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# Evaluation of Sodium Leak Detection Time in SFR

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## Introduction

- In SFR (Sodium-cooled Fast Reactor), a leakage of sodium coolant from the reactor vessel is one of postulated events. Sodium aerosol can be detected by an aerosol ionization detector equipped in inert gas circulation system. To be detected by the aerosol detector, concentration of sodium aerosol needs to be higher than a specified concentration level given by the aerosol detector.
- In order to detect the sodium aerosol generated by sodium leakage from the reactor vessel, nitrogen circulation system for the annulus space between the reactor vessel and the containment (or guard) vessel is generally provided. Detection time is highly dependent on the leak rate, the leak location, and the nitrogen injection rate.
- In this study, for evaluation of a nitrogen circulation system aerosol detection time at a given leakage rate is calculated using an aerosol solver, 'aerosolEulerFoam' developed on the OpenFOAM framework. The 'aerosolEulerFoam' solves GDE (general dynamics equation) for aerosol motion and Navier-Stokes equations for fluid flow.

## Governing Equations & Models

- 'aerosolEulerFoam' is an Eulerian aerosol solver which can simulate nucleation, aerosol coalescence, condensation/evaporation and deposition.
- Generally, continuity, momentum and energy equations need to be solved for fluid flow. For aerosol transport simulation, equations for aerosol number density, mass fraction of vapor and particle are additionally solved

$$\partial_t \rho + \nabla \cdot (\rho \boldsymbol{u}) + \nabla \cdot [\boldsymbol{f}(1-\gamma)] = 0$$

$$\partial_t (\rho \boldsymbol{u}) + \nabla \cdot (\rho \boldsymbol{u}\boldsymbol{u}) = -\nabla p - \nabla \cdot \boldsymbol{\tau}$$

$$c_p[\partial_t(\rho T) + \nabla \cdot (\rho \boldsymbol{u} T)] = \nabla \cdot (k \nabla T) - (\boldsymbol{\tau} : \nabla \boldsymbol{u}) + D_t p$$

$$\partial_t(\rho M_i) + \nabla \cdot (\rho \boldsymbol{u} M_i) + \nabla \cdot (\rho \boldsymbol{u}_i^p M_i) = \nabla \cdot (\boldsymbol{D}_i^p \nabla \rho M_i) + J_{M_i}$$

$$\partial_t(\rho Y_j) + \nabla \cdot (\rho \boldsymbol{u} Y_j) - \nabla \cdot (Y^{-1} \boldsymbol{h} Y_j) = R_j$$

$$\partial_t(\rho Z_j) + \nabla \cdot (\rho \boldsymbol{u} Z_j) - \nabla \cdot (Z^{-1} \boldsymbol{f} Z_j) = S_j$$

- Small-sized particle is deposited on a surface by diffusion. Diffusion flux $\boldsymbol{f}^{\text{diff}}$ mainly depends on $D_i^p$ which is a function of aerosol size. Stokes-Einstein equation, a model for the Brownian diffusivity for a sphere body is given by

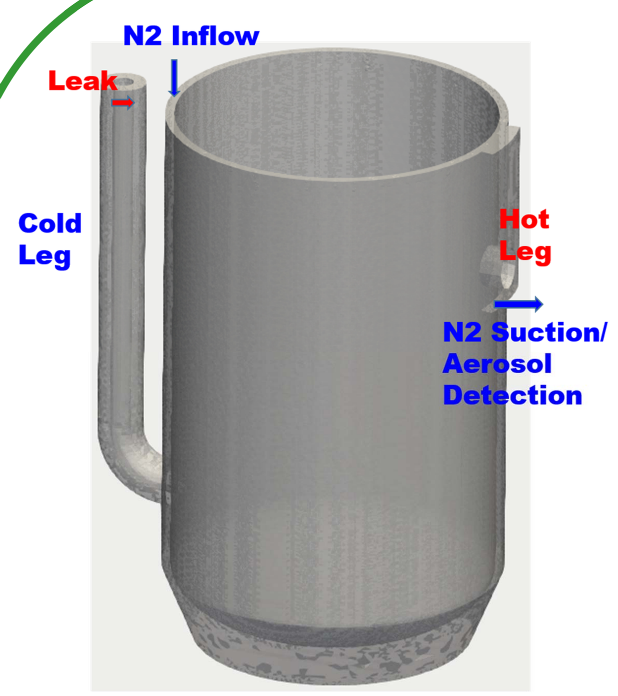
$$D^l(s) = \frac{k_B T C_c}{3\pi \mu d}$$

- where, $k_B, C_c, d$ are the Boltzmann constant, Cunningham correction factor, and aerosol diameter, respectively. Cunningham correction factor accounts for surface slip of small particles.
- Large-sized particle is deposited on a surface by inertial force. Schiller-Naumann model to calculate drift velocity of a particle is written as

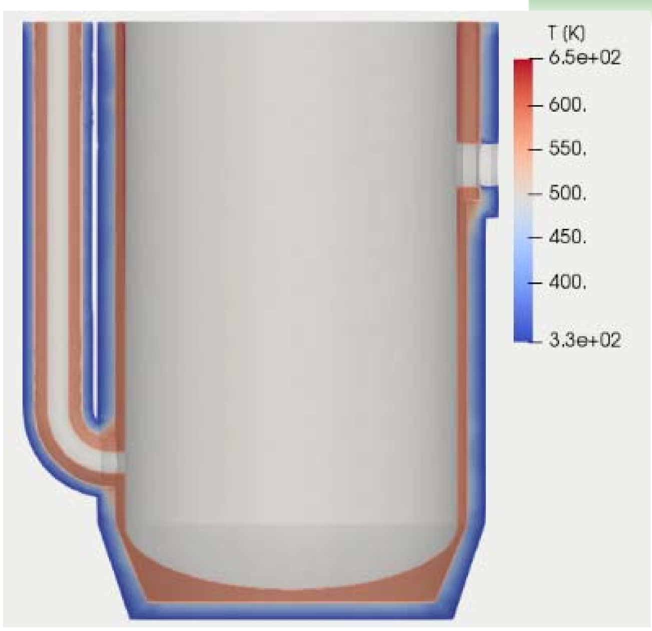
$$\partial_t \boldsymbol{v}(s) + [\boldsymbol{v}(s) \cdot \nabla] = -\frac{1 + 0.15 Re_d^{0.687}}{\tau}[\boldsymbol{v}(s) - \boldsymbol{u}] + (1-\gamma)\mathbf{g},$$

- where, $v, \tau, \mathrm{g}$ are particle velocity, particle relaxation time, gravitational acceleration, respectively. $\tau$ is defined as $\tau = \rho^p d^2/(18\mu)$ and $Re_d$ is a function of $v$.

## Computation & Results

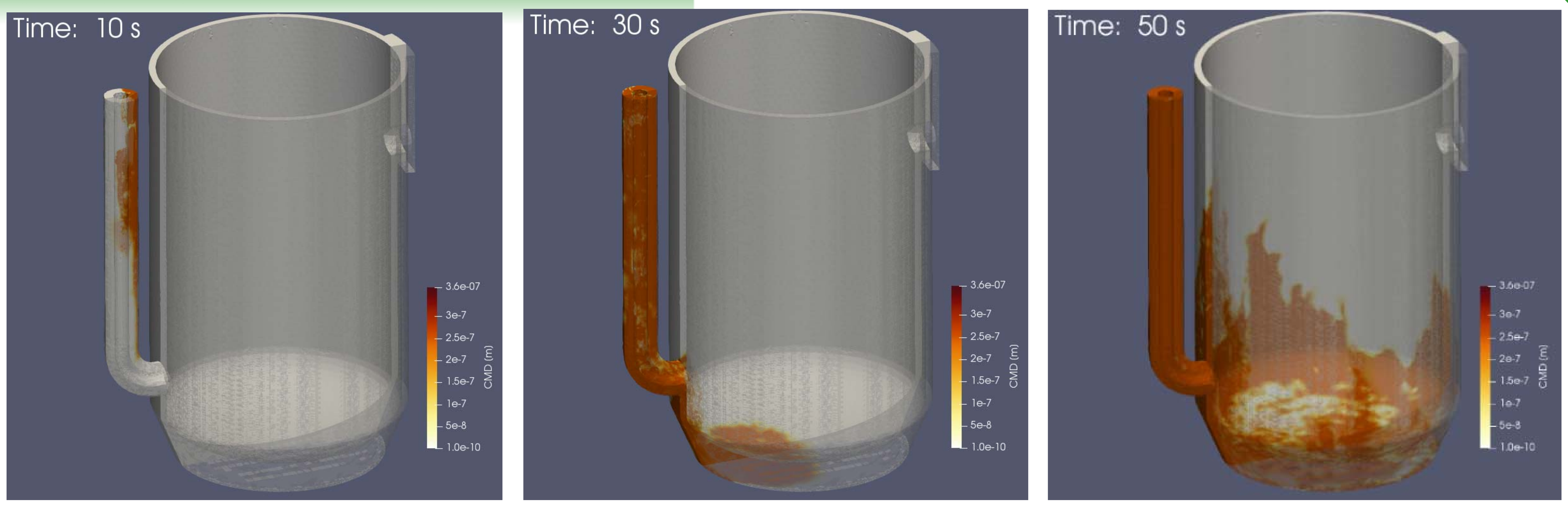


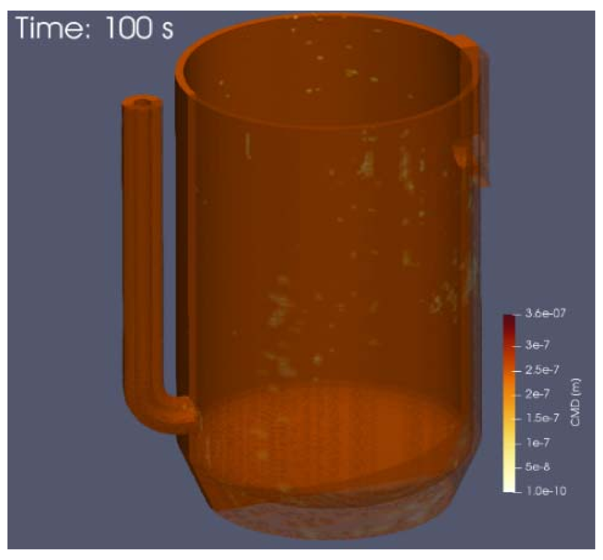

Schematic of FFTF



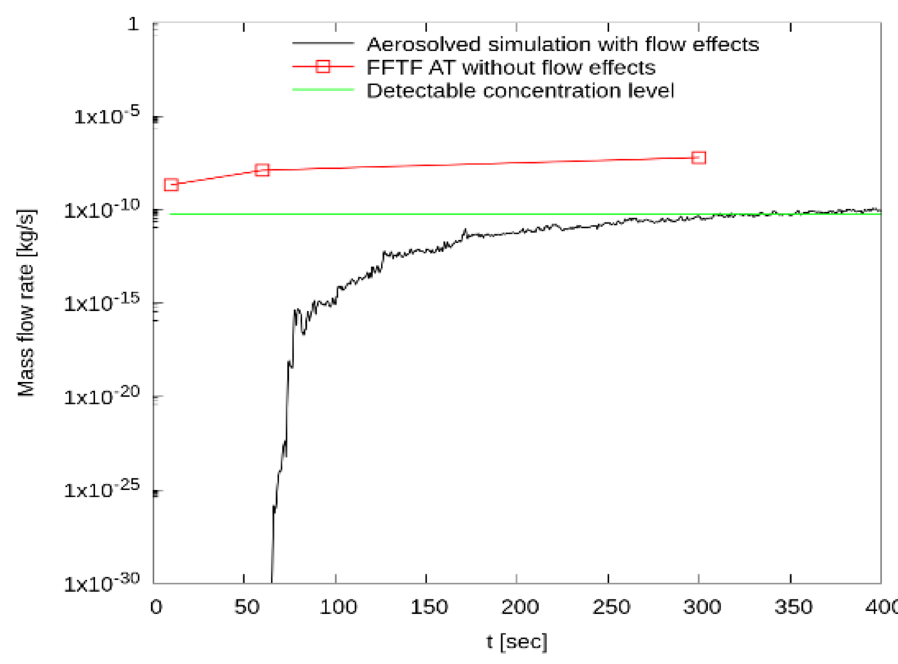
Boundary condition

- Guard vessel and cold leg are insulated. Surface temperature of the reactor vessel varies according to elevation. Sodium is assumed to be leaked from the upper region of the cold leg. Sampling pipe is attached under the hot leg.
- From fixed boundary conditions of temperatures given by the insulation outer surface and the reactor vessel outer surface, temperatures were obtained by CHT (conjugate heat transfer) simulation for the domain including the insulation material and the annulus space between two vessels.
- Number of cells of generated grid system for the computational domain is about 2 million. At a given leak rate, detectable particle mass flow rate at the entrance of the sampling line was 6E-11 kg/s.




Aerosol propagation




Aerosol detection time calculation

## Conclusion

- Sodium leak detection time for FFTF sodium leak case was calculated by an Eulerian aerosol solver.
- Aerosol propagation characteristics from the cold leg upper part to the sampling line was investigated. For the ANL AT document, aerosol dynamics was not coupled with the fluid flow and the detectable time was roughly estimated between few minutes and several hours. It was too uncertain to decide design of measuring system and operating condition of the system.
- Using an Eulerian solver, sodium aerosol detection time was assessed more accurately. Around 100 seconds after the sodium leak, sodium aerosol arrives at the sampling line but the concentration level is not enough to be detectable. Time to detect the aerosol was evaluated to be between 6 ~ 7 minutes.
- The detection time may vary by nitrogen injection rate, leak location, and leak rate. These parameters need to be evaluated for decision of optimal nitrogen injection rate and design of nitrogen circulation system.
- This feasible analysis tool can be applied to decision of operational condition and design of containment nitrogen circulation system for SFR.