GAS DISPERSION WITH OPENFOAM

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AGENDA

Introduction/Motivation

OpenFOAM

Solver

Validation

Test Case

Conclusions

1.0
INTRODUCTION

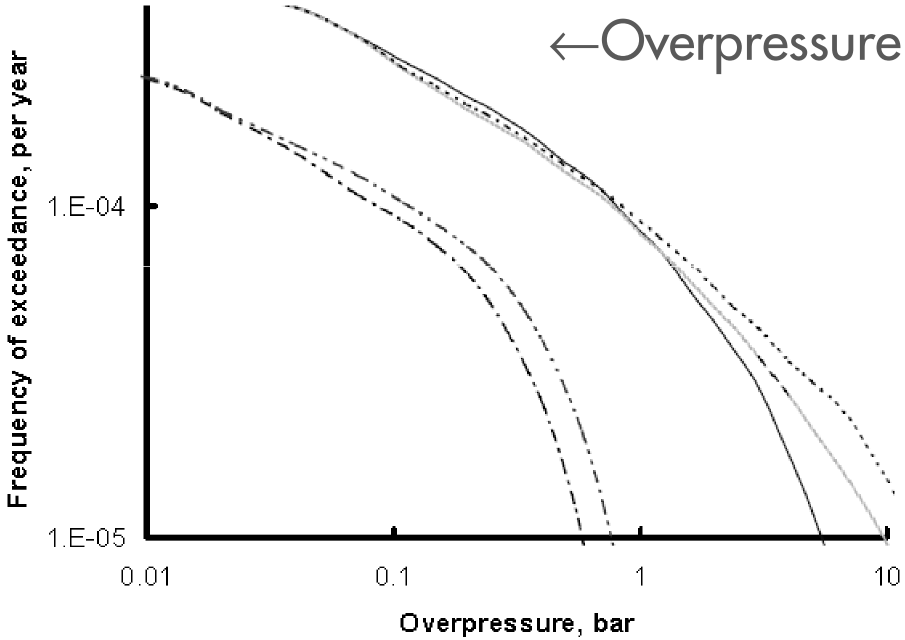
The need for a large number of CFD dispersion calculations.

DESIGN OVERPRESSURE

- Understanding explosion overpressure is important in the design of onshore and offshore plant; for example blast walls, protection of Emergency Shut Down Valves etc.
- The assessment of explosion hazards due to accidental releases of flammable gas often requires the quantification of the likely gas cloud sizes produced by a *range* of potential leak scenarios and wind conditions.
- There is a need to consider a *range* of scenarios because, although the simplest approach in assessing explosion hazards is to calculate a "worst-case" explosion, a genuine worst case is an event of extremely low probability.

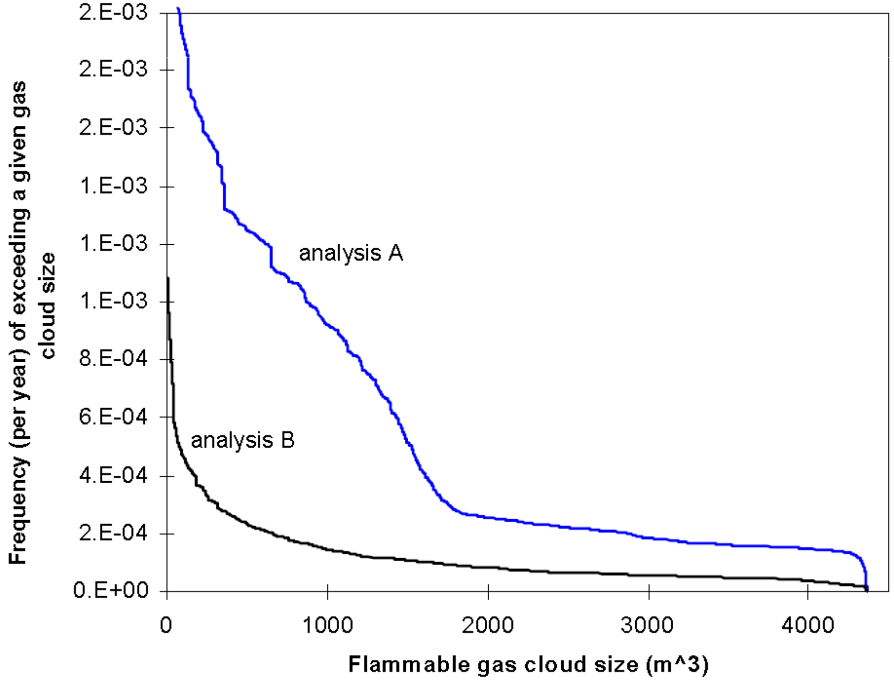
EXCEEDANCE CURVES

- Results normally presented as exceedance curves:



←Overpressure exceedance

Gas cloud size exceedance →



LEAK SCENARIOS

An individual release scenario is typically specified by a number of parameters such as:

- The released material and its conditions (pressure and temperature).
- The location and orientation and the size of the leak.
- The wind speed and direction.

These parameters are not chosen arbitrarily:

- Each leak is associated with some item of equipment, the frequency of leaks of differing sizes is found by a "parts count" which supplies the number of items of various types – valves, flanges etc. – and historical data on failure rates for these items.
- The wind speed and direction are chosen from a probability distribution characterised by the wind rose for the location.

THE MAIN PROBLEM

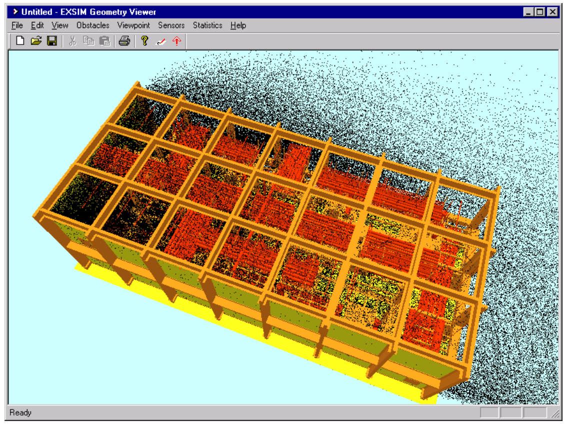
Have two desires:

- Would like to do enough gas dispersion calculations to properly characterise the gas build-up exceedance curve.
- Would like each calculation to be accurate.

These two desires pull in opposite directions:

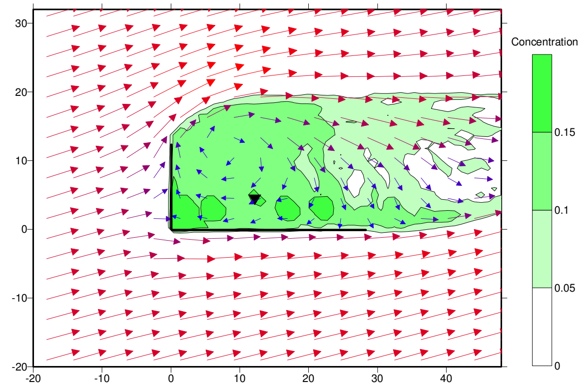
- Using a Monte Carlo approach, over a thousand dispersion calculations may be required.
- CFD calculations have, historically, been too slow to allow this.

PREVIOUSLY...



The Shell methodology has historically emphasised the Monte Carlo aspect of the problem.

- Model dispersion using particle based "random walk" model.
- Particle velocity =
  - velocity due to jet release momentum+
  - background flow velocity +
  - semi-random turbulent component
- Calculate trajectories of 1000s of independent particles and determine gas concentration
- Assume fixed background flow field calculated from CFD.



2.0

OPENFOAM CFD SOLVER(S)

A steady-state PDR solver with sub-grid jet source.

OPENFOAM (1)

- Open source CFD code.
- FOAM = Field Operation and Manipulation.
- Originates from Imperial College.
- Around since ~1998.
- Available to download.
- Support contracts available from OpenCFD.
- Training available from various suppliers.
- Really “multiphysics”, but seems to have moved to CFD.
- Use C++ features to allow solvers to be constructed writing equations as they are written.

OPENFOAM (2)

- Adopted as platform for next-generation explosion CFD code within Shell Major Hazards Group to replace existing in-house code.
- A Porosity/Distributed Resistance solver (PDRFoam) is part of the standard distribution. Development was funded by Shell.
- OpenFOAM chosen because:
  - Modern architecture.
  - Inbuilt Parallelism.
  - Arbitrary meshing.
  - Flexible & extensible.
  - Safe against vendor changes.

SOLVER OVERVIEW

Basis:

- Compressible SIMPLE-based solver.
- Uses Porosity/Distributed Resistance method (if needed).
- Arbitrary mesh.
- Additional species equation.
- Tabulated thermodynamics.
- Sub-grid release model.

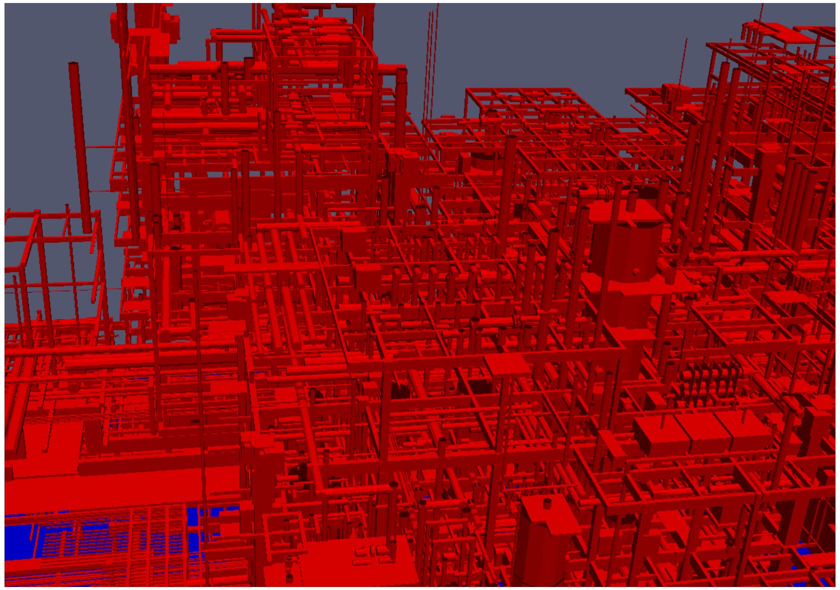
Note:

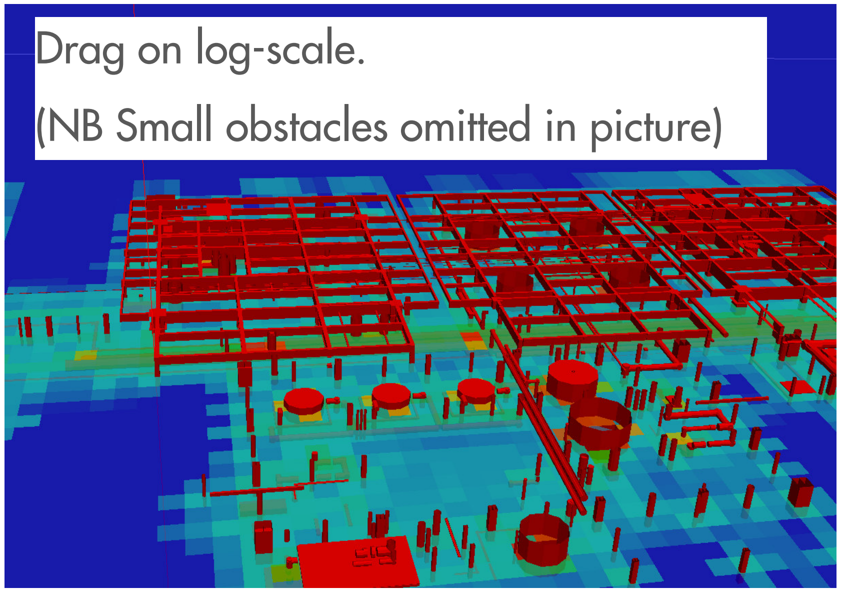
- Transient PDR solver is part of standard OpenFOAM distribution (PDRFoam).
- Solver used here is not PDRFoam, but a steady-state version. Aim is to get "reasonable" dispersion results with short run-time.

POROSITY/DISTRIBUTED RESISTANCE

Convert geometry to cell-wise values of:

- Volume porosity
- Average diameter of obstacles in cell
- Obstacle surface area per unit volume
- (Tensor) drag
- Turbulence generation





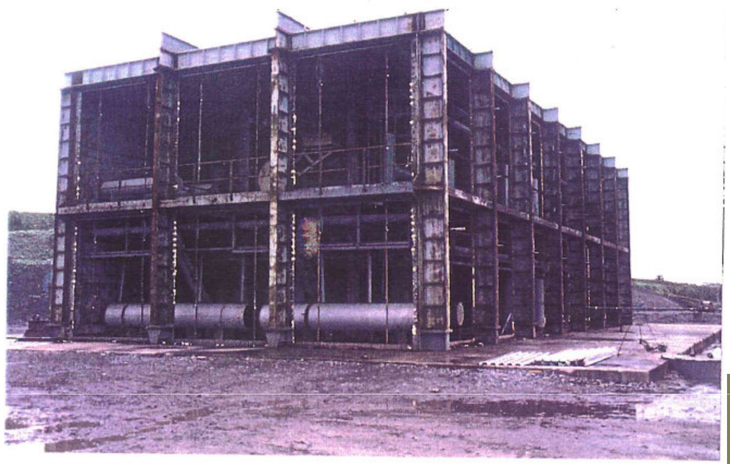
THEMODYMAMICS

- Solver accepts tables, but these produced externally (by any method).
- In this case using Shell in-house thermodynamics code.
- Modified Redlich-Kwong.
- Accounts for condensation/evaporation of ambient water.
- Single species equation (no requirement for water vapour equation etc.)

3.0
VALIDATION

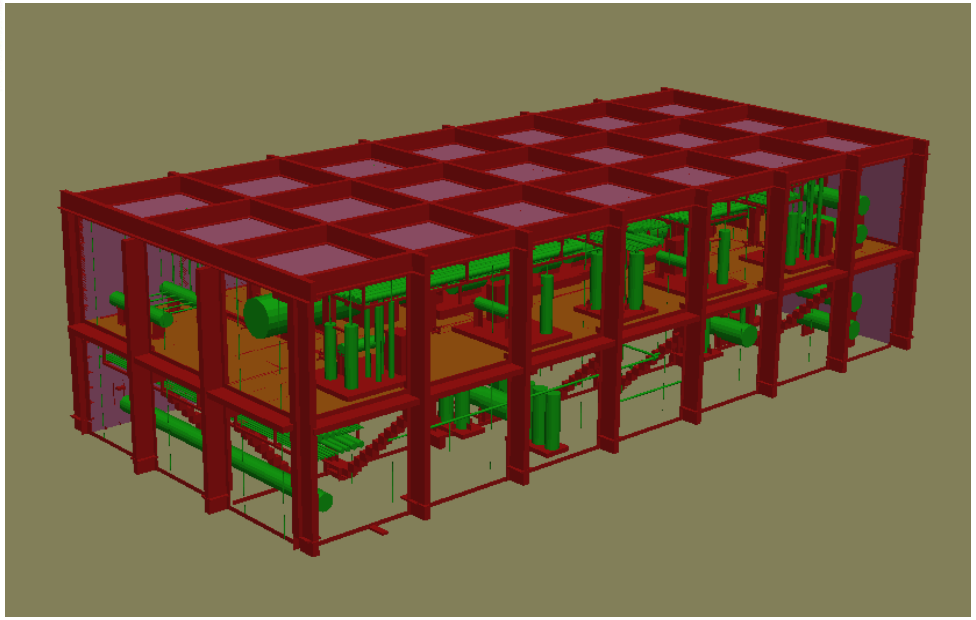
Testing the solver against experimental data.

FULL-SCALE: JIP RIG



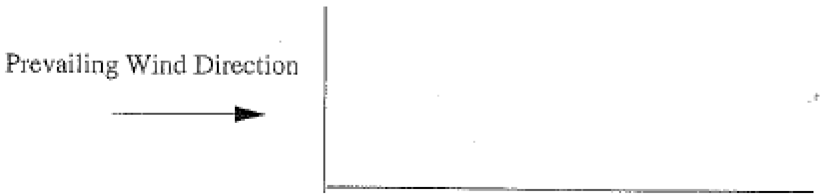
← Physical rig

CAD representation→

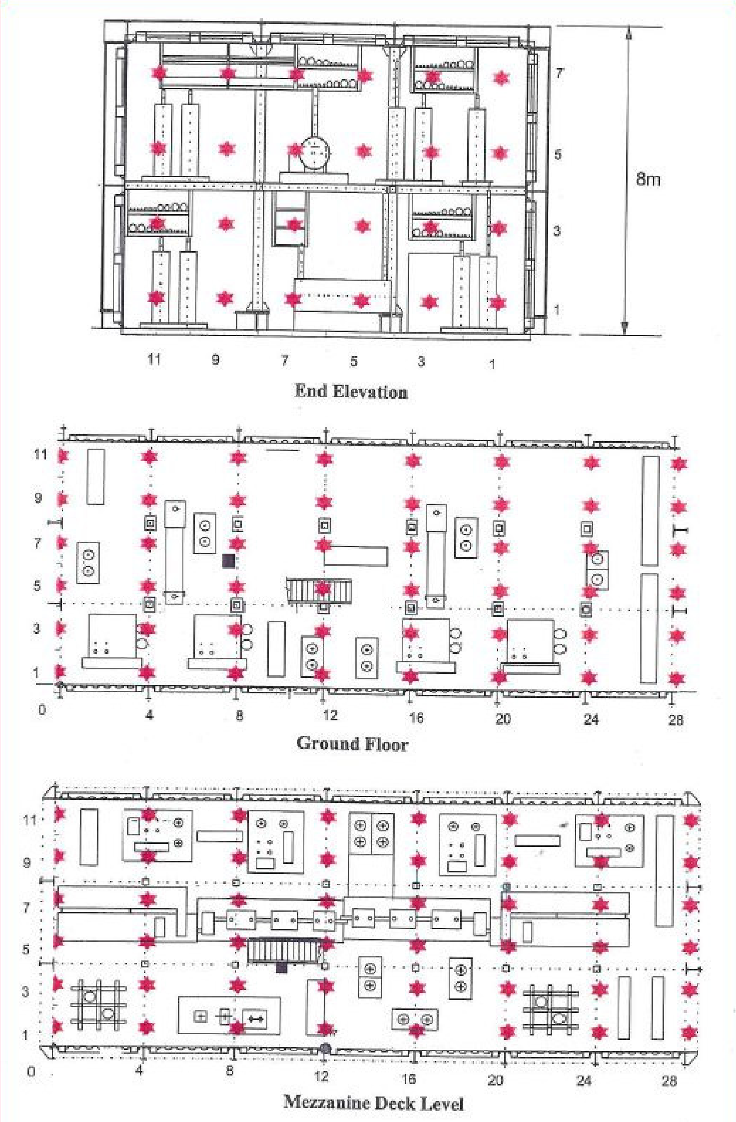


EXPERIMENTAL ARRANGEMENT

Series A & B

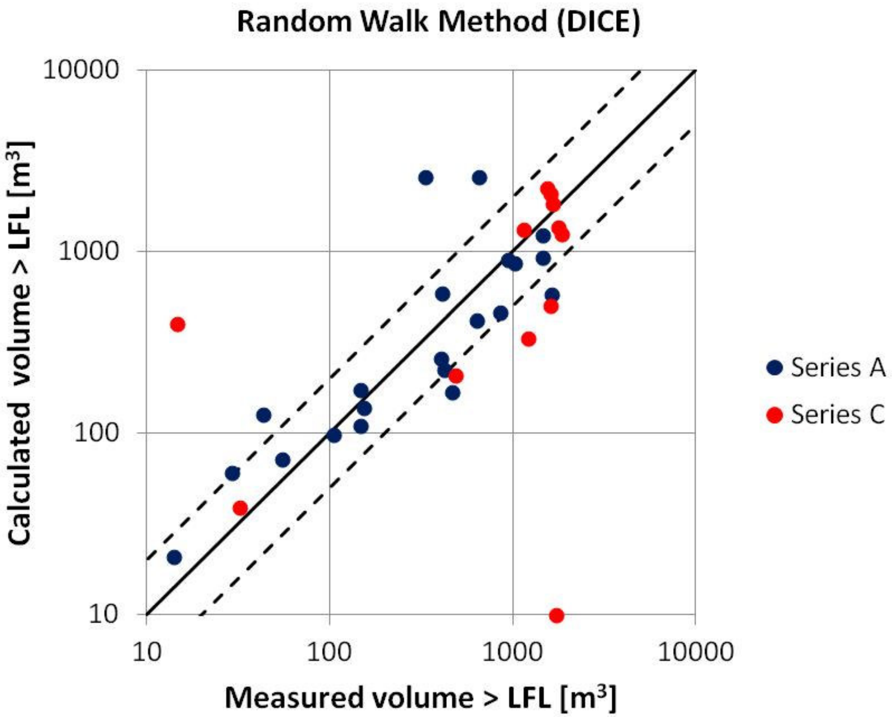


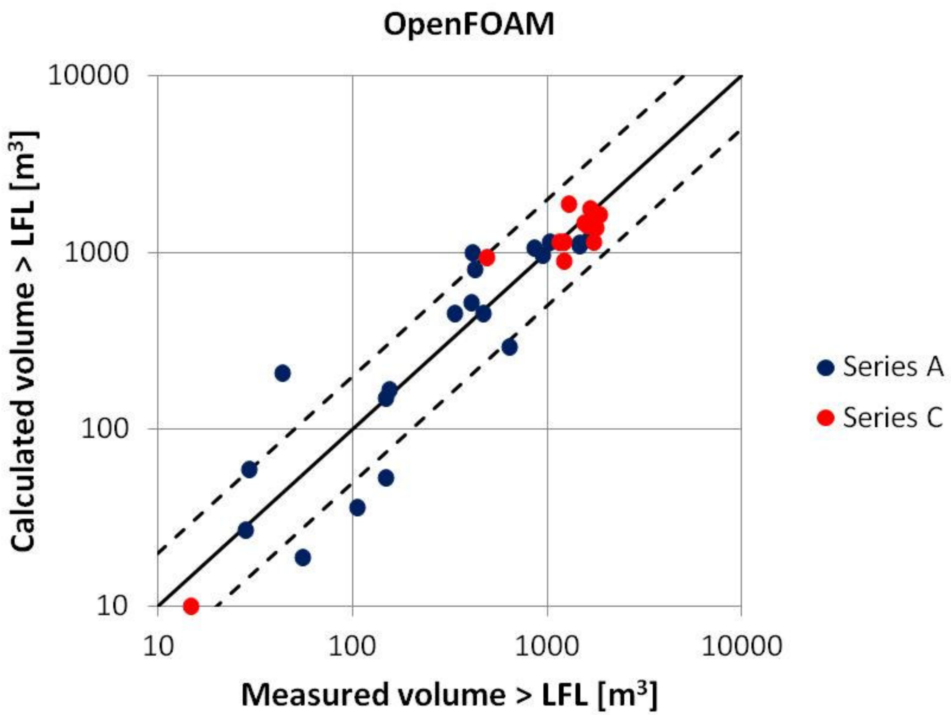
Series C



RESULTS: FLAMMABLE GAS VOLUME

- Experimental gas cloud volume found from number of measurement locations with concentration above lower flammable limit.

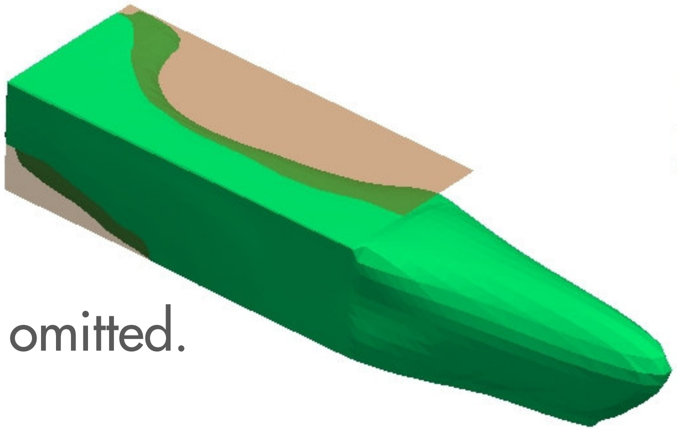


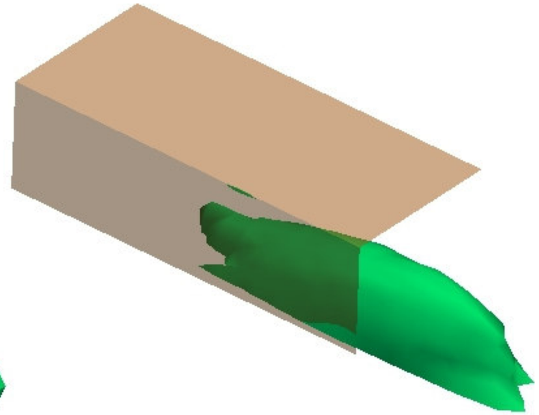


- CFD results are improvement on previous methodology – less outliers.

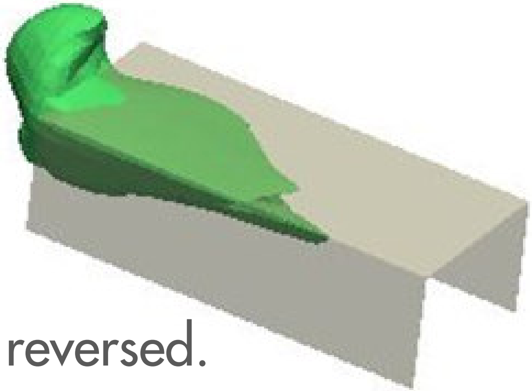
RESULTS: CASES WHERE DICE AND CFD DIFFER

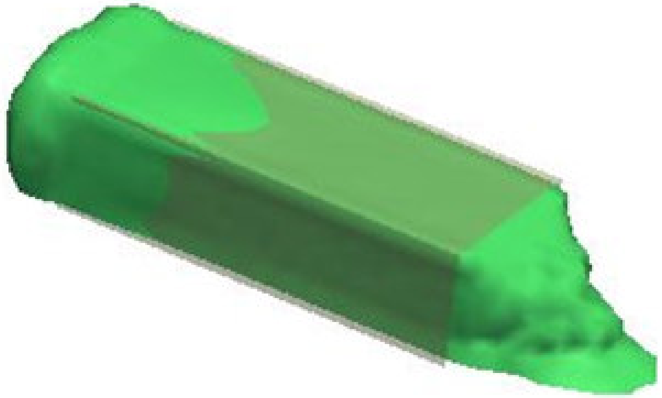
- Some cases where DICE gives poor results:





- Case C05: obstacle omitted.

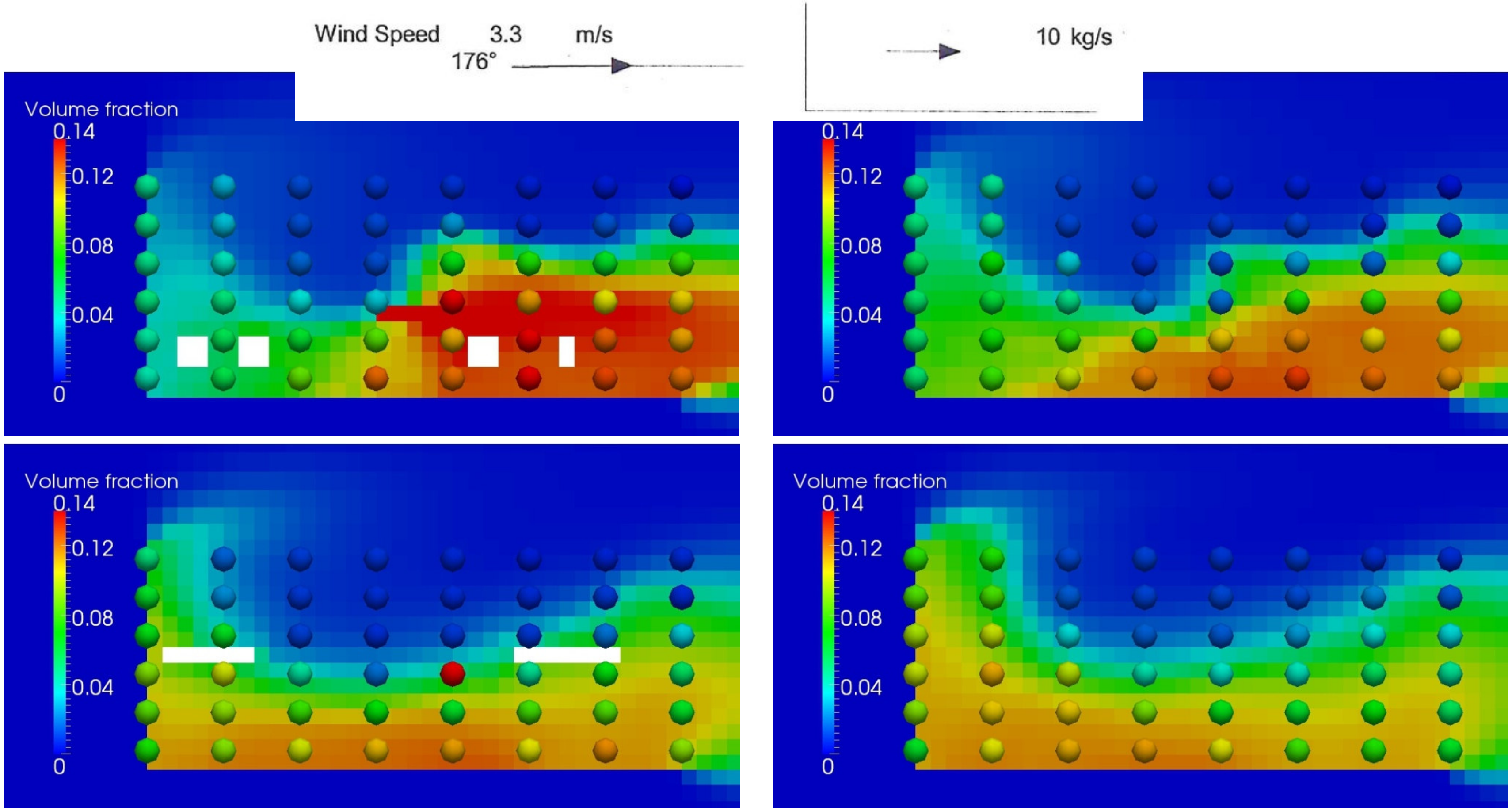




- Case A28: flow reversed.

CASE C05 CFD RESULTS

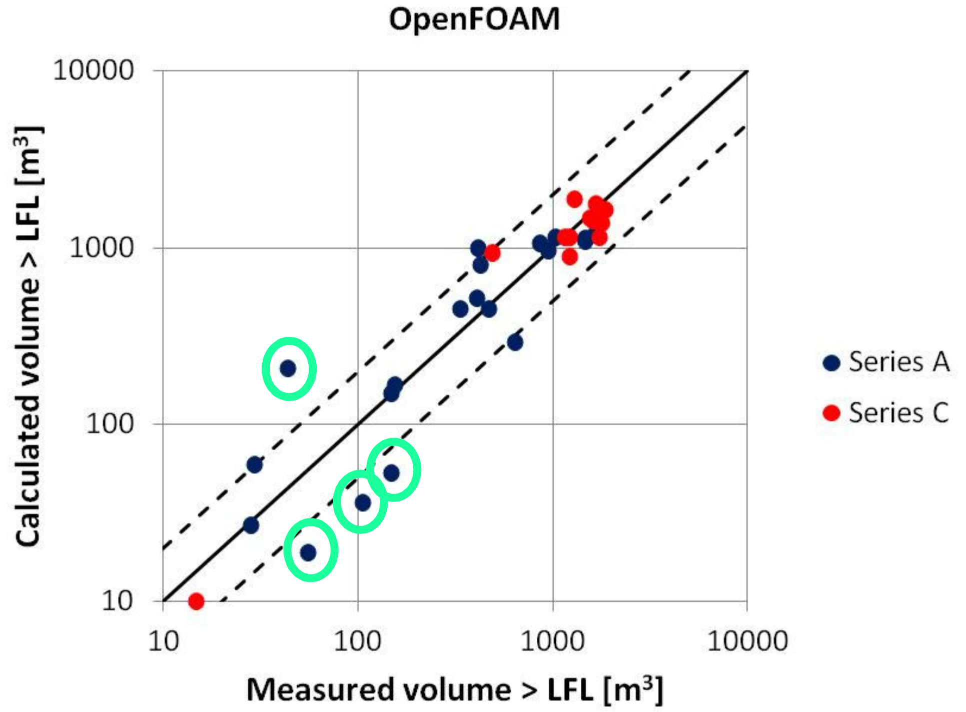
- Concentration on 4 planes at 1, 3, 5 and 7 m above ground.



- CFD results shown by contours, experiment by spheres on same scale.
- Spheres placed at measurement locations.

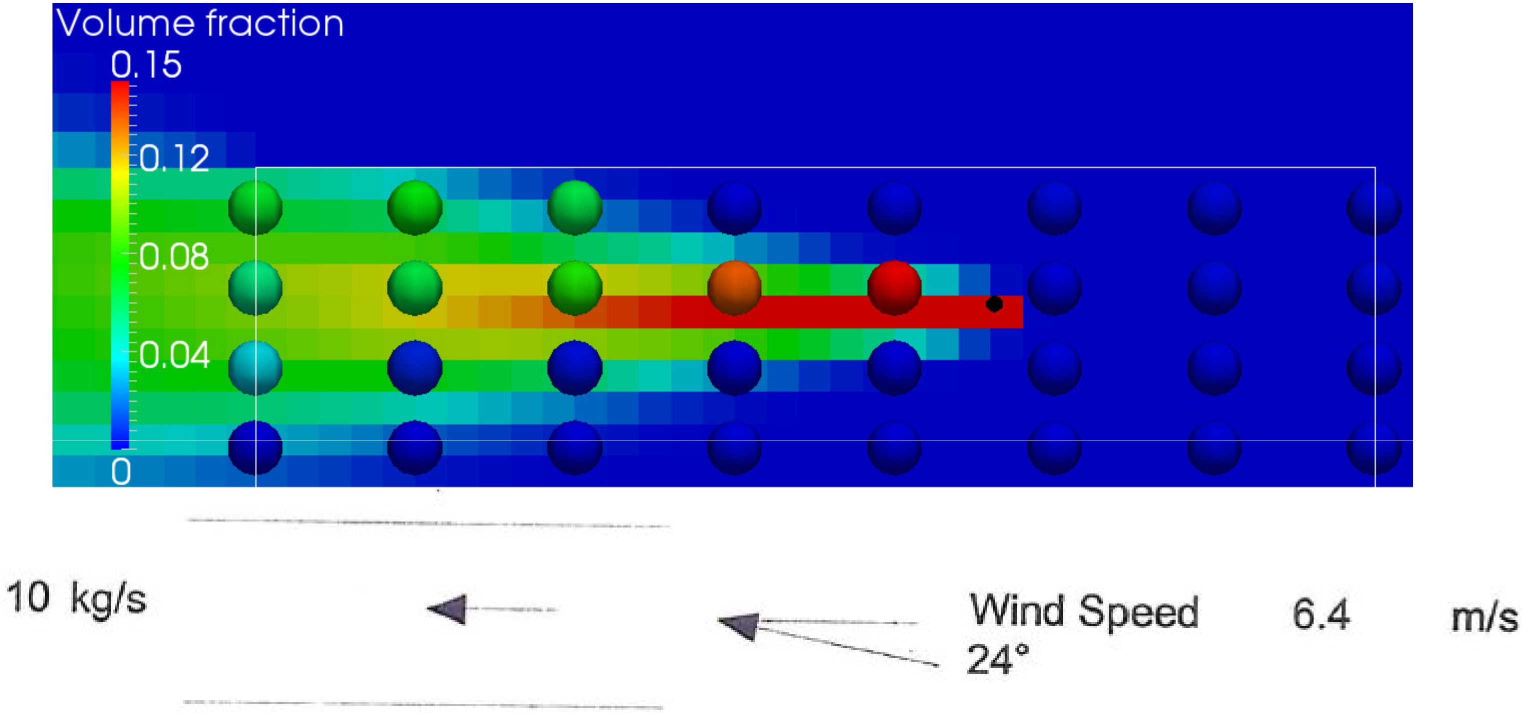
RESULTS: CASES WHERE CFD IS POOR

- Some cases where CFD gives poor results are:
  - For A2, A22, A24 CFD under-predicts.
  - For A8 CFD over-predicts.



CASE A02 CFD RESULTS (OPENFOAM UNDER-PREDICTS)

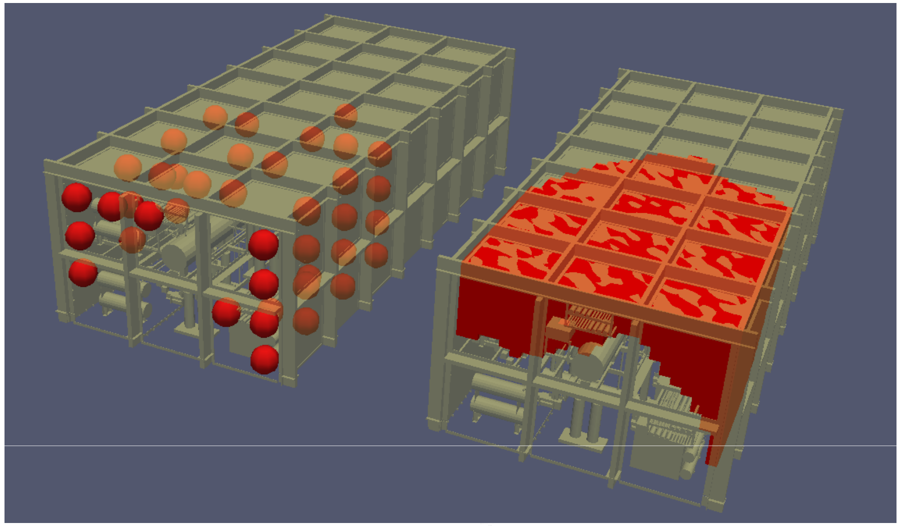
- Concentration on vertical plane though release.

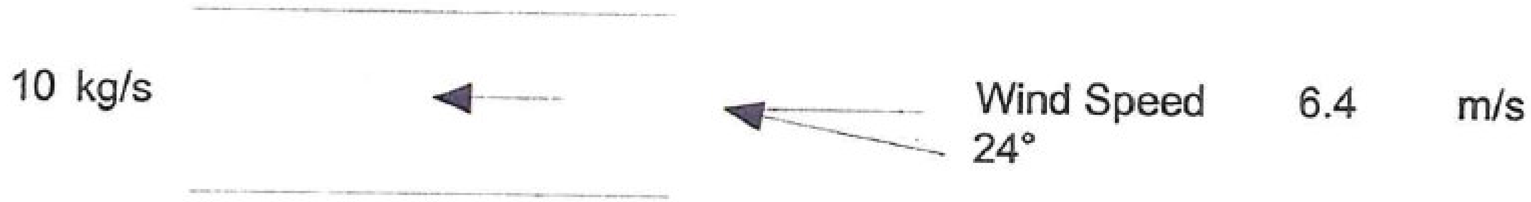


- CFD results shown by contours, experiment by spheres on same scale.
- Spheres placed at measurement locations.
- Black point shows release location.
- Results actually quite reasonable.

CASE A17 CFD RESULTS (OPENFOAM OVER-PREDICTS)

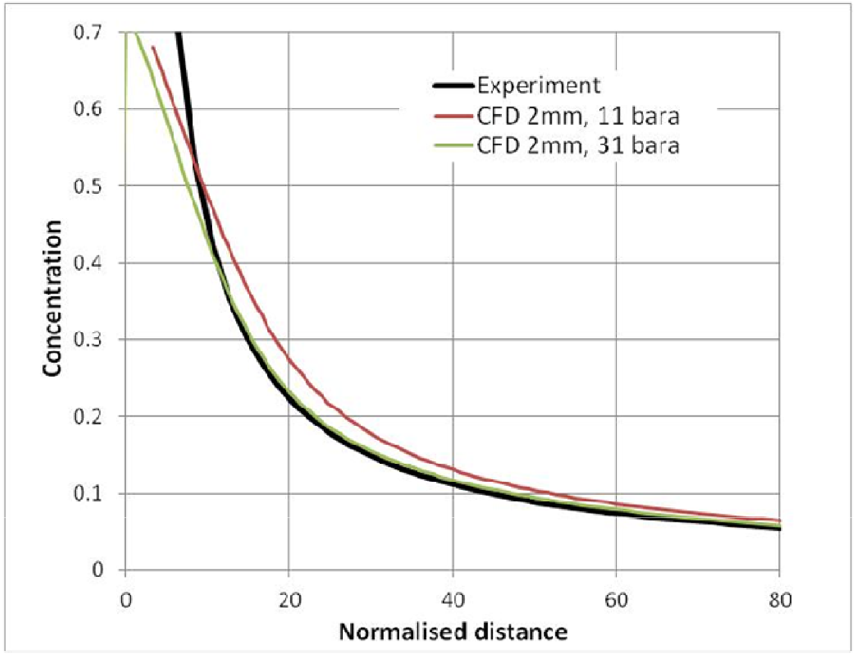
- Locations with concentration above 2.5%.

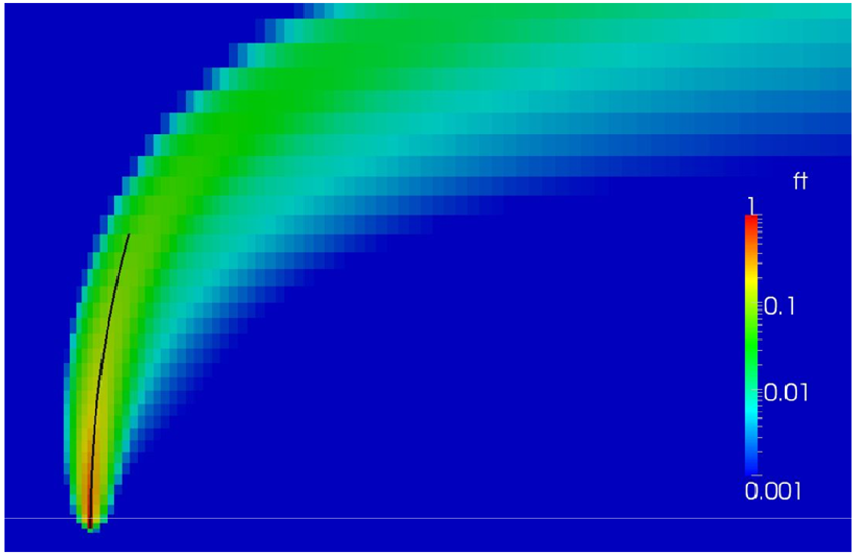




- CFD results shown by isosurface (right).
- Spheres placed at measurement locations (left).
- Cloud shape is reasonable.
- Experiment has large volume a little below LFL, CFD a little above.

SUB-GRID JET MODEL

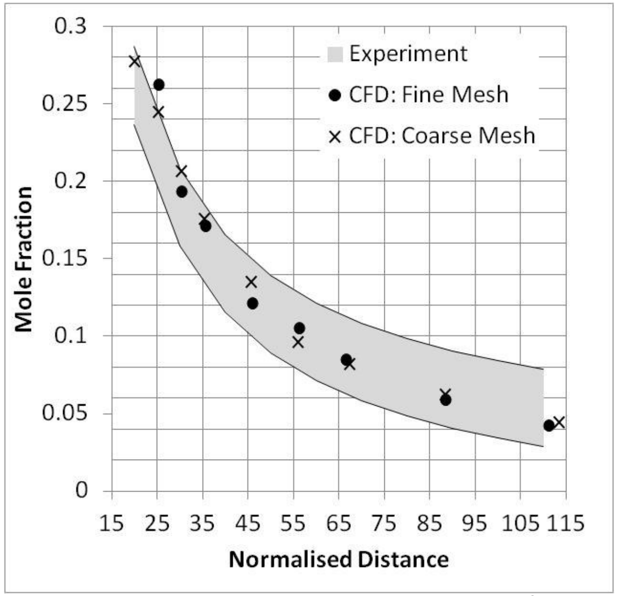




↑

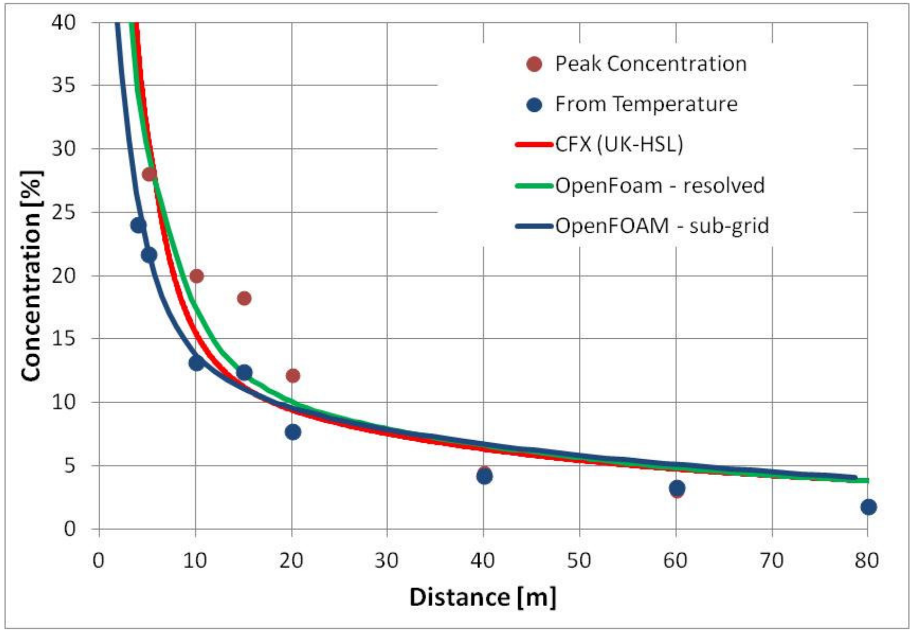
Free choked methane jet

Full scale methane jet in cross-flow →



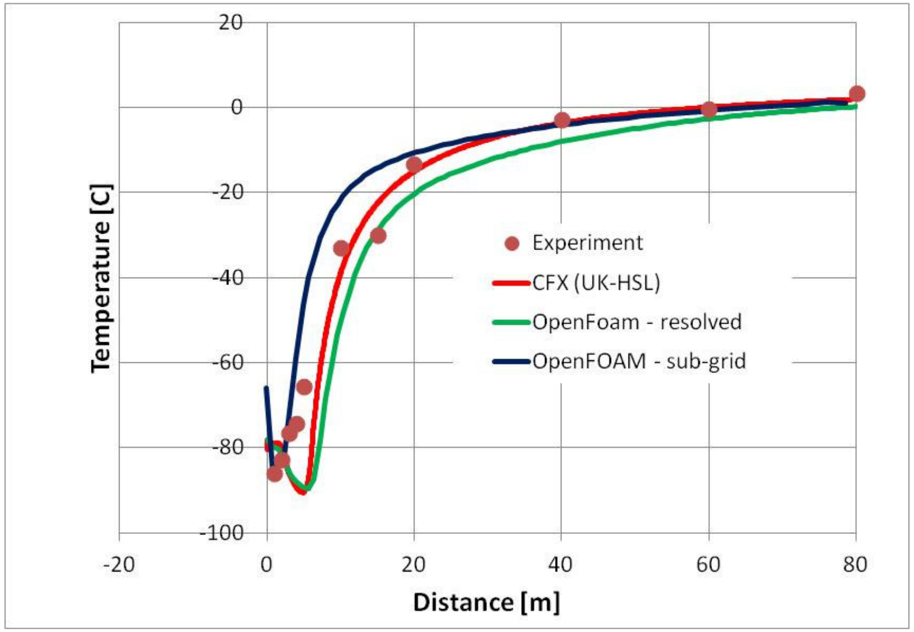
SUB-GRID JET MODEL – FLASHING CASE (CO2)

- Horizontal liquid CO2 release at 150 bar.



←Concentration vs. distance

Temperature vs. distance →

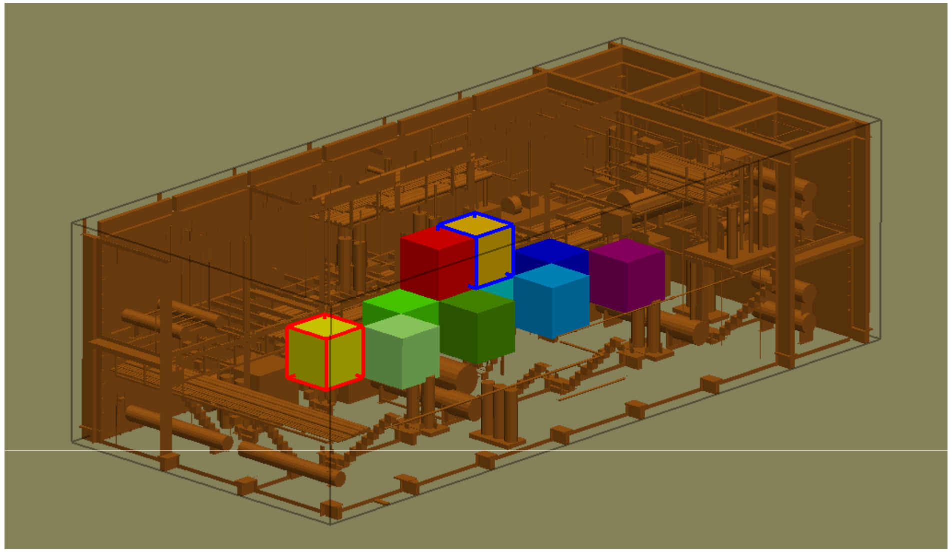


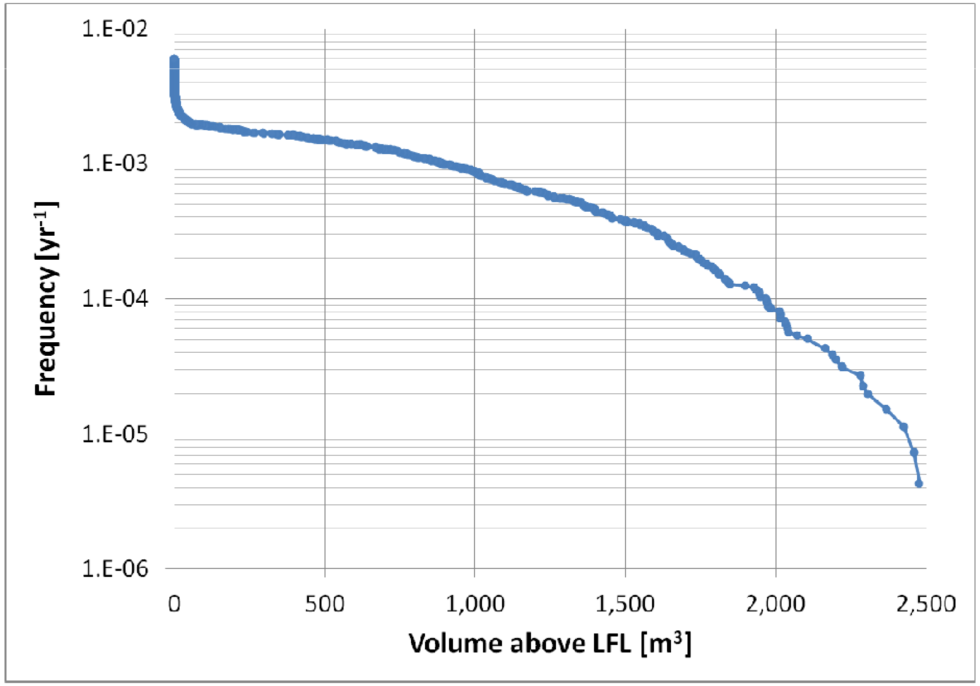
SAMPLE EXCEEDANCE CURVE

- Use JIP rig geometry.
- Use wind rose from a previous project.
- Assume some plant items in 10 distinct 2 m cubes within the rig.
- Assume that each item has 25 and 50 mm releases.
- Assume some leak frequencies.
- Discretize wind into 8 directions (N, NE, etc). For each leak scenario do at least two releases for each wind direction – one in lower half of wind speed probability distribution one in lower half.
- Leak direction is random. Leak location random within cube.
- Number of repeats for each leak scenario depends on leak rate and frequency.

SAMPLE EXCEEDANCE CURVE

- A typical resulting exceedance curve is shown below.





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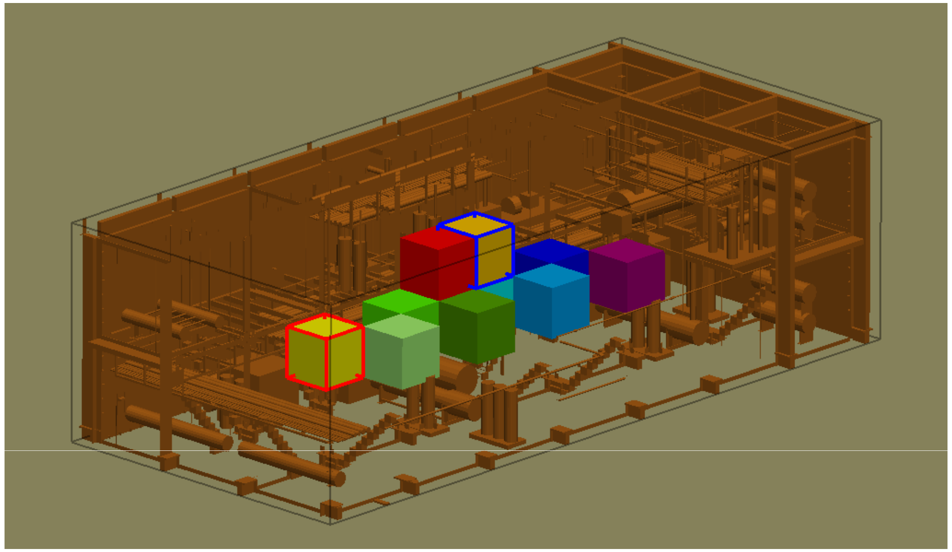

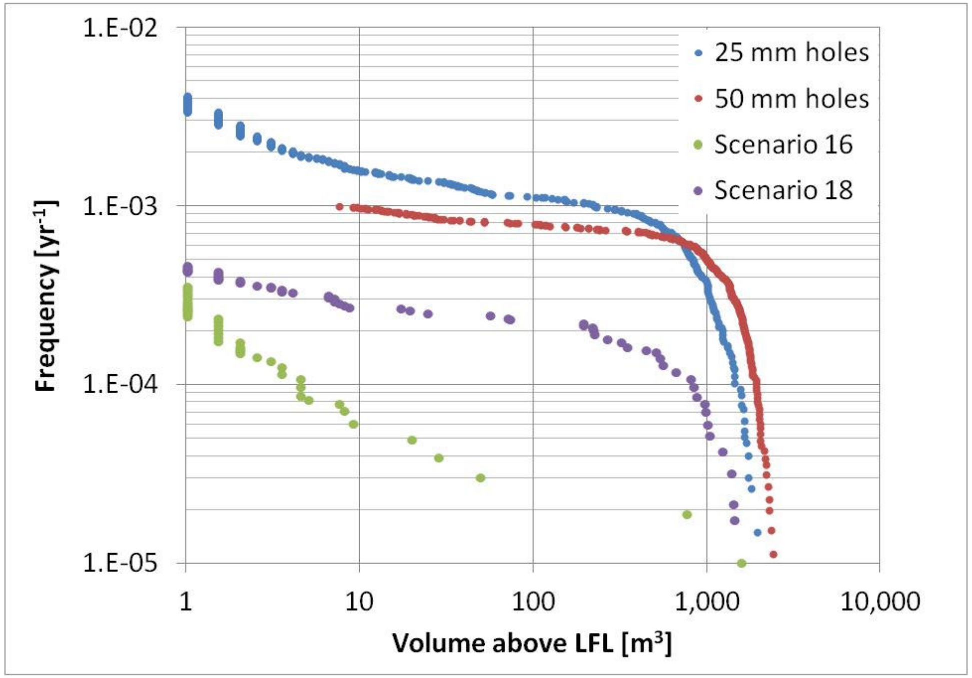

SUMMARY

- OpenFOAM can provide a reasonable platform for gas dispersion CFD:
  - PDR and resolved regions can be mixed and matched.
  - PDR regions can be locally refined.
  - Flexible, extensible…
- Generally gas cloud exceedance calculations accentuate the need for either “accurate” individual dispersion calculations or a statistically meaningful number of calculations. The word “accurate” should be taken in context.
- Until recently it has not been possible to undertake a sufficiently large number of CFD calculations to solve the Monte-Carlo problem.
- It is now becoming possible using a steady-state PDR approach to solve the Monte-Carlo problem directly using CFD calculations.