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

M. Massone, L. Guo, A. Rineiski

YMSR Conference, 2022, June 7th
Introduction

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

**Fluid Dynamics**
- 8 velocity fields
- Multi-phase, multi-component flow
- Phase transition
- Flow regime
- Interfacial area tracking
- Elaborate EOS
- Heat and mass and momentum transfer

**Structure model**
- Pin model
- Advanced fuels
- Loop model (IHX and pumps)
- Axial and radial heat transfer
- Virtual structure model
- Structure disintegration
- Freezing on structures

**Neutronics**
- Neutron transport theory
- Improved quasi-static method
- Cross-section generation
- Heterogeneity treatment
- Decay heating
- External neutron source
- Precursor movement

C₄P
1968/560 Group master library
Basis: JEFF, JENDL, ENDF/B
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

- Multigroup transport equation

\[
\frac{1}{v_g} \frac{\partial \varphi_g(r, \Omega, t)}{\partial t} + \nabla \cdot \varphi_g(r, \Omega, t) + \Sigma_t(r) \varphi_g(r, \Omega, t) = \int \Sigma_{s}^{g' \rightarrow g}(r, \Omega' \cdot \Omega) \varphi_g(r, \Omega', t) \, d\Omega' + \\
+ (1 - \beta) \chi_p \frac{g}{4\pi} \sum_{g'} \nu \Sigma_f^{g'}(r) \Phi_{g'}(r, t) + \frac{1}{4\pi} \sum_{i} \lambda_f \chi_{d,i} C_i(r, t) + S_g(r, \Omega, t)
\]

- Delayed neutron precursors balance equations

\[
\frac{\partial C_i(r, t)}{\partial t} = \beta_i \sum_{g'} \nu \Sigma_f^{g'}(r) \Phi_{g'}(r, t) - \lambda_i C_i(r, t) - \nabla \cdot (u(r, t) C_i(r, t))
\]
Moving precursors

- KIT developed a modification for SIMMERR neutronic solver to deal with moving precursors.
  \[ C(r, t) = C_s(r, t) + C_m(r, t) \]

- The \( C_s \) component is calculated with the usual formulation, with steady state and non-moving material assumptions
  \[ 0 = \beta_f \sum_{g'} n \Sigma_{fg}'(r) \Phi_g(r, t) - \lambda_i C_{s,i}(r, t) \]

- The \( C_m \) component follows
  \[ \frac{\partial C_{m,i}(r, t)}{\partial t} = -\nabla \cdot (u(r, t)C_{s,i}(r, t)) - \lambda_i C_i(r, t) - \nabla \cdot (u(r, t)C_{m,i}(r, t)) \]

- The calculation is iterative with the new guesses
  - \( u \) is provided by the thermal-hydraulics calculation

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

Coolant temperature profile

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

Liquid volume fraction in core

Reactivity

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)

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!

Questions?