Large-scale experiments to capture aerosol particles released from NPP in a severe accident

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1. Introduction

1.1 Background

- After the Fukushima Daiichi accident, public concern has increased regarding the release of radioactive materials during a severe accident. To address the public's fear, decision makers have focused on nuclear safety. As a result, more safety equipment has been installed at nuclear power plants. For example, hydrogen removal equipment can reduce the potential for an explosion in the containment building
- If radioactivity is discharged from leaks or ruptures on a containment building, there is always the potential for public health concerns, environmental damage, and loss of confidence in the nuclear industry
- As a result, the Republic of Korea (ROK) government has revised and tighten up regulations to prevention of a severe accident and to mitigation of the damage during a severe accident situation at nuclear power plants (NPPs)

1.2 Purpose

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- To examine the use of spray technology to capture the radioactive aerosol particles released into the environment during the course of a severe accident

1.3 Approach

- Scaled down (1 : 50) APR-1400 nuclear power plant model was constructed and used
- A spray nozzle was installed outside nuclear power plant model
- TiO_2 aerosol (0.02 μm particle diameter) was released from breached holes on the containment model surface
- Water and foam solution was sprayed to capture TiO_2 aerosol

2. Experiment

2.1 Components of experimental setup

- Large experimental chamber (5 m × 5 m × 5 m)
  - Chamber isolates experimental equipment
- Scaled down (1 : 50) APR-1400 nuclear power plant (NPP) model
  - NPP containment model has breach holes to simulate different rupture and leak positions
- Spray solution tank along with spray pump
  - Sprayed materials are plain water and foam solution which includes 3% by weight of the foaming agent sodium lauryl sulfate ($NaC_{12}H_{25}SO_4$)
- Compressed air system, aerosol generation box and related piping
  - Total 5 grams of non-radioactive TiO_2 (79.866 g/mol) aerosol of 0.02 μm size is released from breach holes
- Spray nozzle mounted on a stand
  - A full-cone 1/8 G5 spray nozzle
- HEPA filters at the outlet section of the chamber
  - HEPA filters are used to prevent aerosol particles from escaping the chamber
- Trays and tank to collect sprayed solution
  - Samples from collecting trays are gathered for each experiment
- Electric fans generate windy conditions
  - The number of fans is 12

2.2 Sample analysis

- UV-Vis spectroscopy
  - Aerosols, when mixed with water or foam solution have different spectra
  - UV-Vis spectroscopy is calibrated by obtaining the absorption spectra of standard solutions of different concentrations and drawing the calibration curve
  - Samples from experiments are analyzed by UV-Vis spectroscopy to determine the concentration of TiO_2 in the collected liquids

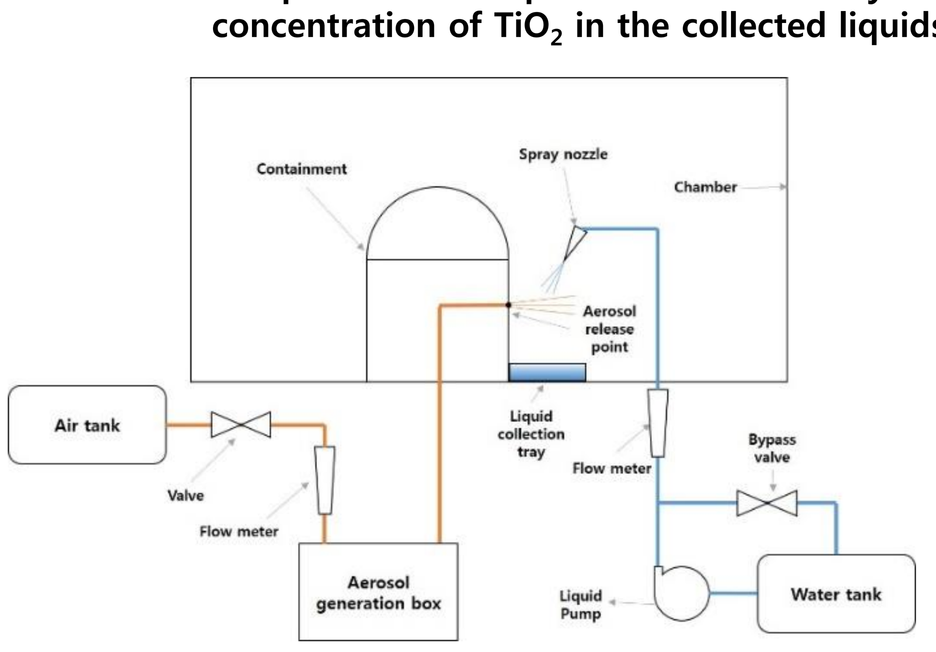


Fig. 1. Schematic diagram of experimental setup

Fig. 2. Scaled down (1 : 50) NPP model

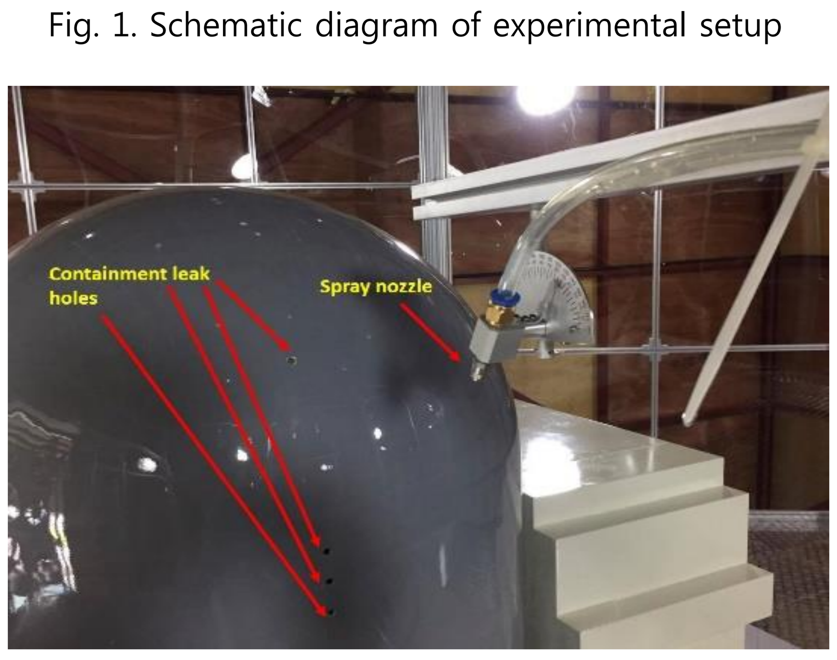


Fig. 3. Experimental arrangement

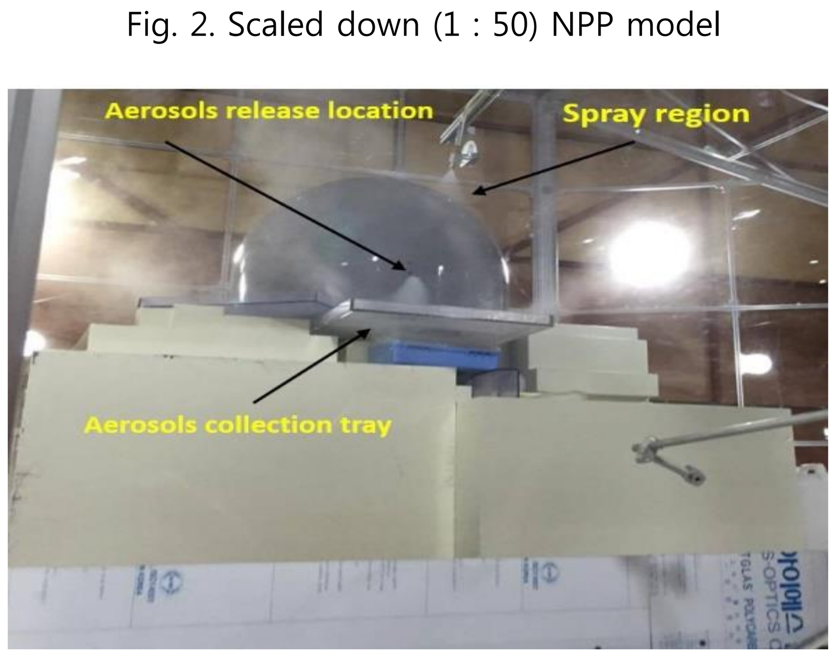
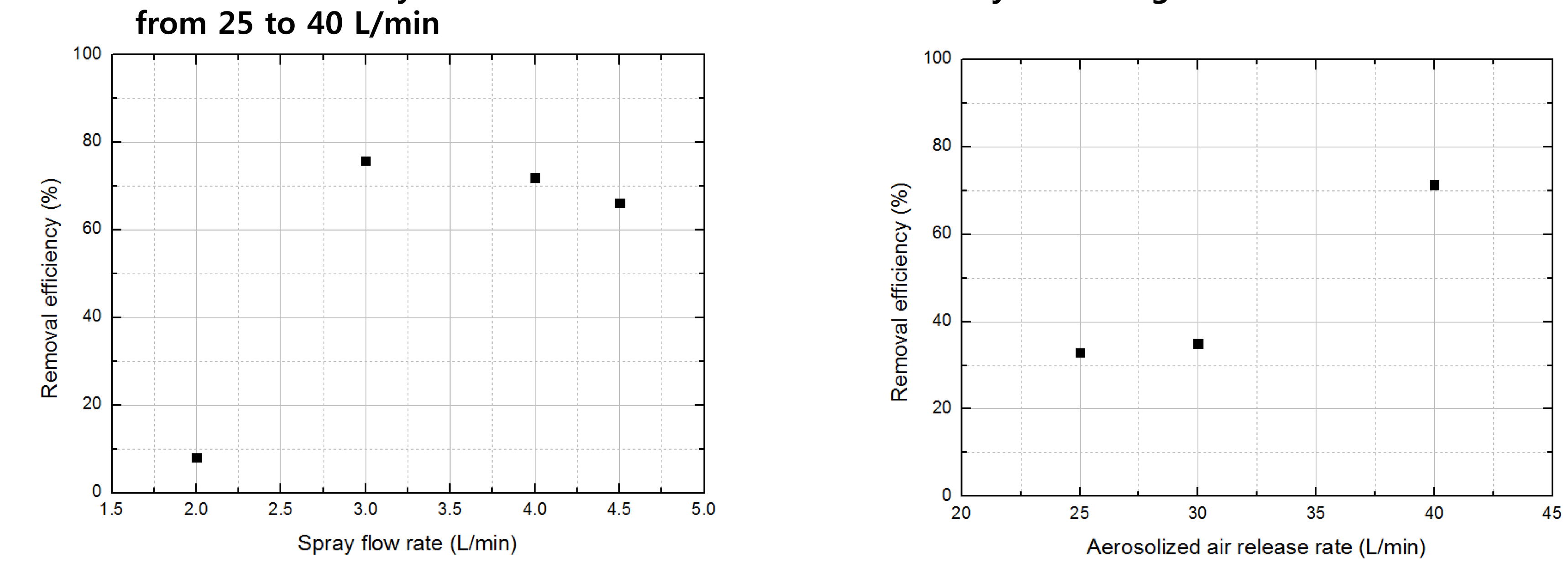


Fig. 4. Experiment in process

3. Results and Discussions

3.1 Effect of water spray flow rate and aerosol release rate on aerosol removal efficiency

- Changing the spray flow rate at 40 L/min of air flow rate
  - Removal efficiency increased from 8.1% to 75.8% by increasing the spray flow rate from 2.0 to 3.0 L/min but decreased to 66.2% by further increasing the spray flow rate (4.0 - 4.5 L/min)
- Changing the aerosol flow rate at 4 L/min of spray flow rate
  - Removal efficiency was increased from 32.9% to 71.3% by increasing the aerosol release rate from 25 to 40 L/min

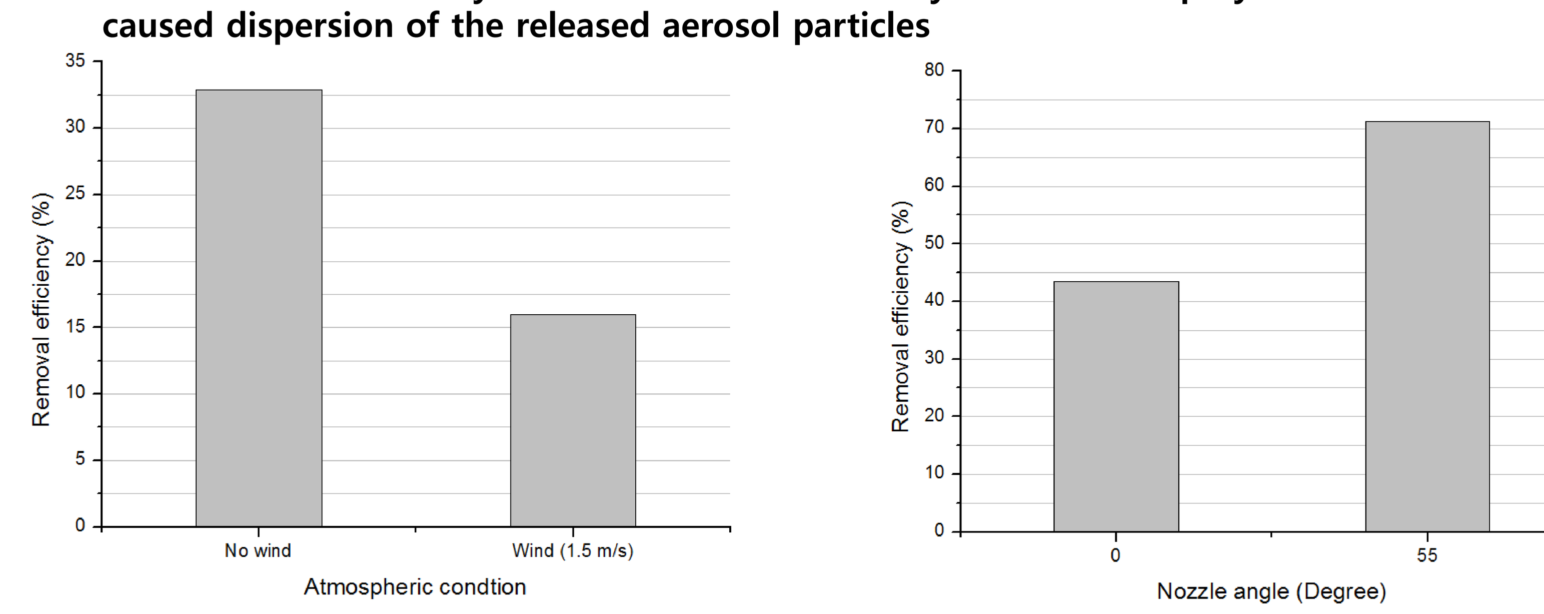


(a) Spray flow rate (b) Air flow rate

Fig. 5. Effect of spray (left) and air (right) flow rate on aerosol removal efficiency

3.2 Wind and nozzle orientation impact on aerosol removal efficiency

- Wind at 25 L/min of air flow rate and 4 L/min of spray flow rate
  - Aerosol removal efficiency was reduced from 32.9% to 16.0% in the presence of an average wind velocity of 1.5 m/sec
- Nozzle orientation at 25 L/min of air flow rate and 4 L/min of spray flow rate
  - The removal efficiency was higher when the spray cone was directed toward the breach hole
  - The removal efficiency was lower with vertically downward spray cone direction which caused dispersion of the released aerosol particles



(a) Wind (b) Nozzle orientation

Fig. 6. Effect of wind (left) and nozzle orientation (right) on aerosol removal efficiency

3.3 Comparison of aerosol particle removal efficiency by water and foam-based sprays

- Aerosolized air flow rate was 40 L/min
- The addition of the foaming agent sodium lauryl sulfate ($NaC_{12}H_{25}SO_4$) to water reduced the water's surface tension, which enhanced the efficiency of capturing TiO_2 aerosols
- Foam-based sprays may have an advantage over water-based sprays in controlling and capturing the TiO_2 particles in the air, which can minimize the volume of liquid waste

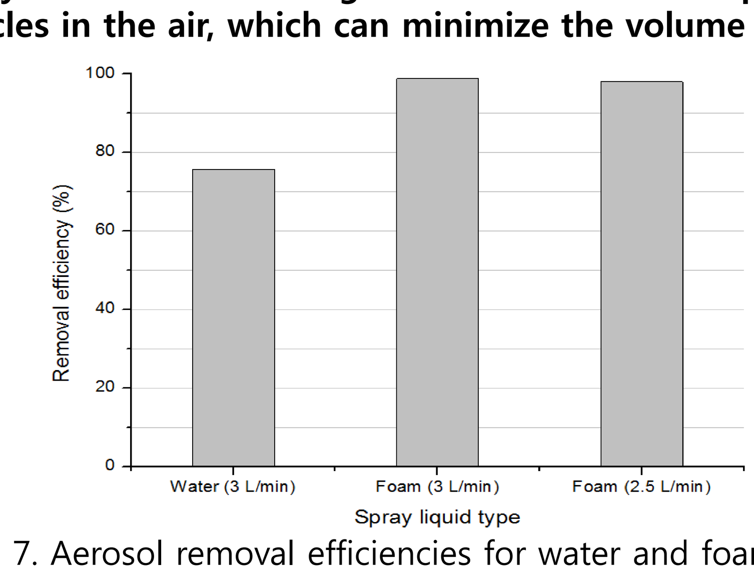


Fig. 7. Aerosol removal efficiencies for water and foam sprays

4. Conclusion

4.1 Conclusion

- The TiO_2 aerosol particle removal efficiency of foam-based spray is higher when compared with plain (city) water-based spray
- The aerosol particle removal efficiency largely depends on relative velocities between spray velocity and the velocity of aerosols released from a containment breach hole
- The nozzle with a large spray coverage area, aimed directly at the leaking containment hole, improved the aerosol removal efficiency
- Foam-based spray used less water than water-based spray, reducing the liquid waste volume
- Windy environment reduced the TiO_2 aerosol particle removal efficiency due to dispersion of both spray droplets and aerosol particles

4.2 Future work

- Spray deployments will be optimized by changing breach locations on the containment building and environmental conditions such as wind and rain
- Dimensionless numbers will be explored carefully using the Buckingham π theorem, since sprayed liquid droplets could have the same behavior when dimensionless numbers are equal
- A scaling analysis and optimization for a spray nozzle will be considered based on dimensionless numbers for actual scale
- A spray system that includes more than one spray nozzle will be designed for actual scale