Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Vortex-Concept for Radioactivity Release Prevention at NPP: Development of Computational Model of Lab-Scale Experimental Setup

Sana Ullah, Man Sung Yim, Jinsoo Park, Hyung Jin Sun

Speaker : Sana Ullah (PhD Student)

Department of Nuclear & Quantum Engineering

KAIST, Daejeon, Republic of Korea

Department of Nuclear and Quantum Engineering

Nuclear Energy Environment and Nuclear Security Laboratory

Contents

- Background
- Experimental setup
- Present study
- Development of computational model
- Conclusions
- Future work

Background

- A severe accident situation may lead to containment failure, releasing airborne radioactive material from reactor containment to the environment.
- Since, existing state of the art systems are not prepared for mitigating leaking radioactivity,
  - Such releases would be uncontrolled.
  - May continue for days.
- In order to prevent/limit dispersion of leaking radioactive material, and reduce overall impact of a severe accident,

“An additional barrier after containment”

Background

- A radioactivity dispersion barrier!
  - Built, maintained and operated Ex-Containment
  - Fulfils the basic SA requirements
    - Proven performance, and robustness under SA conditions!
    - Easy to use, maintain and implement (SAs are rare!)
    - Cost effective.
    - Portable/Mobile?

— We set to explore ideas which can be POTENTIAL CANDIDATE for such systems

— One of those ideas is to extend and utilize AIR-CURTAIN approach for preventing/limiting radioactivity dispersion.

Background

- Air curtains are devices used in many industries for climate control applications (dust or bug control, energy savings etc.).
- An Air-curtain device generates an aerodynamic sealing at an opening to prevent air exchange across the curtain.
- The device is very simple
  - Fan/Blower!
  - Directional Nozzle

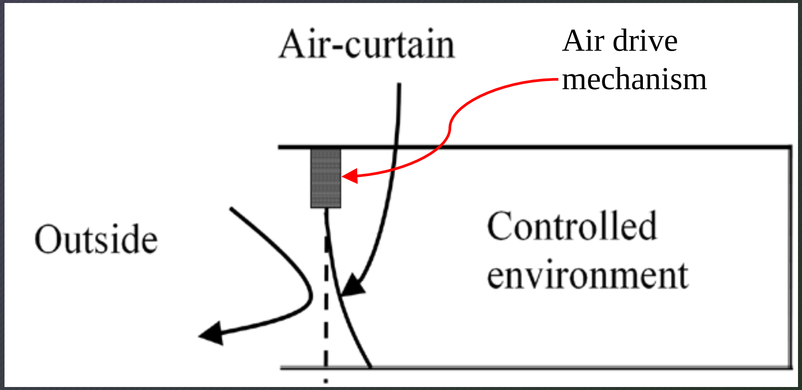


Fig. 1 Basic air curtain concept

Background

- An extension of this concept to a NPP containment requires to simultaneously;
  - Generate an effective air curtain around reactor containment using air-curtain devices by appropriate position of vertical air curtain devices
  - Collect contaminated air using a suction system
  - Filter collected contaminated air using appropriate treatment system

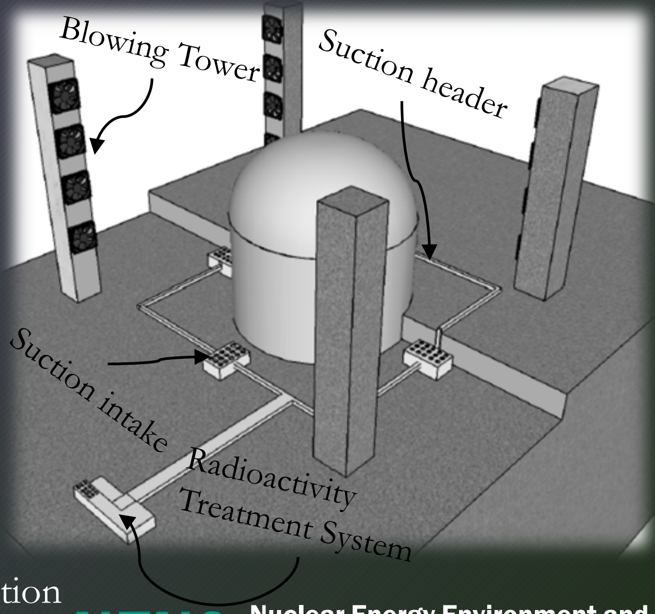


Fig. 2 Conceptual implementation

Background

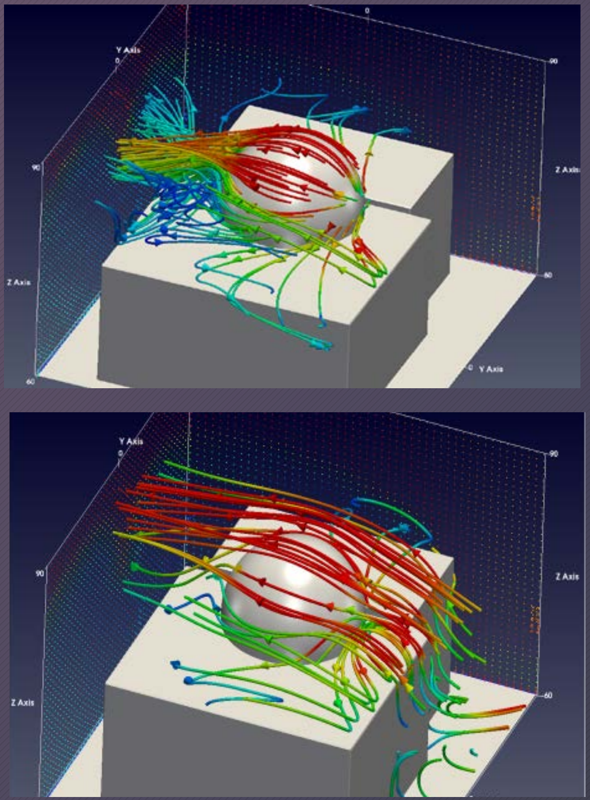


Fig.3 Flow around reactor containment before system implementation

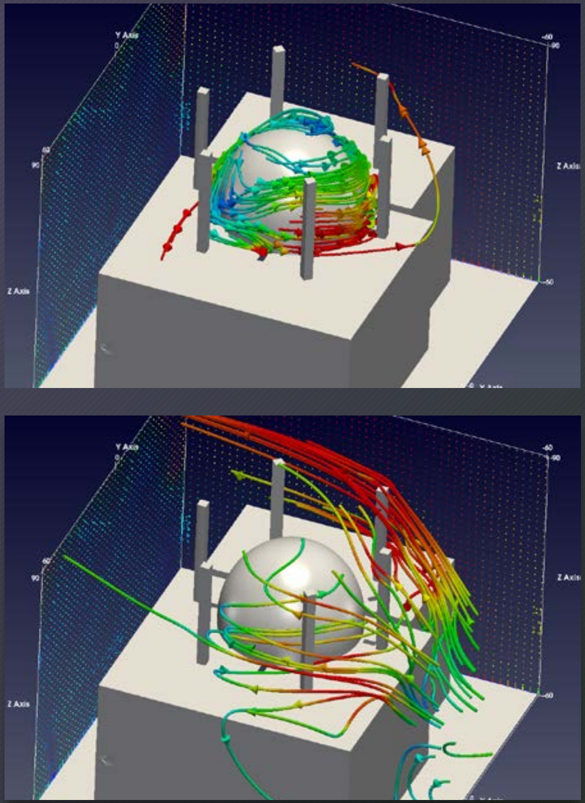


Fig.4 Flow around reactor containment after system implementation

Background

- However, experimental validation of the air-curtain concept, and computational model is required
- For this purpose, a lab-scale experimental setup is developed.
- Additionally, this setup will also be used to study effect of other parameters on air curtain development (e.g. flow rate, angle, and distance)

Experimental Setup

- A scale-down containment model (R=0.15m, H=0.276m) is placed in closed chamber (0.8×0.8×1.05) m^3
- 4 towers are symmetrically placed around the model to generate vortex-like airflow using compressed air.
- Each tower consists of 8 nozzles (bottom 4 are used)
- The nozzle flow, angle and distance are adjustable.
- Exhaust is provided at the top using 42mm pipe driven by a Fan

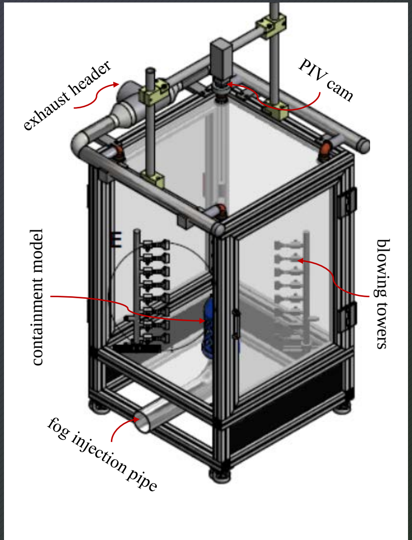
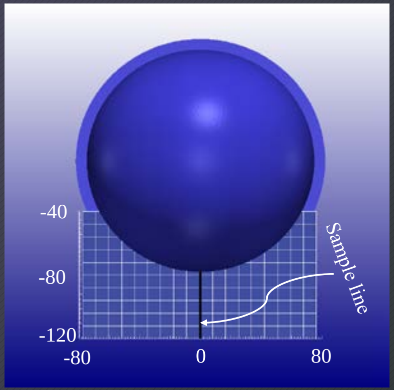


Fig. 5 Experimental setup

Experimental Setup

- A particle image velocimetry (PIV) setup is configured for getting experimental data.
- The light sheet is positioned at a height of 120 mm
- However, due to PIV limitations
  - grid : 11×19
  - region: x (mm): ±80 y (mm): -120:-40



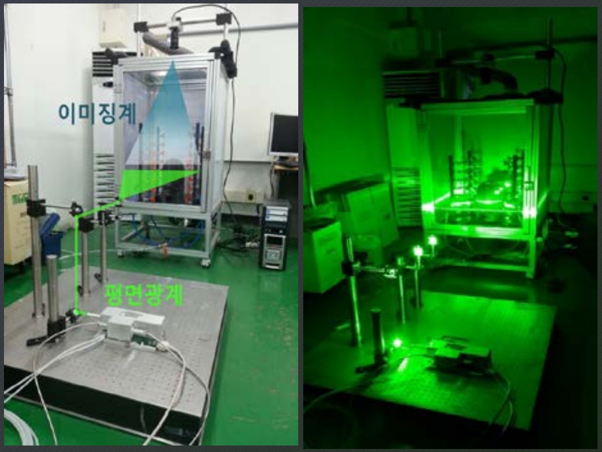


Fig. 6 PIV setup, and measurement zone

Present Study

- A computation model of the experiment setup is developed, as a part of validation process.
- Sensitivity of various model parameters is also studied
- Expected flow field is presented, and compared with measured flow field

Development of computational model

- Software
  - OpenFOAM
    - Collection of C++ libraries
    - Solvers + Utilities
- *Governing Equations*
  - SteadyState incompressible RANS equations
  - Spalart Allmaras (SA) turbulence model for closure of the system

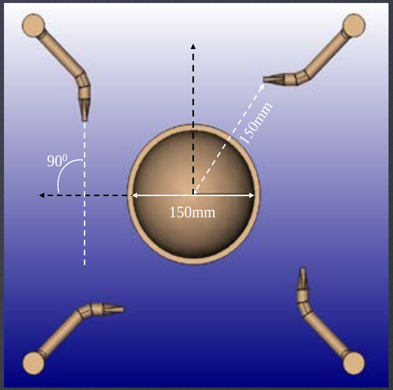
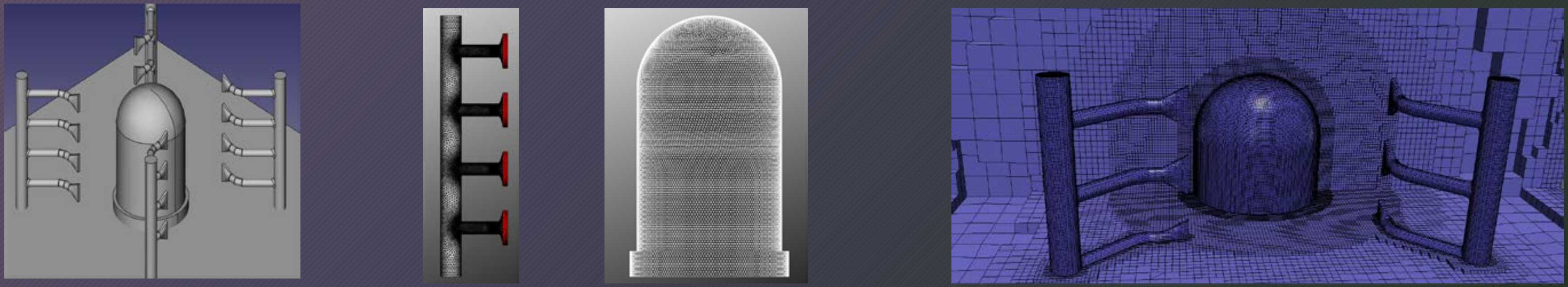


Fig. 7 Tower positioning

Table 1: Flow Conditions	
Freestream	0m/sec
Blowing Tower	3m/sec
Nozzle Distance	150mm
Nozzle Angle	90^0

Development of computational model

- *Preparation of geometry and mesh*
  - Model geometry is prepared using Inventor,
  - Surface mesh is generated using Salome
  - Volume Mesh is generated using OpenFOAM Native Meshing Tool SnappyHexMesh



CAD Model

Tower, and containment surface mesh

Model Volume mesh

Fig. 8 Computational mesh

Development of computational model

- *Mesh sensitivity studies*
  - Mesh independence is performed for 4 mesh sizes
  - Sufficient mesh independence was achieved at M-2, 1.5m cells.
  - It was concluded to use a mesh of the order of 2m cells for all future studies

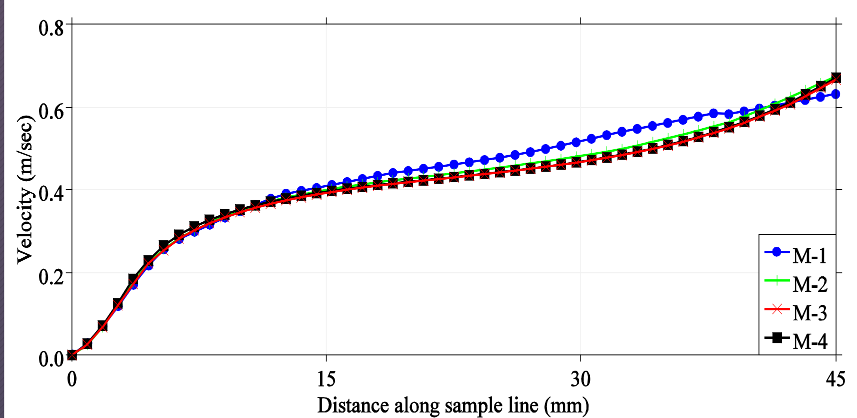


Fig.9 Comparison of velocity profiles along sample line for mesh independence study.

Table-2: Statistics for mesh independence study

Parameters	M-1	M-2	M-3	**M-4**
No. of cells (millions)	1.0	1.5	2.34	3.9

NENS Nuclear Energy Environment and Nuclear Security Laboratory

Development of computational model

- *Boundary conditions sensitivity studies*
  - Outlet BC
    - Modeling of outlet using 42mm pipe, failed to produce any stable solution due to growing continuity imbalance
    - Later, it was confirmed by flow measurement at outlet
    - Therefore, it was recommended to modify the experimental setup, and open chamber top for establishment of stable flow
    - In fact, the model with top open, produced stable and physically correct results

Development of computational model

- *Boundary conditions sensitivity studies*
  - Wall BC
    - Solution in region of interest was virtually independent on the choice of BC.
    - However, saving of 1 hour of computational time was observed for no-slip BC, therefore, no-slip BC was recommended

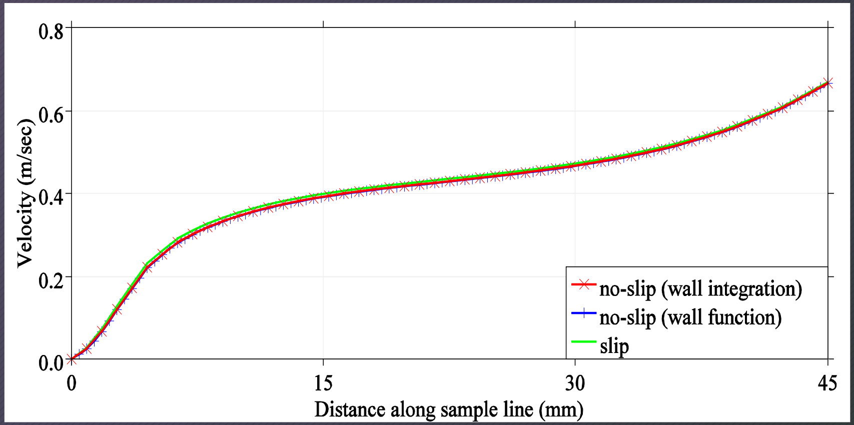


Fig.10 Comparison of velocity profiles along sample line different types of boundary conditions

Development of computational model

- *Discretization Scheme Sensitivity Studies*
  - 1st order *upwind , and* 2nd order *linearUpwindV / limitedLinear1* schemes for divergence were analyzed.
  - The 1st order scheme proved diffusive, as compared to 2nd order (as expected).
  - The 2nd order scheme setup was bounded, and convergent, therefore, 2nd order scheme proved obvious choice.

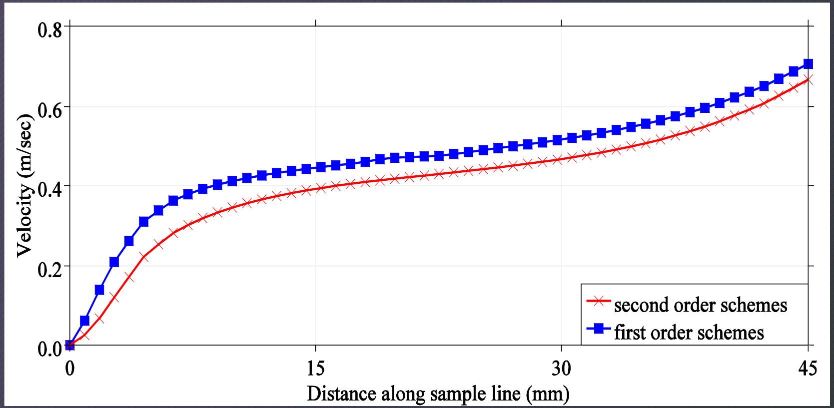


Fig. 10 Comparison of velocity profiles along sample line for first and first-second order discretization schemes.

Development of computational model

- *Recommended computational model parameters, and predicted flow field*

Analysis type	Steady state RANS with SA turbulence model
Solver	simpleFoam
Mesh size	~2 million
Boundary conditions	walls: no-slip (wall resolution) outlet: top wall
Discretization schemes	Div. (V): linearUpwindV Div. (nuTilda): limitedLinear 1 Grad.: linear

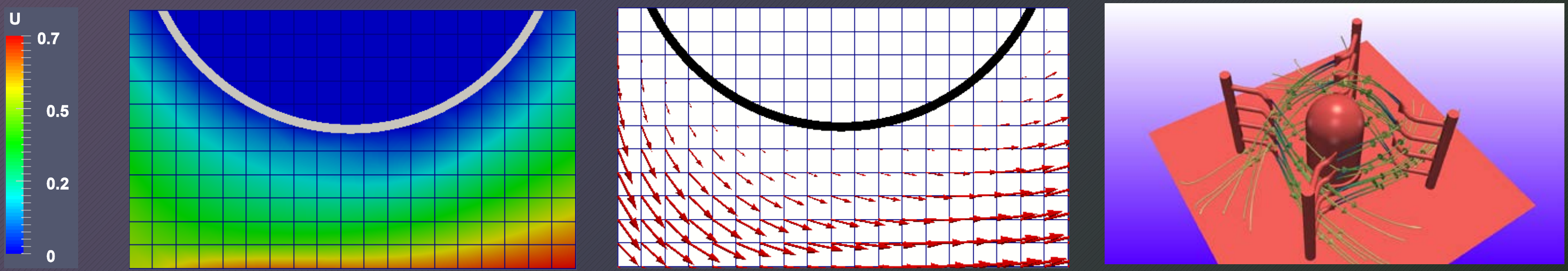


Fig. 11. (Left) Velocity magnitude, (Middle) vector field, and (Right) flow streamlines predicted by CFD model.

Development of computational model

- *Experiment flow field*
  - Several experiments were performed with existing setup configuration, (i.e. exhaust through 42mm pipe).
  - The measured flow field was un-physical due to flow imbalance at exhaust
  - New experiments will be performed after modifying experiment setup

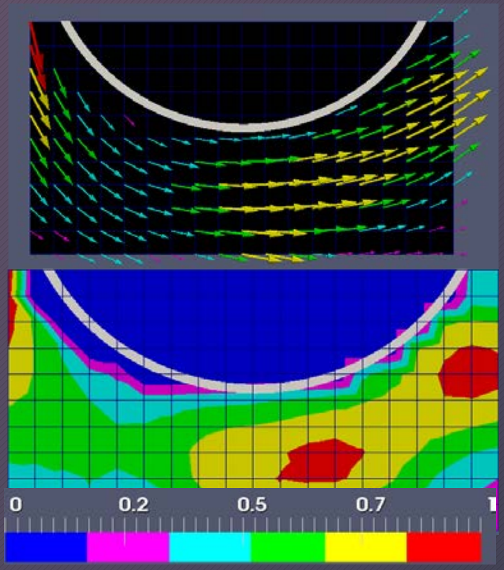


Fig. 12 Experiment Results

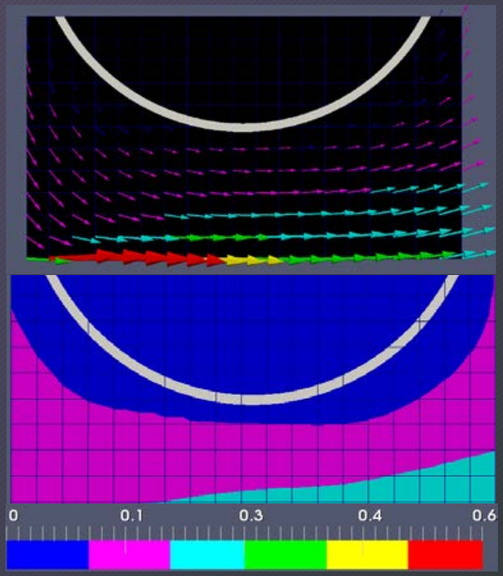
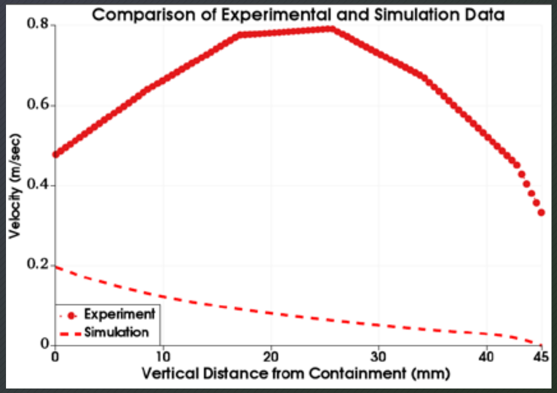


Fig. 13 Simulation Results



Conclusions

- A computation model of a lab-scale experimental setup, designed to validate the concept of artificial vortex-like airflow generation for application to radioactivity dispersion prevention in the event of severe accident, was developed.
- The mesh sensitivity study was performed and a mesh of about 2 million cells was found to be sufficient for this setup.
- The current exhaust configuration proved unstable for any valid experimentation, therefore, opening of one side of the chamber preferably top was recommended.
- The flow within the region of interest was virtually independent of the choice of boundary condition at chamber walls, and surfaces.

Future Work

- The experimental setup will be modified as per recommendation.
- New experiment setup will be used for validation purposes.
- A parametric study will also carried out.
- Once validated, model will be extended to use for investigating actual scale, real system implementation.

References

- Sana Ullah et.al., “Preliminary Investigations of Vortex Based Ex-Containment Safety System for Severe Accident Management at NPPs”, ICAPP 2016, San Francisco, USA
- OpenFOAM, “User's Guide (2.3.0/3.0.0)”, OpenCFD, London, (2014). (http://www.openfoam.com)
- Spalart, P. R. and Allmaras, S. R., "A One-Equation Turbulence Model for Aerodynamic Flows," Recherche Aerospatiale, No. 1 (1994).
- P R. Spalart and C L. Rumsey. "Effective Inflow Conditions for Turbulence Models in Aerodynamic Calculations", AIAA Journal, 45, No. 10 (2007).

Questions & Suggestions
Welcomed!