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MODELLING OF BASIC PHENOMENA OF AEROSOL AND FISSION PRODUCT BEHAVIOR IN LWR CONTAINMENTS WITH ANSYS CFX

global research for safety

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Introduction

Situation:

- In the case of an severe accident radioactive fission products are released from the reactor core into the reactor containment (Iodine, Cesium, Xenon,…)
- Their distribution within the containment has impact on:
  - Local heat release due to their decay heat
  - Radioactive source term within containment and environment

Previous Analyses:

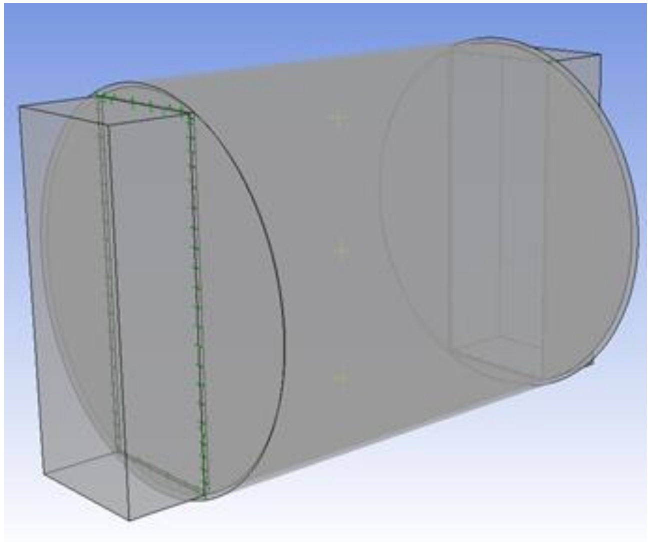
- Validations of CFD models for gas distribution, turbulence, condensation ….

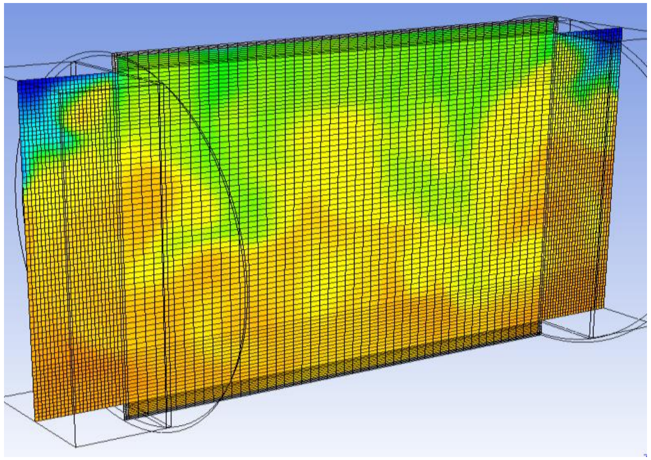
Aims:

- Evaluation of CFD models for the simulation of the basic fission product behavior in a reactor containment – aerosols and noble gases
- Two different models were tested for the simulation of aerosol transport and deposition: Algebraic Slip Model and Lagrangian Particle Tracking
- Different experiments and test cases were simulated to test the CFD models for aerosol deposition, transport, agglomeration and for radioactive noble gases

Aerosol deposition: KAEVER experiment

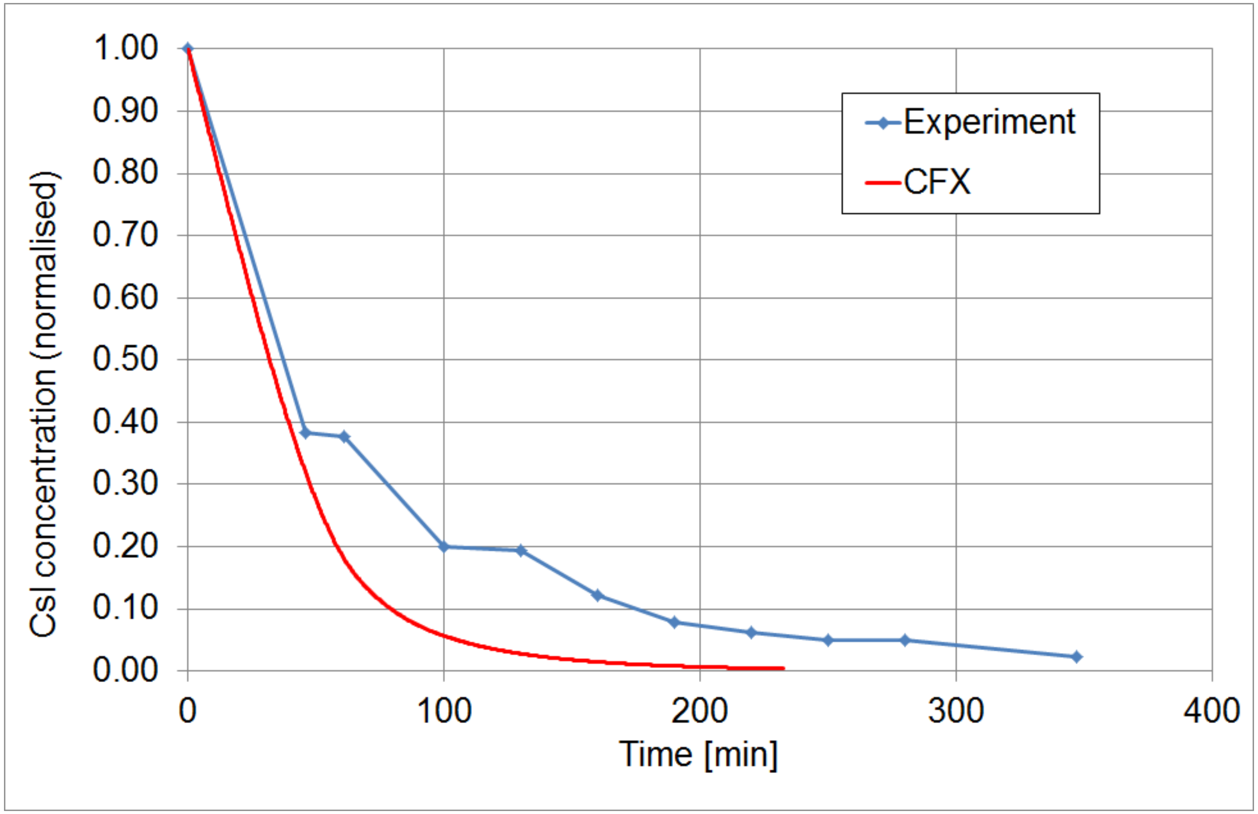
- **Aim: Study of aerosol deposition**
- **KAEVER facility:** Length 3.5 m, diameter 2 m
- CsI aerosol was injected into dry atmosphere
- Airborne CsI concentration was measured over time
- Aerosol concentration decreased slowly due to settling and deposition
- **CFD simulation:**
- ANSYS CFX 15.0
- Mesh: 275 000 elements
- Turbulence model: SST





Aerosol deposition: KAEVER results

- Algebraic slip model: Aerosol particles are modeled as a dispersed phase with an additional slip velocity (ρ_p - particle density, d - particle diameter, g - gravitation constant, η - viscosity of the air): $V_{TS} = \frac{\rho_p d^2 g}{18\eta}$
- CFX results are similar to experimental data
- Decrease of CsI concentration seems to be faster than in the experiment
- There are some experi-mental uncertainties (particle density / dia-meter, not complete quiet atmosphere,…)
- CFX results are in general satisfying



Aerosol transport: Particle spectrometer

Particles settle down with their settling velocity, but they are also taken away by a horizontal air flow

- Simulated example with two different methods:

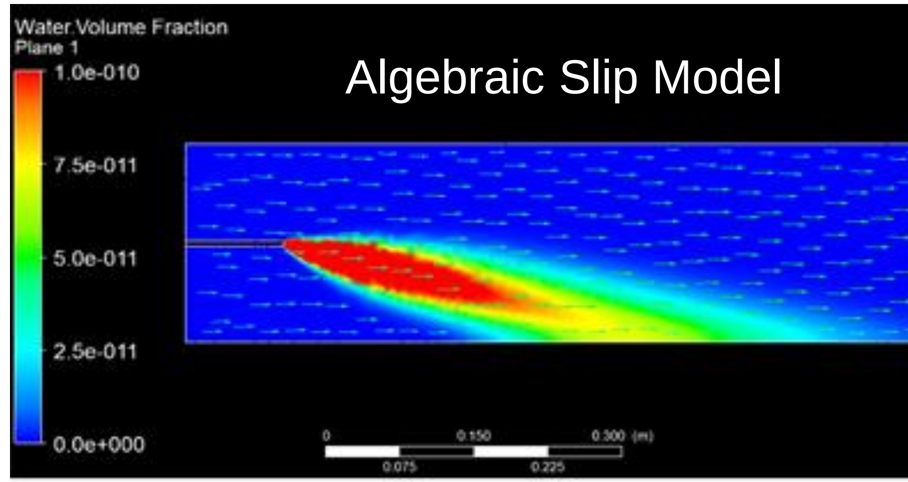
Algebraic slip model (ASM):

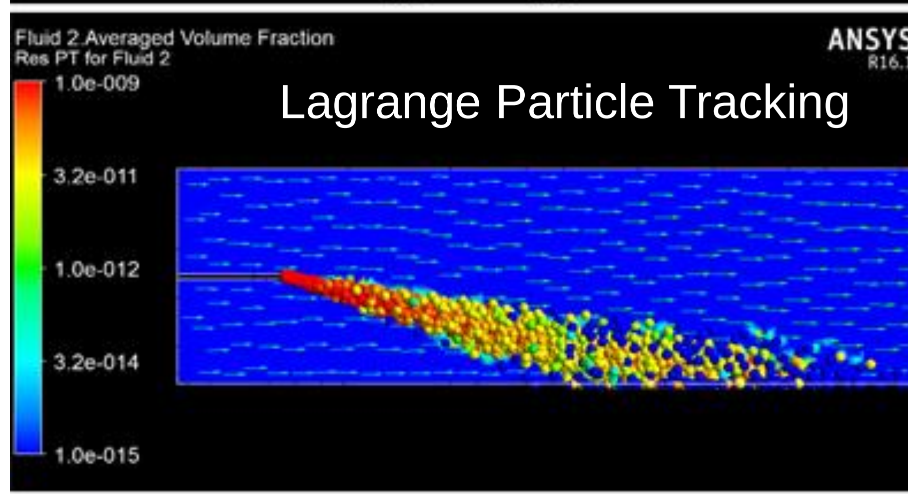
- Particles represented by a new component with additional slip velocity
- Particles are not discrete (Euler model)
- Good suited for simulations with high particle load

Lagrange particle tracking (LPT):

- Particles represented by a new phase
- Particles are discrete (Euler-Lagrange model)
- Good suited for simulations with low particle load

Both results are in good agreement with theoretical values

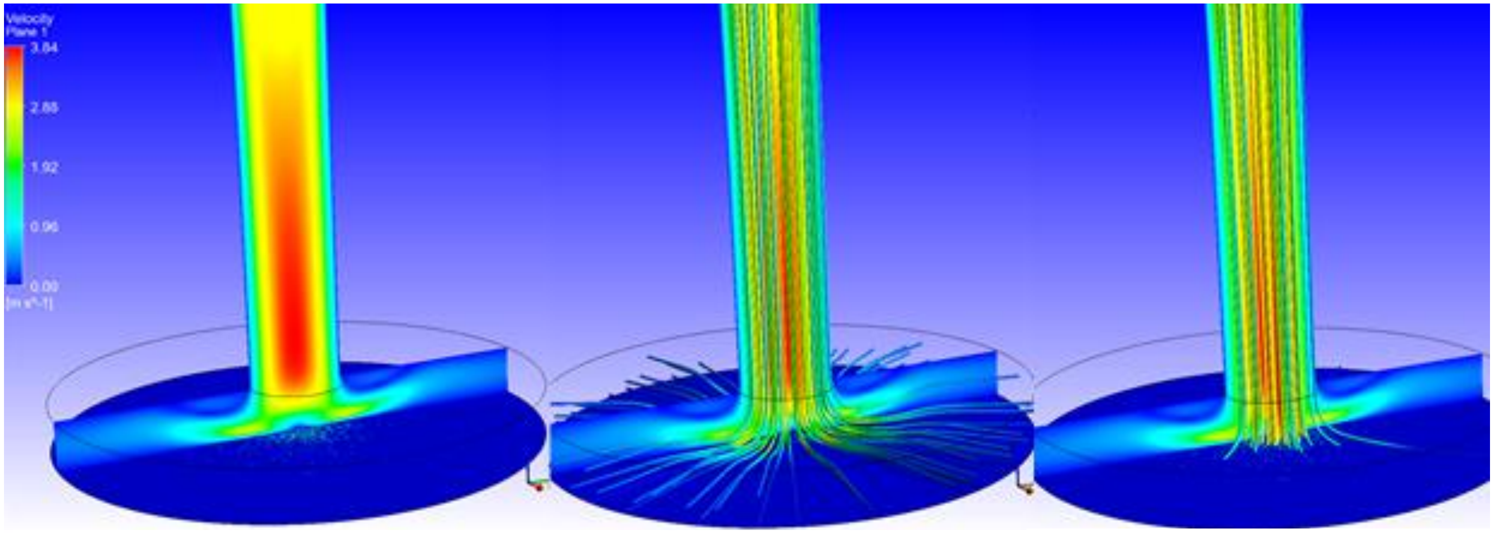




Aerosol transport: Impactor

Impactors are used for experimental determination of particle sizes

- A particle-laden gas jet is deflected around 90° by the impactor geometry
- Small particles could follow the deflection but bigger particles have a higher inertia
- They collide and stick to the lower impaction plate
- CFX: Impactor was simulated with Algebraic slip model and Lagrange Particle Tracking
- CFD mesh: 4 000 000 elements
- Turbulence model: SST



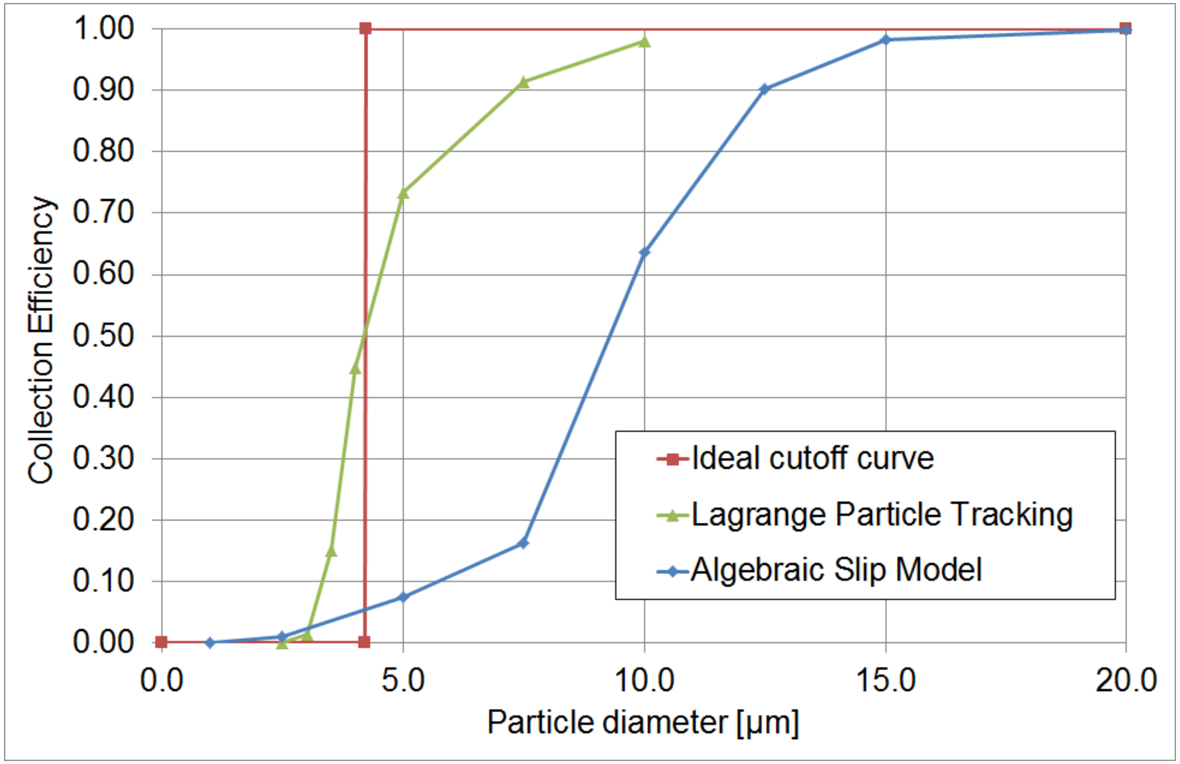
Velocity field (w/o aerosols) | Particle diameter 3.5 µm | Particle diameter 10 µm

Aerosol transport: Impactor - simulation results

- Collection efficiency:
  Ratio of particles sticking to plate / all entering particles

- Results of the Lagrange particle tracking fits better to theoretical values than results with Algebraic slip model

➢ Lagrange particle tracking is more suitable to simulate inertia forces

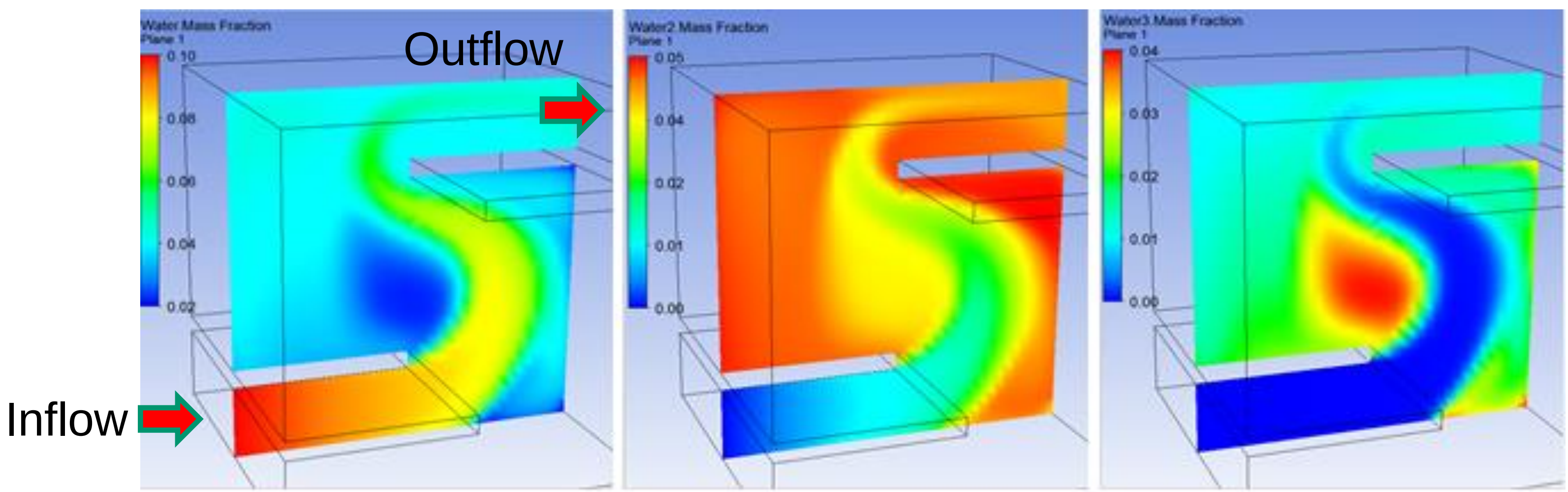


Aerosol agglomeration

Two colliding particles could agglomerate to one bigger particle

- Example Brownian agglomeration: Agglomeration rate depends on local particle density (N - particle concentration, K_0 - agglomeration coefficient): $\frac{dN}{dt} = -K_0 N^2$
- In CFX agglomeration could be modeled as a transition of particles into bigger size classes

➢ Agglomeration was tested successfully in a test case geometry

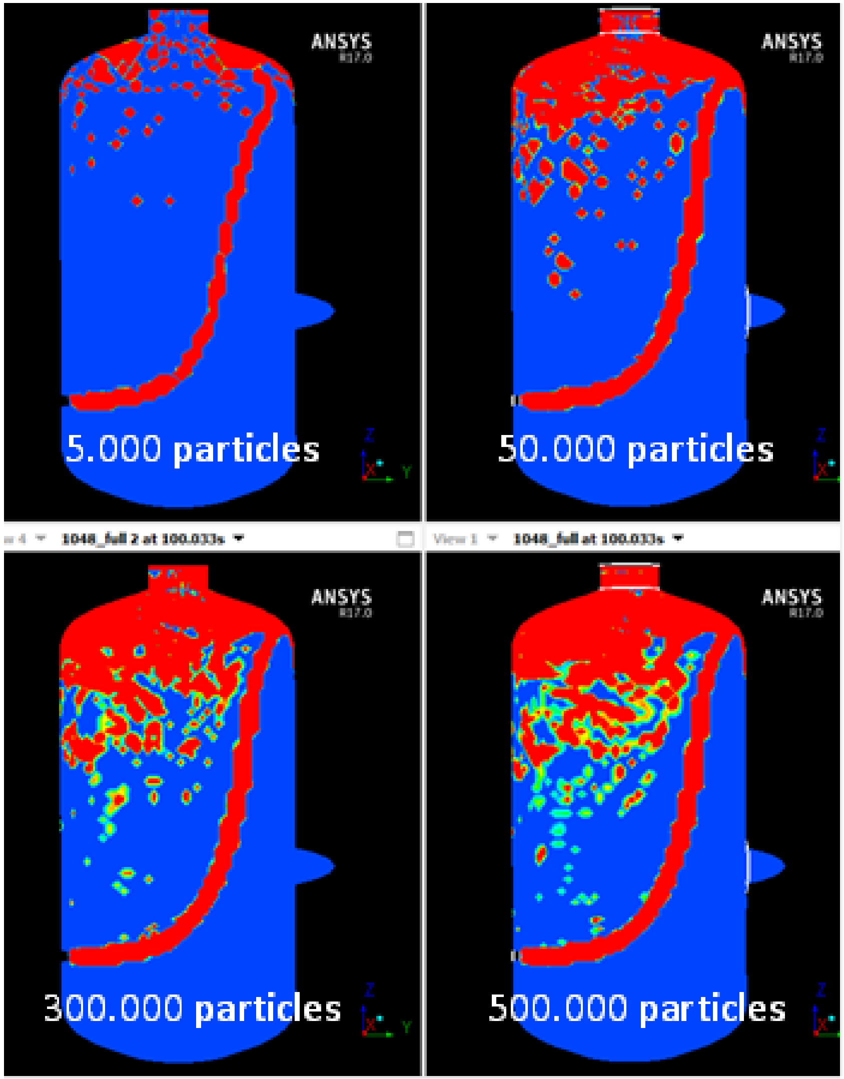


1.00 micron | 1.26 micron | 1.59 micron

Particle statistics (Lagrange Particle Tracking)

How big must an adequate (particle) sample be?

- Different numbers of CsI particles were injected together with an air jet into a test geometry
- The total mass flow of CsI is the same for all cases; only the number of representative particles was varied

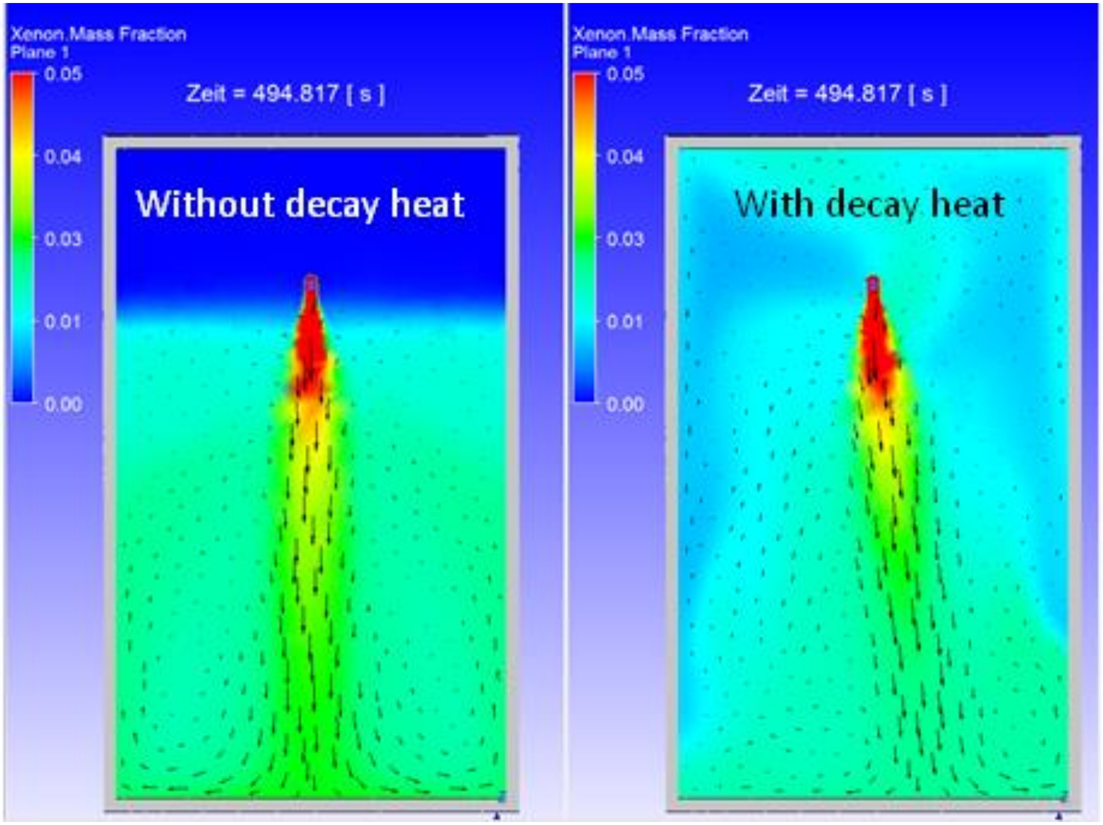


- The general pattern of aerosol density is the same for all simulations, but in detail lots of small differences could be found
- Parameter study is recommended for all accident simulations (containment)

Radioactive noble gases

Radioactive noble gases like Xe-133 are released into the containment in the case of an severe accident. They act as a distributed heat source in the gas phase.

- They could be modeled in CFX as an ideal gases
- The decay heat of α- and β-decays could be modeled by local heat sources dependent on the fission product concentration
- γ radiation could in principle be modeled with the radiation heat transfer models
- ➢ The decay heat has a significant effect on temperatures and local Xenon concentrations



Conclusions and outlook

- Different experiments and test cases have been simulated to study the CFD simulation of aerosol transport, deposition, agglomeration, decay heat and radioactive noble gas distribution
- There are two different methods:
  Algebraic slip model and Lagrangian particle tracking
- Both methods showed some advantages and drawbacks
- But most of the CFX simulations showed satisfying results

- It could be shown that fundamental aspects of fission product behavior could be modeled with ANSYS CFX
- Some aspects have been neglected until now (steam condensation on aerosols,…)
- More validations are necessary in future

ACKNOWLEDGMENTS

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Thank you for your attention!