Institute of Particle Science and Engineering
FACULTY OF ENGINEERING

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Large-Scale Validation of a Numerical Model of Accidental Releases from Buried CO_2 pipelines

Dr Chris Wareing

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University of Leeds, UK: C J Wareing, R M Woolley, M Fairweather, S Falle
GL Noble Denton: D Allason, K Armstrong, R P Cleaver

Overview

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- Brief introduction to Carbon Capture and Storage
- The COOLTRANS Research Programme
- Near-field sonic dispersion of carbon dioxide (CO_2) from high pressure pipelines
  - Thermodynamic model
  - Numerical method
  - Validation
    - Liquid phase release
    - Gas phase release
- Application to buried CO_2 pipelines

Carbon Capture and Storage

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- Climate change has emerged as society's biggest ever environmental challenge.
- Carbon Dioxide (CO_2) in the upper atmosphere reflects the Sun's heat back down to Earth, further warming the atmosphere like a greenhouse.
- Carbon Capture and Storage (CCS) presents a viable short-term option to reducing CO_2 emissions.
- The simple premise is that CO_2 is captured at the emitter (e.g. power plant or industrial source) and then stored, thereby avoiding release into the atmosphere and exacerbating any man-made climate change.
- But, storage sites, for example disused oil fields or saline aquifers are not usually close to the CO_2 emitter.

COOLTRANS Research Programme

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- The electricity and gas global company National Grid's expertise in building and running safe and effective pipeline networks could play a critical role in helping the UK to meet its obligation to cut CO_2 emissions by 20 per cent by 2020 through provision of CO_2 transport services to support deployment of CCS technology.

- National Grid initiated the TRANSport of Liquid CO_2 (COOLTRANS) Research Programme to address knowledge gaps relating to the safe design and operation of onshore high pressure pipelines for transporting liquid CO_2 from industrial emitters to storage sites offshore.

- As part of this programme, the University of Leeds is undertaking research into the near-field sonic dispersion of CO_2 from an accidental puncture or rupture of the high pressure pipeline.

Near-field dispersion model

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(Wareing et al. 2013, AIChE J. doi:10.1002/aic.14102)

- Thermodynamic model:
  - Near-field dispersion of CO_2 in the gas, liquid and solid phases into dry air.
  - Novel composite equation of state for pure CO_2 employing:-
    - the Peng-Robinson equation of state in the gas phase;
    - tabulated data derived from the Span & Wagner equation of state for the liquid phase and vapour pressure;
    - and NIST/DIPPR data for the solid phase and latent heat of fusion.
  - Calculations were undertaken using the Helmholtz free energy in terms of temperature and molar volume, as all other thermodynamic properties can be readily obtained from it.
  - Homogeneous equilibrium model, but a simple sub-model for relaxation to equilibrium is required for the solid phase, as it would appear that the particles are not sufficiently small enough to be in equilibrium.

Near-field dispersion model

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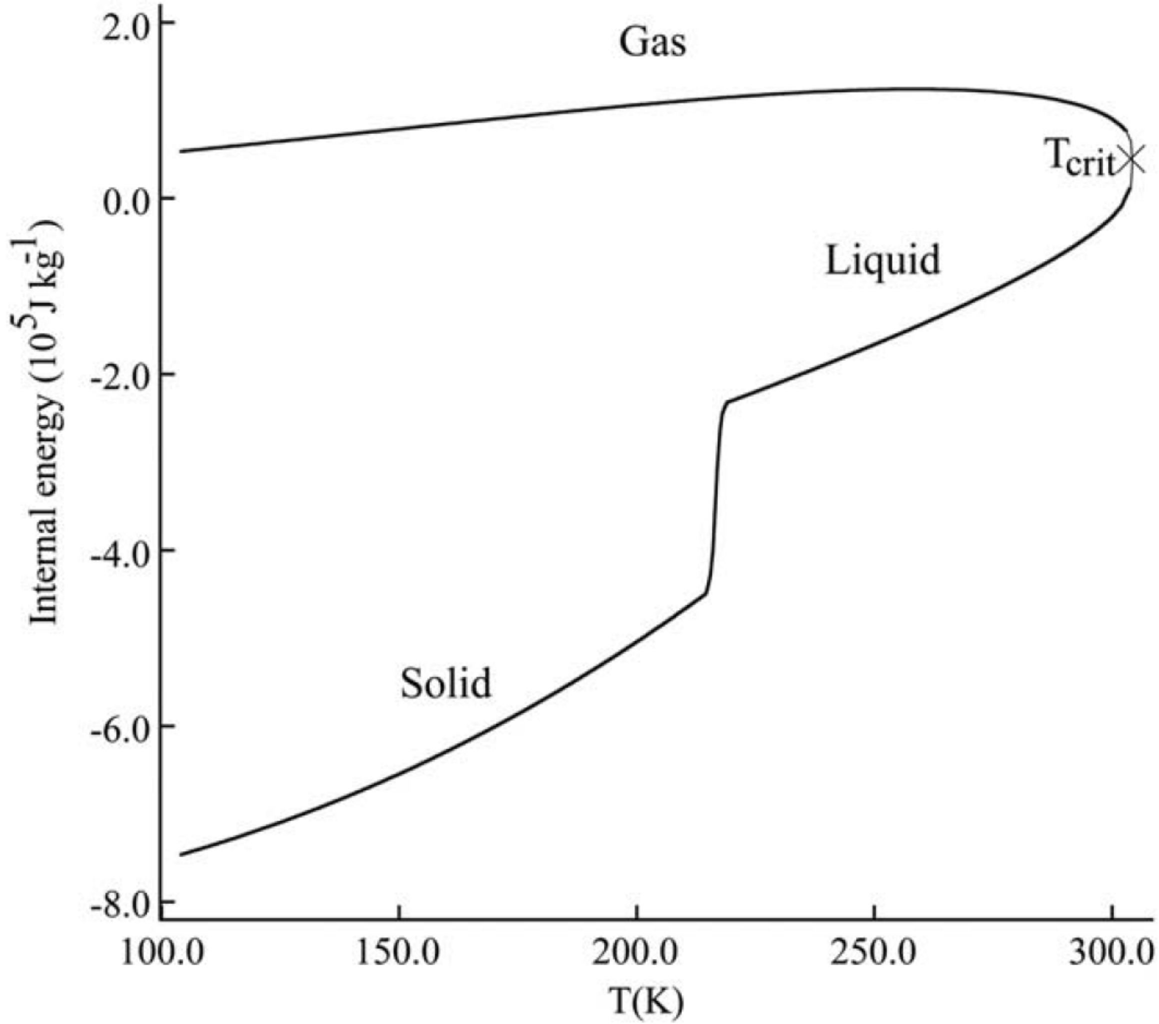
- Thermodynamic model (continued):



- Internal energy on the saturation line.
- T_{crit} marks the critical temperature.
- The triple point can be identified by the steep connection between the liquid and solid phases – the latent heat of fusion.

Near-field dispersion model

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- Numerical method:
  - Adaptive, finite-volume grid algorithm with 2D or 3D rectangular mesh.
  - Grid adaption achieved successive overlaying of refined layers of computational mesh.
  - Where steep gradients of variable exist, such as at the Mach shock in this case, the mesh is more refined. This technique enables the generation of fine grids in regions of high spatial and temporal variation. Conversely, coarser grids are allowed where the flow field is smooth.
  - Turbulence model: we employ a standard k-ε model, but since performance is poor for prediction of compressible flows, we include a compressibility correction.
  - Solutions obtained for the time-dependent, density-weighted equations.
  - Efficient, general-purpose shock-capturing, upwind, second-order-accurate Godunov numerical scheme with a HLL Riemann solver.

Near-field dispersion model

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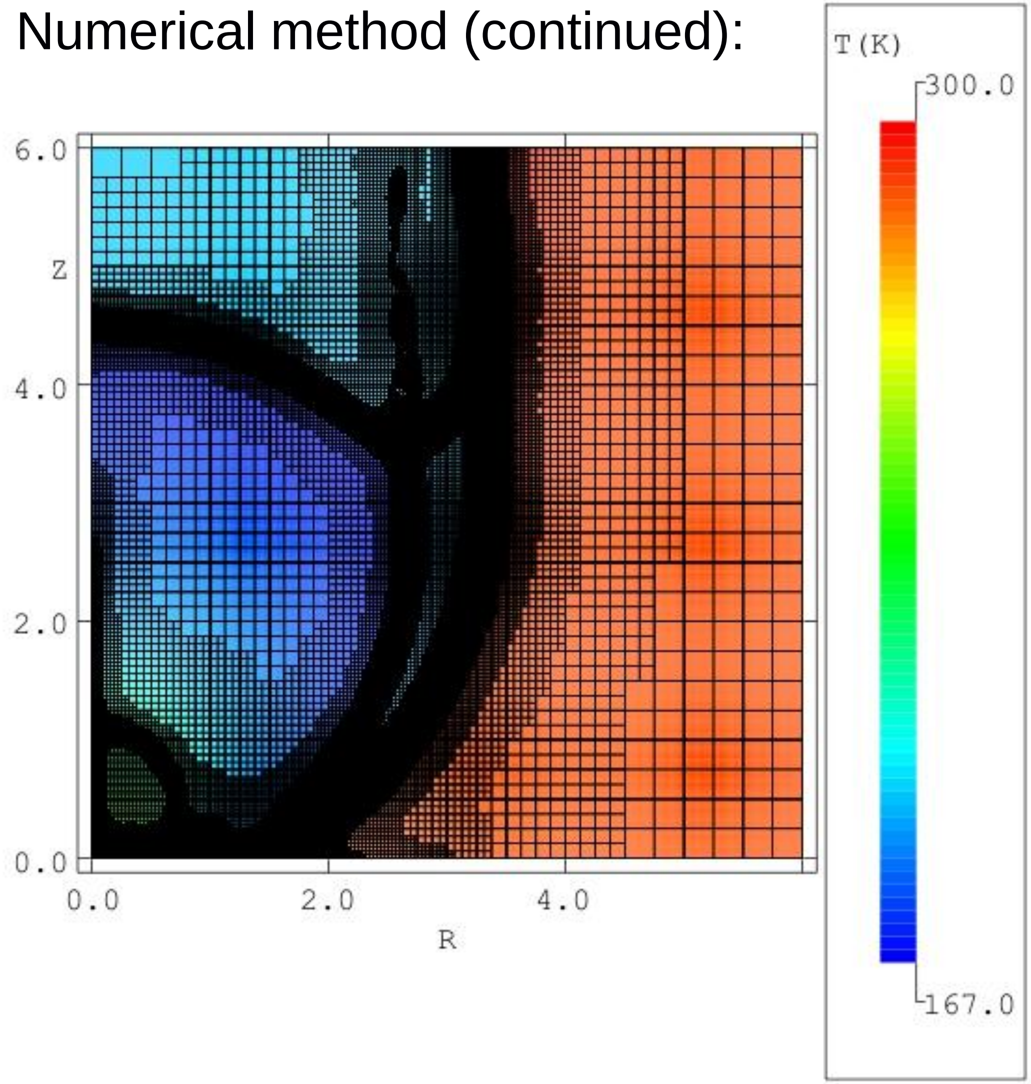
- Numerical method (continued):



- Adaptive meshing around the Mach shock in a dense high pressure release of CO_2.

Note the axis units are in release diameters.

Validation: dense phase release

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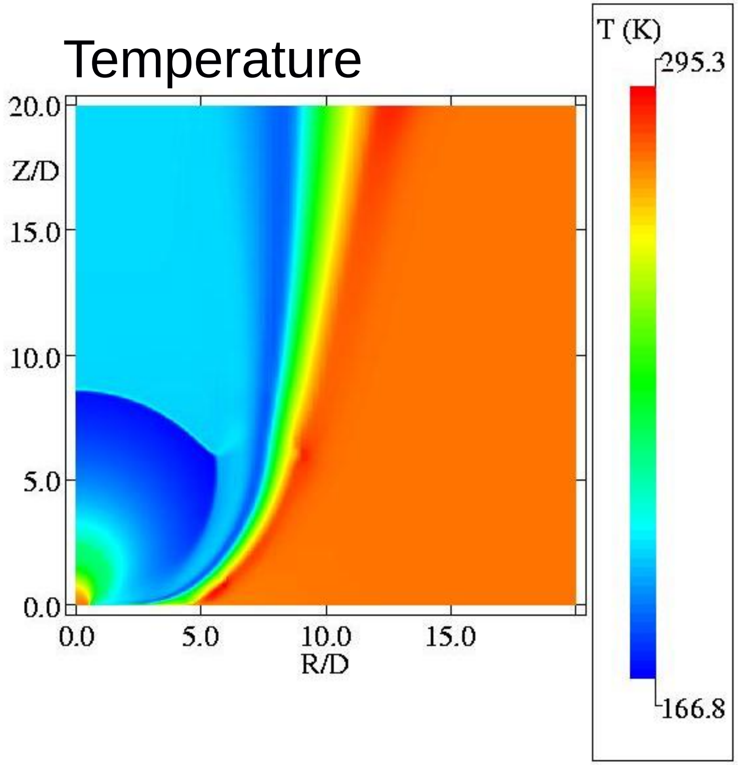
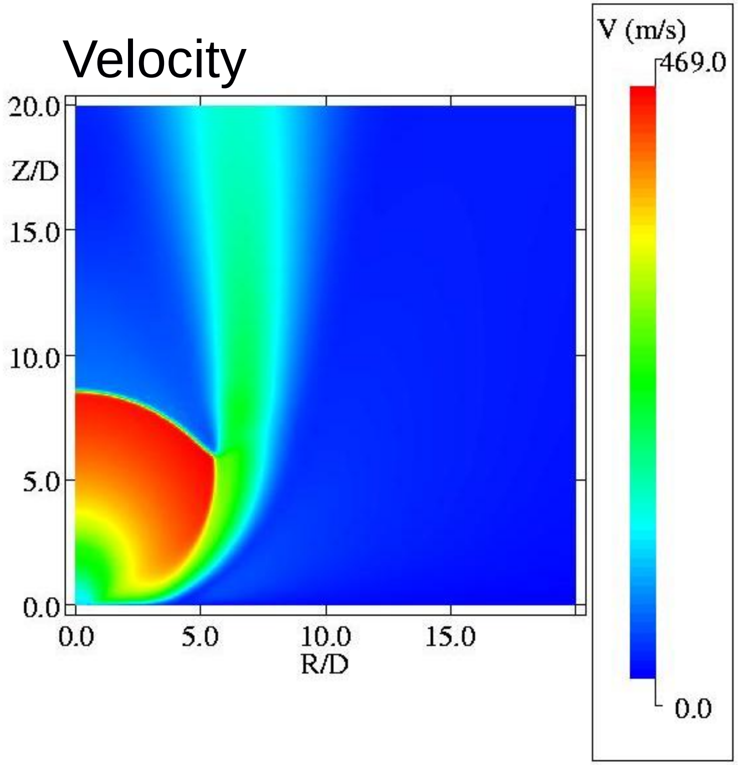
- Dense phase release from a 150bar reservoir through 25mm (D) vent pipe.
- Steady state release conditions achieved by supplying a driving pressure

Temperature



Velocity



Near-field shock containing region: 20D x 20D (0.5m x 0.5m)

Validation: dense phase release

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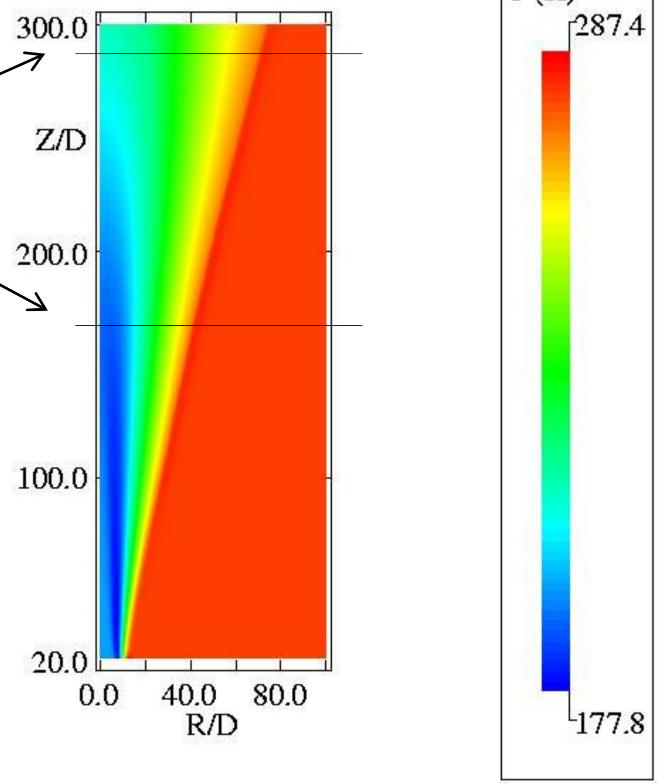
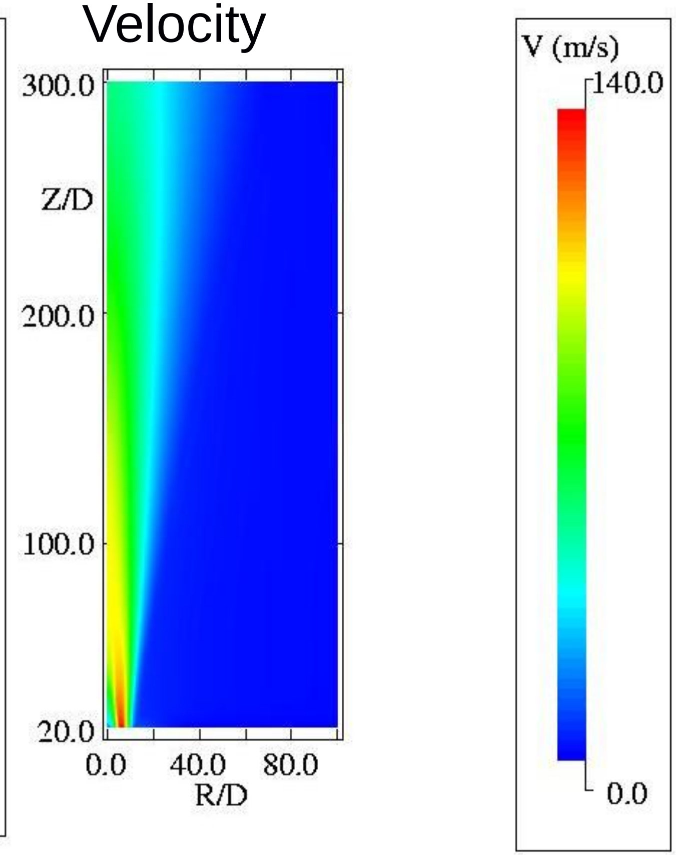
Measuring planes at:

- 4m (165D)
- 7m (288D)

Temperature



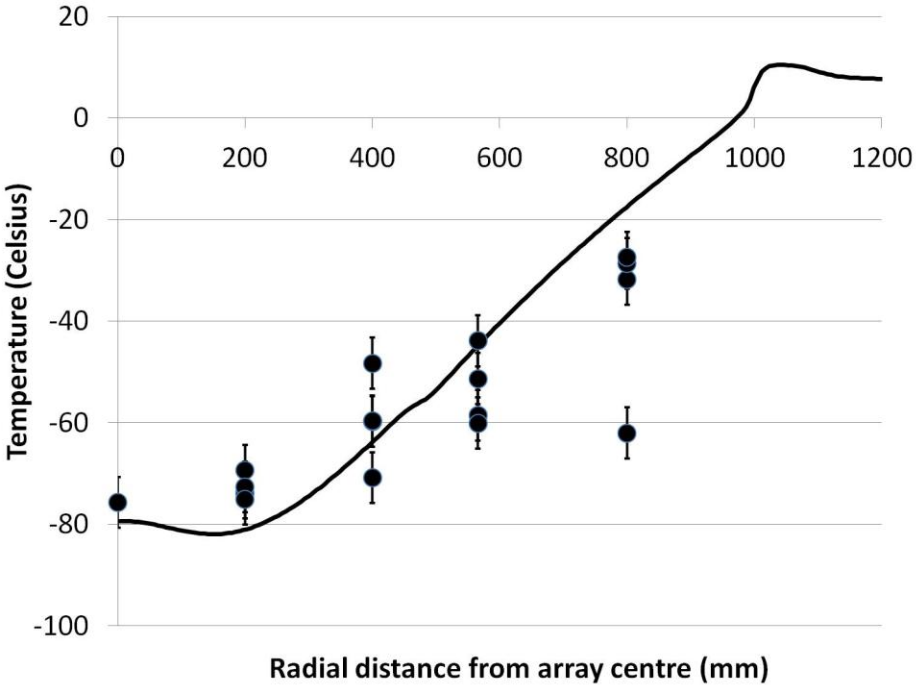
Velocity



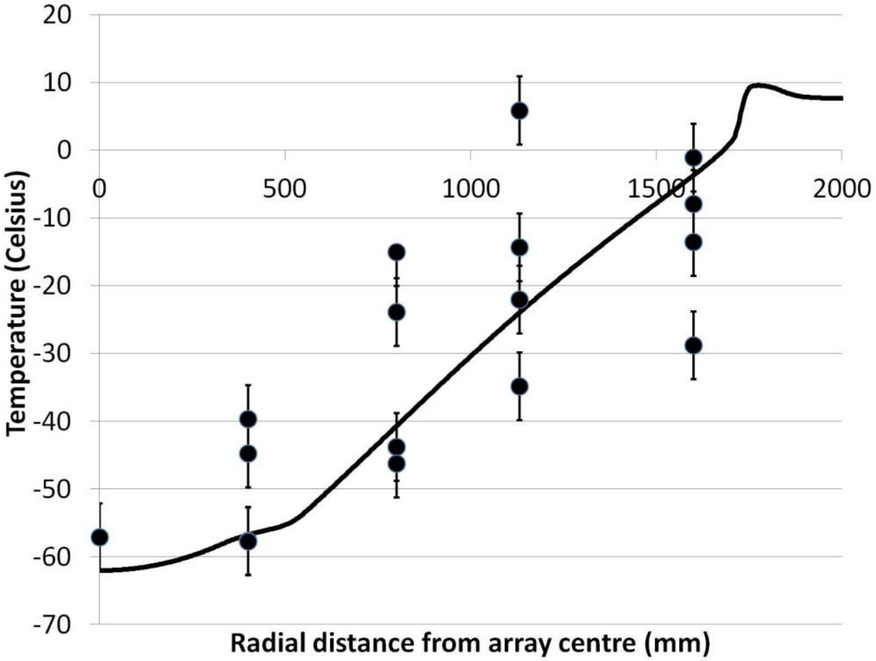
Far-field region up to 300D (7.5m) from the release

Validation: dense phase release

(a) 4m above the vent



(b) 7m above the vent



- Core temperature prediction in good agreement with data at 4m and 7m.
- Predicted jet widths also in good agreement with data.
- A cross-wind of 2.5 m/s has led to some spread in the data at 7m.

Validation: gas phase release

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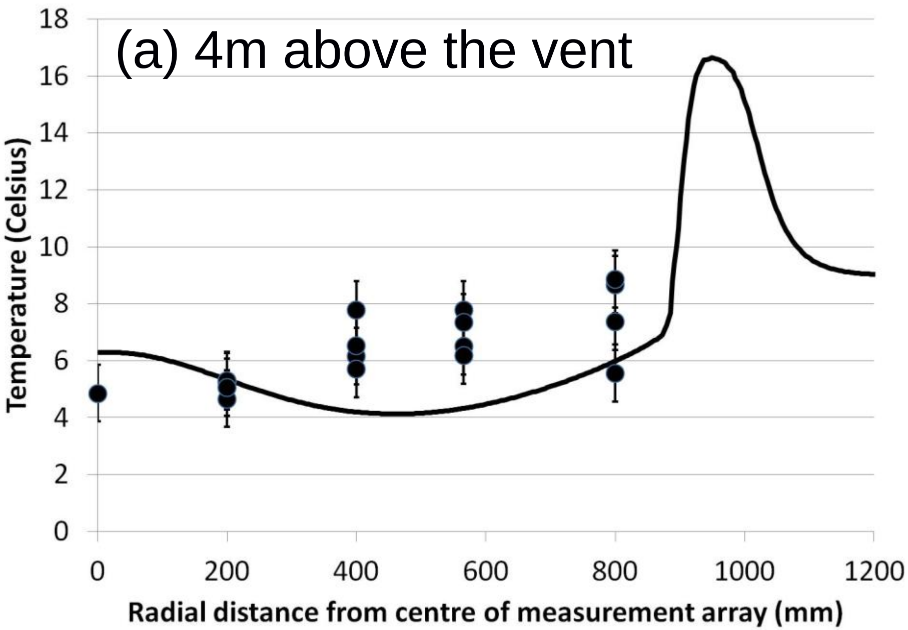
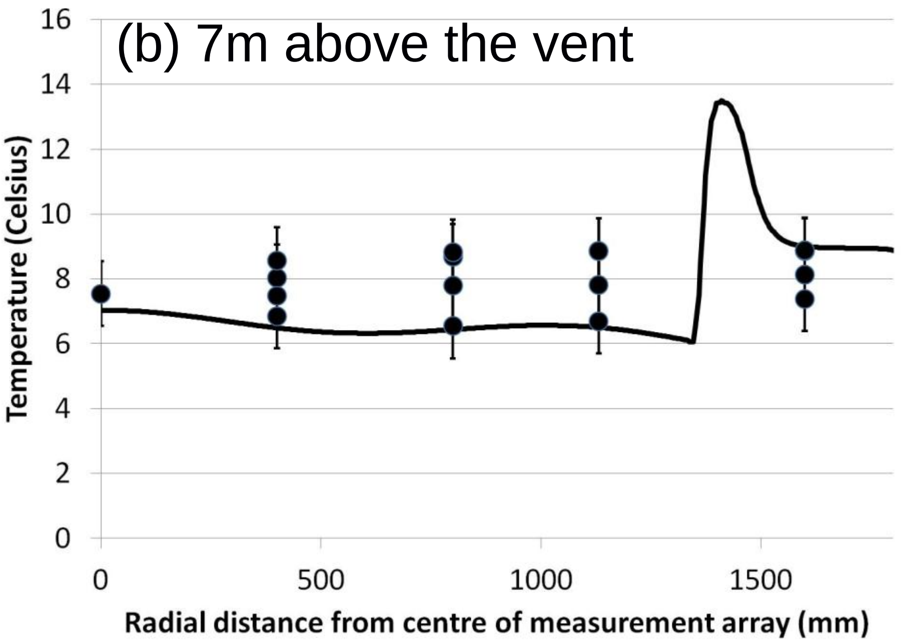
- Gas phase release from a 35bar reservoir through a 25mm vent pipe.
- Steady state release conditions achieved by supplying a driving pressure





- Despite the considerably different temperature range observed as compared to the dense phase release, predicted core jet temperatures and widths are again in good agreement with the data on both planes

Puncture of a buried pipeline

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- Experimental setup
  - 0.9m diameter pipeline buried at typical depth.
  - Pipeline pressurised to 150bar.
  - 25mm diameter circular puncture on the side of the pipe.
  - Preformed crater based on observations of real craters.
  - Experimental measurements taken on arrays 1m and 2m above ground level.

Results

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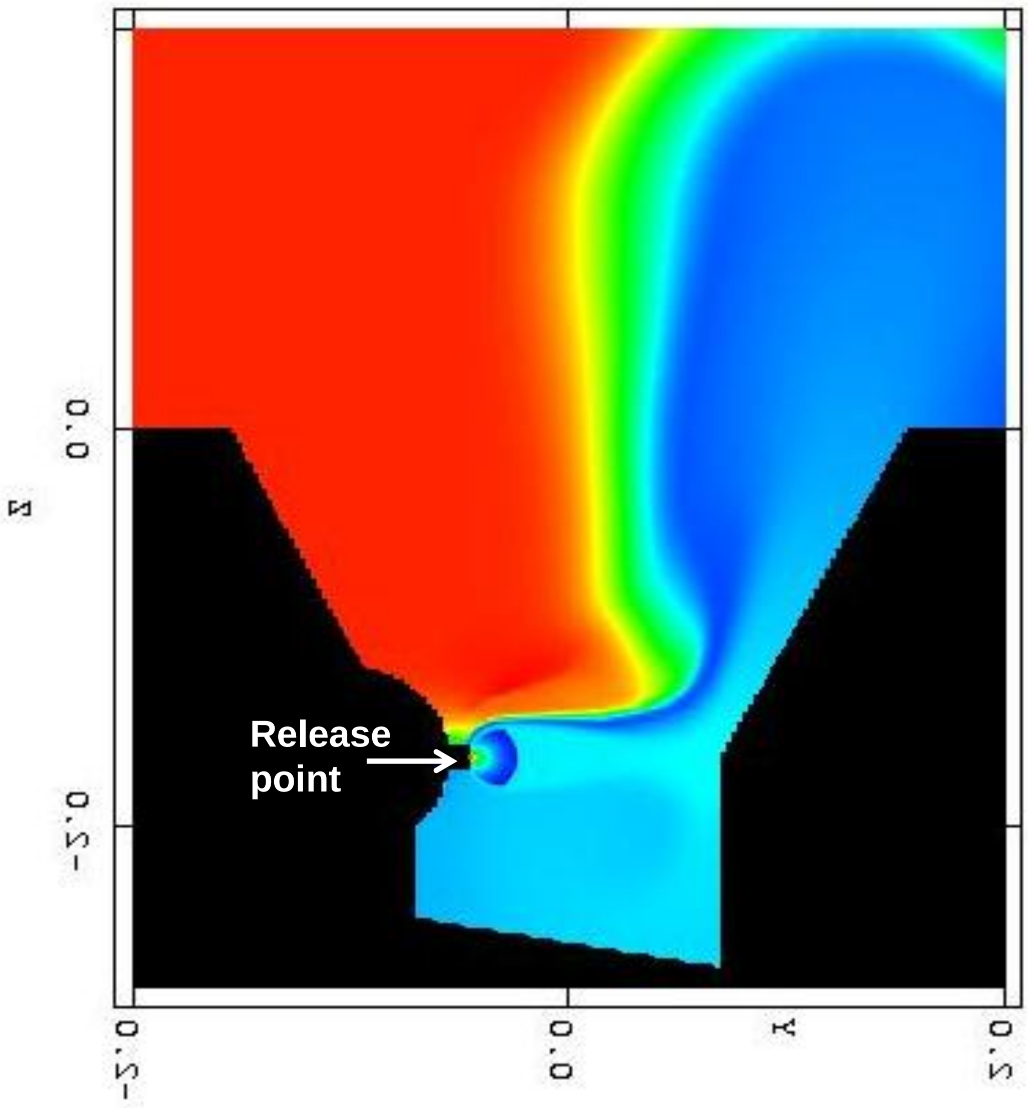

- A slice through the temperature field in the simulation.
- Mach shock structure is clear 0.2m from the puncture.
- When the jet impacts against the opposite crater wall, the flow is divided equally up the crater wall and down into the crater.
- Bottom half of the crater is full of cooled CO_2, 30% of which is in the solid phase, at the sublimation temperature.

Results

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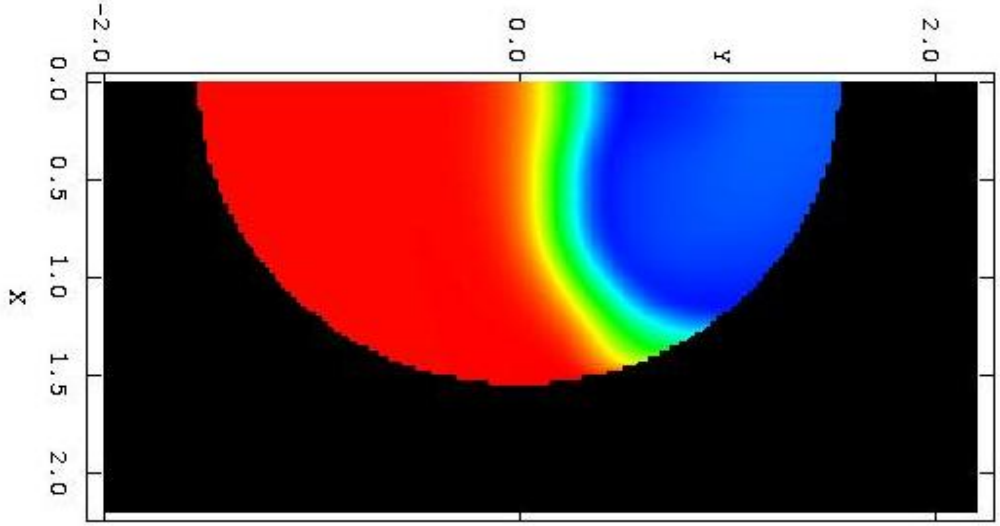

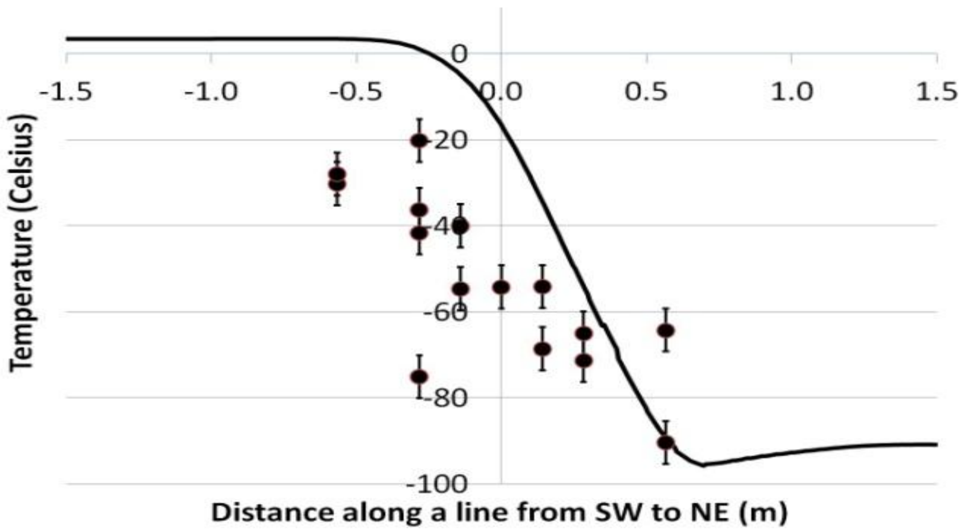

- Upward jet emerges from the crater at atmospheric pressure at ~25 $m\,s^{-1}$ following the angle of the crater wall.

- Upwards jet is approximately 50% CO_2, 25% of that in the solid phase.

- Predictions at 1m above the crater are in good general agreement with the data.

Conclusions

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- Novel dispersion model covering the necessary range of pressures and temperatures in accidental releases of CO_2.
- Validated against dense phase and gas phase free releases and then applied to a puncture in a buried pipeline.
- Future work
  - Impurities in the CO_2 stream.
  - PDF and Lagrangian particle tracker to model particles more accurately.
  - Particle evolution.
  - Reynolds-stress turbulence model.
  - Crater model development.
- Application to:-
  - Further venting events through narrow pipeline.
  - Full-scale ruptures of above and below ground pipelines.

Preliminary particle simulations

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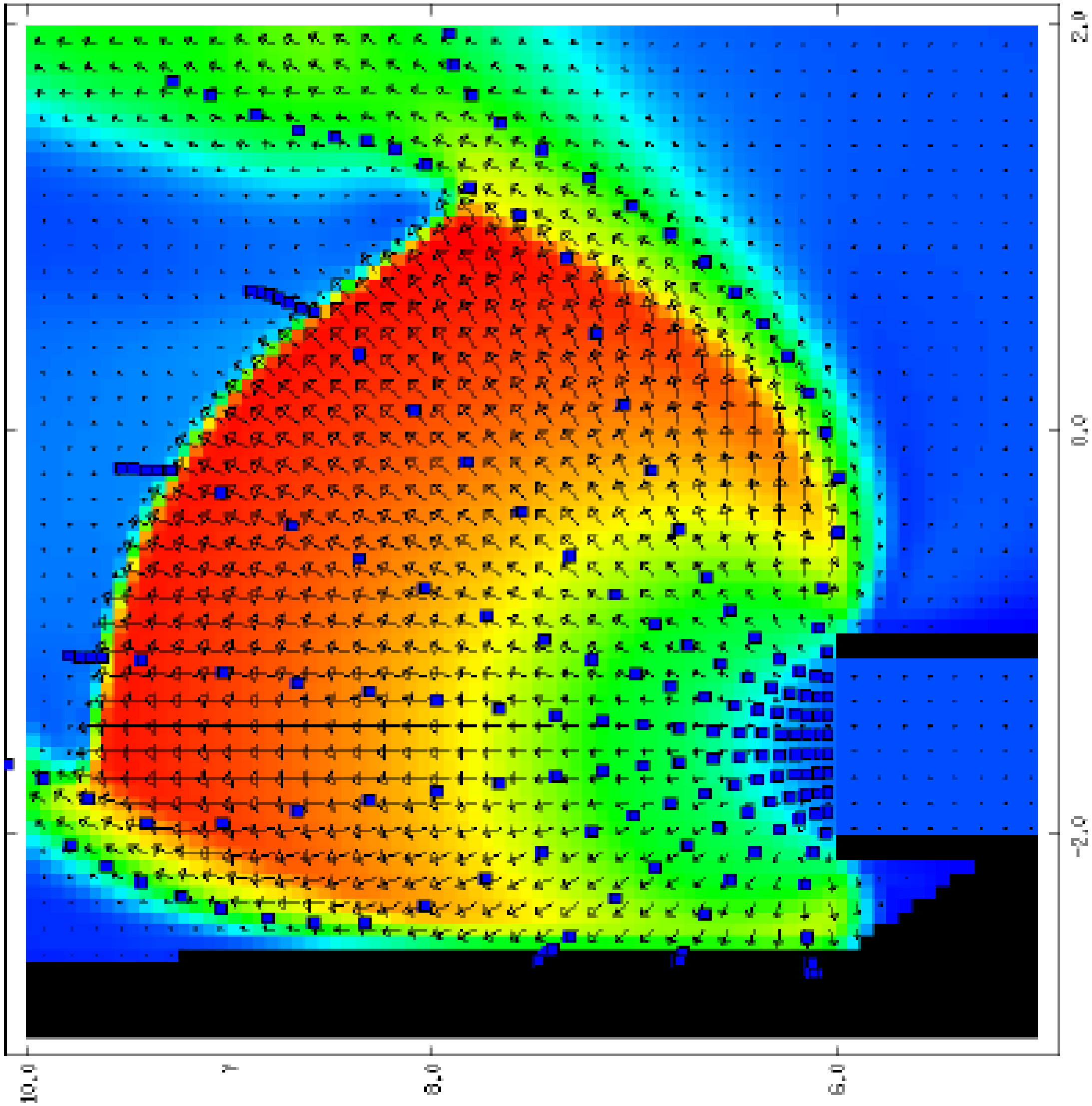

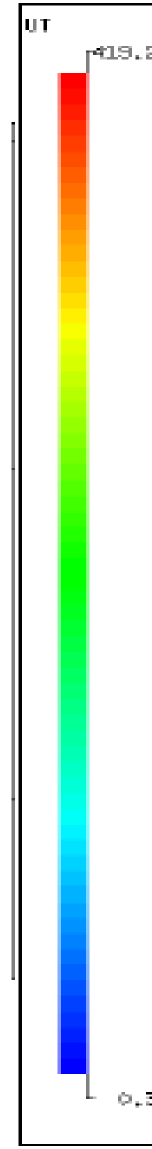

Crater

Equilibrium

Velocity

Blue: 0 m/s

Red: ~400 m/s

Squares indicate particles. Uniform size of 1mm.

← Pipe in-flow

Small particles follow the stream

Thank you for listening

Any questions or comments?

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Contact details: Dr Chris Wareing
C.J.Wareing@leeds.ac.uk
+44 113 343 1619

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UK University partners: Leeds, Manchester, Newcastle, Nottingham, University College London, Warwick.

National Grid Carbon Ltd
National Grid Carbon Ltd is a non-regulated, independent subsidiary of National Grid, created to develop carbon dioxide transportation infrastructure in the UK. National Grid is an international electricity and gas company and one of the largest investor-owned energy companies in the world.

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