2020 KNS Autumn Meeting

Numerical Analysis for Liquid Droplet Behavior in the CALIST Test Using OpenFOAM

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3-D Analysis of Spray Droplet Flow in a Rx Containment

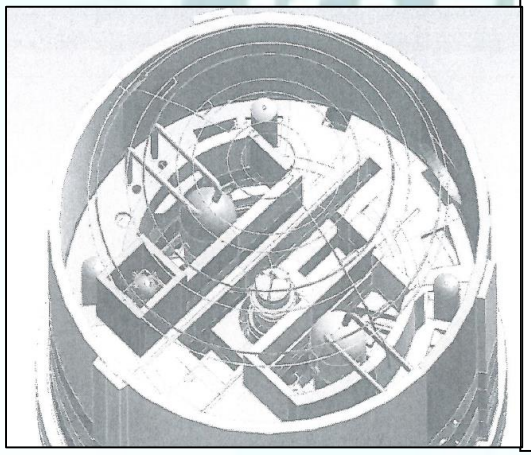
❑ Spray Operation during Severe Accidents

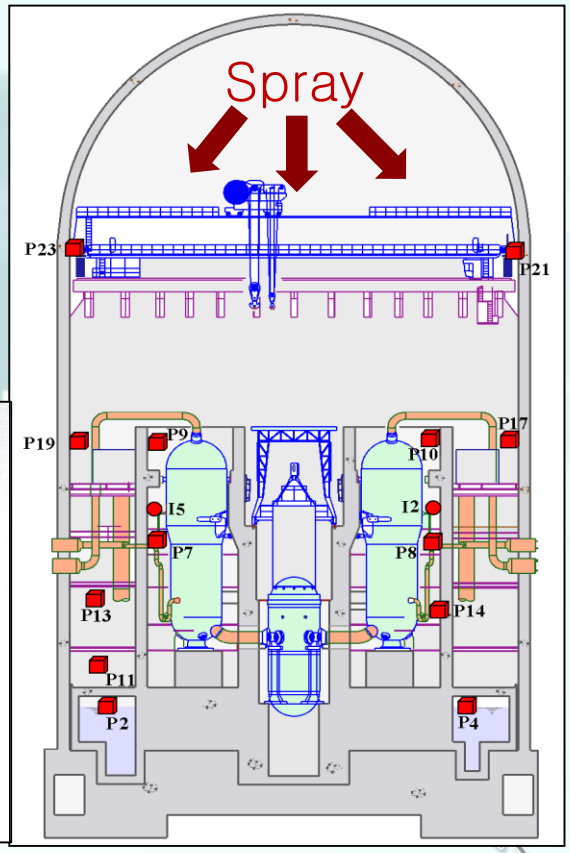
- ❍ Steam & H_2 are released to the containment during the severe accident
- ❍ Pressure decrease in the containment through the steam condensation
- ❍ Hinder the hydrogen flame propagation by reducing the gas temp.

❑ Spray Analysis Module using OpenFOAM

- ❍ Ref : KAERI/TR-7992/2019
- ❍ Lagrangian & Eulerian method
- ❍ Particle Size Distribution
- ❍ Heat and Mass Transfer
- ❍ Spray Injection Nozzle
- ❍ Validation

Spray Nozzle Ring





CALIST Experiment (IRSN in France)

❑ Validation using CALIST test data

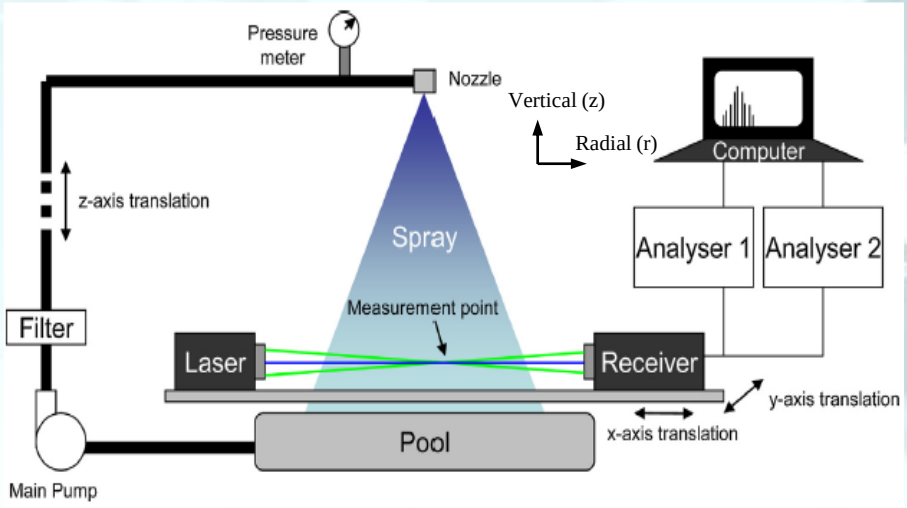
❍ Spray water(liquid droplet) Behavior

⏩ Diameter, Vertical/Radial Velocity

Test Condition

Water Condition at upstream of nozzle	Spray Water Flow	Ambient Condition
3.5 bar, 20 ℃	1 kg/s	1 bar, 20 ℃

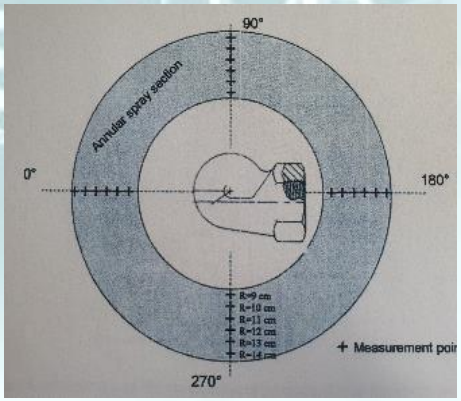
Test Facility



Ref : NED, Vol. 282, pp. 44-53 (2015)

Spray Nozzle (Hollow Cone)

Measurement Locations

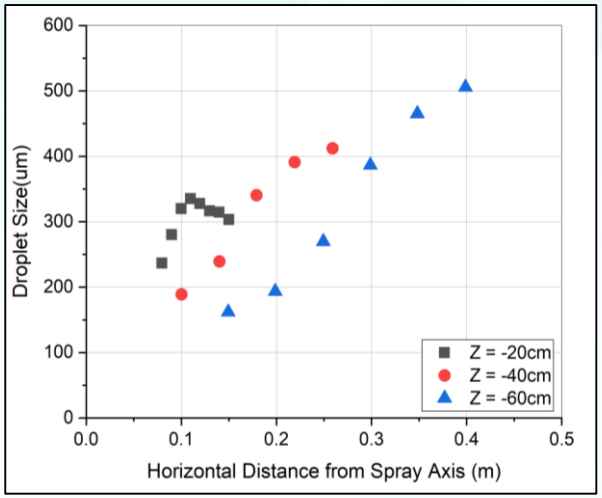


CALIST Test Data (IRSN in France)

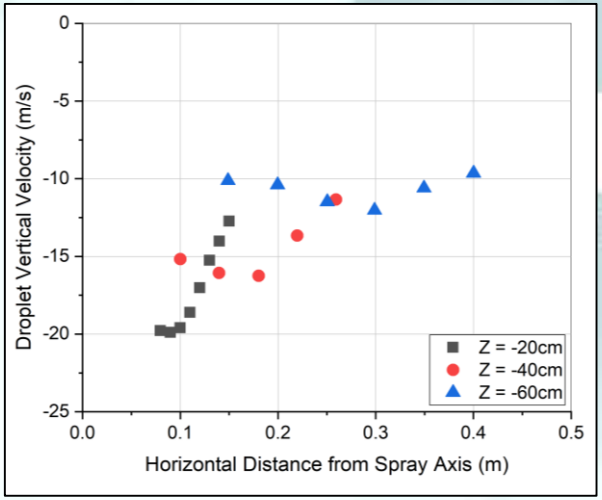
❑ Phase-Doppler Interface

- ❍ At 20cm, 40cm, 60 cm from the spray nozzle
- ❍ Diameters increases as the vertically measuring length increases
- ❍ Vertical/Radial velocity decreases
- ❍ Range of positions along the horizontal direction increases
  - ⏩ Width of the spray water increases

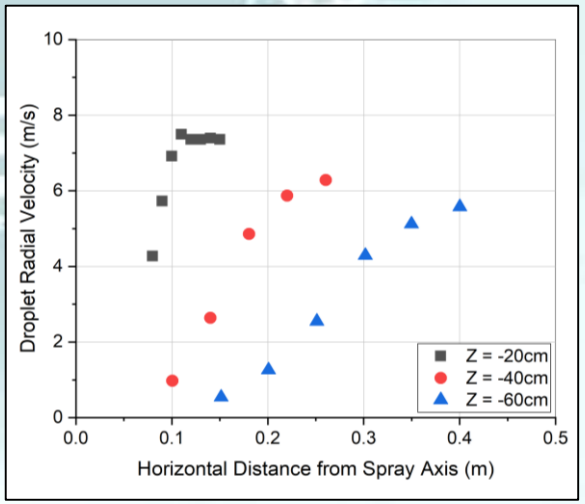
Diameter



Vertical Velocity



Radial Velocity



Spray Analysis Module Using OpenFOAM

❑ OpenFOAM V.1912 (www.openfoam.com)

❍ Lagrangian-Eulerian method

- ⏩ Spray water : Lagrangian, Environment air : Eulerian

❍ Lagrangian Governing Equations

- ⏩ Mass / Momentum / Gas Species conservation equations

$$m_p \frac{du_p}{dt} = F_D + F_G + F_P$$

Momentum eq. for spray water

$$F_D = C_D \frac{\pi d_p^2}{8} \rho (U - u_p) \left| U - u_p \right|$$

Drag force

$$F_G = m_p g \left(1 - \frac{\rho}{\rho_p} \right)$$

Gravity force

$$F_P = -\frac{\pi d_p^3}{6} \nabla p$$

Pressure force

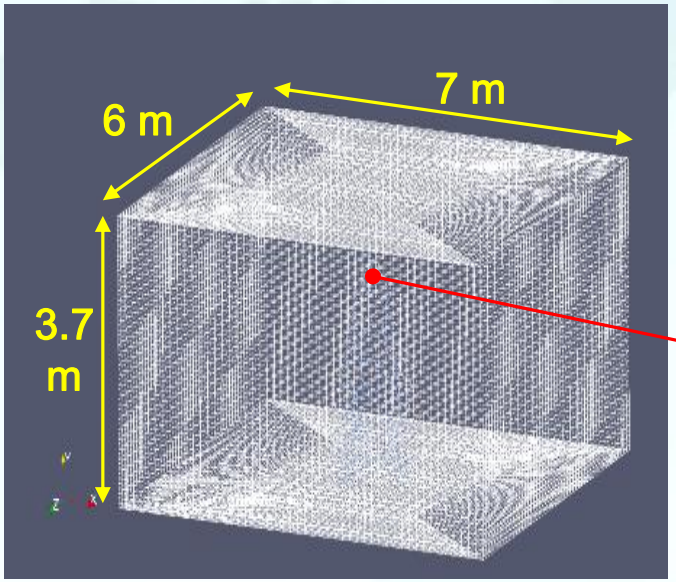
Grid Model and Boundary Condition

❑ Grid Model

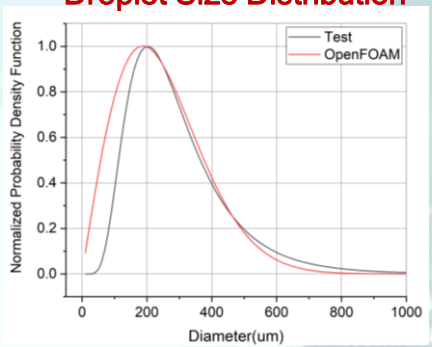
- ❍ 477,015 Hexahedral Cells for spray water and environment

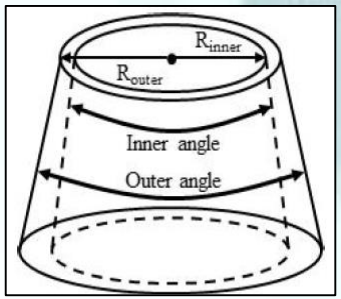
❑ Inlet Boundary Condition

- ❍ Measured data at Z=20 cm below from the spray nozzle
- ❍ Cone Nozzle Injection Model



Droplet Size Distribution





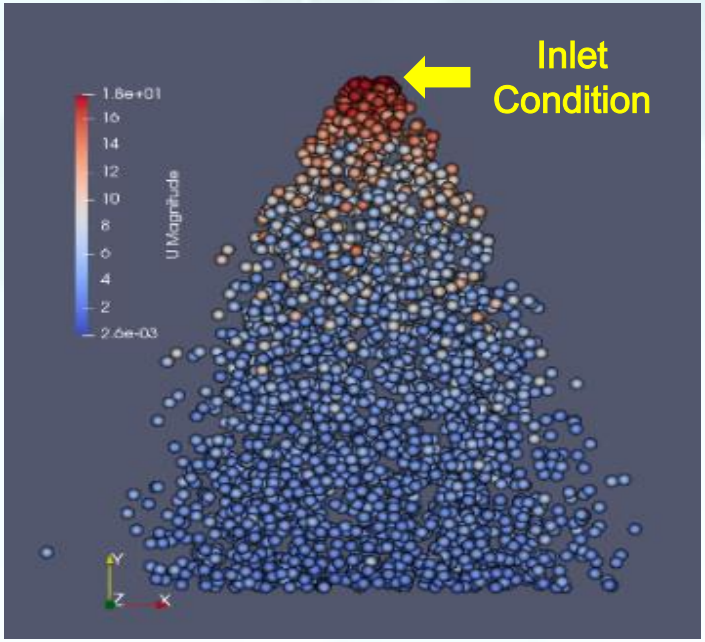
Inlet Condition

Spray Model (Lagrangian method)
- Diameter (d_{10}) distribution = mass Rosin Rammler model - Mass flow rate = 1 kg/s - U_{mag} = 18.02 m/s - Nozzle inner/outer diameter = 0.16 m / 0.30 m - Nozzle inner/outer angle = 21.80° / 36.87° - Parcel Per Second (PPS) = 5000 [#/s] *Inlet conditions were determined based on measured data at Z = -20 cm from the nozzle outlet.
mass Rosin Rammler model
$f(d, D, k) = \frac{k}{D}\left(\frac{d}{D}\right)^{k-1} \exp\left[-\left(\frac{d}{D}\right)^{k}\right]$ - Diameter : d - Min. / Max. diameter = 30 μm / 970 μm - Mean diameter (D)= 260 μm - Shape factor (k) = 1.8

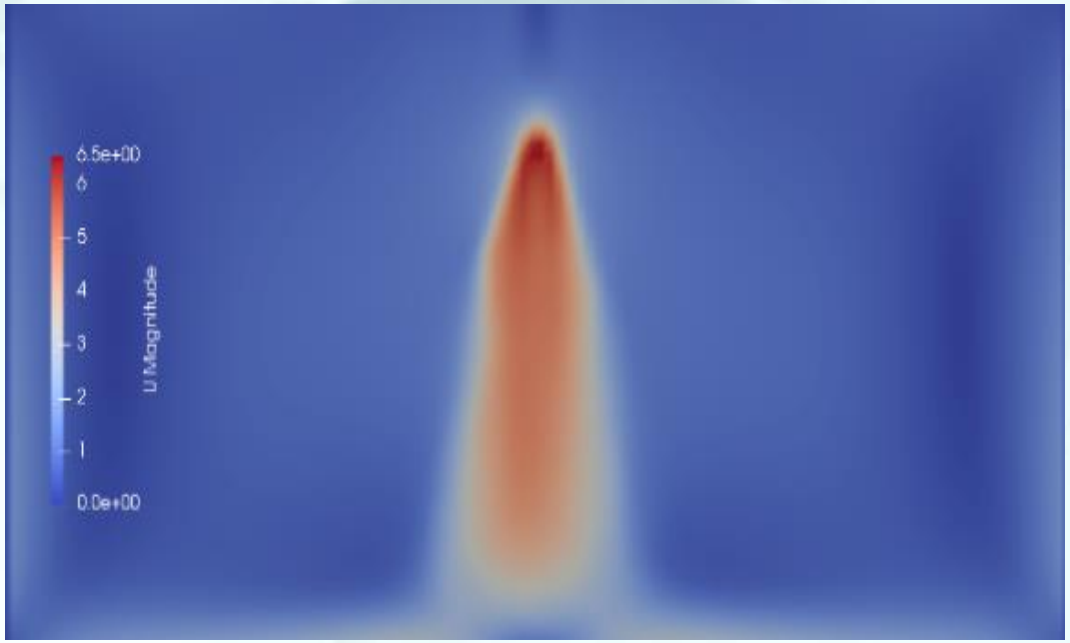
OpenFOAM Analysis Results (1)

- Injected spray water (liquid droplet) induced the air flow in the CALIST test
  - This phenomenon was simulated by Lagrangian and Eulerian method

Injected Spray Water
(Velocity Contour)

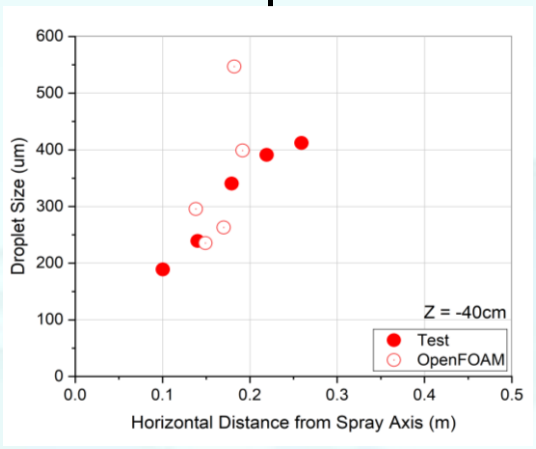
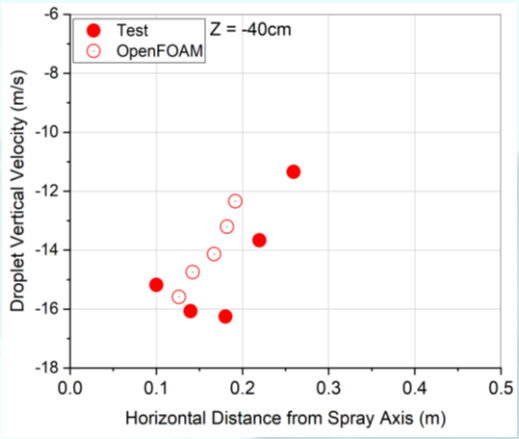
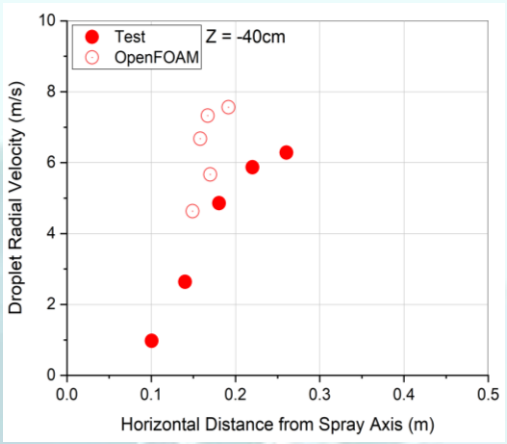
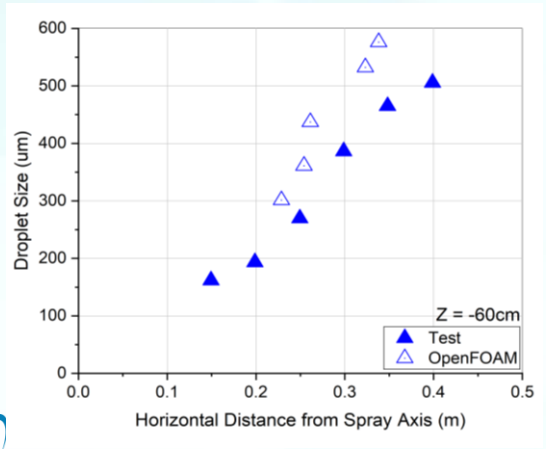
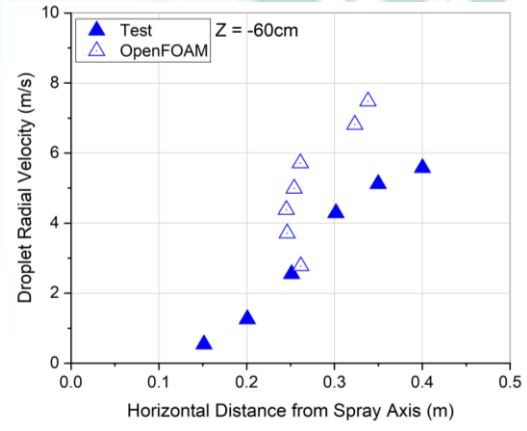
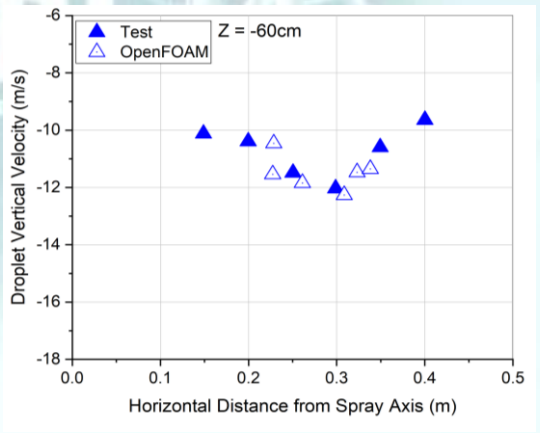


Air Flow
(Velocity Contour)



OpenFOAM Analysis Results (2)

- Comparison results of droplet size and vertical/radial velocities between test data and OpenFOAM results

	Droplet Size	Vertical Velocity	Radial Velocity
Below spray nozzle 40cm			
60cm			

OpenFOAM Analysis Results (3)

❑ OpenFOAM Results

- ❍ can reasonably simulate the behavior of the spray water.
  - ⏩ Discrepancy when compared to test data is approximately 20%.
- ❍ predicted the droplet existence in the range of approximately from 0.15 m to 0.2 m whereas the droplets locate in the range of approximately 0.1 m to 0.26 m in the measured data.
- ❍ may be improved if a multi-cone nozzle injection model is used for simulating the inlet boundary condition which is the measured data at 20 cm below from the spray nozzle.
  - ⏩ Uniform velocity of 18.02 m/s was used instead of the measured velocity profile in the test because the one injection model can not simulate the velocity profile.

Conclusion and Further Work

❑ Conclusion

- ❍ We performed the CFD analysis against the measured data of the spray water in the CALIST test to validate the spray analysis module developed using OpenFOAM-1912.
- ❍ OpenFOAM results reasonably predicted the droplet size and vertical/radial velocities with an error range of approximately 20% when compared to the test data.

❑ Further Work

- ❍ If the multi-cone nozzle injection model is used, better simulation results may be produced.