CERN

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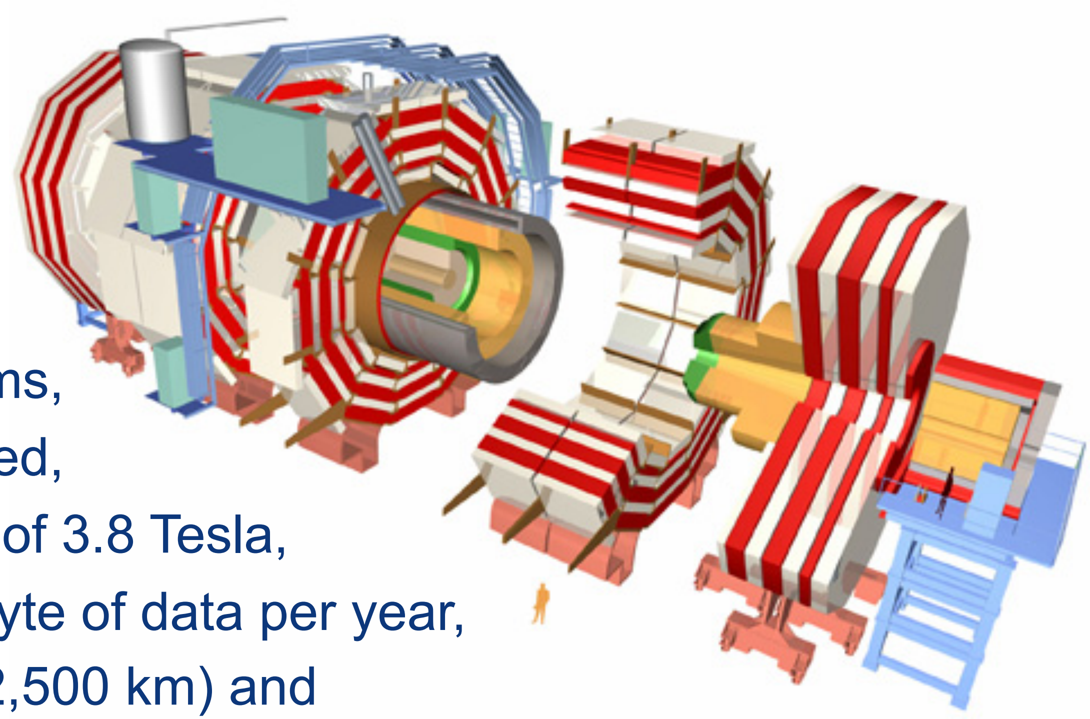
Fire-induced multi-phase flow through complex geometry


LHCb
ATLAS
CERN Meyrin
PS 628 m
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km
® CERN

Compact Muon Solenoid

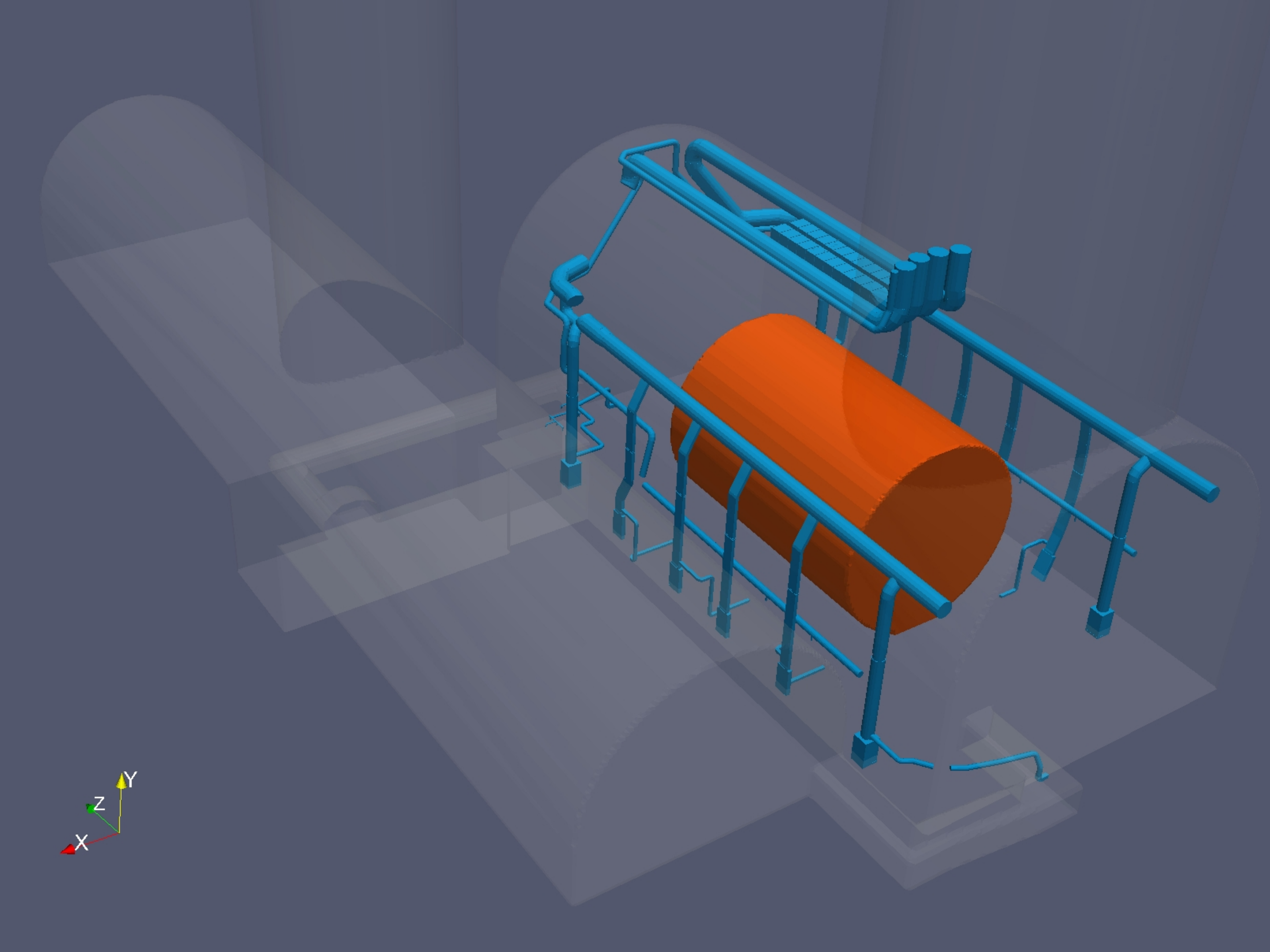


Detector features

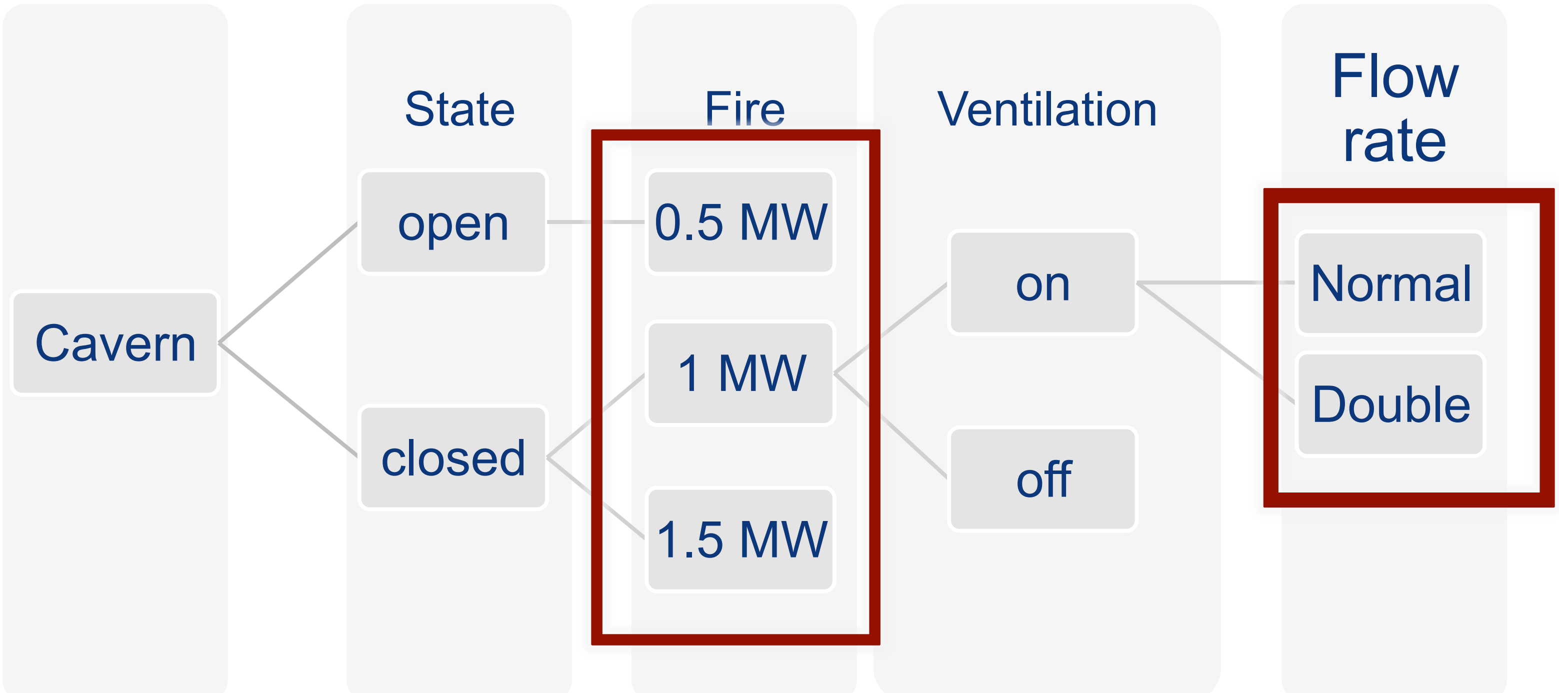
- a weight of 14,000 tons,
- a size of 15 x 15 x 21 m,
- 5 particle sub detection systems,
- 2.65 GJ magnetic energy stored,
- a homogenous magnetic field of 3.8 Tesla,
- it produces about 5,000 Terabyte of data per year,
- uses about 40,000 cables (~2,500 km) and
- is housed in a 50,000 m^3 cavern 100 m under ground.

About 35 years of work and 1 billion CHF = unique piece of equipment.

http://cds.cern.ch/record/1193034
http://cds.cern.ch/record/1474902/


Y
Z
X

Fire scenario variations



Is there a scaling factor hidden?

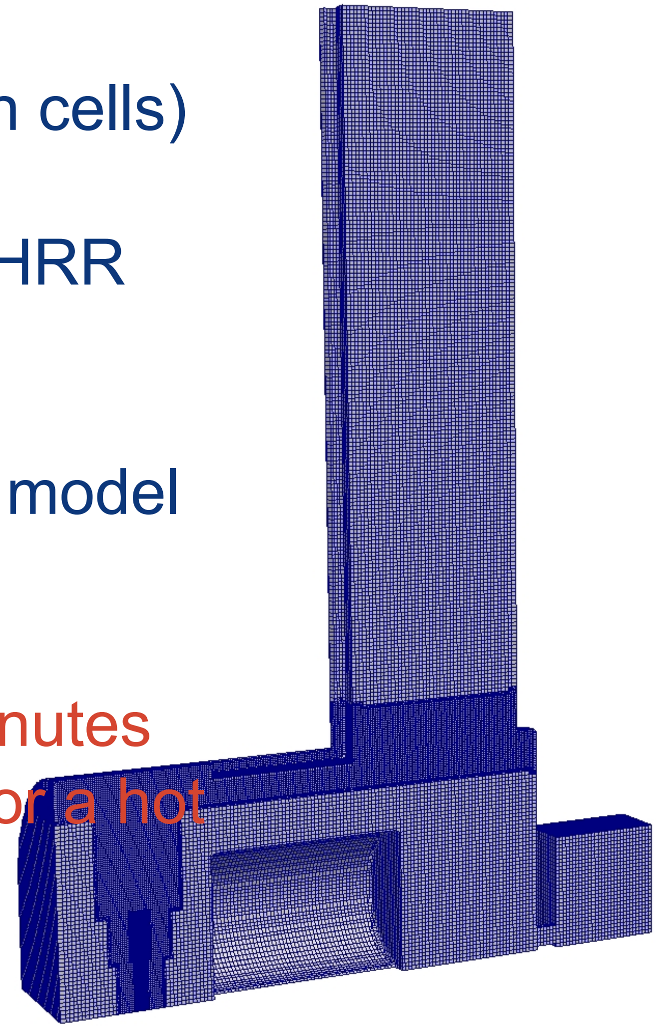
Various possibilities: Geometry, HRR, fire position, air management, etc.

Fire scenario: closed cavern

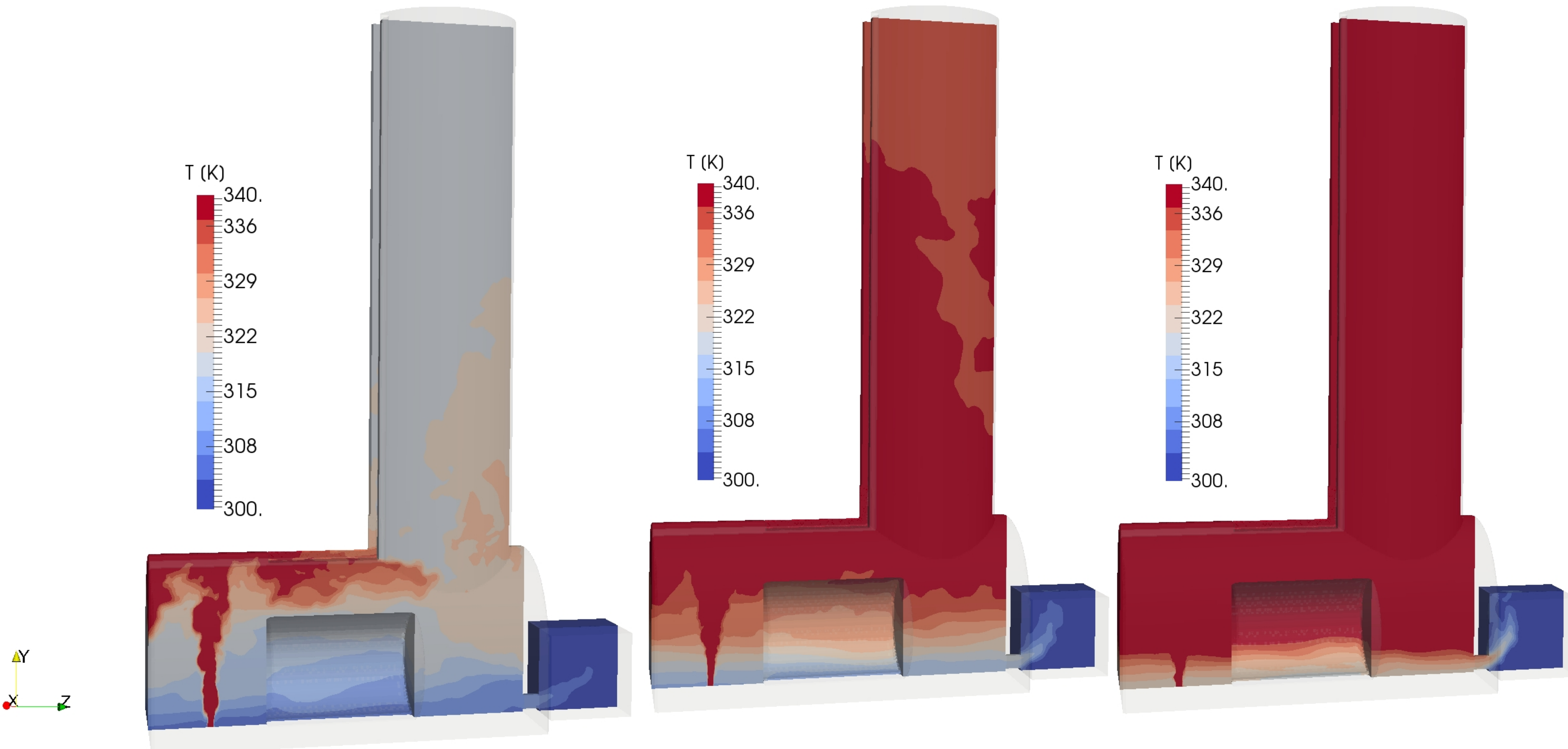
- Use of FM Global's fireFoam
- Geometry adapted mesh (1.6 Million cells)
  - Via STL and snappyHexMesh
- Simple diffusion burner with preset HRR
  - 1 MW over 30 minutes
- Infinitely fast combustion
- One-Equation-Eddy turbulence sub model
- No heat radiation sub model

Goals:

- Temperature distribution after 30 minutes
- Submergence time of the detector for a hot gas layer of T ≥ 340 K
- Hot air extraction behaviour

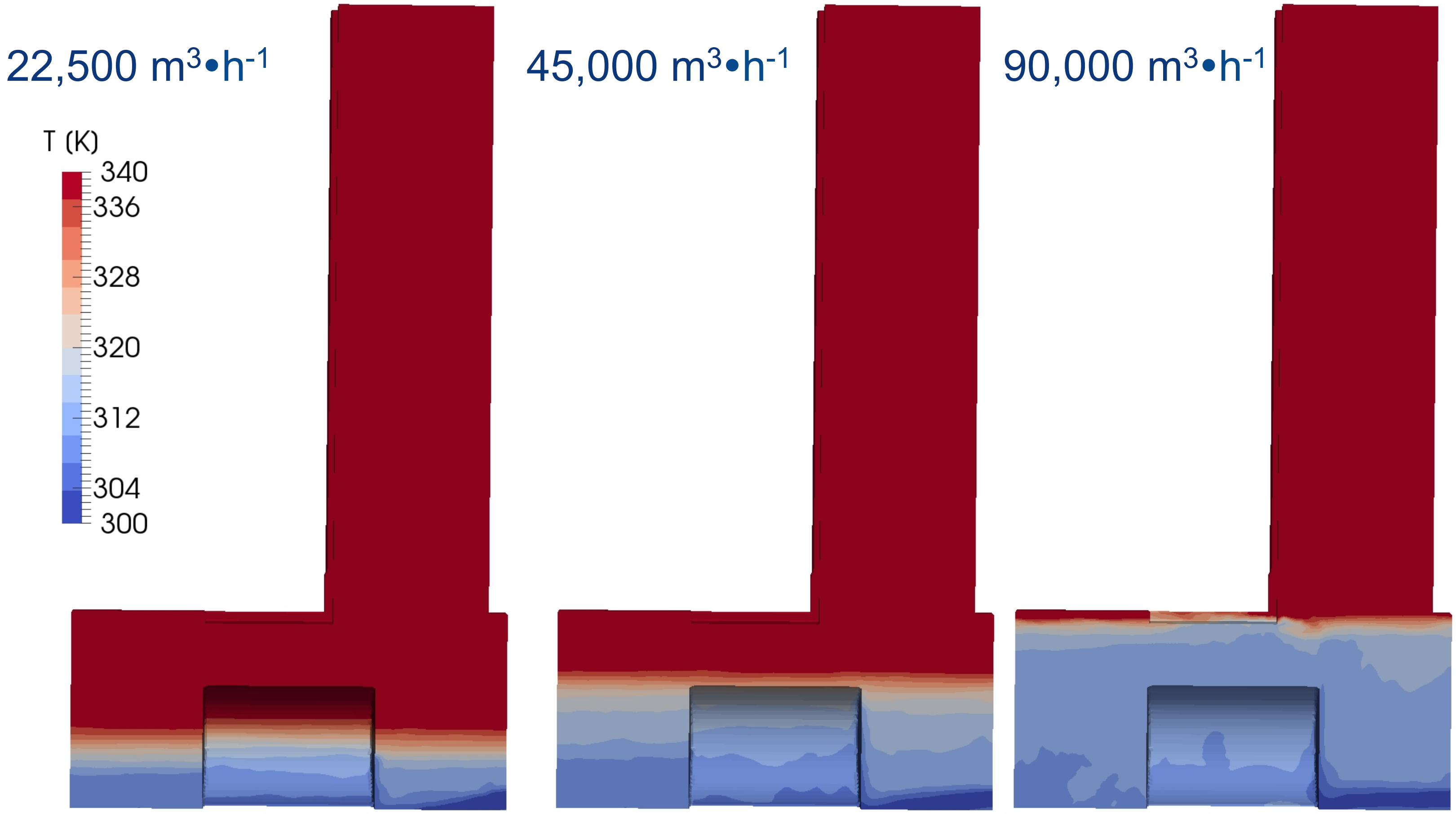


Fire scenario: closed cavern



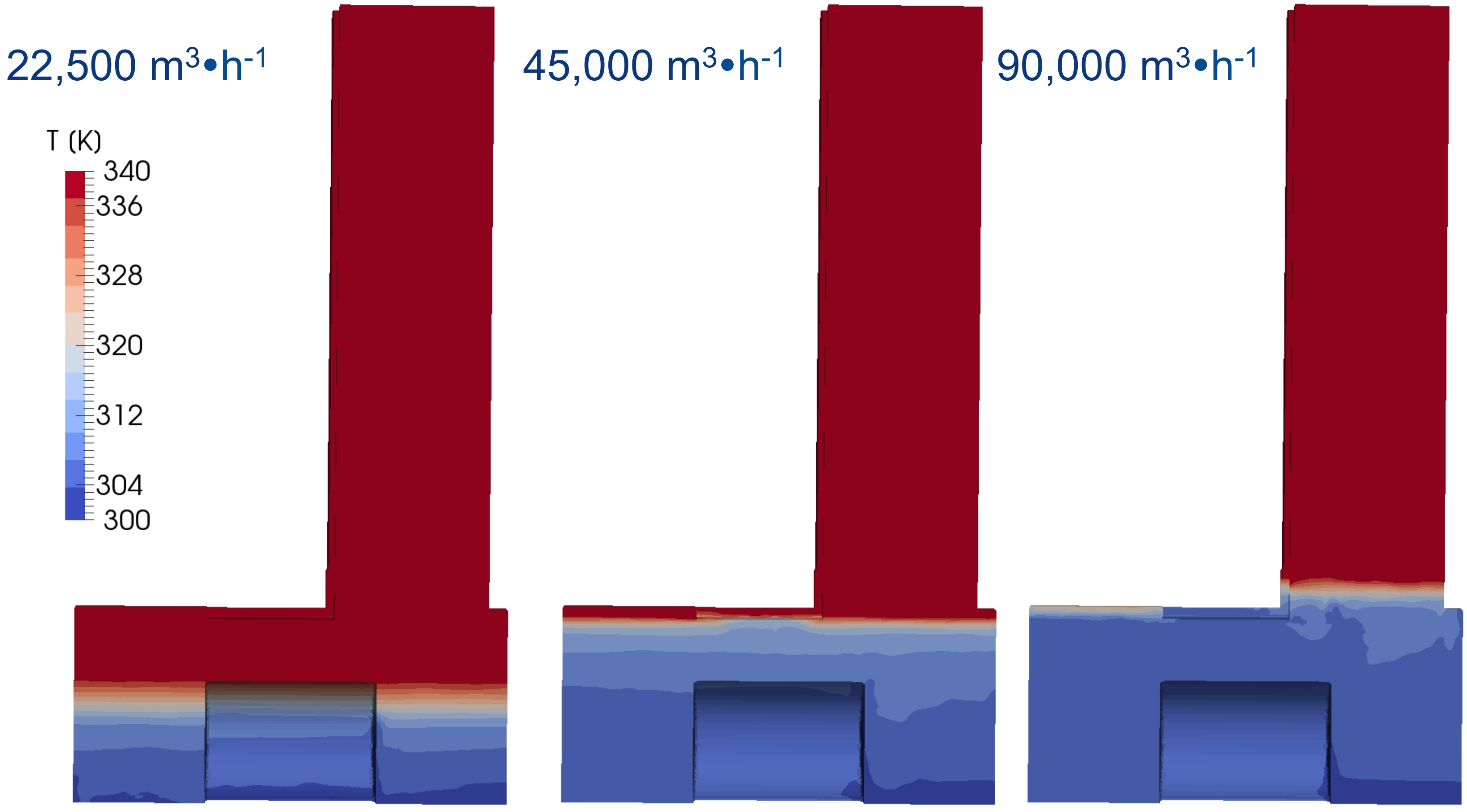
1 MW, temperatures after 10, 20 and 30 minutes steady HRR.

Hot air extraction



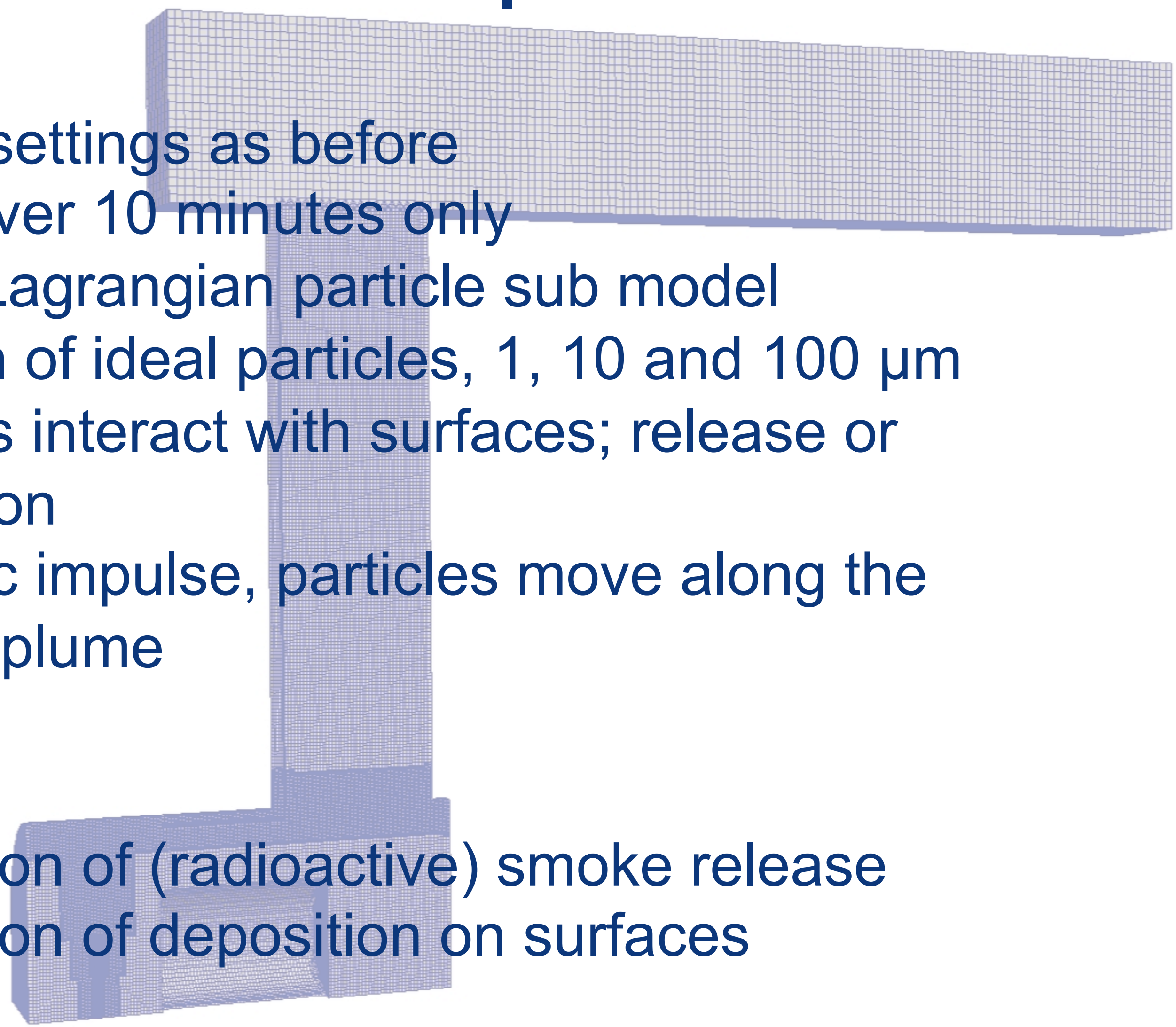
t=30 min “fire” + 10 min extraction

Hot air extraction



t=30 min "fire" + 20 min extraction

Fire scenario: open cavern



- Similar settings as before
- 1 MW over 10 minutes only
- Use of Lagrangian particle sub model
- Injection of ideal particles, 1, 10 and 100 µm
- Particles interact with surfaces; release or deposition
- No basic impulse, particles move along the thermal plume

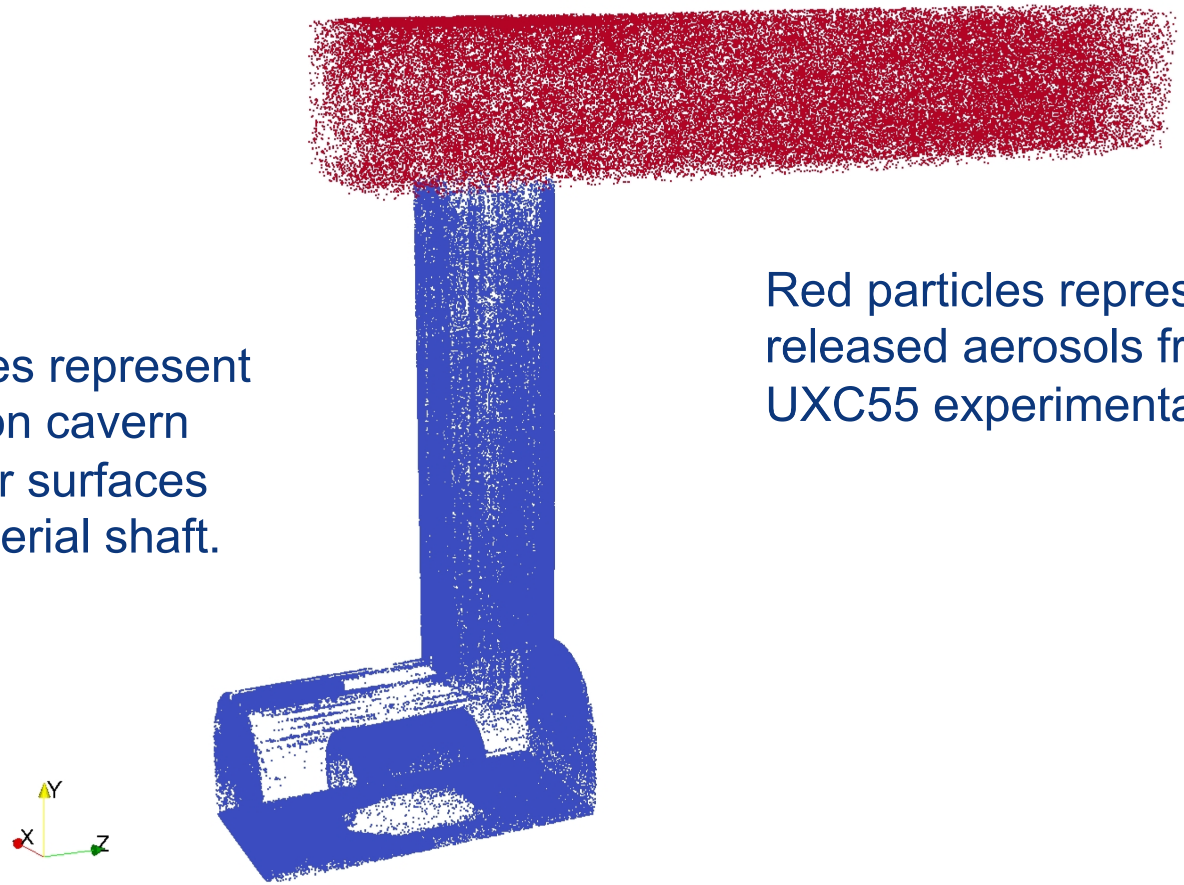
Goals:

- Estimation of (radioactive) smoke release
- Estimation of deposition on surfaces

Aerosol behaviour

Aerosol behaviour

Blue particles represent deposition on cavern and detector surfaces and the material shaft.



Red particles represent released aerosols from the UXC55 experimental cavern.

Distribution after 20 minutes; 10 min of 1 MW fire and 10 min of settlement time. Particles still dissolved in air are not shown at the lower part.

Aerosol results

Aerodynamic diameter [µm]	Released [%]	Deposited [%]	In air [%]
1	22.1	55.9	22
10	23.8	62.9	13.3
100	0.5	99.5	0

- Injection of 200,000 parcels per aerodynamic diameter
- Nearly linear behaviour with more particles, e.g. 400,000 or 600,000
- Results to be scaled with FLUKA calculations or measurements

Example: known mass of 1* µg of ^{60}Co in present fire load

- 221 ng release in case of 1 µm aerosols ≈ 9.4 MBq
- 238 ng release in case of 10 µm aerosols ≈ 10.1 MBq
- 5 ng release in case of 100 µm aerosols ≈ 0.2 MBq

* Assumption. Arbitrary value not connected to any calculation or measurement.

Aerosol deposition

Aerodynamic diameter [µm]	Floor [%]	Cavern surface [%]	Detector surface [%]
1	0.5	16.0	1.4
10	1.3	14.4	2.8
100	41.8	4.7	45.0

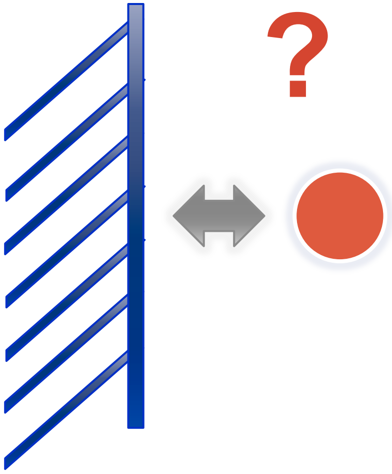
Example:

- ^{60}Co, $T_{1/2} \approx 5.2714$ a, attached to 100 µm aerosols
- Swiss limit is 3 Bq·cm² (ORAP), max. $3 \cdot 10^4$ Bq per m²
- Detector surface is about 914 m², thus not more than 27.4 MBq allowed
- To respect the limit not more than 1.4 µg ^{60}Co may be combusted

Aerosol approach

Current model:

- Release
- Deposition
- Dispersed in air



Reality:

- Surface adhesion forces
- Agglomeration
- Turbulent dispersion
- Gravitational settling
- Thermophoresis
- …

➔ Could be all implemented, but would be hardly usable for application purposes.

➔➔ New statistical approach underway at this very moment

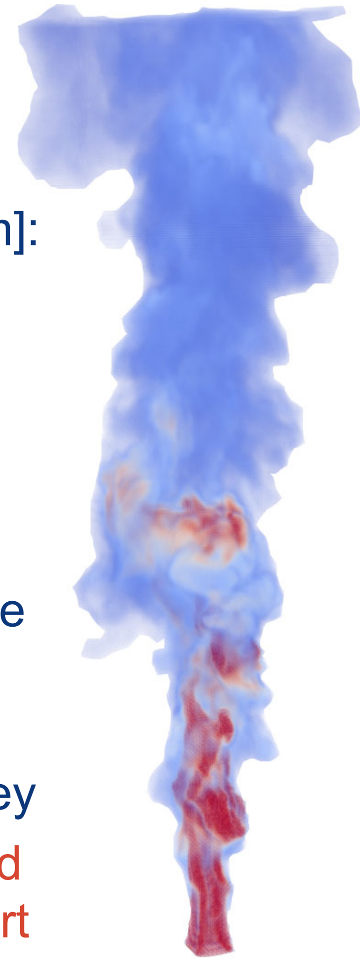
Verification

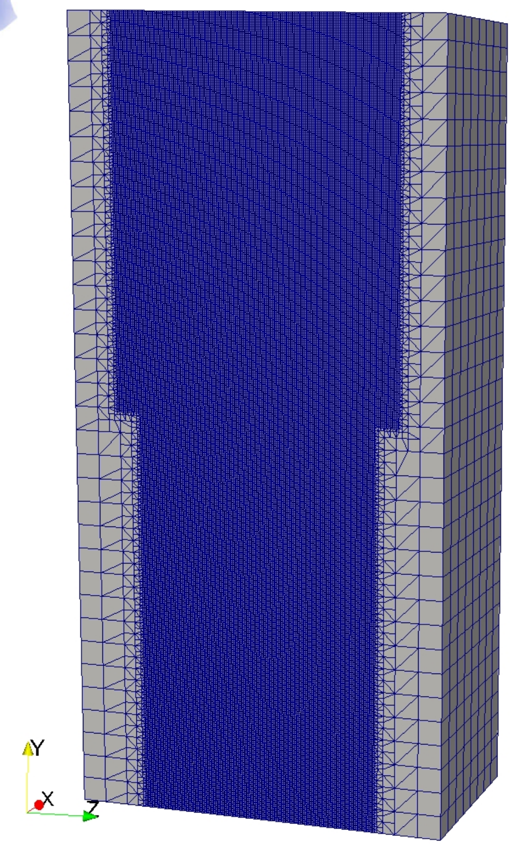
- Model independency in space and time
- Sub model error analysis
  - Combustion,
  - Thermal radiation
  - Turbulence
  - Lagrangian parcels
- Initial and boundary conditions

HRR verification

- Small pool fire 3D "extended"
- 3.6 x 3.6 x 10 m, ≈ 130 m^3
- Two different mesh size ranges [cm]:
  40, 20, 10, 5 and 2.5;
  30, 15, 7.5 and 3.25
- Courant number = 0.5
- Mean T and Uy sampled for 15 s after 15 s initialization time**
- Comparison with McCaffrey's plume equations (NBSIR 79-1910)
- Requirement: not more than 20% conservative difference to McCaffrey

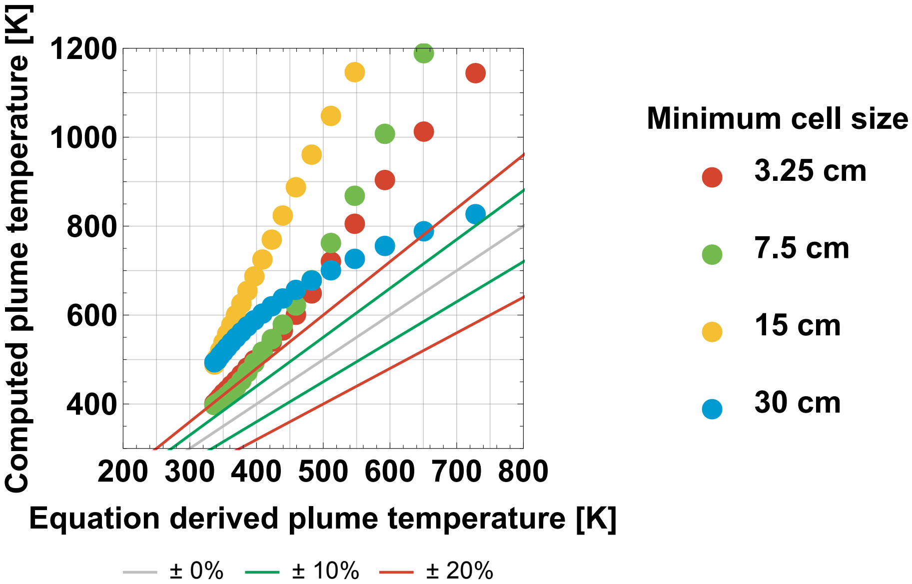
Goal: suitable balance between required mesh resolution and computational effort

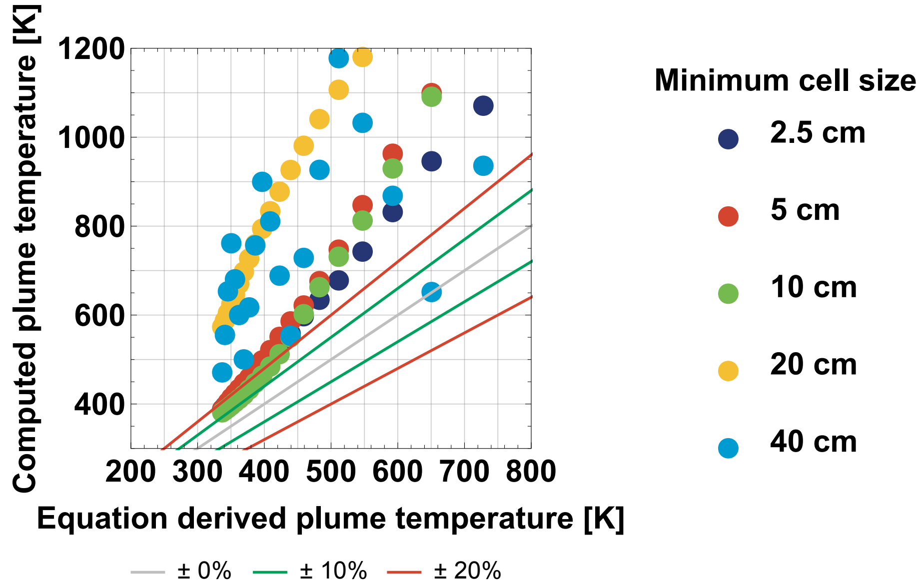




* Inspired by Chatterjee, P. et al., Numerical simulations of strong-plume driven ceiling flows, IAFSS, 2014
** Following best practice suggestion by Prateep Chatterjee, FM Global

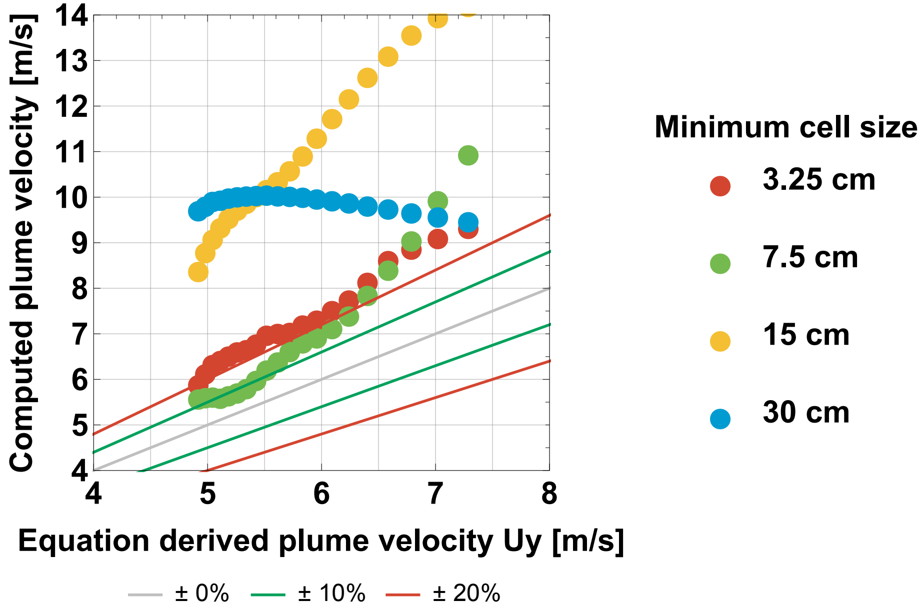
HRR verification

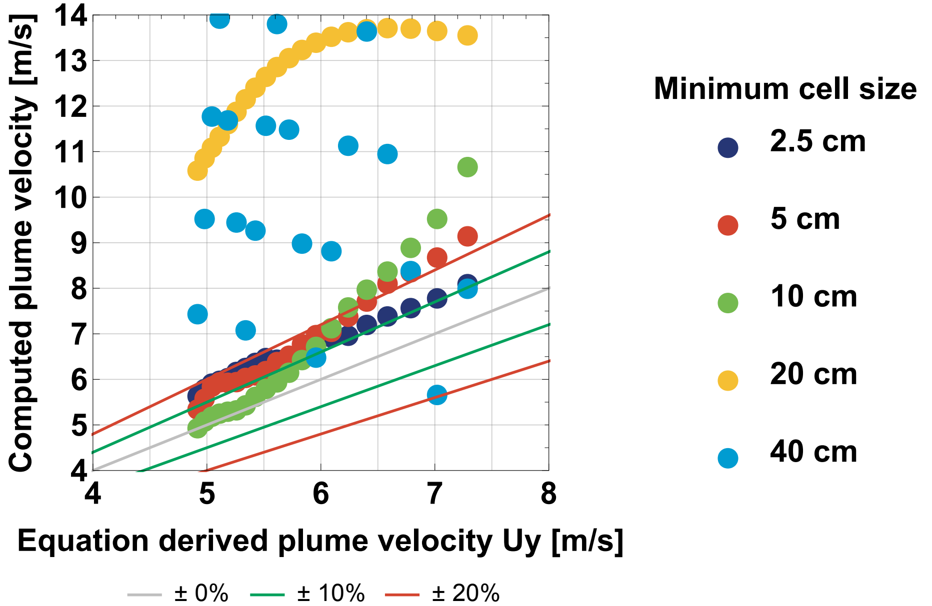




- 40 cm shows most arbitrary behaviour
- Computed plume temperature is within 20% range of plume equations for 10 cm cells and below for y+ ≈ 7 m and above
- First refinement after crossing 10 cm threshold does not provide better results

HRR verification





- 40 cm shows most arbitrary behaviour
- Computed plume velocity is within 10% range of plume equations for 10 cm cells (y+ ≈ 7 m and above)
- Refinements to 5 cm and 2.5 cm show enhancements towards mean flame height

Summary

- Use of CFD for unique installations
- Full scale validation hardly possible
- FM Global's fireFoam applied to CMS
- First estimation of aerosol release and deposition by using a present Lagrangian approach
- Code modification will allow further insight
- Verification is ongoing

➔ Final approach will enhance significantly scenarios dealing with the release and deposition of radioactive material

Acknowledgements

- FM Global's fireFoam team
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  INURI GmbH, Berlin, DE
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  Yverdon-les-Bains, CH
- CERN
  - CMS collaboration
  - Director General's safety
  - EN/CV/PJ's CFD team

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Backup information

Software used

Operating systems: Mac OS X 10.8.5 and Scientific Linux 6

GCC 4.7.4, OpenMPI 1.8.4

OpenFOAM Build : 2.2.x-5cc33a231685

FireFOAM Build Version: 70b3e6a20900683fba46801c31725a9197954ecb

ParaView 4.3.1