# Aerial spraying to capture released radioactivity from NPP in a severe accident

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# Contents

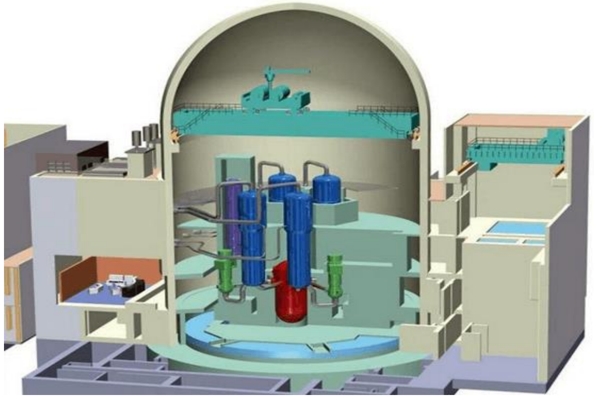
# Introduction

- **Reactor containment is the last barrier in NPP** which envelopes reactor core and prevent the release of radioactivity into the environment in a nuclear accident
- **But in a long run, this barrier can be leaked or failed** to perform its function due to over pressurization after core melt or containment bypass event can occur
  - Large amount of radioactivity can be released to the environment
  - Radioactive fallout can contaminate near by homes and cities
  - Trans-boundary impacts
  - Loss of public trust on Nuclear power
  - Serious impact on economy and energy policy

**How to meet these challenges if reactor containment leaks/fails in future ?**

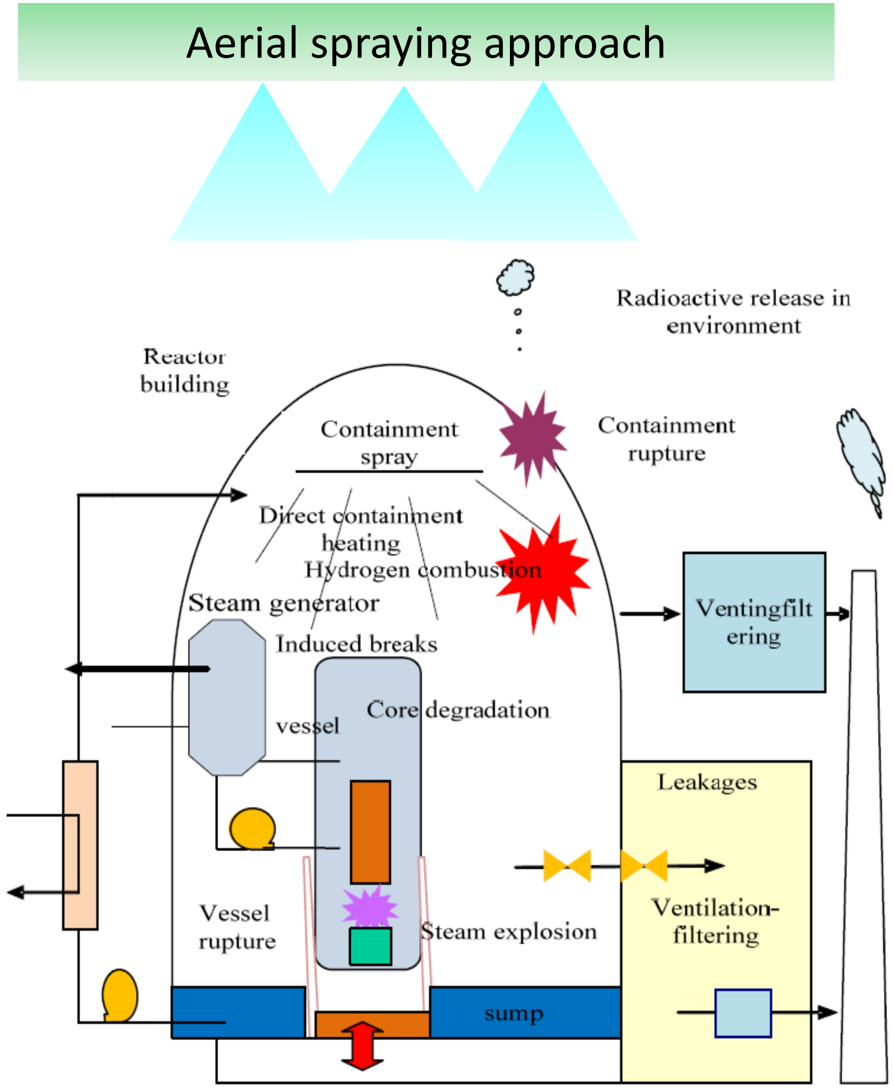
- **Currently,** no emergency response safety system available to capture the released radioactivity after containment leakage/failure
- **Therefore**, It is highly desirable to have new strategies to capture released radioactivity into the environment and to reduce the dose levels

NPP Containment




# Aerial spraying approach to capture released radioactivity

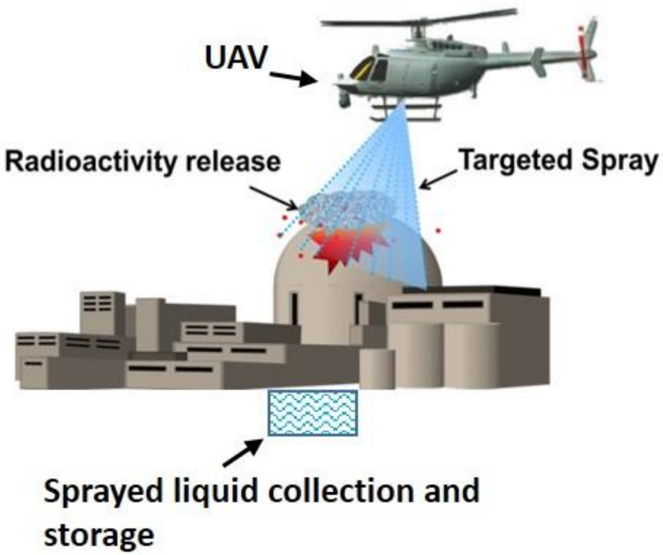
- ➢ In case of containment leakage/rupture in a severe accident
- ✓ Aerial spraying system is suggested
  - to capture the released radioactive material
  - Re-volatilization of captured radioactive material can be prevented
  - can reduce the decay heat at plant site
  - Radiation dose to the plant workers and public can be reduced
  - Public trust on NPPs can be enhanced

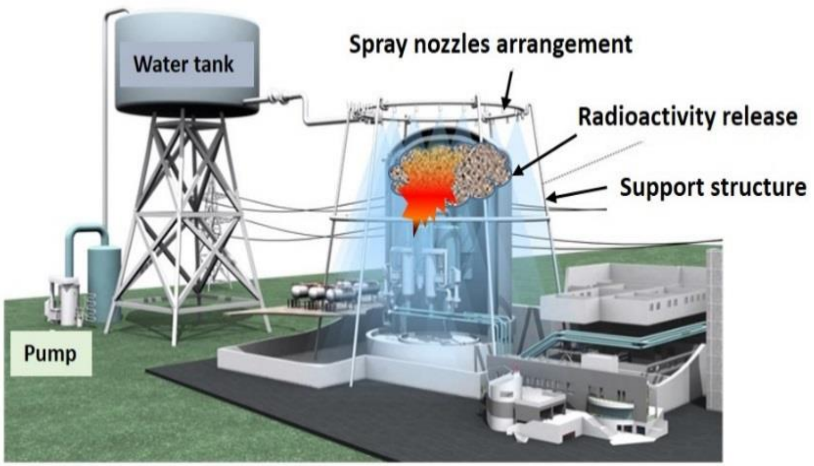


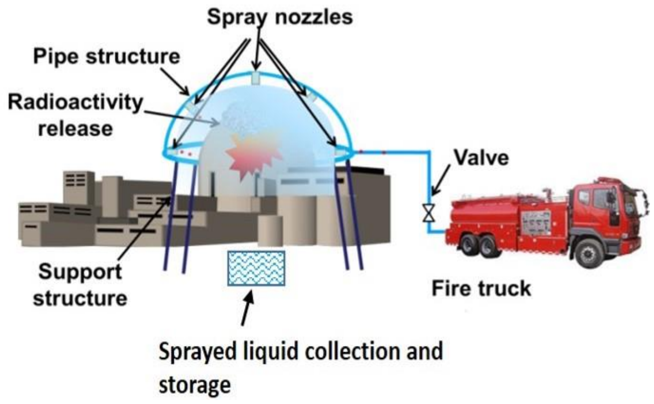
# Research objectives

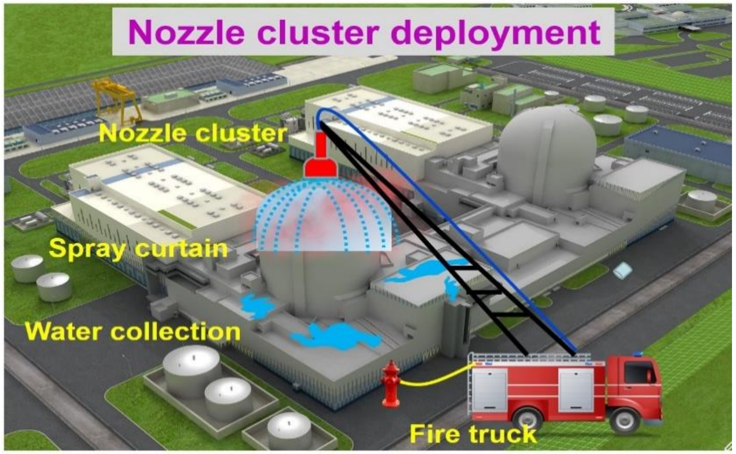
- To  examine the spray removal efficiency of gaseous iodine and aerosol particles by
  - Alkaline water
  - Foam (Sodium lauryl sulphate)
- To examine the impact of aerosol particle size on spray removal efficiency
- CFD modeling and simulations of spray removal efficiency in CFX
- To compare the experimental results with CFD simulations
- CFD simulations of spray removal efficiencies in windy conditions

# Water/foam spray deployment strategies



# Selection of gas contaminants for experiments

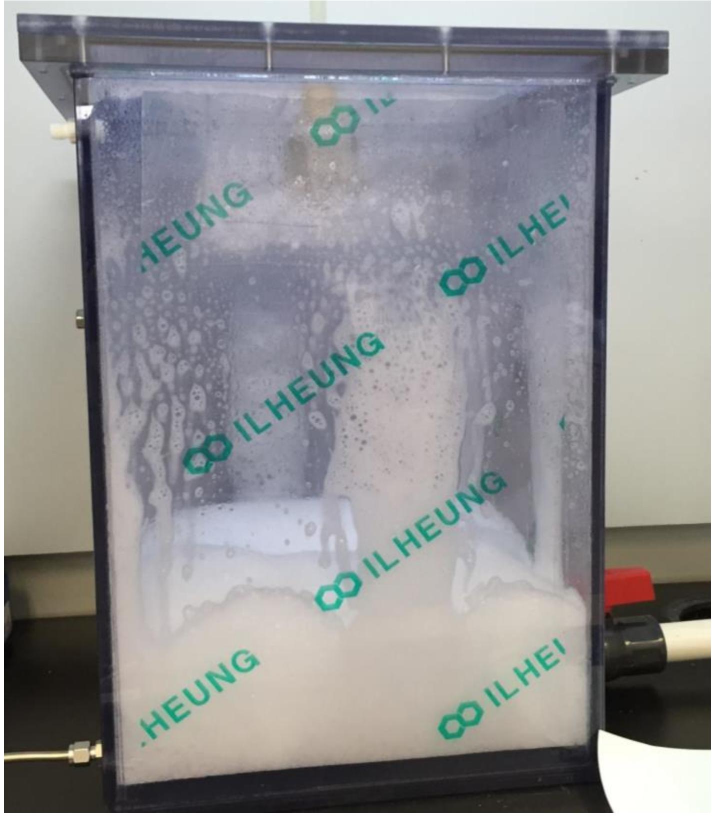
- Gaseous iodine and aerosol particles were selected as gas contaminants in experiments
  - radioiodine  and particles are considered most hazardous fission products
  - Large fractional releases from core and highly volatile
  - particles typically have a range of sizes (0.01-20 µm)
  - exhibit very dynamic physical and chemical behavior
  - significant dose contributors to the plant workers and general public through inhalation

# Spraying solutions to capture airborne contaminants

- ✓ Alkaline Water ($NaOH.Na_2S_2O_3$)
  - pH ~ 13
  - Highly reactive and converts iodine into stable and non-volatile species ($NaI^-$)

**$10NaOH\ (aq) + Na_2S_2O_3 + 4I_2 \rightarrow 8NaI + 2Na_2SO_4 + 5H_2O$**

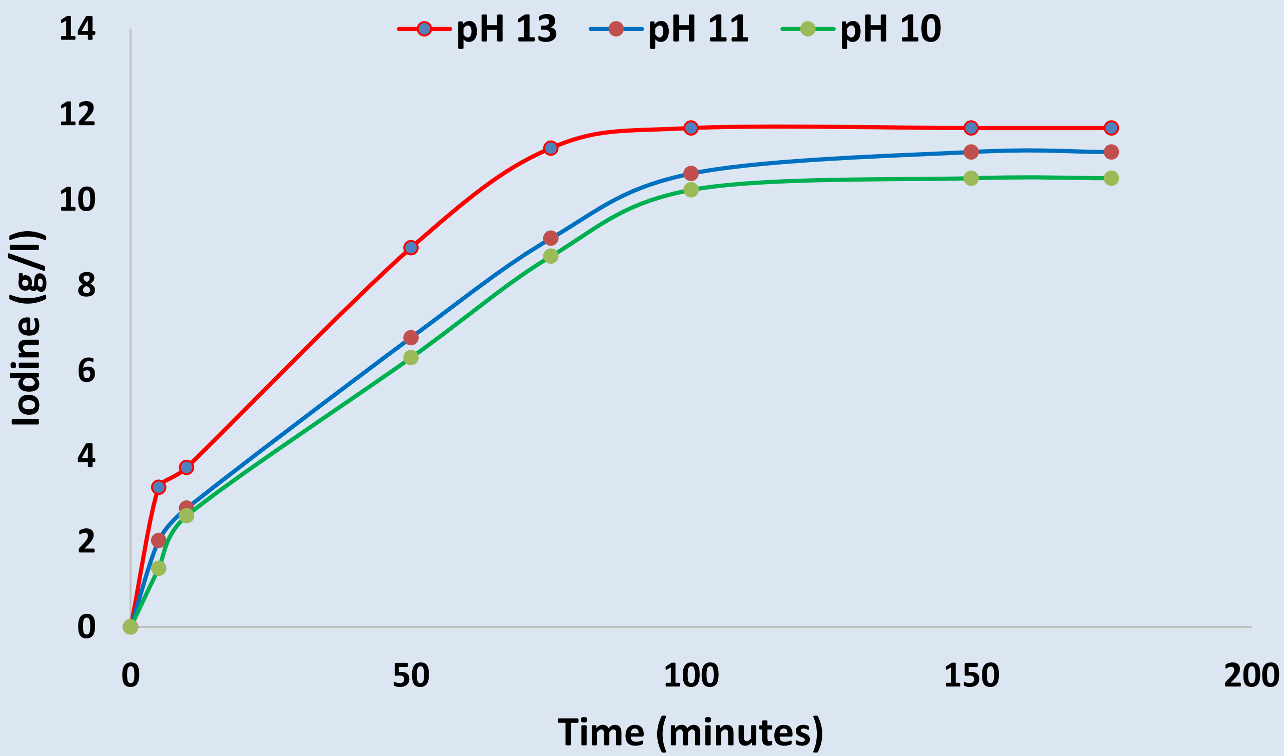
- ✓ Aqueous Foam (Sodium lauryl sulpahte)
  - Aqueous foam is highly expandable after releasing from nozzle
  - Capable of rapid covering of leaked area
  - Enhances the capturing ability of water by reducing the surface tension
  - Minimizes the water consumption and secondary waste
  - Adding reactive chemicals ($NaOH.Na_2S_2O_3$) in foam reduce the volatility of captured radioactive contaminants
  - Adding foam thickening agents e.g. gelatin can immobilize the foam
    - easily and safely removable



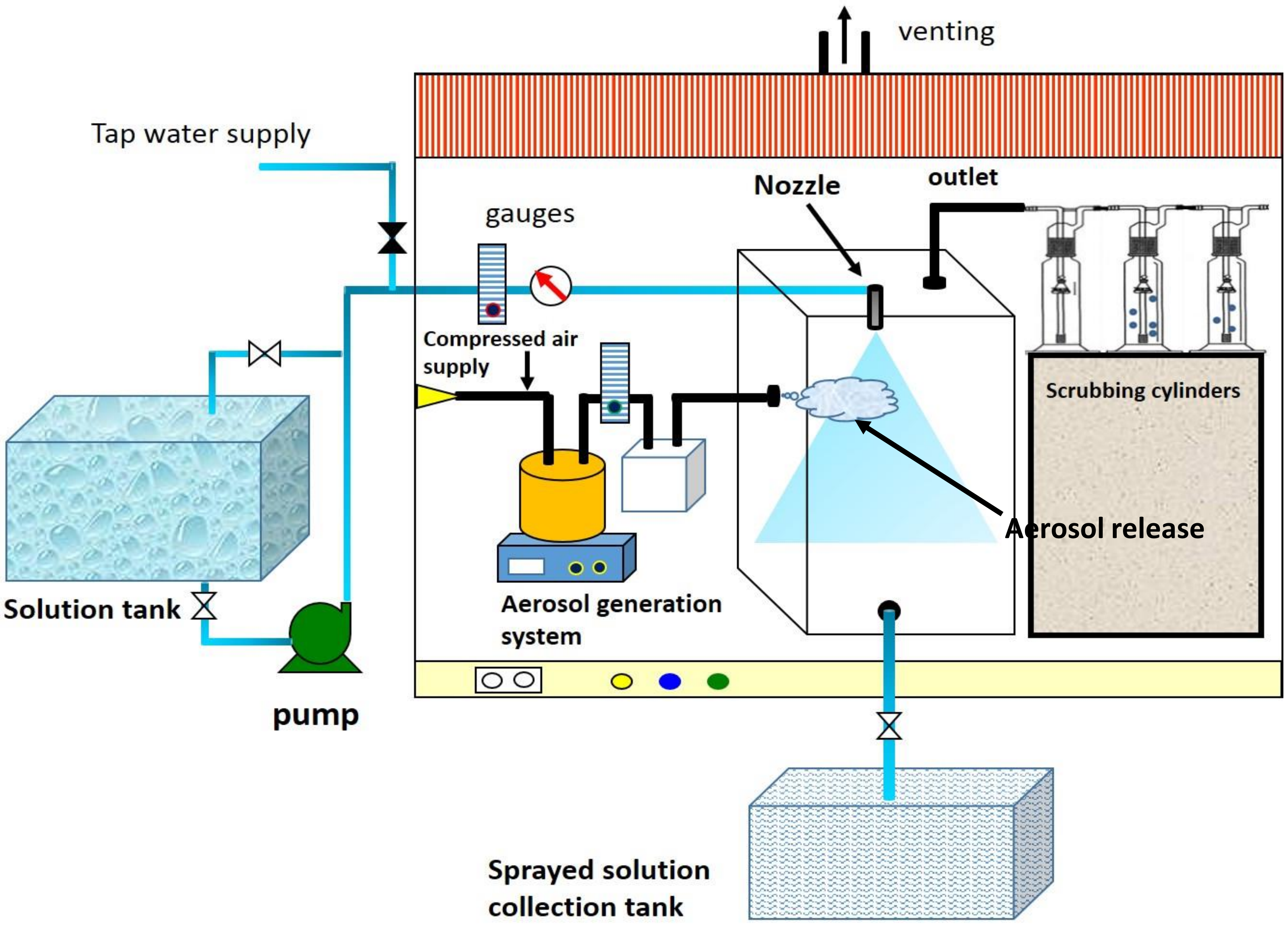

**Foam spray demonstration**

**3 % Sodium lauryl sulfate ($NaC_{12}H_{25}SO_4$)**

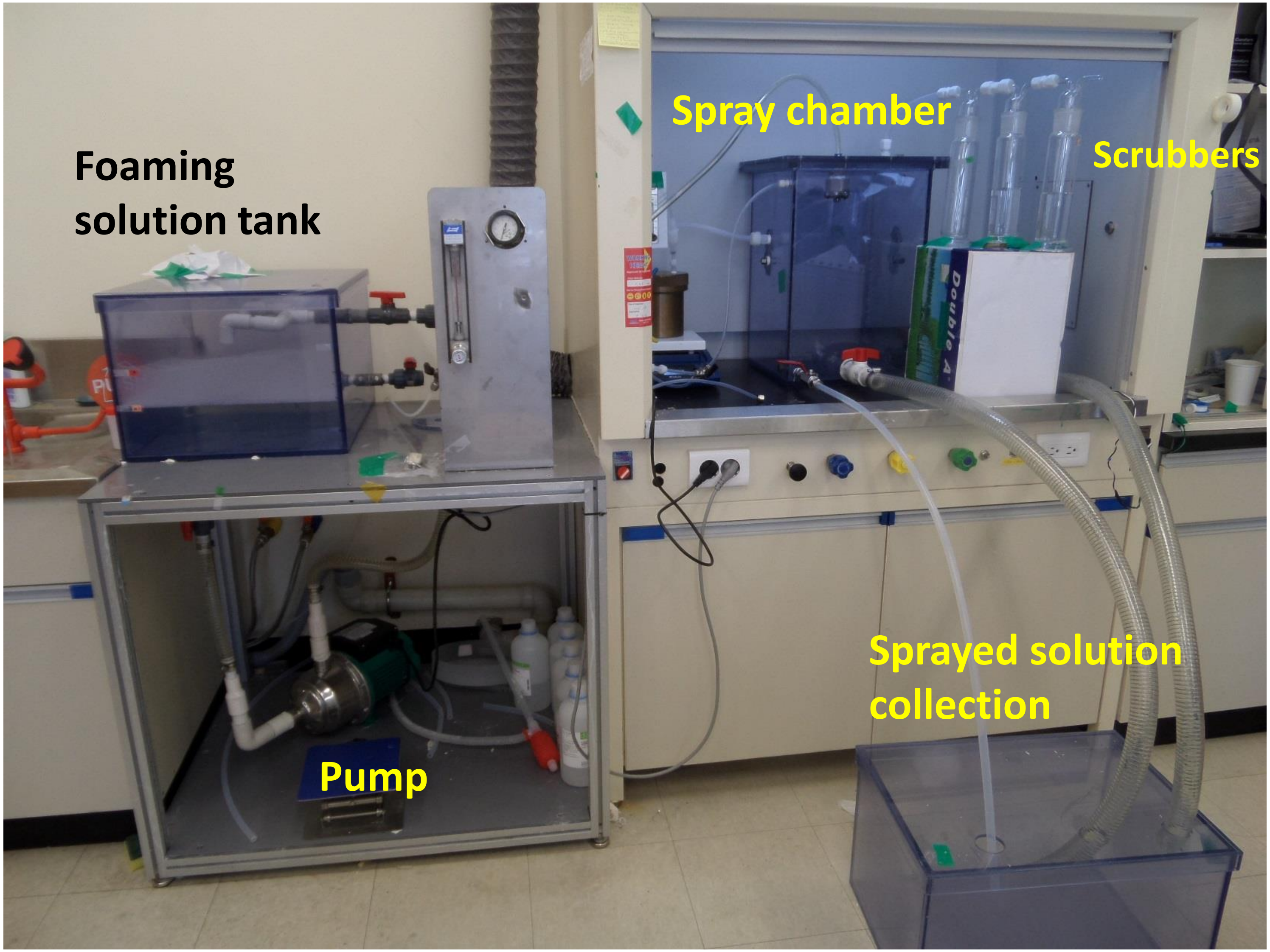
# Reaction rate of iodine in spray solution of different pH to form $NaI^-$



# Experimental setup for capturing gas contaminants by spray



# Whole experimental arrangement

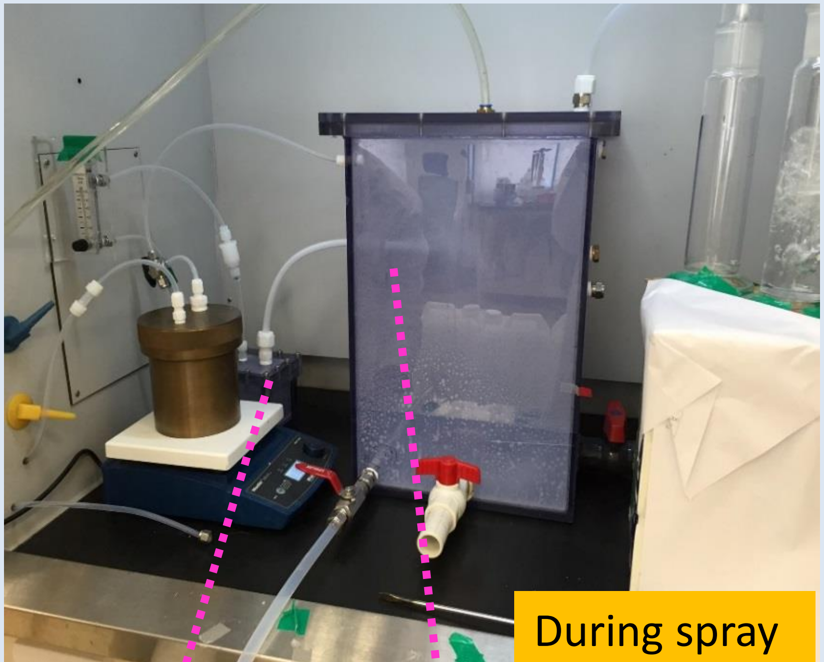


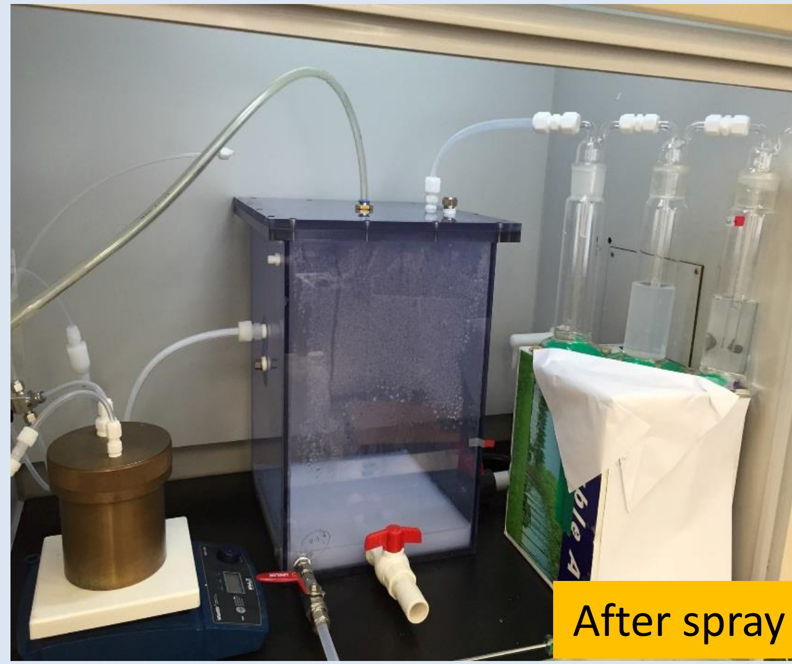
# Foaming solution preparation

- **Foaming agent (Sodium lauryl sulphate) mixing in water**



# Aerosol particles capturing experiments



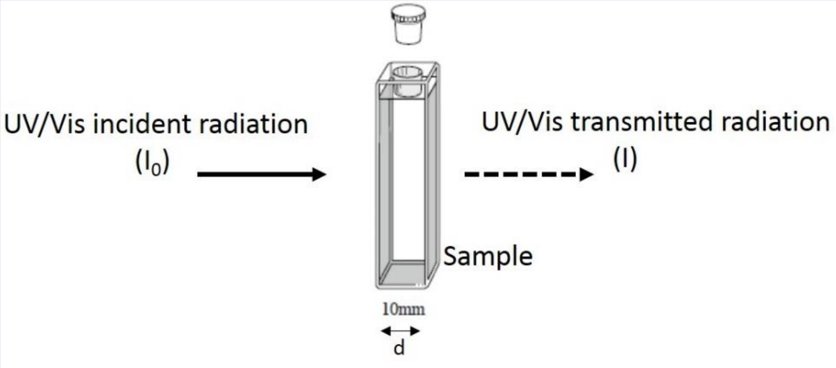

Aerosol box

Aerosol release

**Particles used in our experiments**

- **$TiO_2$ (0.02, 0.15 and 5 μm sizes)**
- **Non-radioactive**
- **Highly dispersive in the air**
- **Human respirable size**

# Iodine and particles measurement in spray solution by UV-Vis Spectrometer



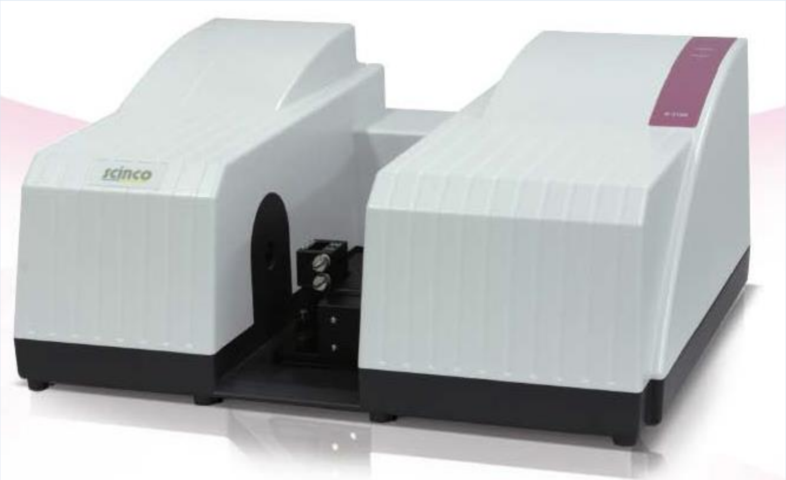

**$A = \varepsilon \times C$**

A = absorbance

Ɛ = absorption coefficient ($dm^3 mol^{-1} cm^{-1}$)

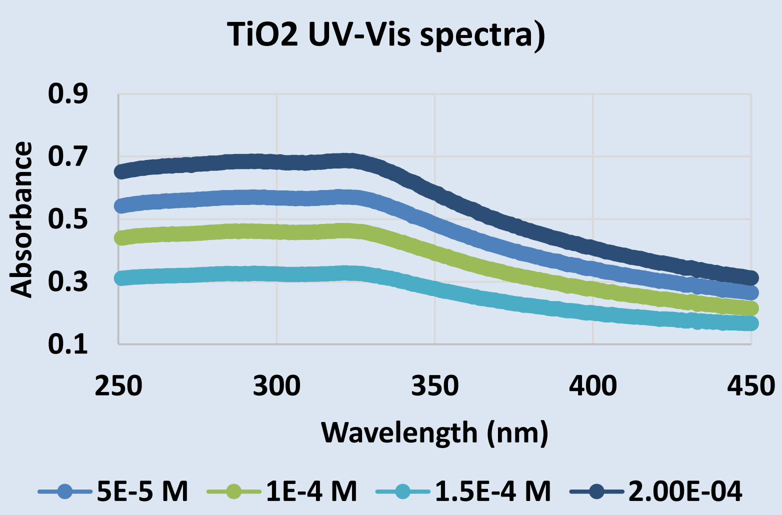
X = path length of sample (cm)

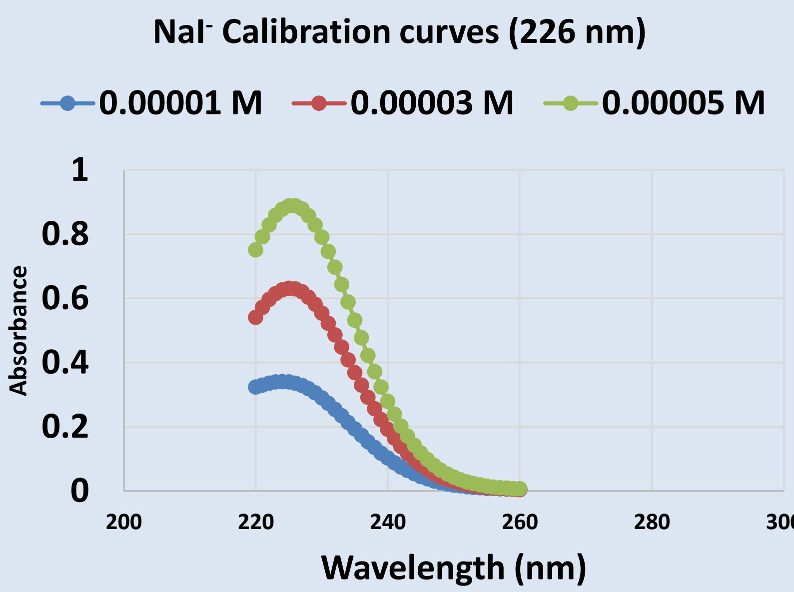
C = concentration (M)

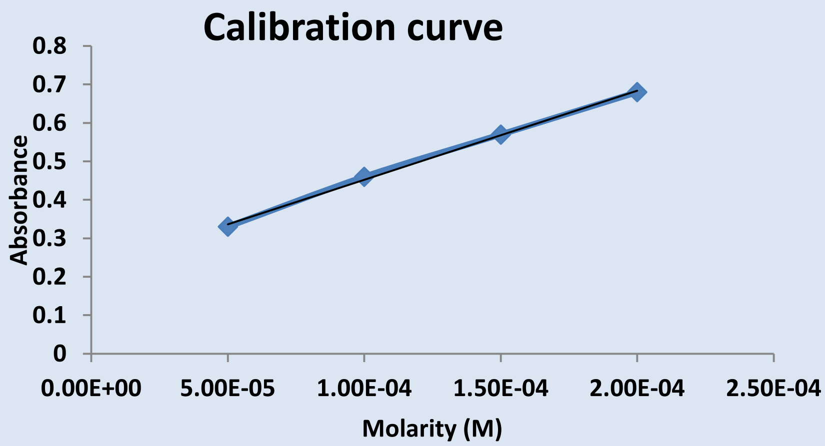


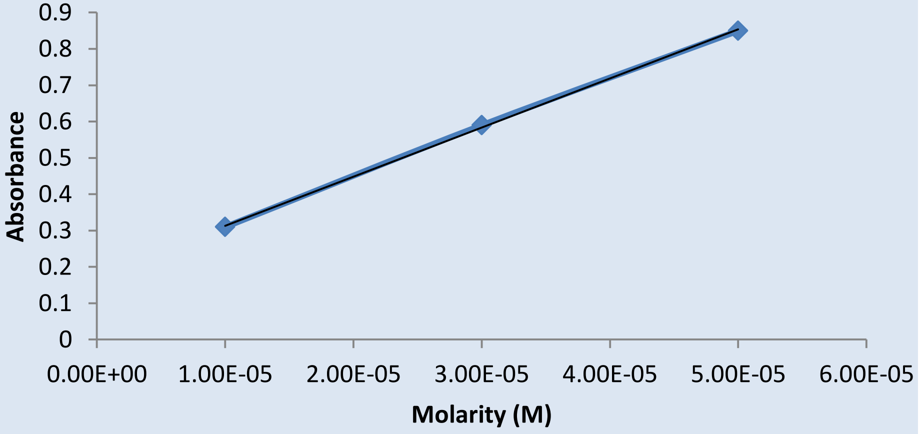

S-3100 UV-Visible spectrometer
Wavelength range (190-1100 nm)

# Calibration curves of UV-Vis Spectrometer



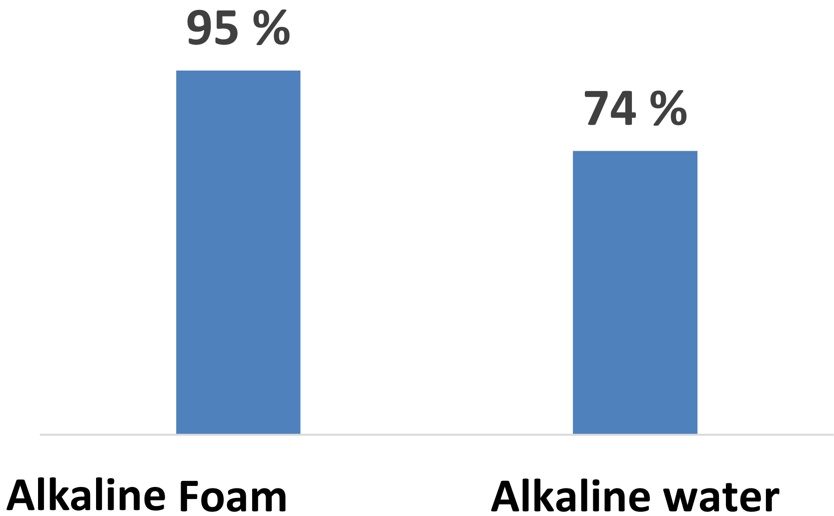



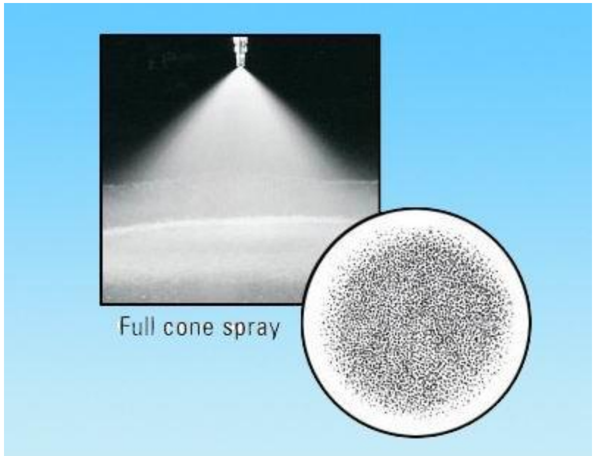



# Iodine removal efficiencies by foam and water

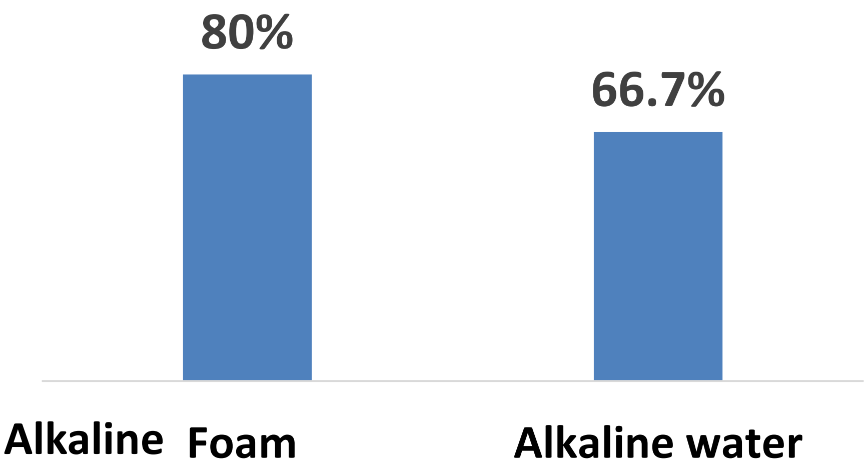
(Full cone spray pattern)



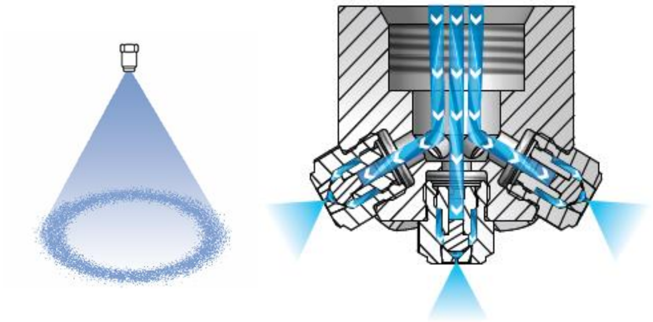

Full cone nozzle



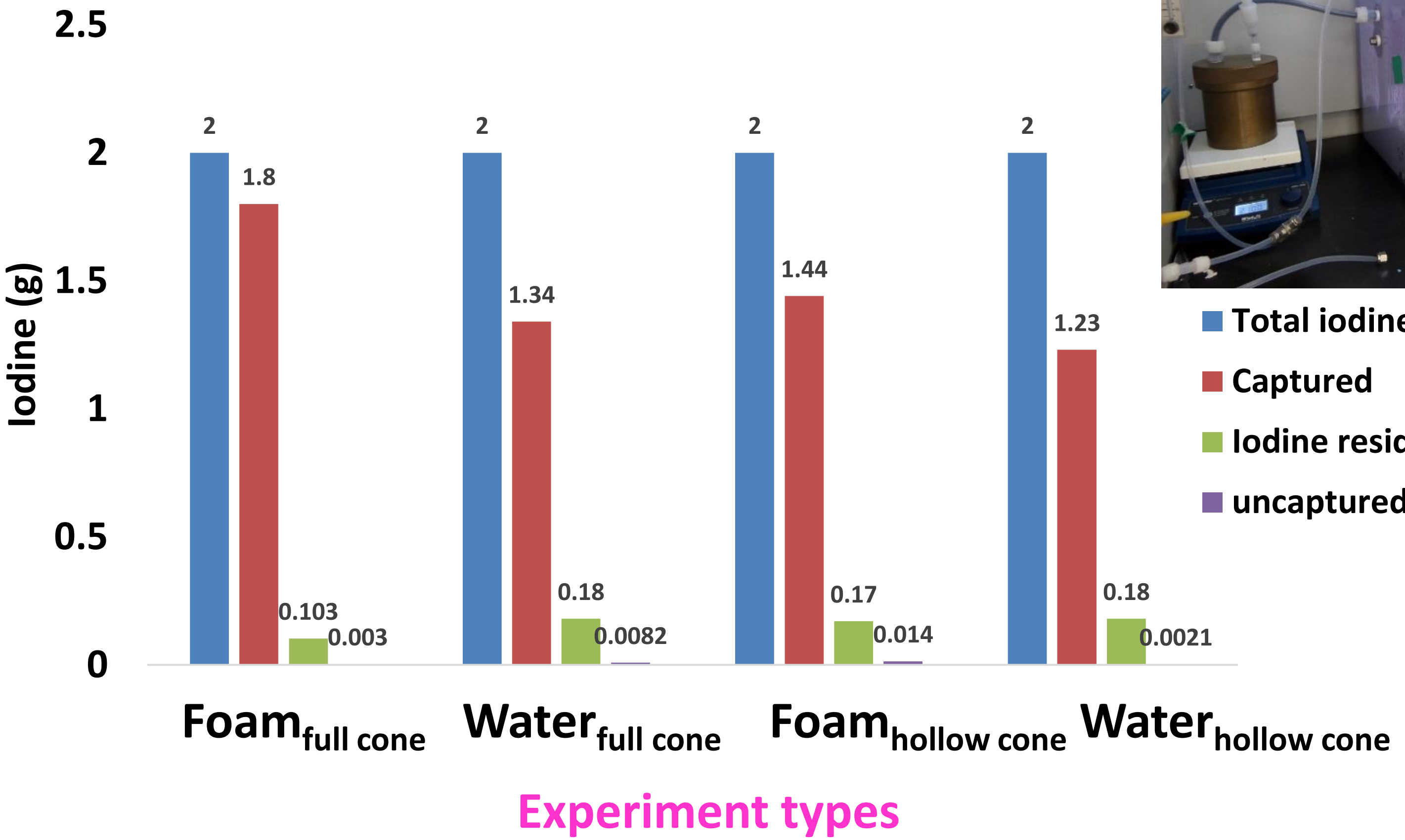

(Hollow cone spray pattern)

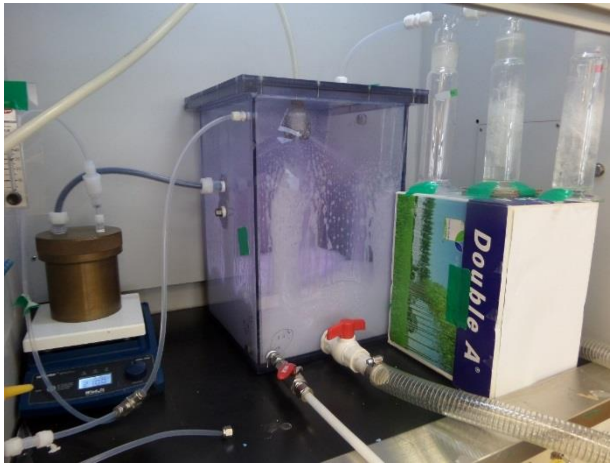



Hollow cone spray

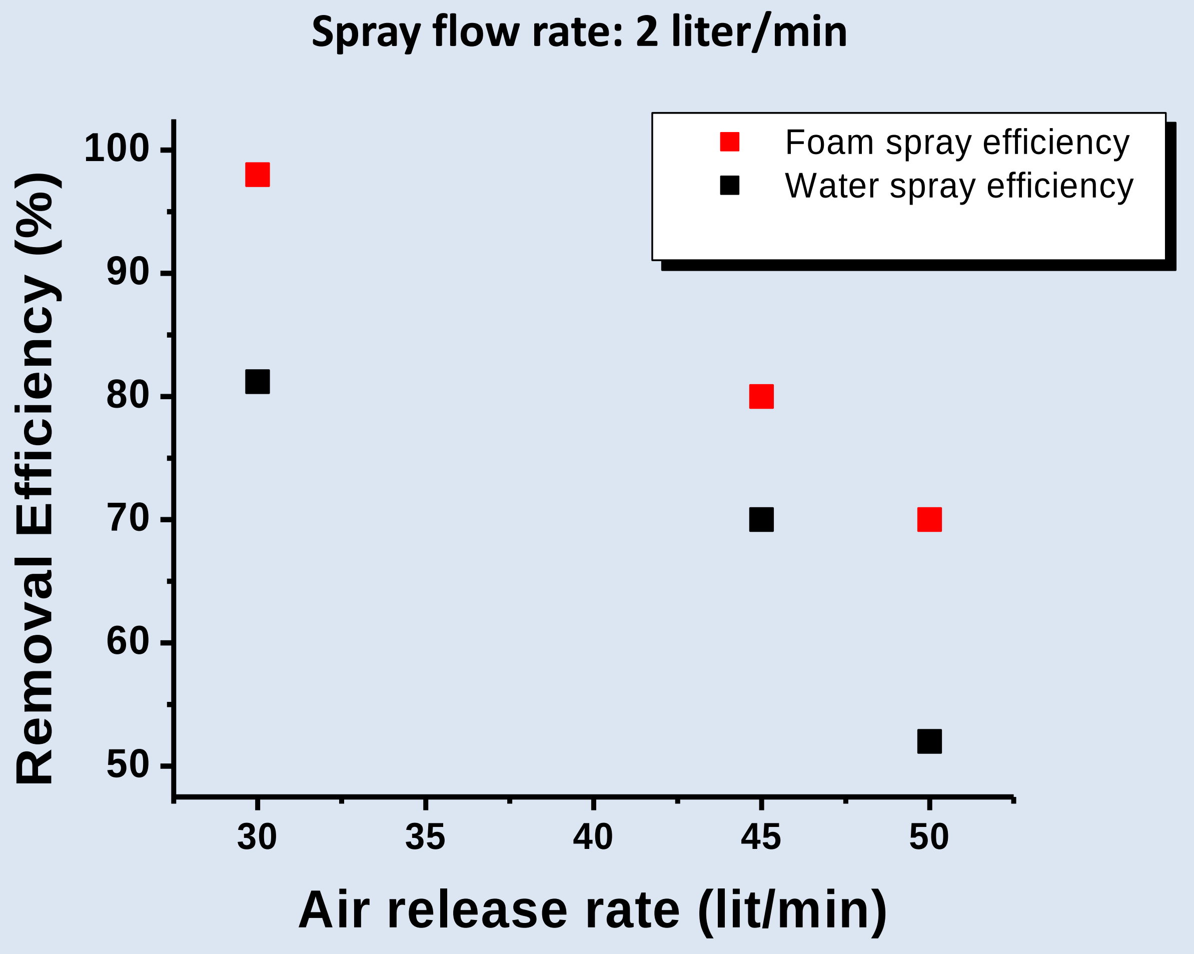


# Iodine mass balance in experiments



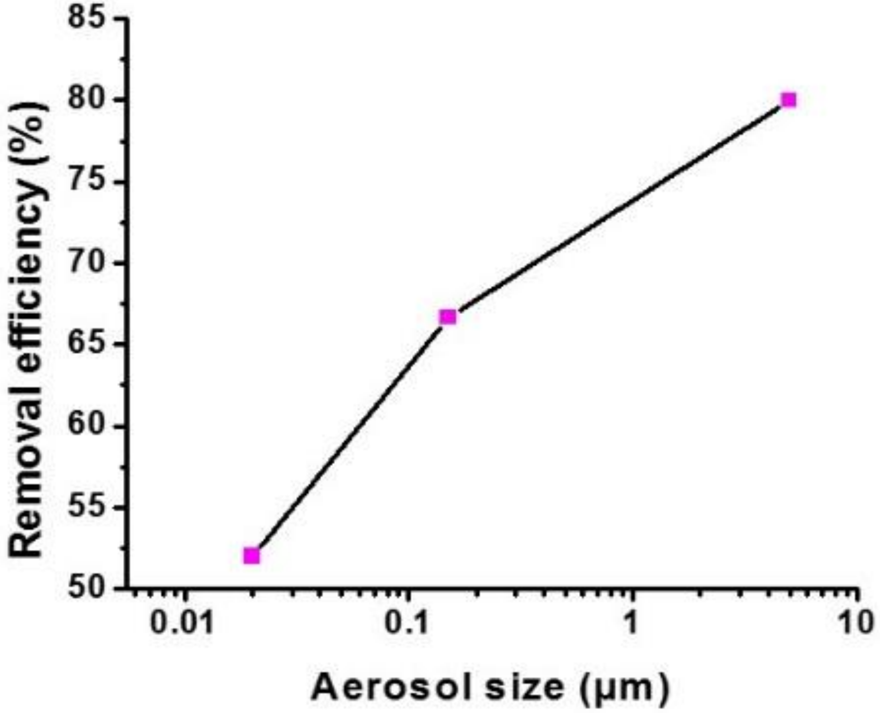



# Experimental results of capturing aerosols by foam and water sprays



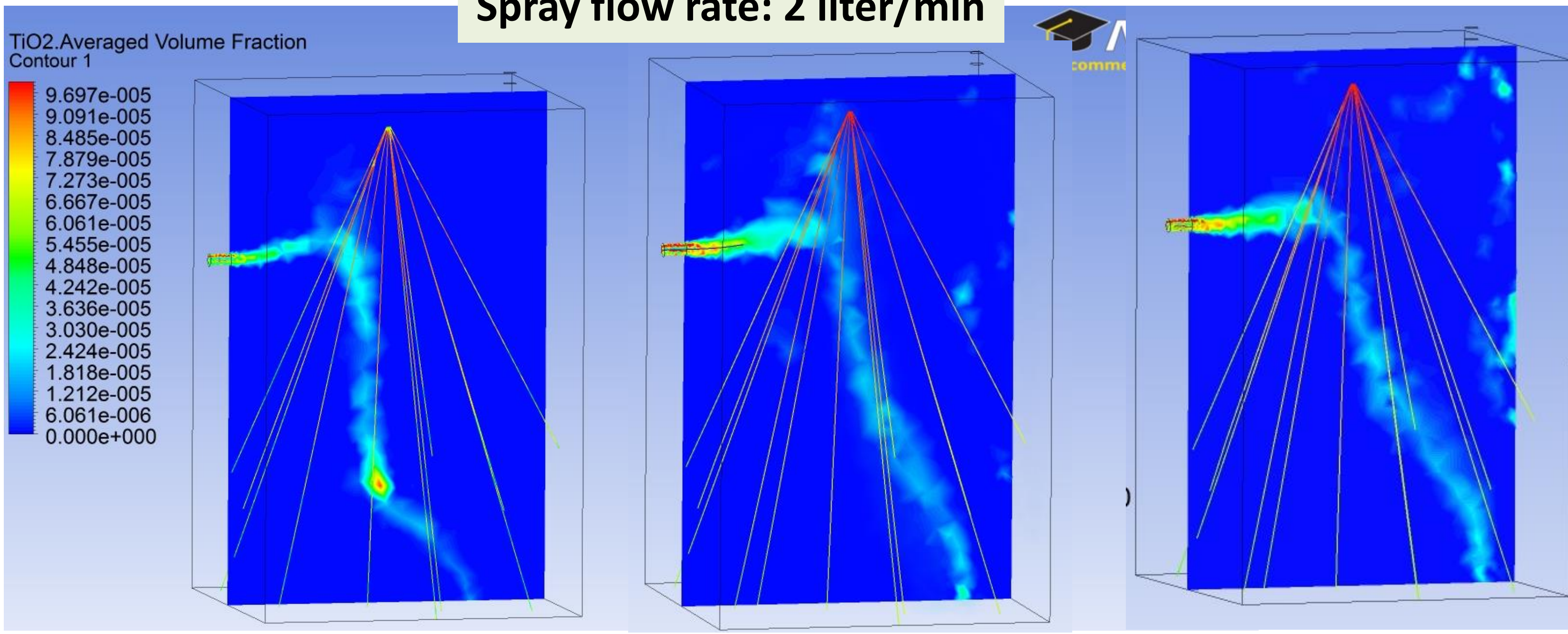
# Effect of aerosol size on spray removal efficiency

**Spray flow rate: 2 liter/min**



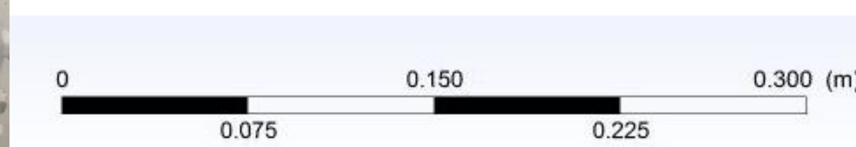
# CFD simulations of aerosols capturing in spray chamber

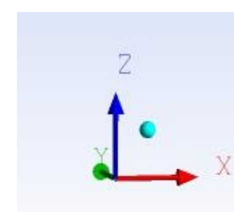
**Spray flow rate: 2 liter/min**




30 lit/min　　45 lit/min　　50 lit/min

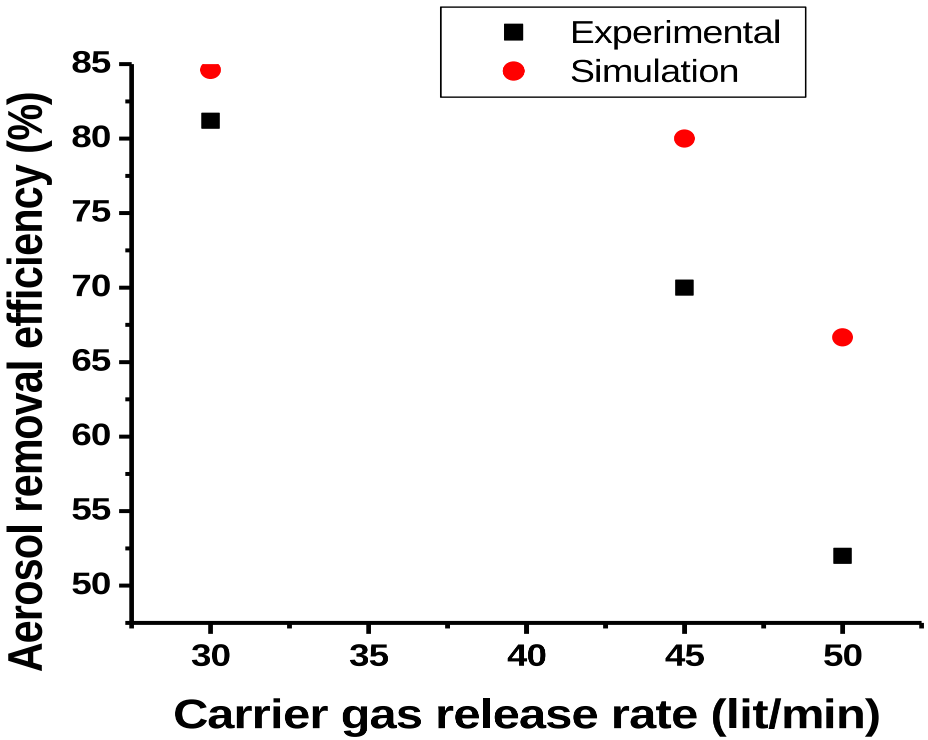
**Aerosol release rates**



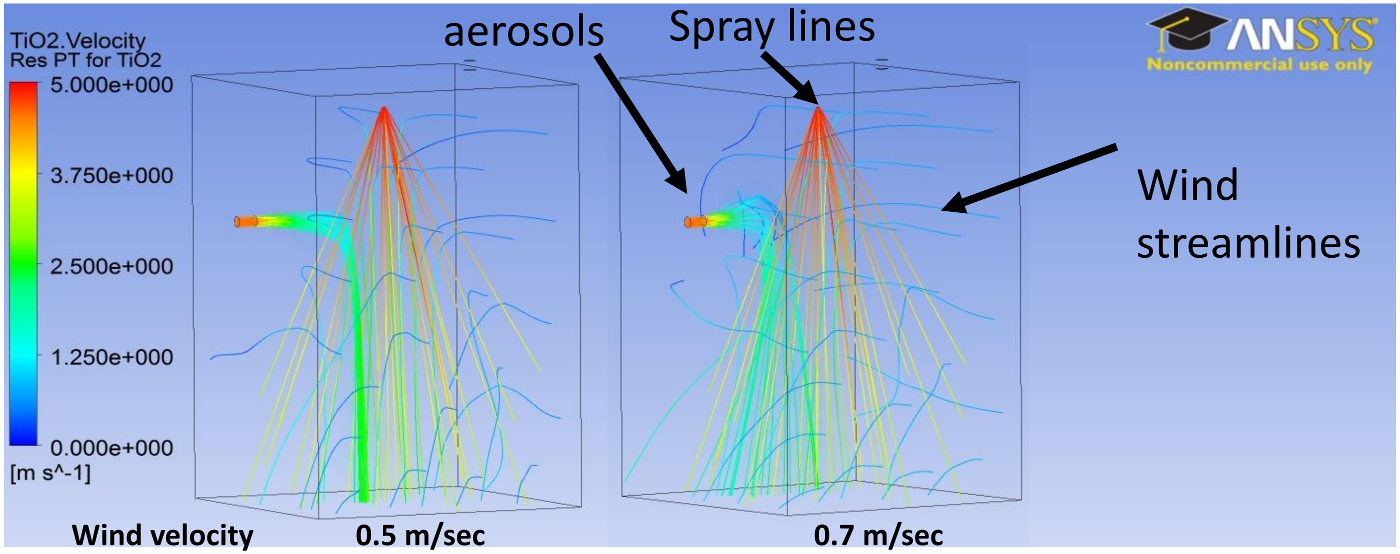
# Comparison of simulations and experimental results

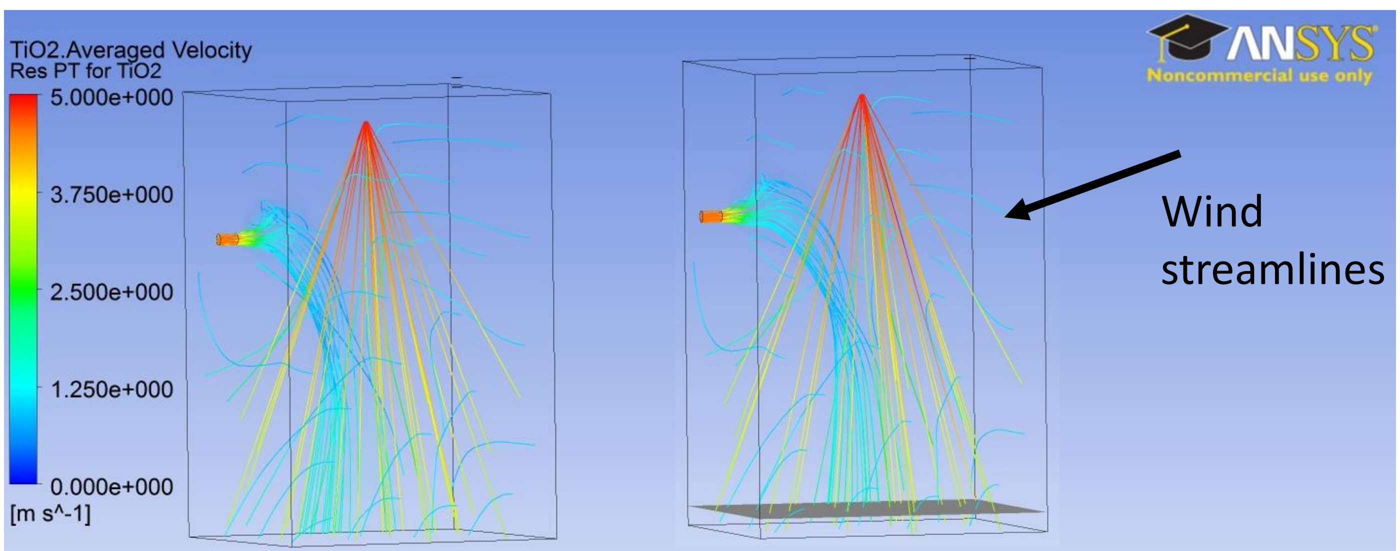
Spray flow rate: 2 liter/min



# Wind impact on aerosol removal efficiency

Spray flow rate: 2 liter/min, Aerosol release rate: 30 lit/min

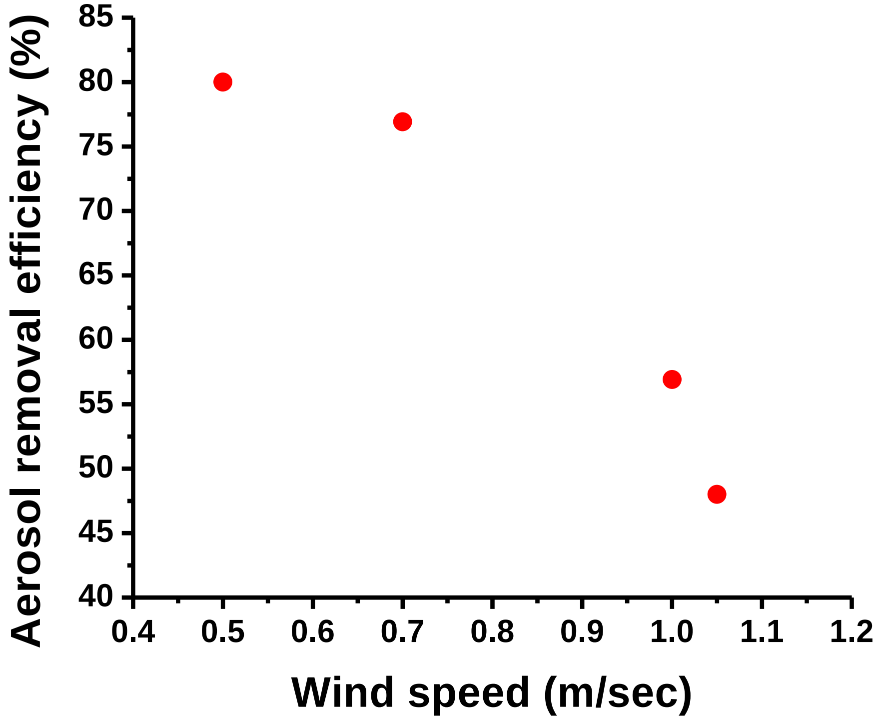



**Wind velocity** **1 m/sec** **1.05 m/sec**

# Wind impact on aerosol removal efficiency

Spray flow rate: 2 liter/min, Aerosol release rate: 30 lit/min



# Future Work

- Development of large scale experimental setup (scaled down NPP model)
- Demonstration of aerosol release phenomena through leak points
- Impact of distance between nozzle and release point and nozzle angle
- The impact of environmental conditions (e.g. wind) on the spray efficiency
- CFD simulations along with model validations
- Field experiments in collaboration with fire station

# Conclusions

- Sprays can effectively capture the gases/aerosol particles
- Foam-based spray system have high removal efficiency of aerosols as compared to water-based spray system
- Full cone nozzles are more effective in removing gas contaminants
- Spray have better removal efficiency for large sized particles
- Foam-based spray can be helpful in liquid waste minimization
- Radiation dose levels outside the containment can be minimized significantly after deployment of  spray system

# References

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# Thank you !