymbol{\Omega}},t)=\oint\sum_{g'}\Sigma_{\mathrm{s}}^{g'\to g}(\boldsymbol{r},\widehat{\boldsymbol{\Omega}}'\cdot\widehat{\boldsymbol{\Omega}})\varphi_g(\boldsymbol{r},\widehat{\boldsymbol{\Omega}}',t)\,\mathrm{d}\widehat{\boldsymbol{\Omega}}'+$$

$$+(1-\beta)\frac{\chi_{\mathrm{p}}^{g}}{4\pi}\sum_{g'}\nu\Sigma_{\mathrm{f}}^{g'}(\boldsymbol{r})\Phi_{g'}(\boldsymbol{r},t)+\frac{1}{4\pi}\sum_{i}\lambda_f\chi_{\mathrm{d},i}^{g}C_i(\boldsymbol{r},t)+S_g(\boldsymbol{r},\widehat{\boldsymbol{\Omega}},t)$$

- Delayed neutron precursors balance equations

$$\frac{\partial C_i(\boldsymbol{r},t)}{\partial t}=\beta_i\sum_{g'}\nu\Sigma_{\mathrm{f}}^{g'}(\boldsymbol{r})\Phi_{g'}(\boldsymbol{r},t)-\lambda_i C_i(\boldsymbol{r},t)-\nabla\cdot\big(\boldsymbol{u}(\boldsymbol{r},t)C_i(\boldsymbol{r},t)\big)$$

Moving precursors

- KIT developed a modification for SIMMER neutronic solver to deal with moving precursors.

$$C(\boldsymbol{r},t) = C_{\mathrm{s}}(\boldsymbol{r},t) + C_{\mathrm{m}}(\boldsymbol{r},t)$$

- The C_{s} component is calculated with the usual formulation, with steady state and non-moving material assumptions

$$0 = \beta_f \sum_{g'} \nu\Sigma_{\mathrm{f}}^{g'}(\boldsymbol{r})\Phi_{g'}(\boldsymbol{r},t) - \lambda_i C_{\mathrm{s},i}(\boldsymbol{r},t)$$

- The C_{m} component follows

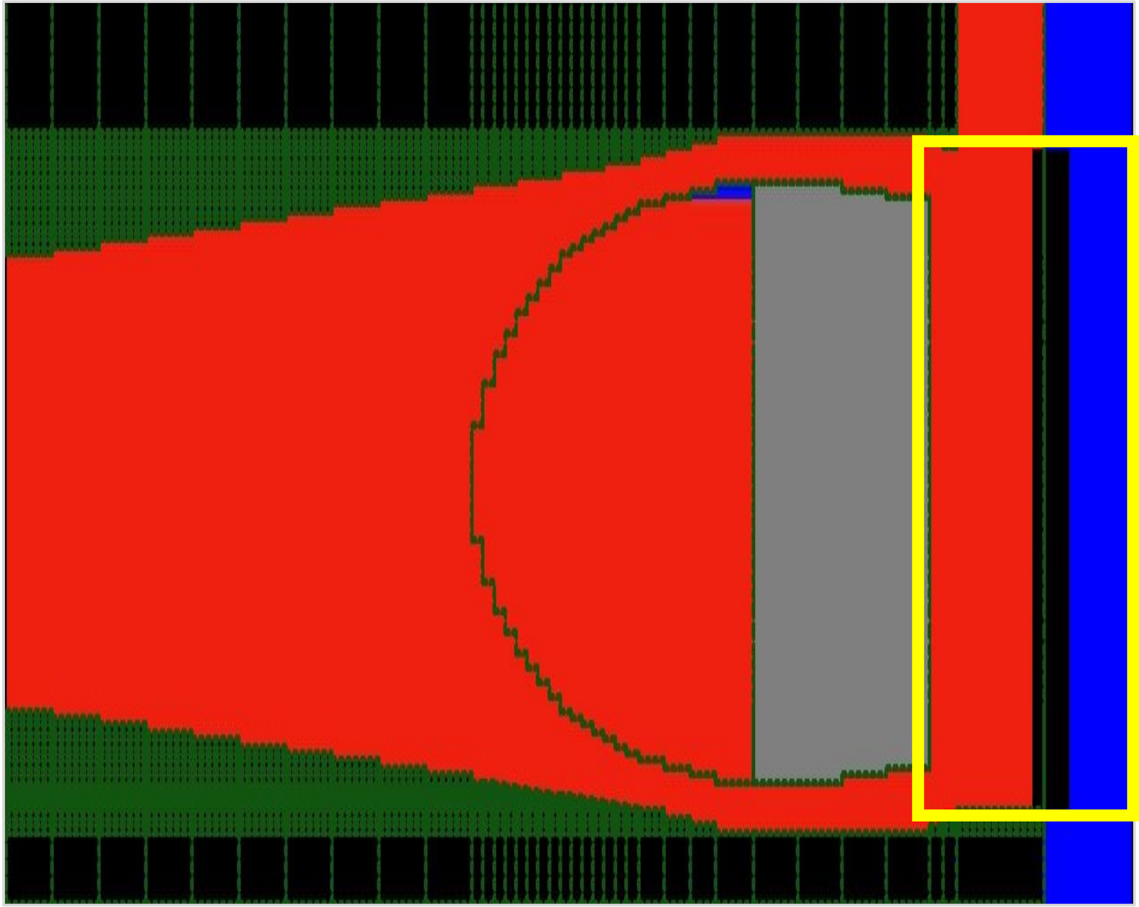
$$\frac{\partial C_{\mathrm{m},i}(\boldsymbol{r},t)}{\partial t} = -\boldsymbol{\nabla}\cdot\left(\boldsymbol{u}(\boldsymbol{r},t)C_{\mathrm{s},i}(\boldsymbol{r},t)\right) - \lambda_i C_i(\boldsymbol{r},t) - \boldsymbol{\nabla}\cdot\left(\boldsymbol{u}(\boldsymbol{r},t)C_{\mathrm{m},i}(\boldsymbol{r},t)\right)$$

- The calculation is iterative with the new guesses
  - $\boldsymbol{u}$ is provided by the thermal-hydraulics calculation

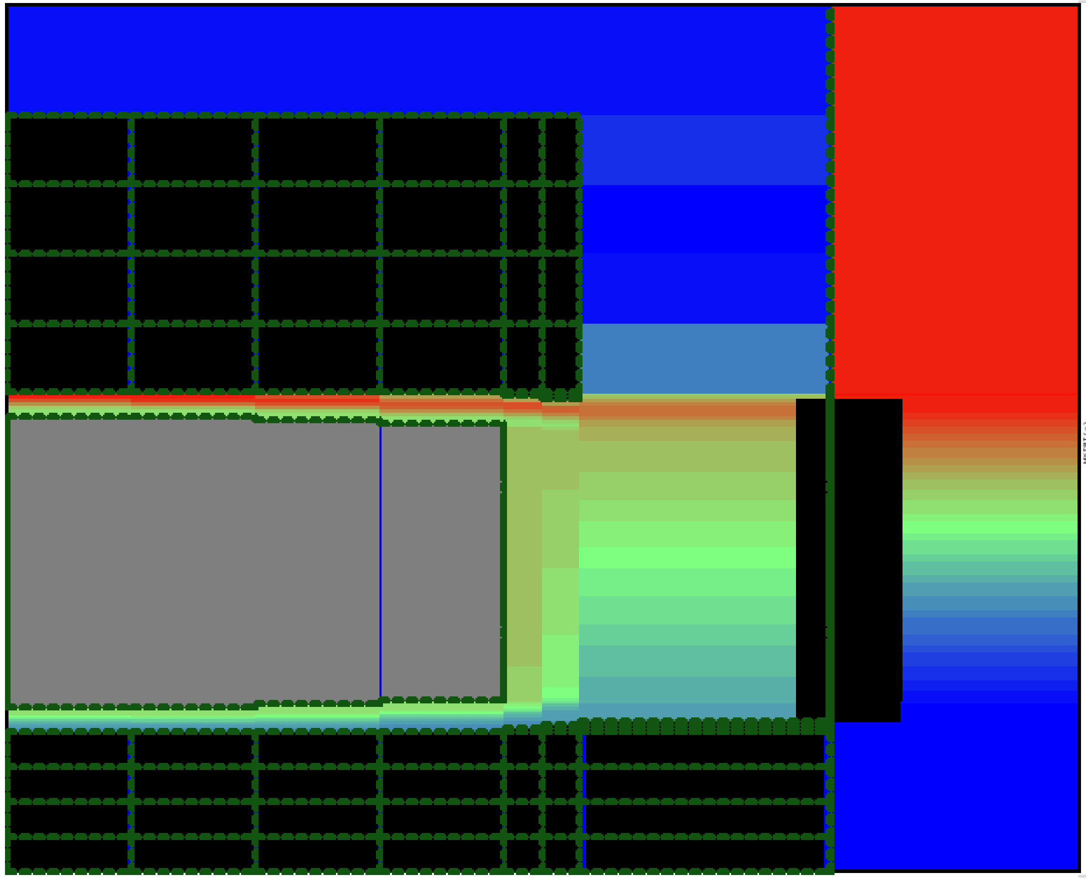
A. RINEISKI, V. SINITSA, W. MASCHEK, S. WANG, „Kinetics and Cross-Section Developments for Analyses of Reactor Transmutation Concepts with SIMMER", Int. Conf. M&C, Avignon, France, September 12-15, 2005

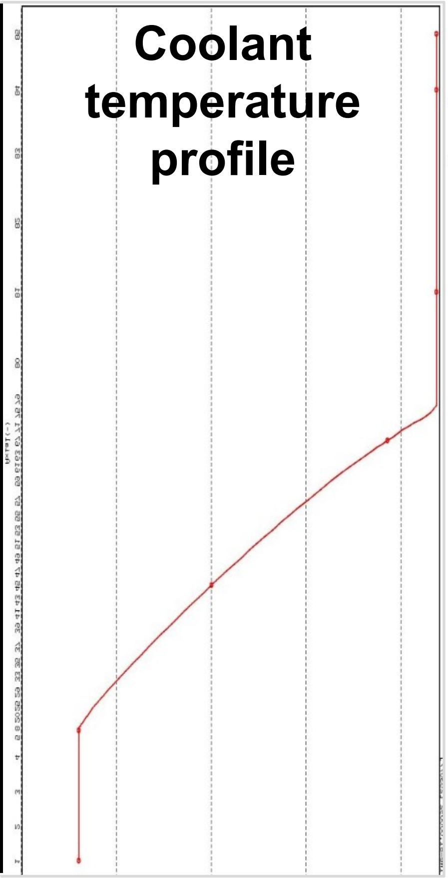
Heat exchanger model

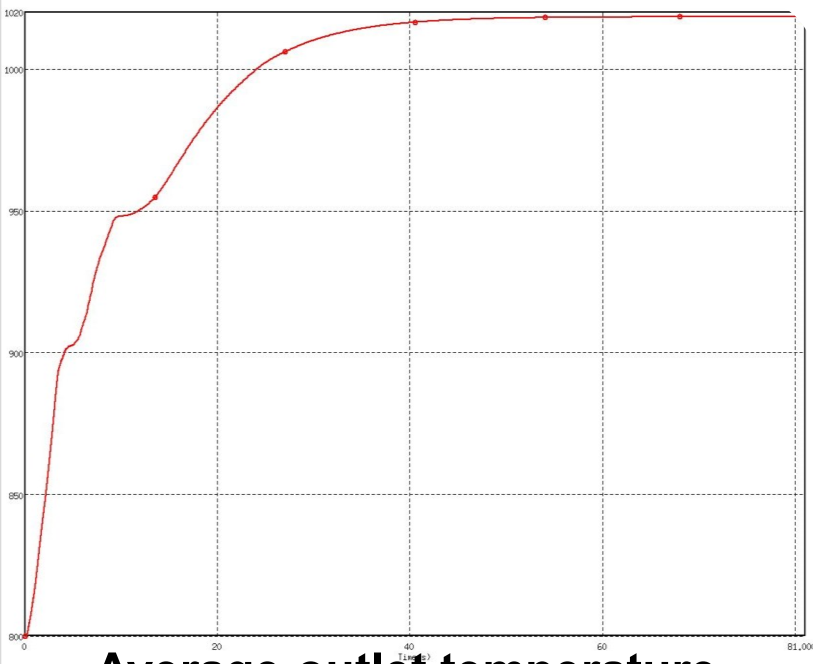
- Developed a new heat exchanger model
  - Improvement from constant outlet T
  - More flexibility
  - Full vessel model
- Parameters that can be changed
  - IHX mass flow rate
  - IHX inlet temperature
  - Primary pump head
- Required for modeling
  - Loss Of Heat Sink Accident
  - Loss Of Flow Accident



Heat exchanger model



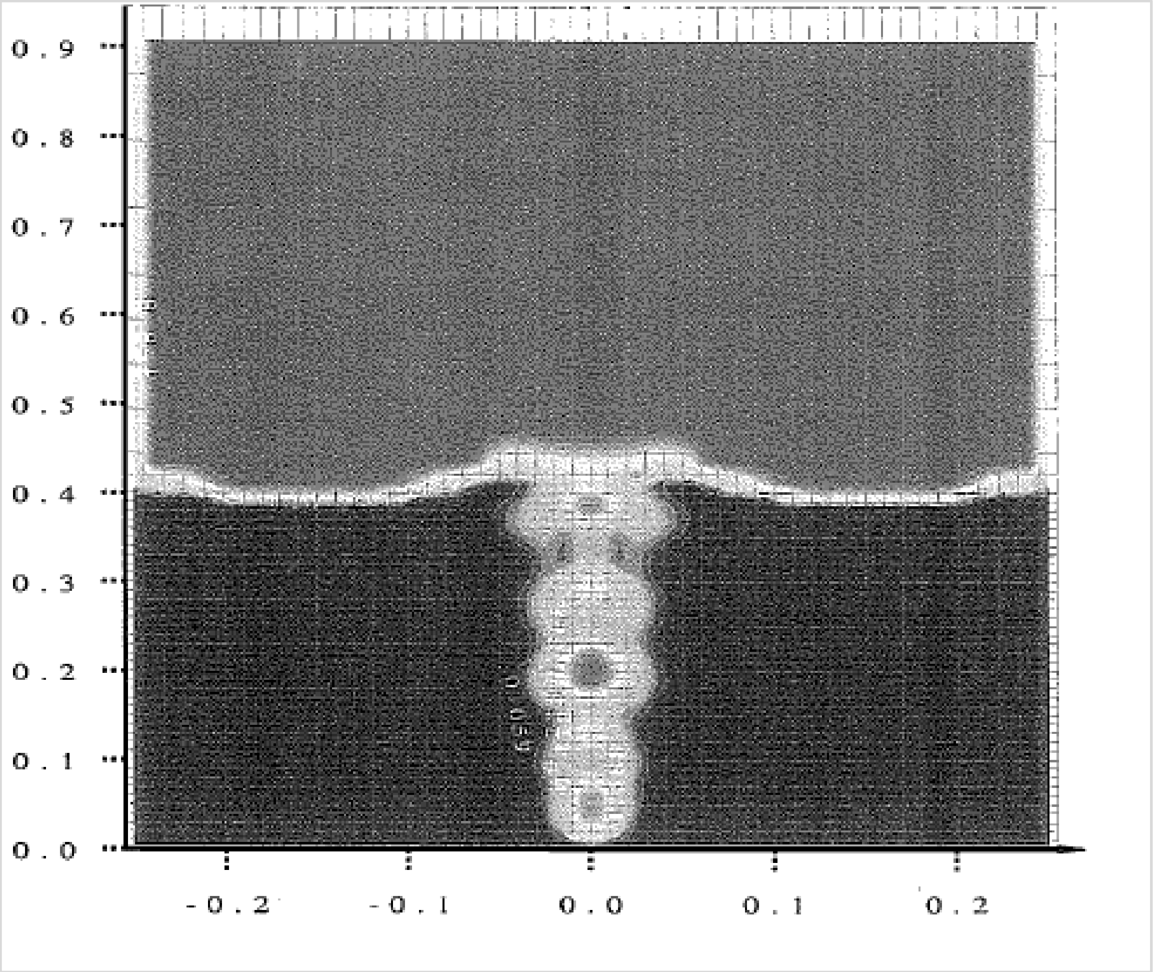




Average outlet temperature

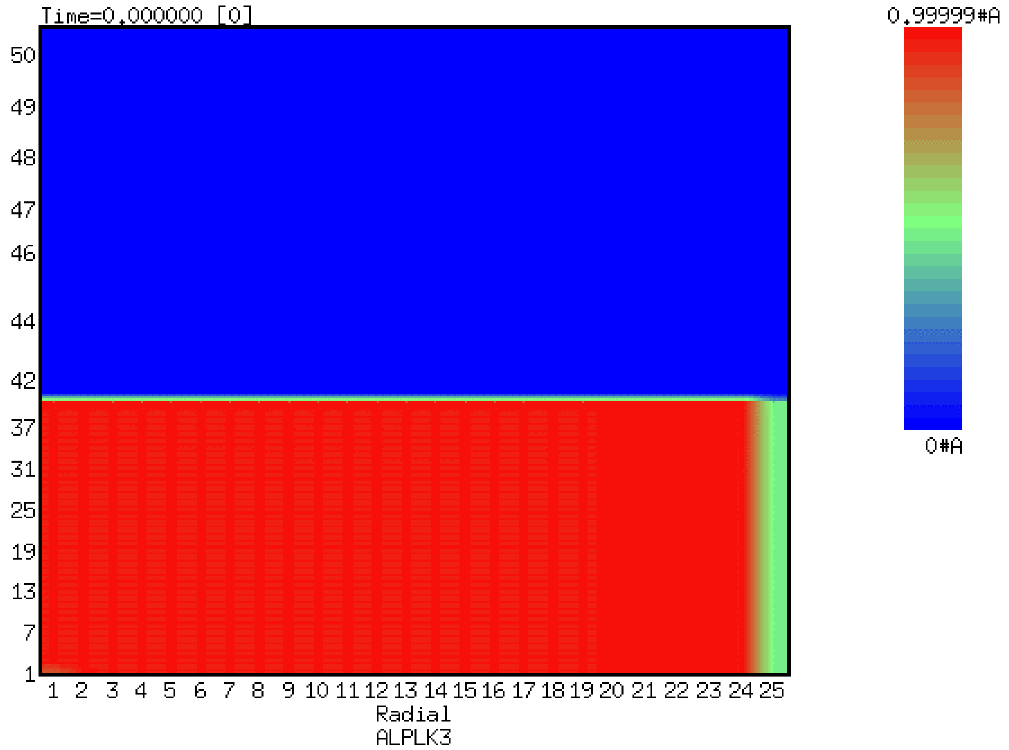
Gas injection

- Castillejos experiment
  - One of SIMMER validation experiments
  - Based on the model used in the past, new computation options
- Air injected in a water-filled cylindrical tank
- Water is initially still
- Inlet gas velocity linearly increases from 0 to 22.76 cm/s until 10 s



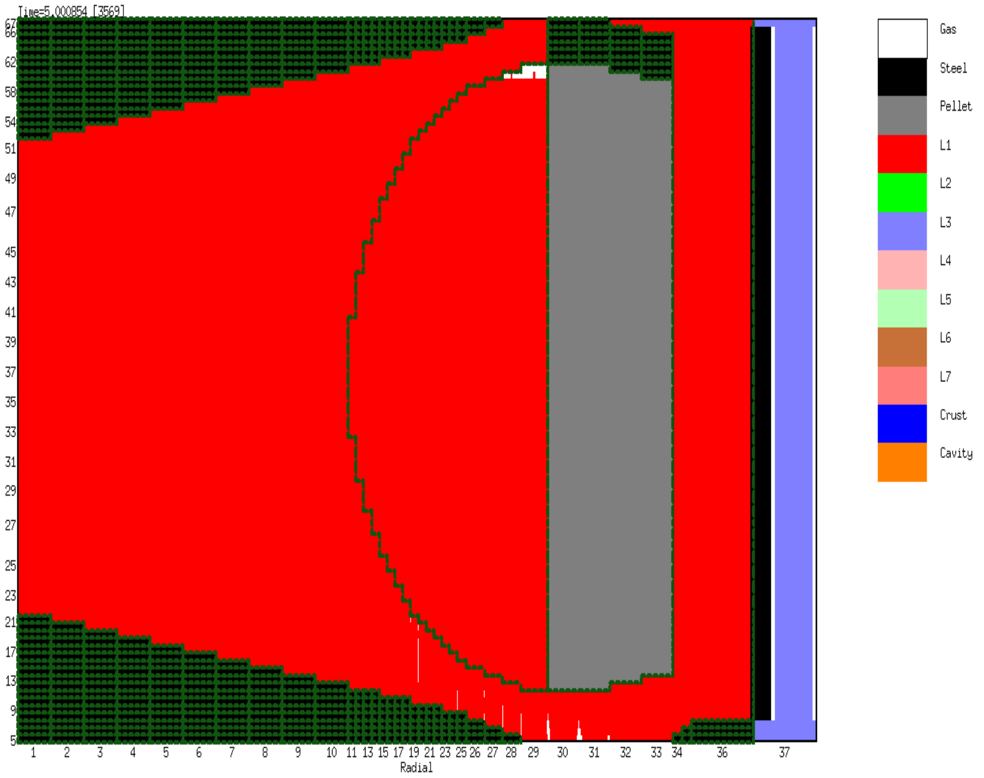
Gas injection

- Reasonable results obtained
  - Some phenomena difficult to address
  - According to experiment, the bubble should split as rising
  - This could not be observed in SIMMER
- Mesh effect investigated
  - No strong influence observed
- More refined calculation in time planned
- Comparison with other codes planned

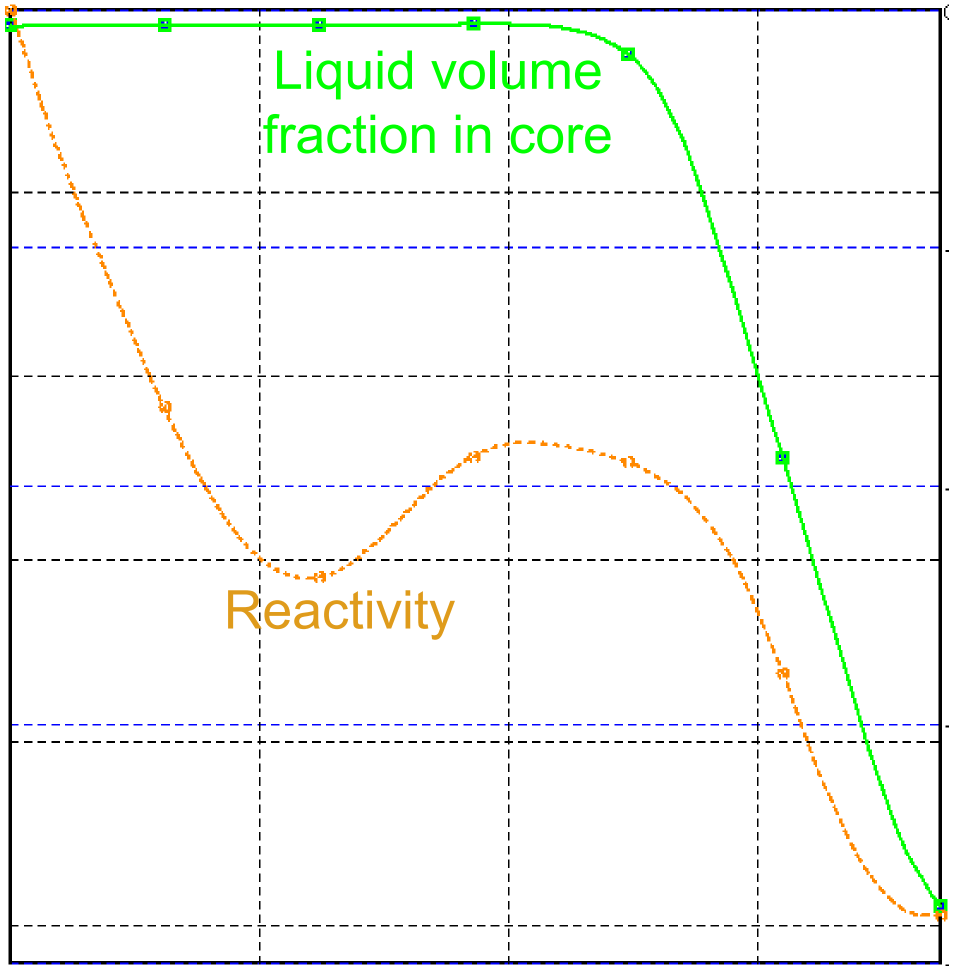


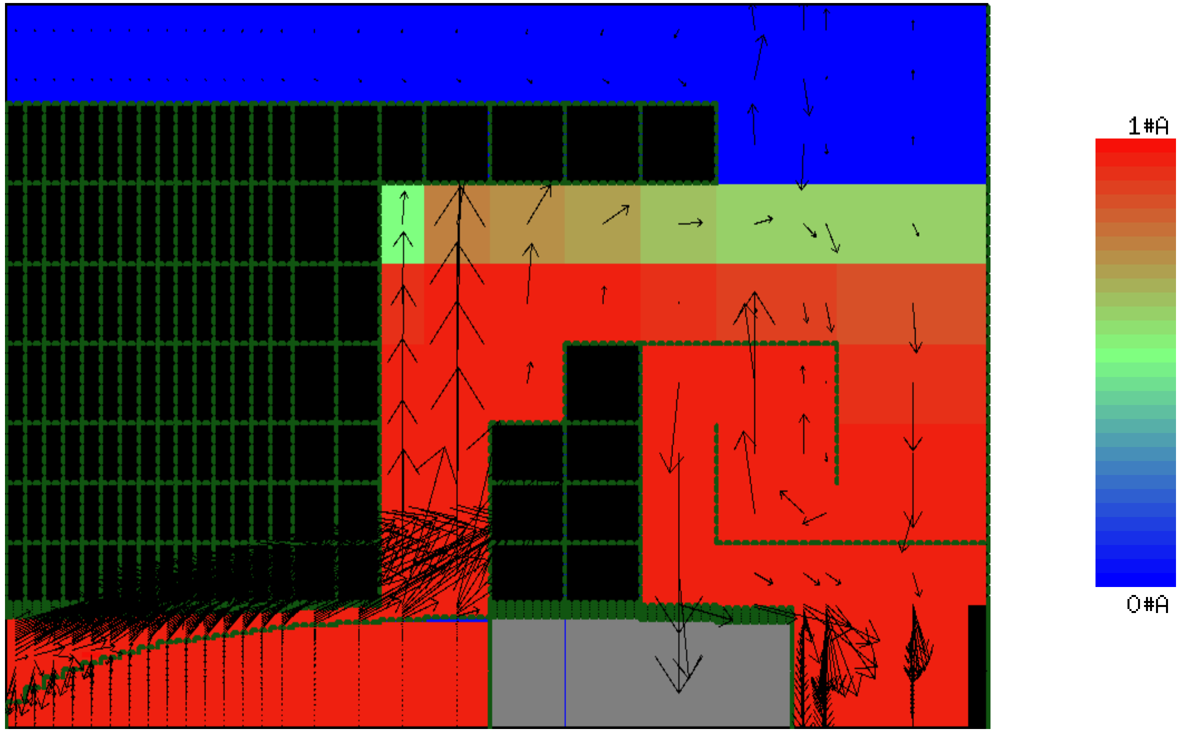
Bubbling system – injection

- Improve fission product removal (both gaseous and solid)
- Strong impact on the reactivity
  - Locally and globally
  - Void feedback
- Tight coupling between thermal-hydraulics and neutronics
  - Flux shape (and amplitude) is influenced by dimension, distribution and behavior of the bubbles



Bubbling system – removal

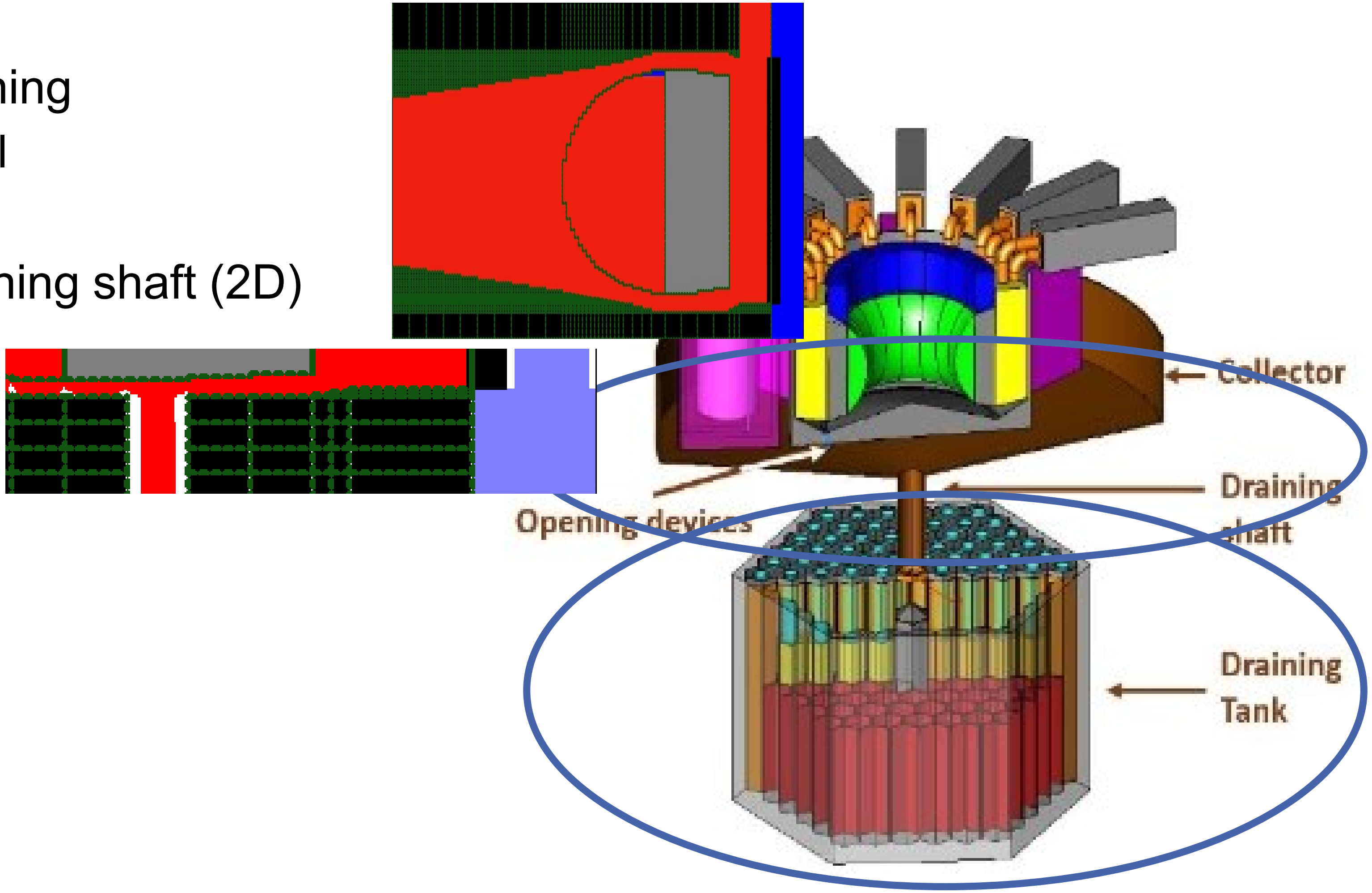




Helium removal detail
Liquid volume fraction

Planned: Draining and EDT

- Complete simulation of the draining
  - And of the decay heat removal
- Establish the core model
- Freeze plugs, collector and draining shaft (2D)
- Emergency Draining Tank (3D)



- Solidification/Melting
  - Freeze plugs
  - Salt freezing in EDT
- Liquid fuel movement (sloshing)
  - Collector
  - Filling of the tank
- Natural circulation

Recap (and ongoing work)

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Precursor movement

MSFR model

- Revise EOS based on new salt properties
- Test alternative turbulence models

Bubbling system

- Compare the gas injection test outcomes with CFD tools
- Tuning of the flow

Simulations

- LOHS
- Draining operation
- Emergency draining tank

Thank you for your attention!

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Questions?