TRACTEBEL Engineering
GDF SUEZ

USE OF MELCOR IN CONJUNCTION WITH SOPHAEROS FOR BELGIAN STUDIES ON FILTERED CONTAINMENT VENTING SYSTEMS

INTERNAL

7th Meeting of the "European MELCOR User Group", 17th-18th march 2015, Brussels

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INTRODUCTION

- Safety enhancement foreseen for the long term operation then endorsed during the Belgian stress tests for protection against Fukushima-type events

  → Commitment to install Filtered Containment Venting Systems (FCVS) on Belgian units (PWR 3 loops, ~1000 MWe)

- MELCOR is Tractebel Engineering (TE) reference code for severe accident calculation

  – Lacks aerosols impaction deposition phenomena

- Use of ASTEC modules for specific applications

  – Aerosols deposition in the venting line → SOPHAEROS module

INTEREST OF USING MELCOR-SOPHAEROS

MELCOR-SOPHAEROS comparison for aerosols behaviour

	MELCOR	SOPHAEROS
Nucleation	✓	✓
Agglomeration	✓	✓
Interaction with water	✓	✗
Gravitational settling	✓	✓
Brownian diffusion	✓	✓
Phoresis	✓	✓
Impaction deposition	✗	✓
Resuspension (shear stresses)	✗	✓

- Relatively high gas velocity in FCVS piping:

  →Potential influence of impaction deposition

→Impaction deposition assessed using SOPHAEROS

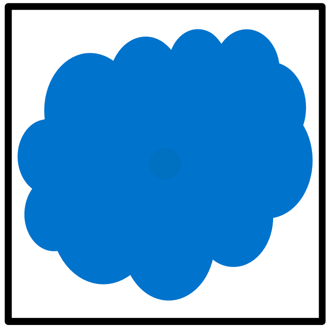
- No interaction of aerosols with water in SOPHAEROS

→Results representative of an FCVS insulated piping (no steam condensation)

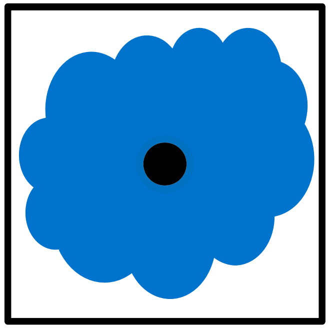
AEROSOLS BEHAVIOUR

Growth phenomena

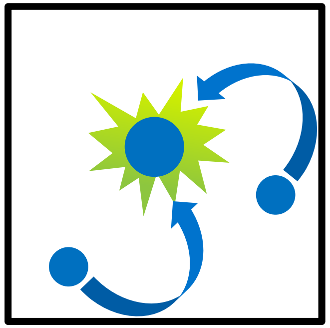
Homogeneous nucleation:
$T<T_{sat}$ → droplet formation



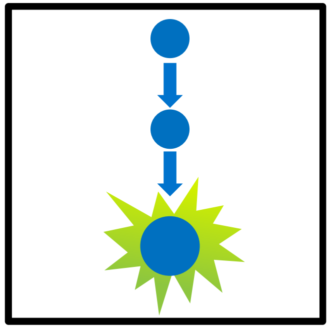
Heterogeneous nucleation:
Condensation on existing aerosols



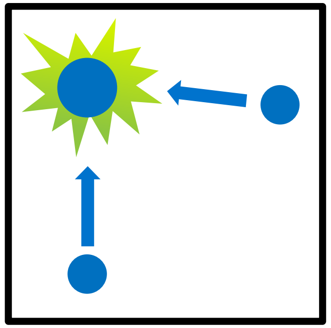
Turbulent agglomeration:
Collision of aerosols due to turbulences



Gravitational agglomeration:
Collision of aerosols due to settling



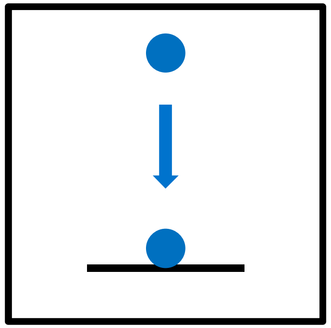
Brownian agglomeration:
Collision of aerosols due to Brownian movement



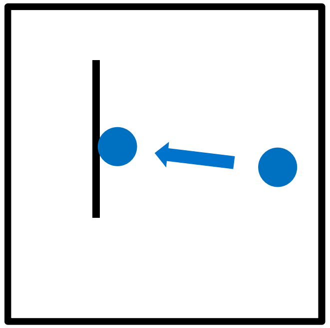
AEROSOLS BEHAVIOUR

Deposition/resuspension phenomena

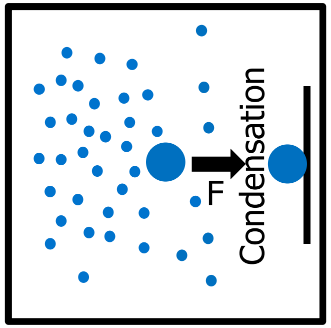
Gravitational settling:
Fall-down of heavy aerosols



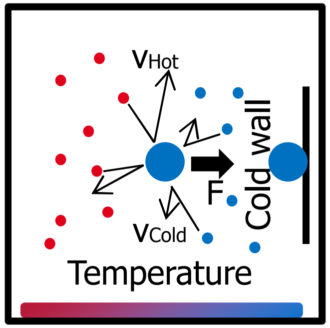
Brownian diffusion:
Diffusion toward wall due to Brownian movement



Diffusiophoresis:
Condensation induces pressure gradient → Force towards wall



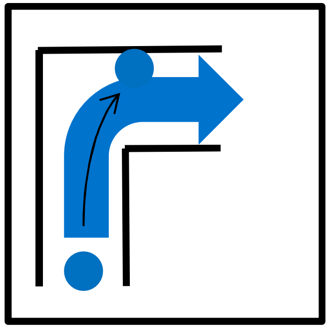
Thermophoresis:
$V_{Hot} > V_{Cold}$ → Force towards cold wall



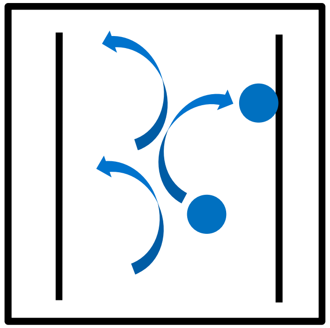
AEROSOLS BEHAVIOUR

Deposition/resuspension phenomena

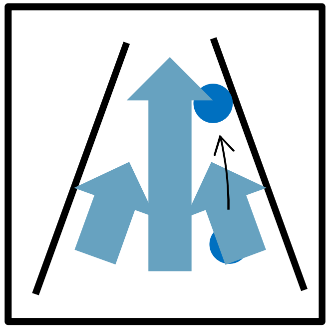
Bend impaction:
Drag force too weak to entrain
aerosols in bends → impact in wall



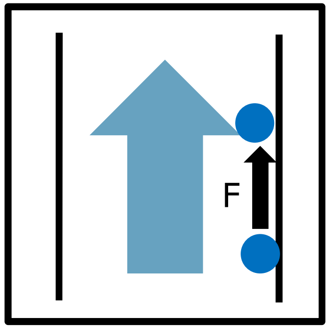
Turbulent (EDDY) impaction:
Turbulences drive aerosols
towards wall → impact in wall



Contraction impaction:
Drag force too weak to entrain
aerosols in contractions → impact in wall

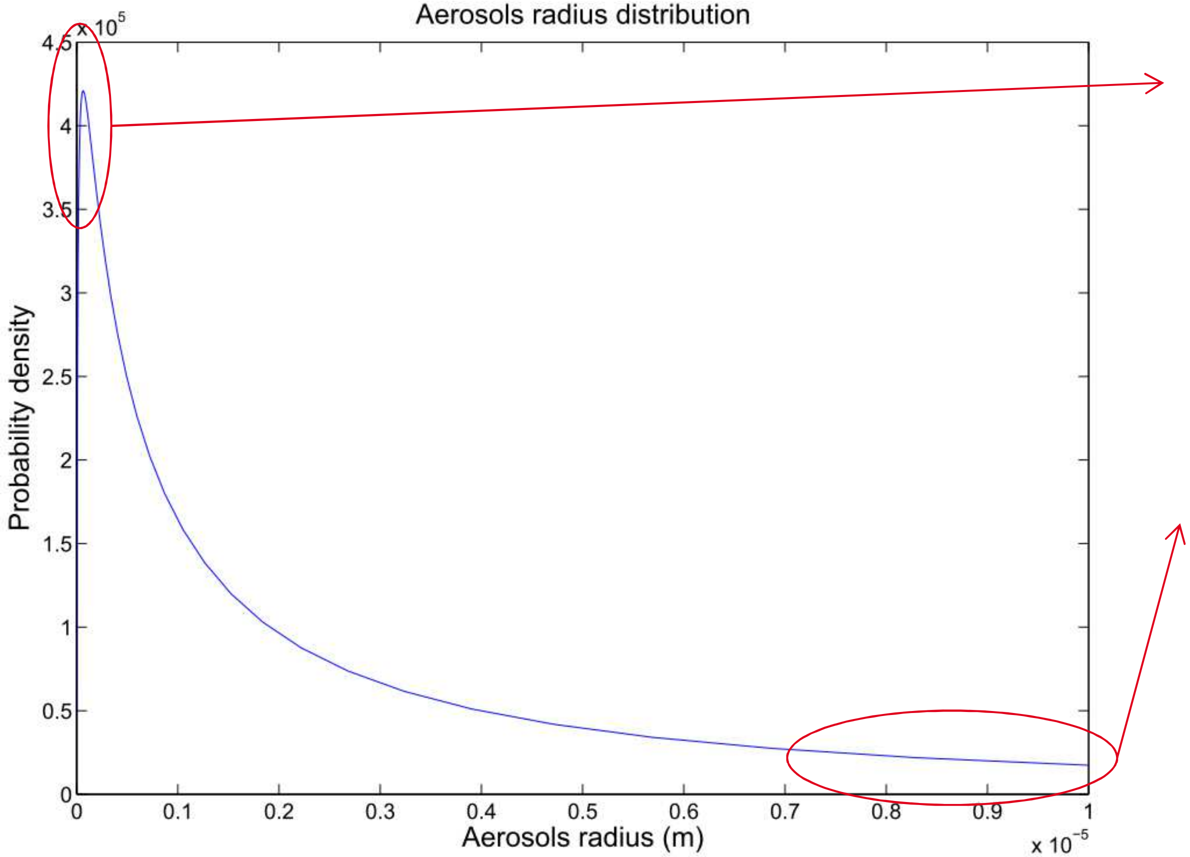


Resuspension:
Shear stresses detach aerosols from wall



AEROSOLS’ SIZE DISTRIBUTION (EXAMPLE)

The aerosols’ radius is distributed according to a lognormal distribution



High number of small size aerosols primarily affected by:

- Thermophoresis
- Diffusiophoresis
- Account for a relatively small mass

Low number of high size aerosols primarily affected by:

- Bend impaction
- Gravitational settling
- Account for the majority of the mass

BINDING FORCES BETWEEN AEROSOLS AND WALLS

Phenomena are responsible for aerosols adhesion to walls:

- Van der Waals forces (dry aerosols)
- Electrostatic forces
- Surface tension (wet aerosols)
- Sintering
- Chemical forces

Force balance approach in SOPHAEROS for mechanical resuspension (not considered in MELCOR)

MELCOR-ASTEC DATA TRANSFER

Full scope MELCOR calculation including piping model

Writing of basic data in binary External Data Files (EDFs)

Post-treatment of MELCOR calculation results

Calculation of SOPHAEROS input data and writing in ASCII file

Generation of SOPHAEROS input file

Automatic writing of ASCII files content in SOPHAEROS input file template

SOPHAEROS calculation

Writing of SOPHAEROS raw results

Post-treatment of SOPHAEROS raw results

SEVERE ACCIDENT SCENARIO

- Complete station black out
- Assumption on systems:

System	Availability
Internal electrical power	✘
External electrical power	✘
Steam Generators Auxiliary Feed Water	✘
Steam Generators Relief Valves	✘
Pressurizer Relief Valves	✓
Alternative Sprays	✘
Water Injection to Reactor Pit	✓
FCVS	✓

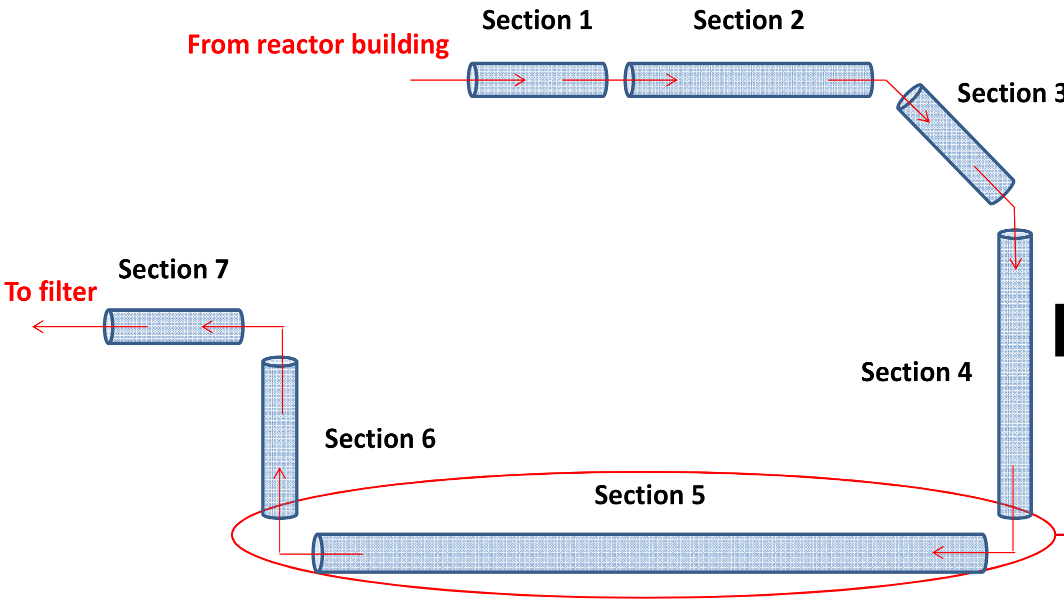
MELCOR/SOPHAEROS PIPING MODELS

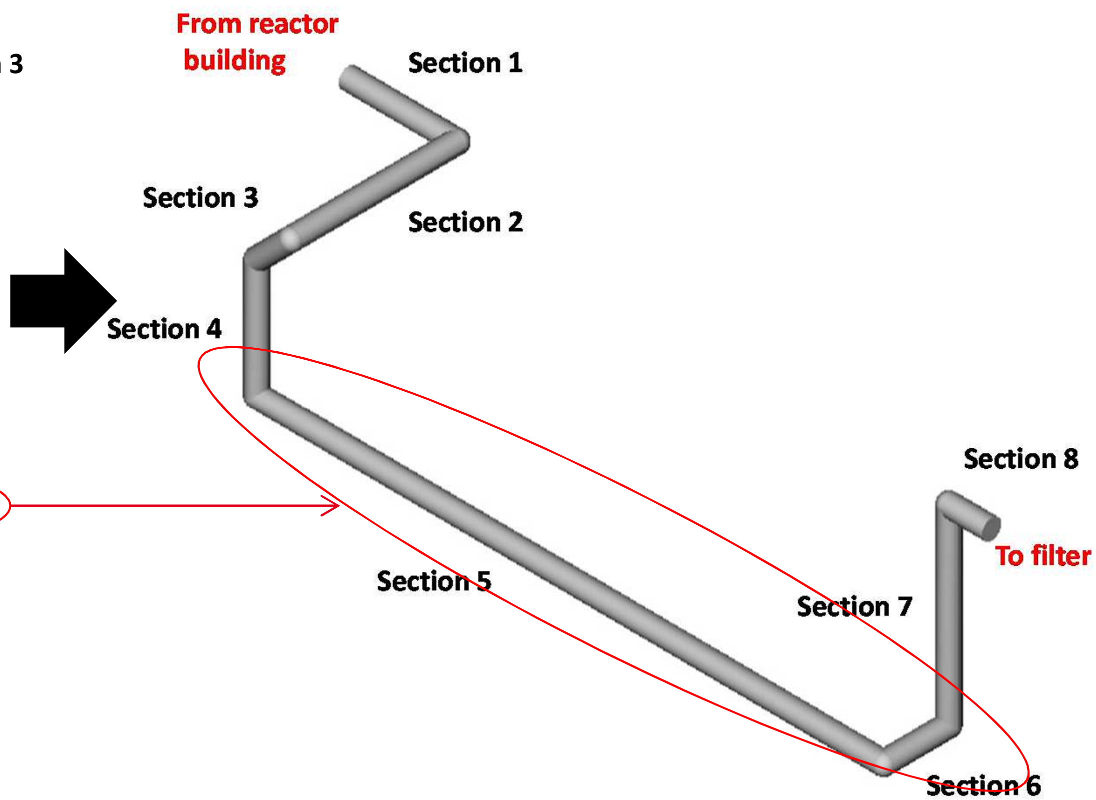
MELCOR piping model:

- no consideration of the azimuthal angle
- used in full scope MELCOR calculation to obtain thermal hydraulic data and aerosols source term

SOPHAEROS model:

- azimuthal angle taken into account →MELCOR section 5 divided in sections 5 and 6 in SOPHAEROS
- used to assess aerosols behaviour



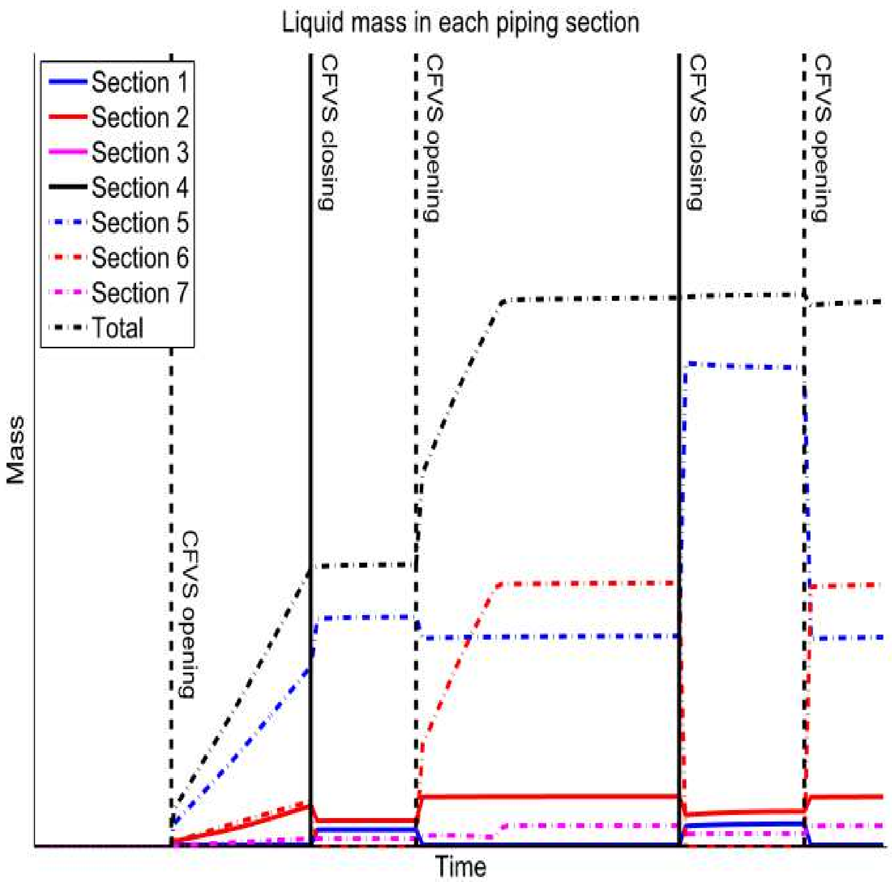


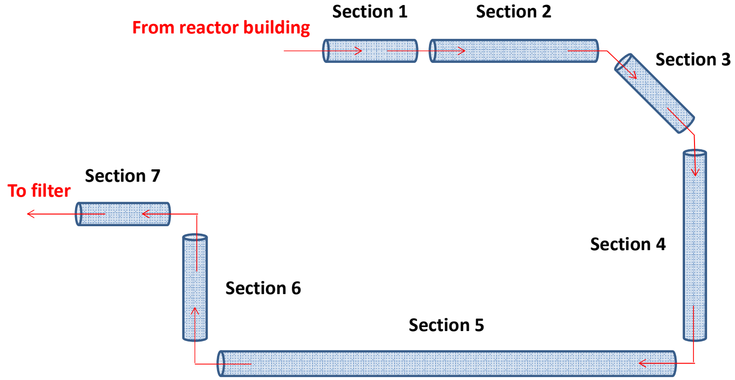
MELCOR CALCULATION

- Main hypothesis for MELCOR piping model:
  - MELCOR default parameters used
  - Low inclination in the piping sections not taken into account
  - Piping not insulated to maximize deposition through diffusiophoresis and thermophoresis
- Recorded data during MELCOR calculation (transferred to ASTEC/SOPHAEROS):
  - Thermal hydraulic-data inside the piping (e.g. atmosphere, liquid phase and piping wall temperature as well as condensation rate)
  - Composition of the piping sections' atmosphere
  - Atmosphere and liquid phase mass source to the VSV
  - Mass flow of both gas and liquid between the piping sections
  - Mass source of aerosols to the inlet of the piping
  - Aerosols size distribution at the inlet of the piping

MELCOR CALCULATION RESULTS

Water mass in the piping

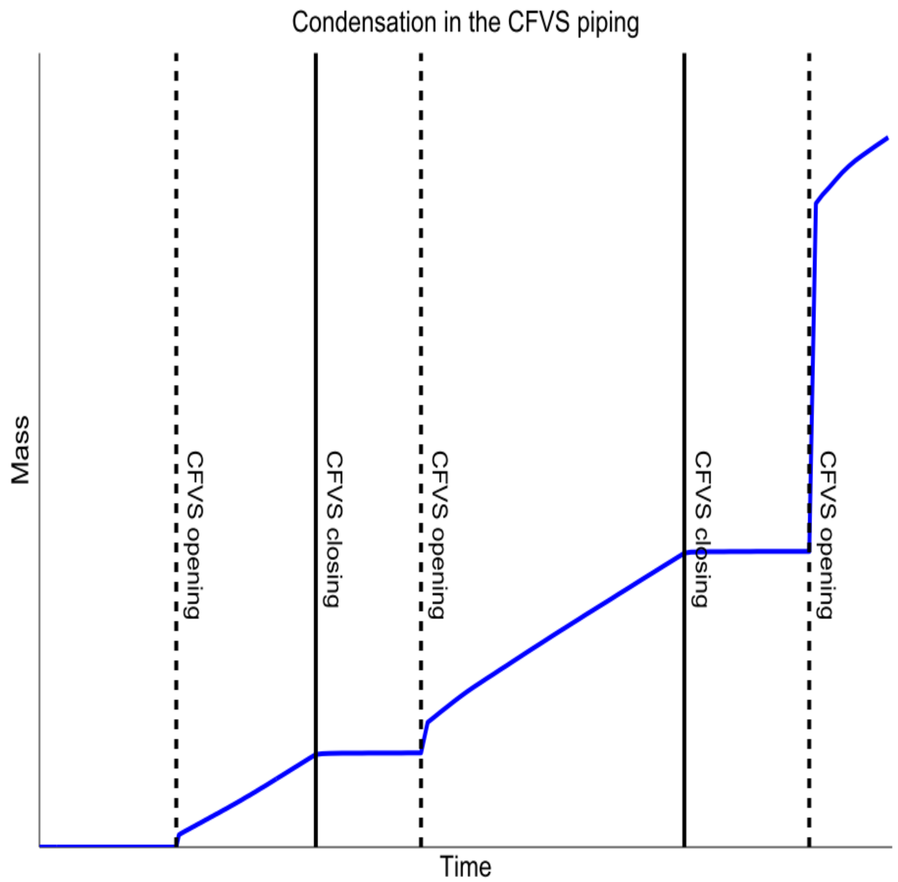




- Important mass of liquid water in the piping
- Apparition of a water column in section 6 (vertical) during second venting
  - Water column creates a counter pressure prolonging second venting period
  - MELCOR has limited capabilities to model such phenomenon

MELCOR CALCULATION RESULTS

Water condensation in the piping

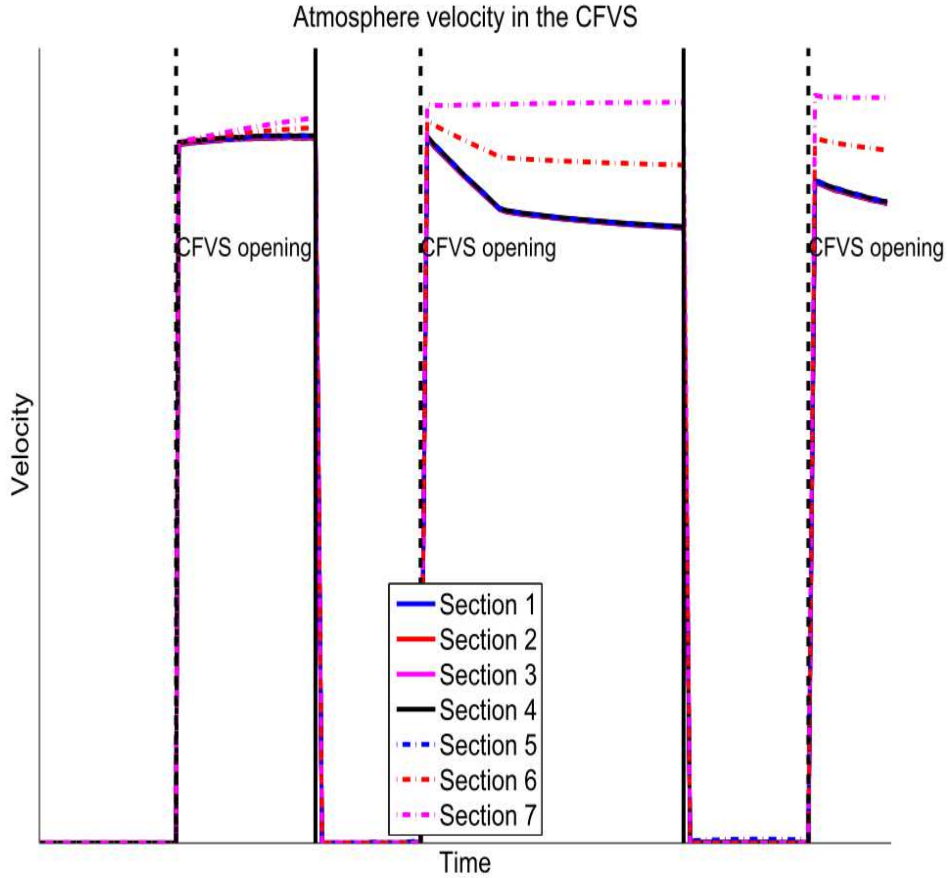


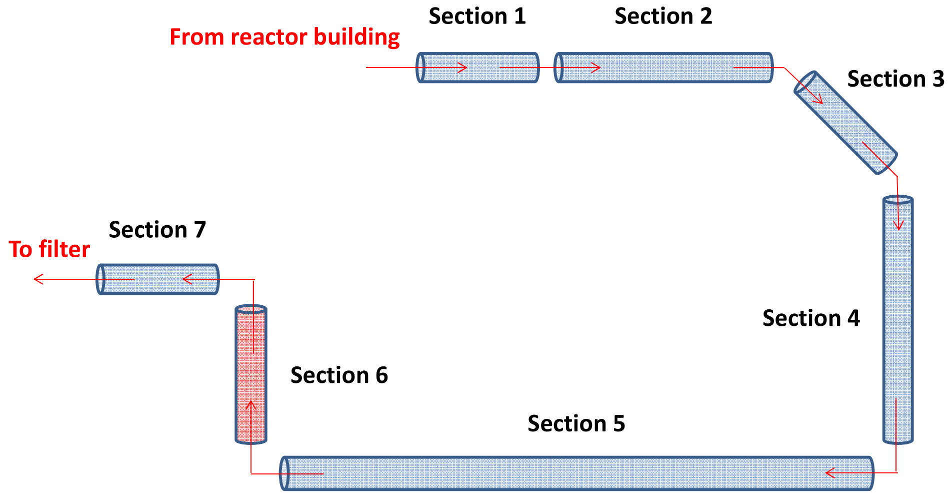
- Important mass of water condensed however accounts only for a small fraction of the steam source to the piping
- Important condensation at beginning of third venting because of the water column forming in section 6 (vertical)

→ Deposition by thermophoresis and diffusiophoresis strongly increased

MELCOR CALCULATION RESULTS

Gas velocity in piping



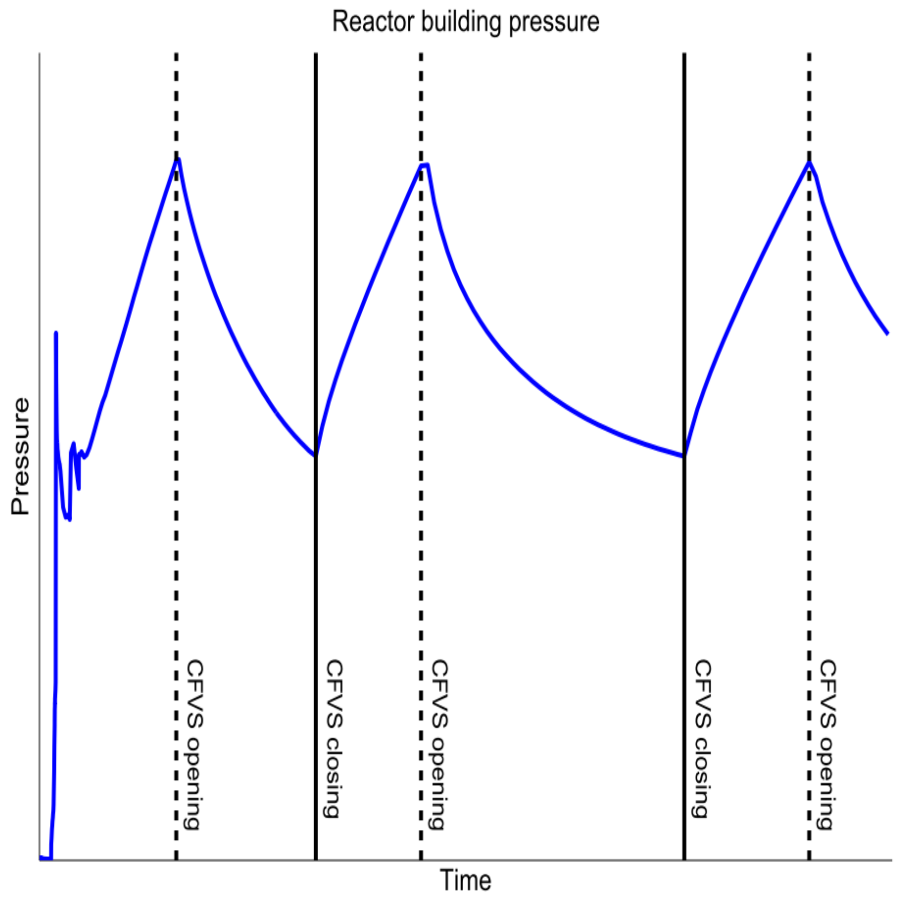


- Gas velocity impacted by water column apparition in section 6 during second and third venting

  → Deposition by bend and turbulent impaction considerably reduced (aerosols results)

MELCOR CALCULATION RESULTS

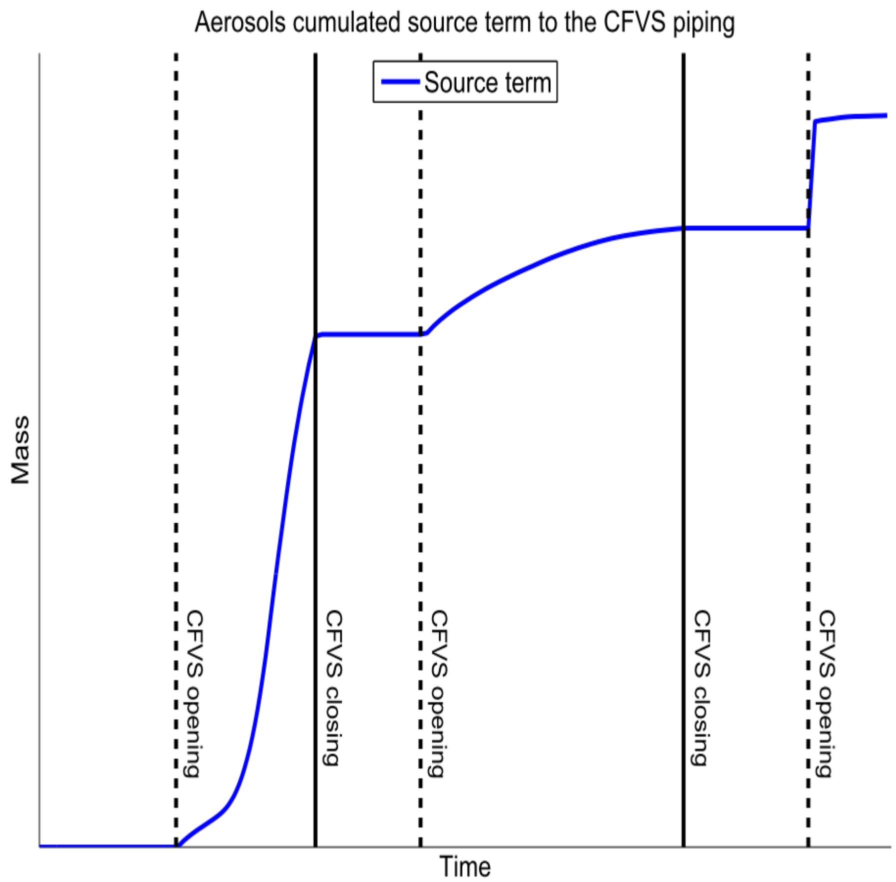
Reactor building pressure



- Slower gas velocity in the FCVS line increases venting period length

MELCOR INPUT FOR SOPHAEROS

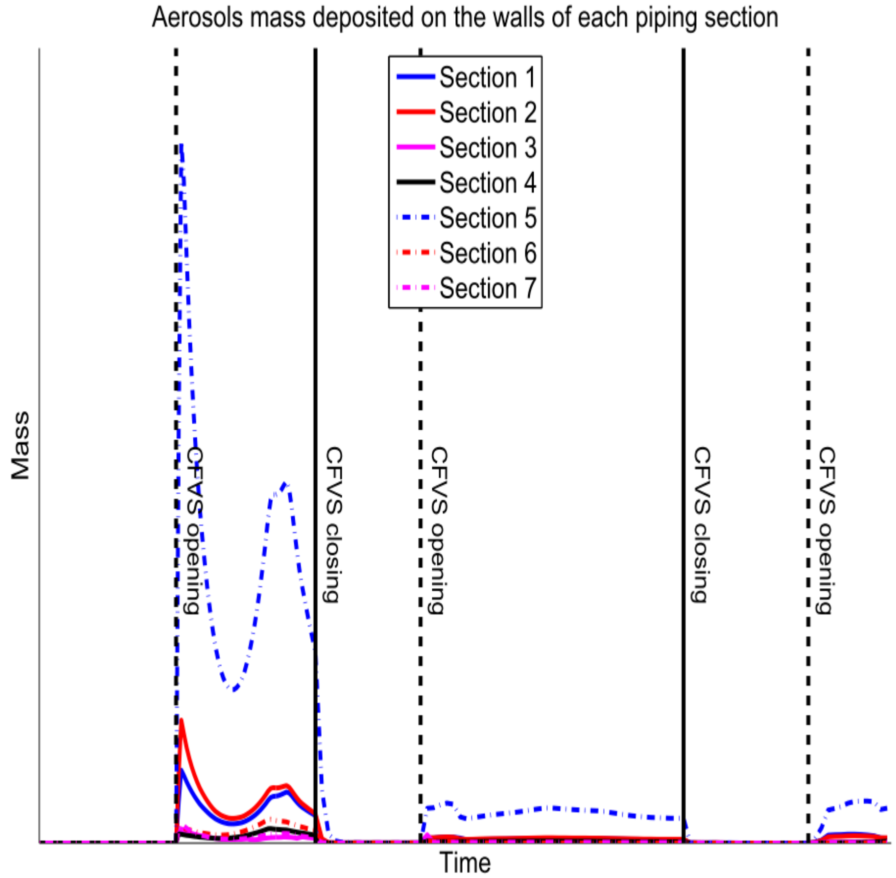
Aerosols mass source term

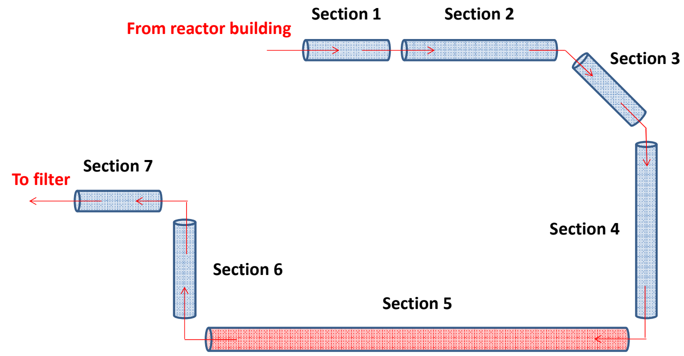


- Aerosols cumulated mass source term to the piping between the reactor building and the filter
- Majority of the source term passes during the first venting period

MELCOR CALCULATION RESULTS

Mass of aerosols deposited in piping

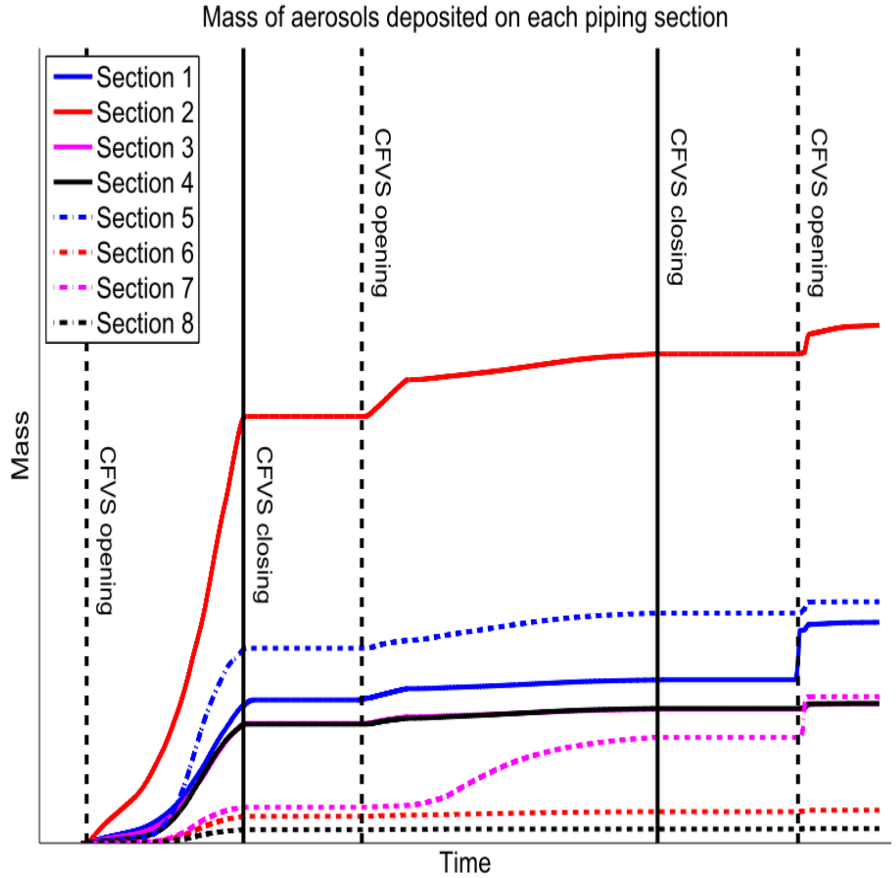


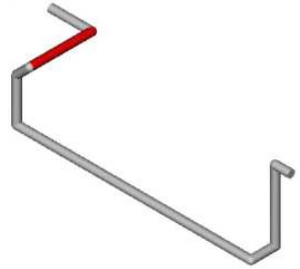


- Maximum deposition occurs in section 5 (longest)
- Deposition occurs during venting periods when aerosols are present in the piping atmosphere
- Almost all aerosols are washed off the walls by condensation between venting periods

SOPHAEROS CALCULATION RESULTS

Mass of aerosols deposited in piping

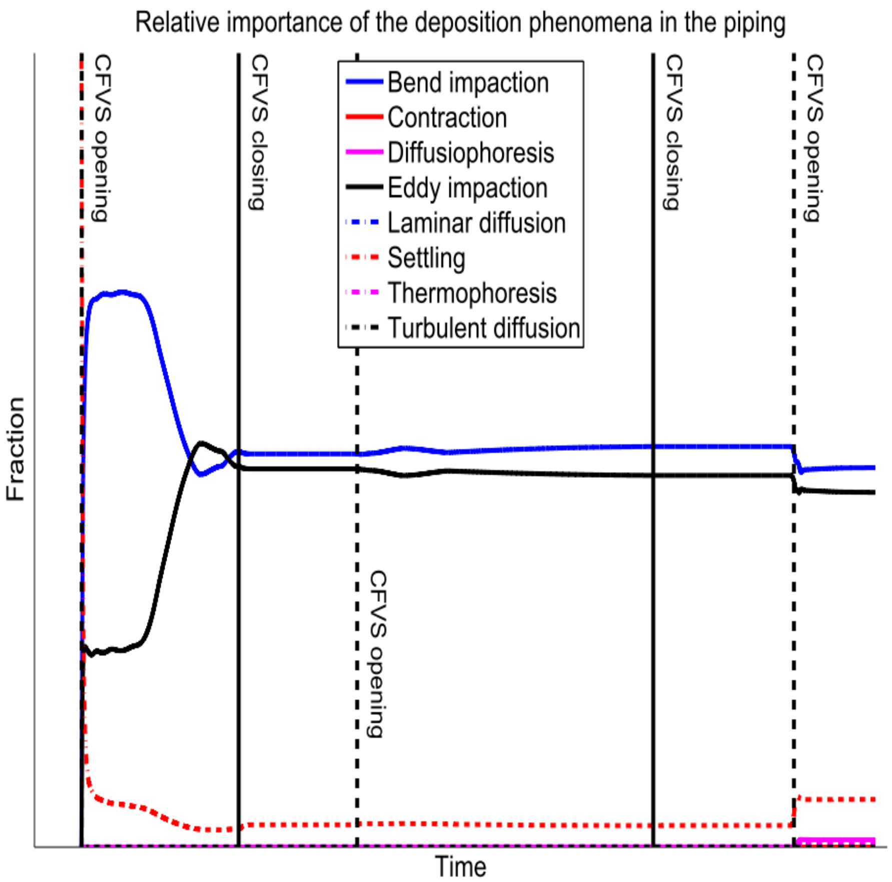




- Consequent aerosols deposition (mainly in section 2)
  - First section to contain a bend
  - bend impaction most important deposition mechanism in this section
  - The remaining is attributable to turbulent impaction
- Some limitation in SOPHAEROS regarding aerosols detachment from the walls
  - Only mechanical resuspension is modelled
  - No piping wall wash-off by condensation

SOPHAEROS CALCULATION RESULTS

Relative importance of deposition phenomena



- Turbulent and bend impaction each responsible for the majority of deposition
- Increase of condensation and lower gas velocity during third venting:

→Thermophoresis and diffusiophoresis increased

→Gravitational settling increased

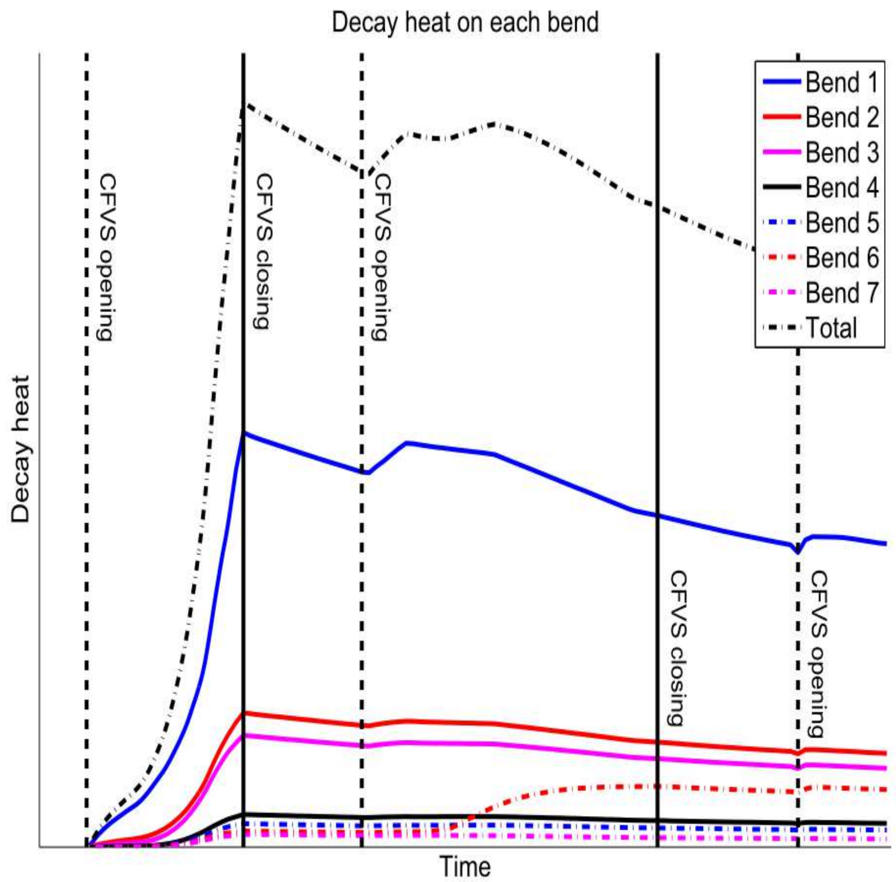
→Bend impaction decreases

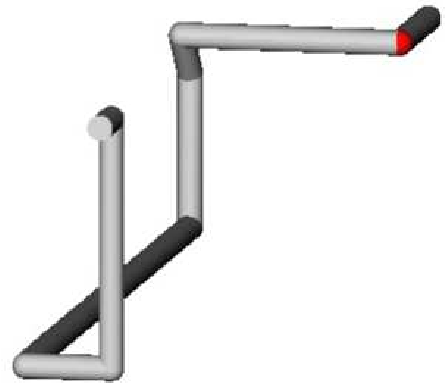
→Turbulent impaction decreases

→Globally less deposition

SOPHAEROS CALCULATION RESULTS

Decay heat in the bends





- Maximum decay heat in the first bend during the first venting period
- Natural decay process then decreases the decay heat

CONCLUSIONS

- Tractebel Engineering has developed an interface between MELCOR and ASTEC to model aerosols impaction deposition in the FCVS piping line
- Potential MELCOR improvement points for data transfer between codes and model building
  - Increase the amount of information writable on each ASCII EDF file line
  - Include data on aerosols transfer between volume (in flow path)
  - Include the possibility to define objects (volumes, HS, etc..) in loops
- Results used to calculate the aerosols’ mass deposited in each piping section and bend obtained and used to calculate
  - The decay heat evolution
  - The radioactive source term