Skylark CO_2 Dispersion Project - update

Simon Gant, Fluid Dynamics Team, Health and Safety Executive (HSE) Science and Research Centre
Daniel Allason, Energy Systems, DNV Spadeadam

CCSA Health and Safety Task Subgroup meeting on CO_2 venting
27 November 2023

Outline

- Quick summary of Skylark project plans
  - Work packages
  - Expressions of interest

- CO_2 venting discussion
  - Motivation
  - Questions for operators and consultants

Timeline of recent meetings where Skylark was discussed

- **20 – 22 June**: George Mason University (GMU) Conference on Atmospheric Transport and Dispersion Modeling
- **6 July**: UKCCSRC webinar on “Regulating UK CCS deployment: experience to date and research needs”
- **31 August**: CCSA Health and Safety Task Sub-Group meeting
- **6 October**: Skylark project meeting at DNV Spadeadam and online
- **31 Oct – 1 Nov**: PHMSA Pipeline Safety Research and Development Forum, Arlington, Virginia, USA
- **16 – 17 Nov**: Pipeline Safety Trust annual conference, New Orleans, USA

Plans for Joint Industry Project

- Work Package 0: Project Management – **DNV**
- Work Package 1: CO_2 pipeline craters and source terms – **DNV**
- Work Package 2: Wind-tunnel experiments – **University of Arkansas**
- Work Package 3: Simple terrain dispersion experiments – **DNV**
- Work Package 4: Complex terrain dispersion experiments – **DNV**
- Work Package 5: Model validation – **HSE**
- Work Package 6: Emergency response – **NCEC**
- Work Package 7: Venting – **DNV**

with support from the **Met Office** for the DNV field trials

Work Package 1: CO_2 pipeline craters and source terms

- **Aim**: to improve our understanding of source characteristics for CO_2 pipeline releases from craters, using field-scale experiments
- Review existing data for CO_2 pipeline craters, both punctures and ruptures (some data is not yet publicly available)
- Conduct pipeline rupture tests
  - Both gas-phase and dense-phase CO_2
  - 6-inch or 8-inch diameter buried pipelines
  - At least two soil types (e.g., clay/sandy)
  - Assess size/shape of craters produced in soil
  - Construct realistic-shaped metal crater
  - Perform further tests using metal crater with near-field instrumentation
  - Repeat tests: puncture tests, light and moderate wind speeds

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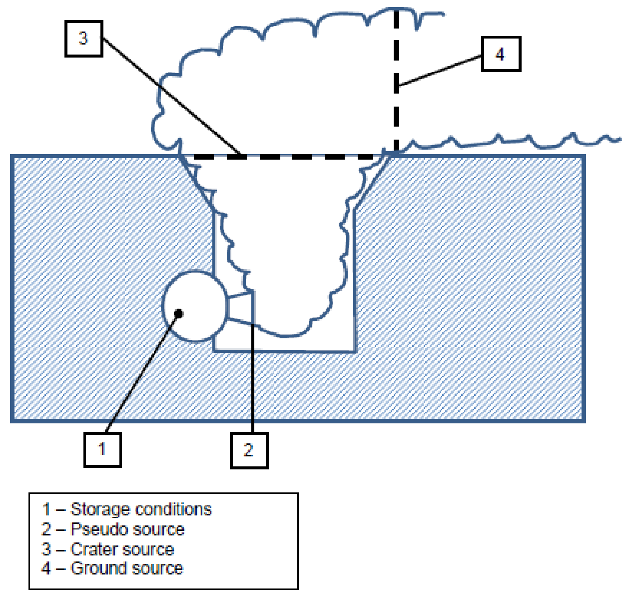


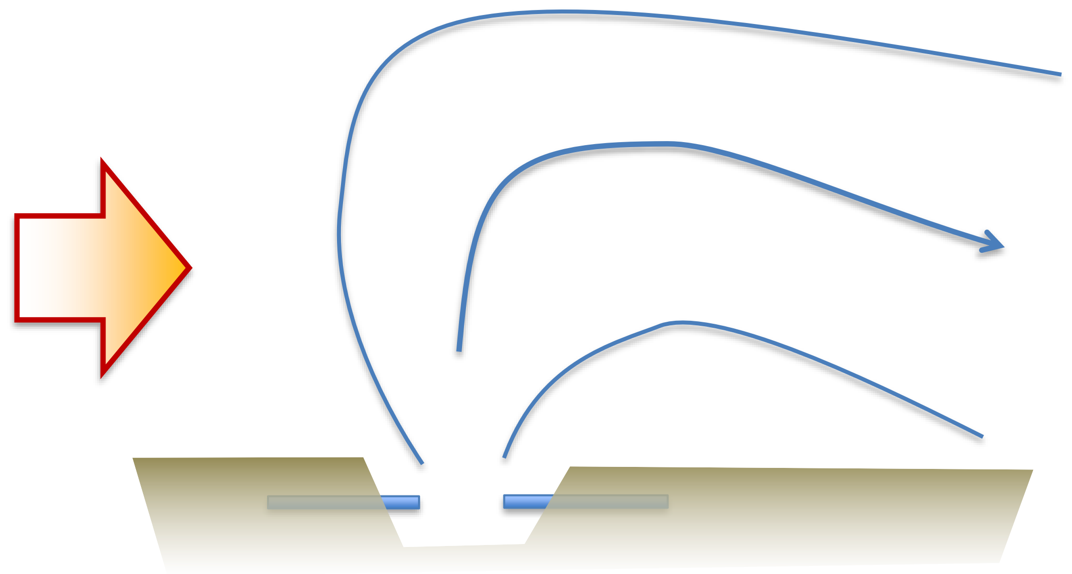
Figure 1 Puncture and crater sources

DNV

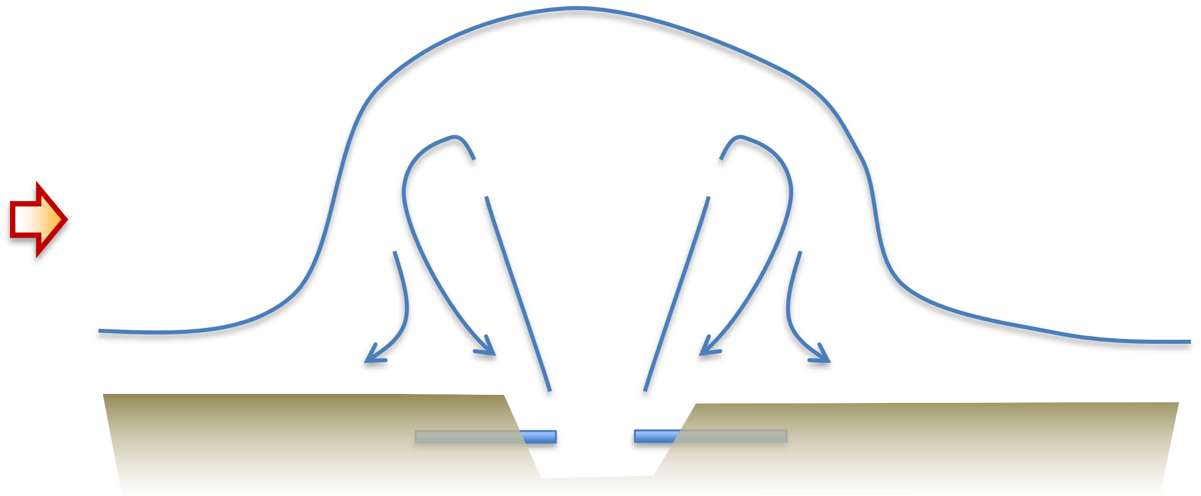
Work Package 2: Wind tunnel studies

- **Aim 1**: to conduct wind-tunnel experiments on crater source behaviour across a wide range of carefully-controlled conditions, with detailed measurements
- Variables: source area, initial jet velocity and density, wind speed
- Answer question: what are the criteria that control when the plume falls back onto the crater, producing re-entrainment and a source blanket?

When is it:



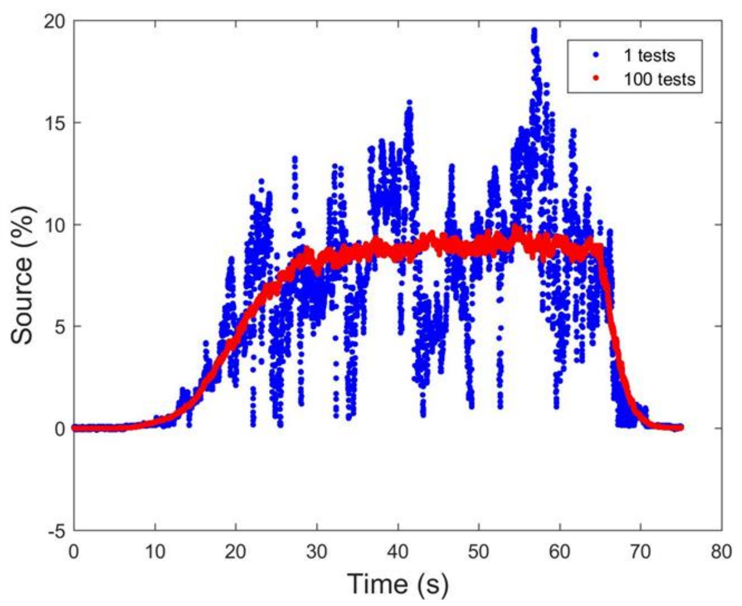
Or ?

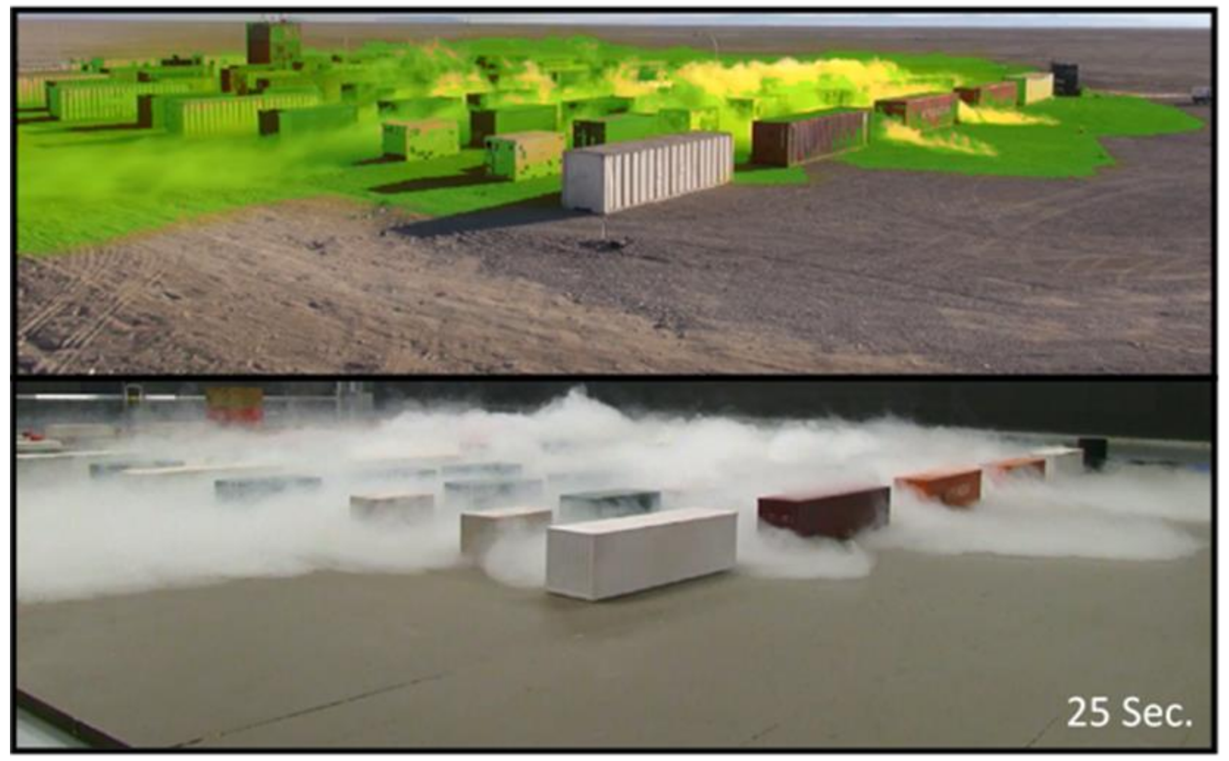


- **Aim 2**: to conduct wind-tunnel experiments on dense-gas dispersion in sloping terrain, comparing flat terrain to cases with uniform slopes in different directions with range of wind speeds
- **Aim 3**: to conduct wind-tunnel experiments to support complex terrain field trials

Work Package 2: Wind tunnel studies

- Chemical Hazards Research Center (CHRC), University of Arkansas
  - Largest ultra-low speed wind tunnel
  - 24 m long working section with a 6 m × 2.1 m cross section
  - Capable of wind speeds as low as 0.3 m/s and still air experiments
  - State of the art instruments for velocity and turbulence (LDV and PIV) and gas concentration (FID, PLIF, PID)
  - Data from CHRC wind tunnel has previously used for:
    - PHMSA/NFPA model evaluation protocol for LNG siting applications
    - DNV Phast model development
    - Jack Rabbit II chlorine trials assessment





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Work Package 3: Simple sloping terrain dispersion exps

- **Aim**: to conduct dense-gas dispersion experiments on "simple" uniform sloping terrain to provide data to validate dispersion models
- Idealised gaseous CO_2 source configuration to produce radially-spreading cloud, using a circular outlet similar to the Thorney Island dispersion trials
  - Avoid modelling uncertainties associated with two-phase CO_2 release from crater
- Main focus of experiments is to understand effect of slope on dense gas behaviour

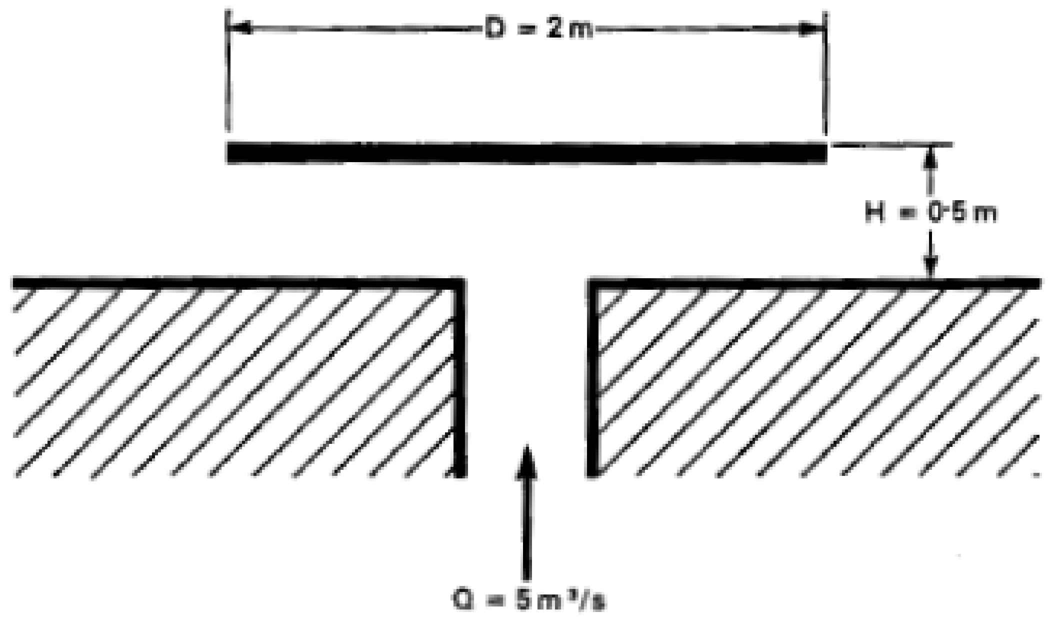


Fig.22.4 Geometry of ground-level source for continuous release experiments

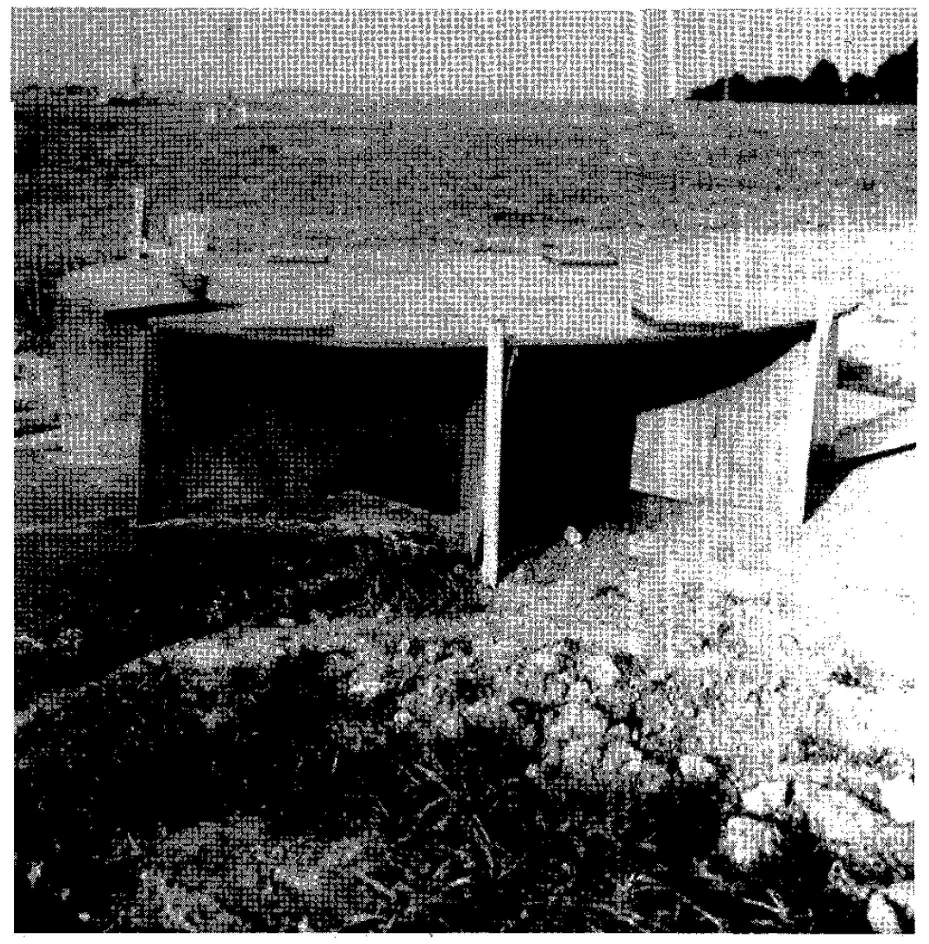
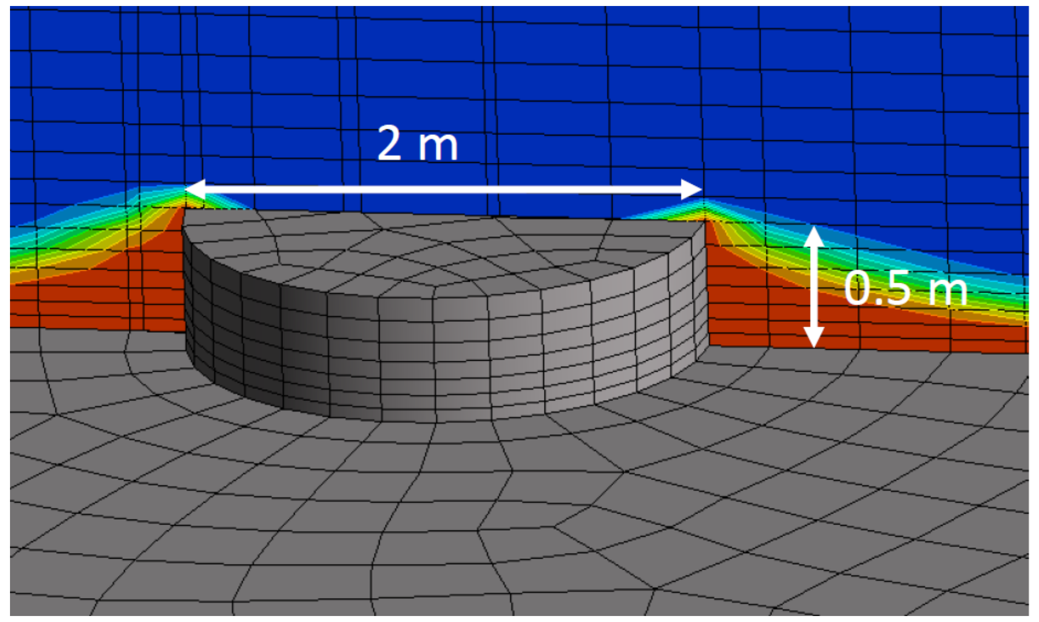
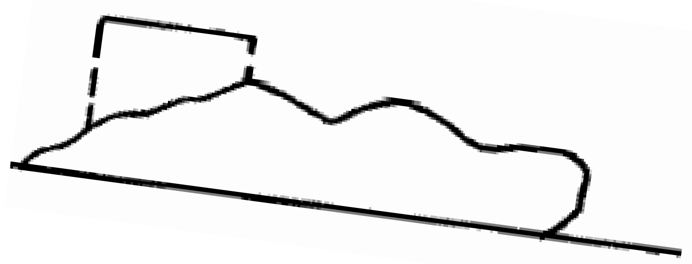


Fig. 22.2 Outlet from the gas supply duct at the release point



McQuaid & Roebuck (1985) Thorney Island
https://admlc.com/thorney-island/
CFD modelling
https://doi.org/10.1504/IJEP.2018.093026



Shallow slope

Steep slope

How does dispersion behaviour compare to flat terrain?

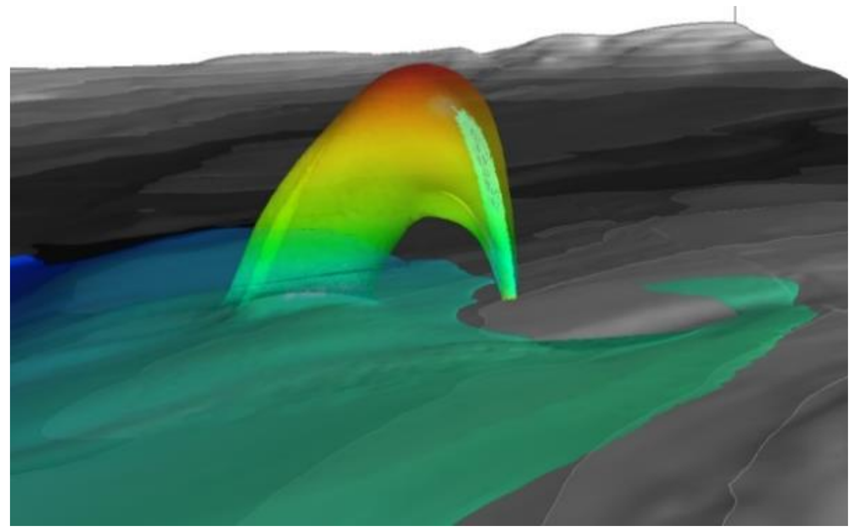
Work Package 4: Complex Terrain Dispersion Exps

- **Aim**: to conduct series of CO_2 release experiments with complex terrain including valleys, hills, obstacles, changing roughness, buildings etc.
- DNV Spadeadam ideally suited to these tests, with multiple possible release locations and large exclusion distances
- Proposed to use mobile rig with 20 – 40 tonne CO_2 capacity with option to use preformed craters
- More challenging configurations for dispersion modelling
- Aim to answer practical questions:
  - How long does CO_2 persist in depressions?
  - What is the effect of obstacles (trees, hedgerows, buildings)?

~15m in 300m
~20m in 500m
~3m in 500m
DNV Spadeadam
DNV Spadeadam
~3m in 500m
~10m in 700m
1186 m
Image © 2023 Getmapping plc
Image © 2023 Maxar Technologies
DNV
Google Earth

Work Package 5: Model validation

- **Aim**: to test and validate dispersion models that can be used for CO_2 pipeline risk assessment and emergency planning/response
- Many international modelling teams and software developers are keen to test and validate their models against this data (DNV, Gexcon, Kent, CERC, MES etc.)
- Opportunity to involve research groups who are developing rapid dispersion models (e.g., Texas A&M, Leeds University) to inform future commercial software development
- Aim to have an open and collaborative approach, like in Jack Rabbit projects
- Welcome input from government labs, industry, academia and consultants
- Aim to test spectrum of models, e.g., correlations, Gaussian puff, shallow layer, machine learning, CFD
- Modellers given access to data in return for sharing results and collaborating
- Requests to join project approved by project steering committee
- Modelling exercises coordinated by HSE



Work Package 6: Emergency response

- **Aim**: to engage with emergency responders and make best use of the CO_2 dispersion trials: help to prepare responders to deal with possible CO_2 release incidents
- Identify knowledge gaps in emergency response, working with Hazmat teams, Fire and Rescue Services and other emergency responders
- Test gas sensors, breathing apparatus, PPE etc. used by responders in the trials?
- Test vehicles can be used to evacuate casualties? (learning from Satartia incident)
- Opportunity for emergency responders to witness trials and review video footage as learning and training exercise
- Work package led by UK National Chemical Emergency Centre (NCEC)



Examples of emergency responders' involvement in the Jack Rabbit II project https://www.uvu.edu/es/jack-rabbit/
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NCEC RICARDO

Work Package 7: Venting

- **Aim**: to assess if CO_2 vents could give rise to harmful concentrations downwind, near ground level
- Input from sponsors sought on defining range of conditions to be tested experimentally: vent diameter, temperature, pressure
- Planned to test:
  - Two vent diameters (up to 2” NB diameter pipes)
  - Dense, supercritical and gaseous CO_2
  - Repeated tests on three days (low, moderate and high winds)
- Measure outflow rate, vent conditions (pressure / temperature), CO_2 concentrations near ground level, plume temperature, videos (normal, thermal and high-speed)
- Conducted alongside other work packages whilst rigs are available
- Is interest in testing certain valve designs, following reports of some blowdown valves blocking in the open position due to solid CO_2?

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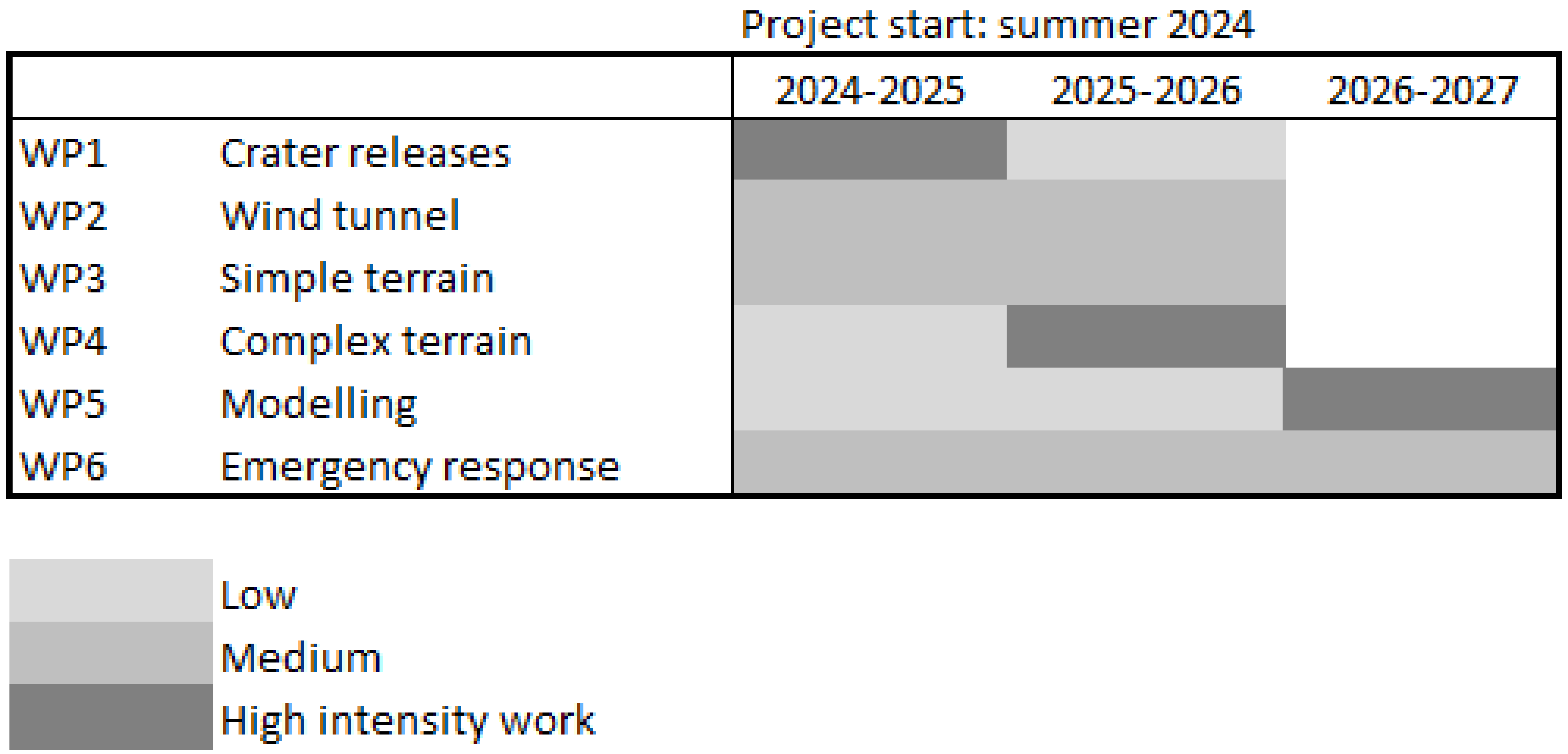
Work Package 0: Project Management

- Project delivery team
  - DNV (experiments): Dan Allason, Rob Crewe, Keith Armstrong
  - DNV (modelling): Ann Halford, Karen Warhurst, Mike Harper, Jan Stene and Gabriele Ferrara
  - HSE: Simon Gant, Zoe Chaplin and Rory Hetherington
  - University of Arkansas: Tom Spicer
  - NCEC: Ed Sullivan
  - Met Office: Matt Hort and Frances Beckett
  - External advisers: Steven Hanna (USA), Joe Chang (Rand Corporation), Gemma Tickle (UK)
- Technical steering group
  - Representative from each of the project sponsors (or their appointed technical consultant)
- Modellers working group
  - Representative from each of the modelling teams contributing and analysing results
- Safety/environmental regulators participating in peer-review capacity
  - E.g., Environment Agency, PHMSA

Timeline (approximate)



Costs

- Summary of costs (approx. estimate, non-binding)
  - DNV
  - HSE
  - University of Arkansas
  - NCEC
  - Met Office
  - External advisors

Total cost, approximately £10M

No. Sponsors	Ticket Price (after DESNZ)	Per Year for 3 Years
4	£1.25M	£416k
5	£1.0M	£333k
6	£1.0M	£333k
7	£0.71M	£238k
8	£0.63M	£208k
9	£0.56M	£185k
10	£0.5M	£167k

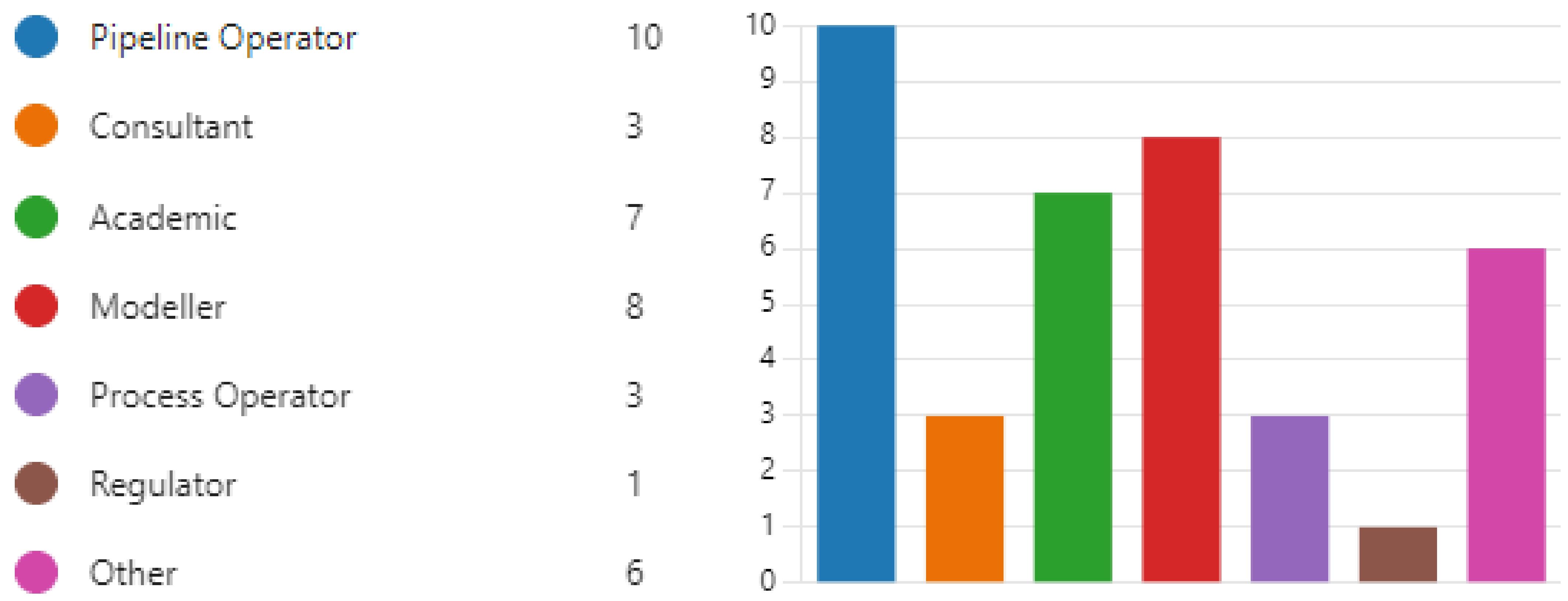
- Department of Energy Security and Net Zero (UK Government) contribution: circa £5M
- Ideal ten sponsors: £0.5M per sponsor, spread over 3 years
- Discussions ongoing with US Department of Energy, potential contribution $1.5M
- Discussions with consortium partners (e.g., PRCI) welcomed

Interest in Skylark project

- Feedback from DNV form circulated in email from Dan Allason on 10 Oct https://forms.office.com/e/DyLkS24C5z

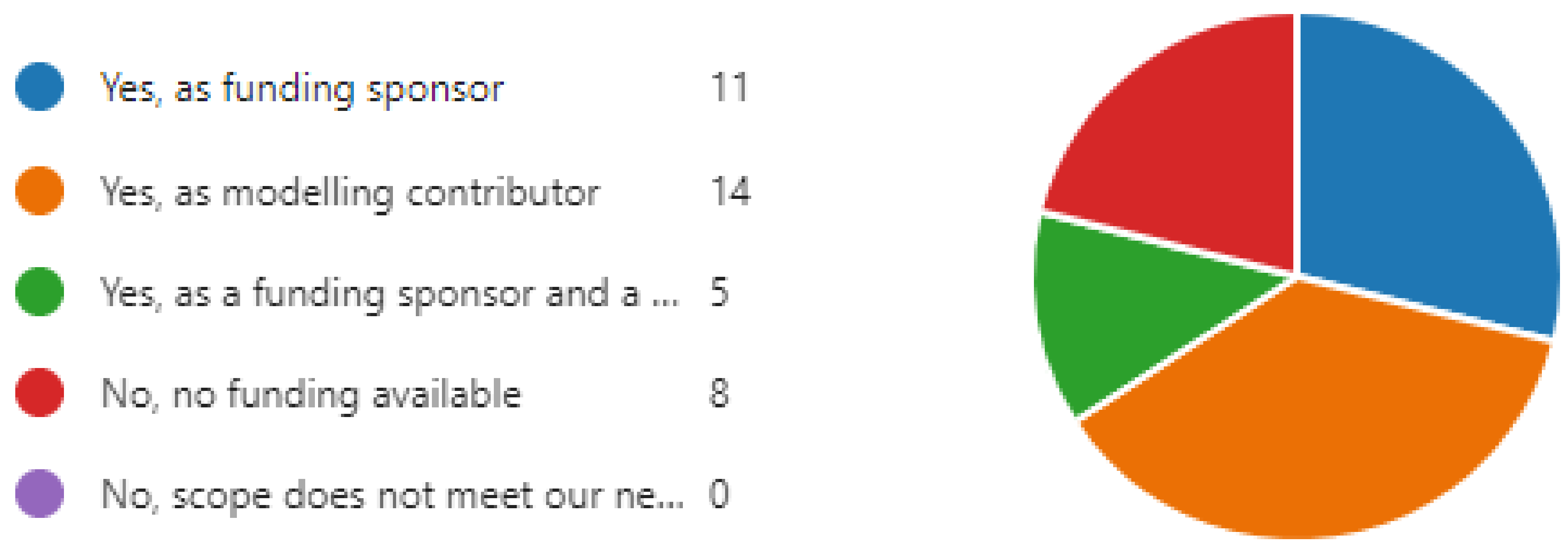
6. What is your Organisation's interest in the project?

More Details



8. Would your organisation be interested in participating in this project?

More Details Insights



CO_2 Venting

Motivation

- Skylark project team is keen to maximise value of work package on CO_2 venting
- Useful to understand from operators and industry consultants:
  - What are the main knowledge gaps that we need to address?
    - Uncertainties in CO_2 dispersion behaviour?
    - Vent pipe temperatures?
    - Dry-ice formation? (e.g., blocking valves in open position)
    - Producing experimental data to validate dispersion model predictions?
  - What operating conditions should be studied?
    - Vent diameter and vent pipe configuration
    - Flow conditions: pressure and temperature (supercritical, dense-phase or gaseous?)
    - Gas composition: presence of impurities from process upset in capture plant?
    - Vent location: stack height, wake effects from nearby obstacles?
  - Modelling of CO_2 dispersion from vent releases: what models and methods are being used?
    - What validation exists for these modelling approaches? Confidence in model predictions?

Thank you

- Contact: simon.gant@hse.gov.uk, daniel.allason@dnv.com

- The contents of this presentation, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy

Extra material

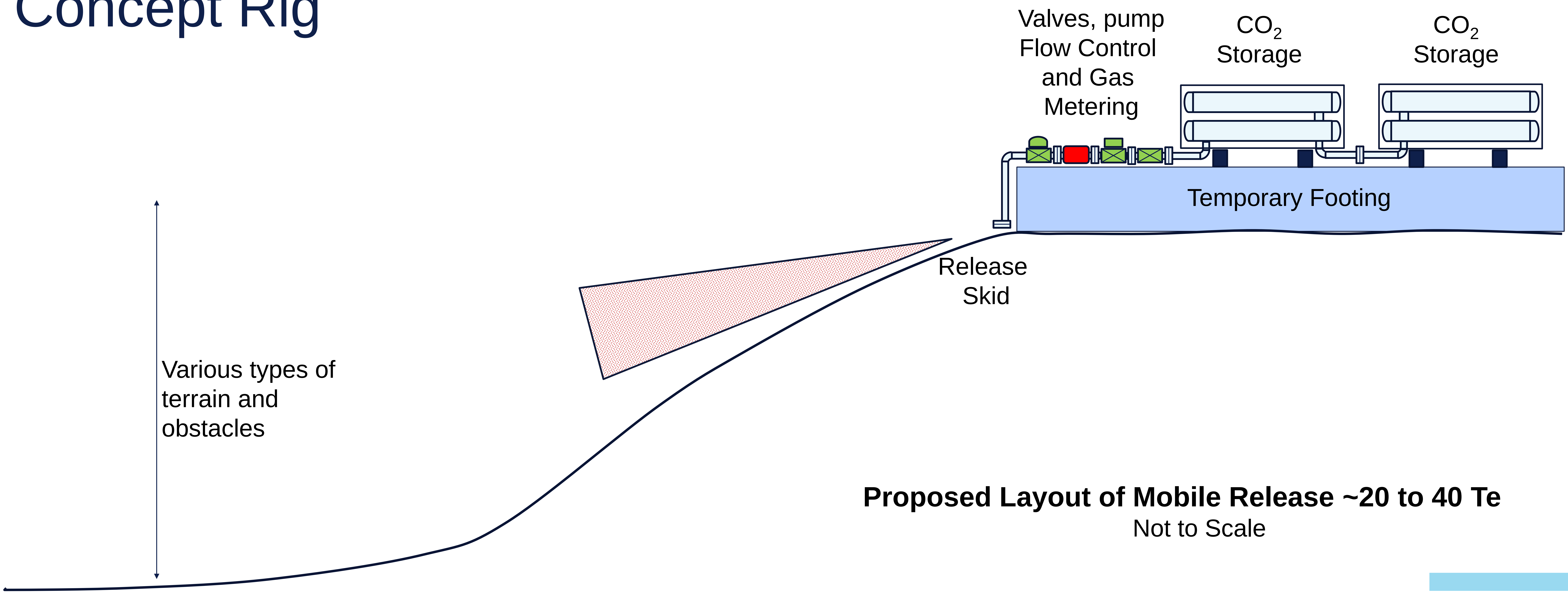
Why the name Skylark?

- Historical dispersion trials
  - Avocet: LNG
  - Burro: LNG
  - Coyote: LNG
  - Desert Tortoise: ammonia
  - Eagle: nitrogen tetroxide
  - Falcon: LNG
  - Goldfish: hydrogen fluoride
  - Kit fox: carbon dioxide
  - Jack Rabbit: chlorine and ammonia
  - Red Squirrel: ammonia
  - **Skylark: carbon dioxide**

https://www.birdguides.com/gallery/birds/alauda-arvensis/1003602/

Work Package 4: Complex Terrain Dispersion Exps

Concept Rig



Proposed Layout of Mobile Release ~20 to 40 Te
Not to Scale

COOLTRANS Research Programme

Proceedings of the 2014 10th International Pipeline Conference
IPC2014
September 29 - October 3, 2014, Calgary, Alberta, Canada

IPC2014-33370

THE COOLTRANS RESEARCH PROGRAMME – LEARNING FOR THE DESIGN OF CO_2 PIPELINES

Julian Barnett
National Grid Carbon
Solihull, UK

Russell Cooper
National Grid Carbon
Solihull, UK

Proceedings of the 2016 11th International Pipeline Conference
IPC2016
September 26-30, 2016, Calgary, Alberta, Canada

IPC2016-64456

ANALYSIS OF A DENSE PHASE CARBON DIOXIDE FULL-SCALE FRACTURE PROPAGATION TEST IN 24 INCH DIAMETER PIPE

Andrew Cosham
Ninth Planet Engineering
Newcastle upon Tyne, UK

David G Jones
Pipeline Integrity Engineers
Newcastle upon Tyne, UK

Keith Armstrong
DNV GL
Spadeadam Test & Research Centre, UK

Daniel Allason
DNV GL
Spadeadam Test & Research Centre, UK

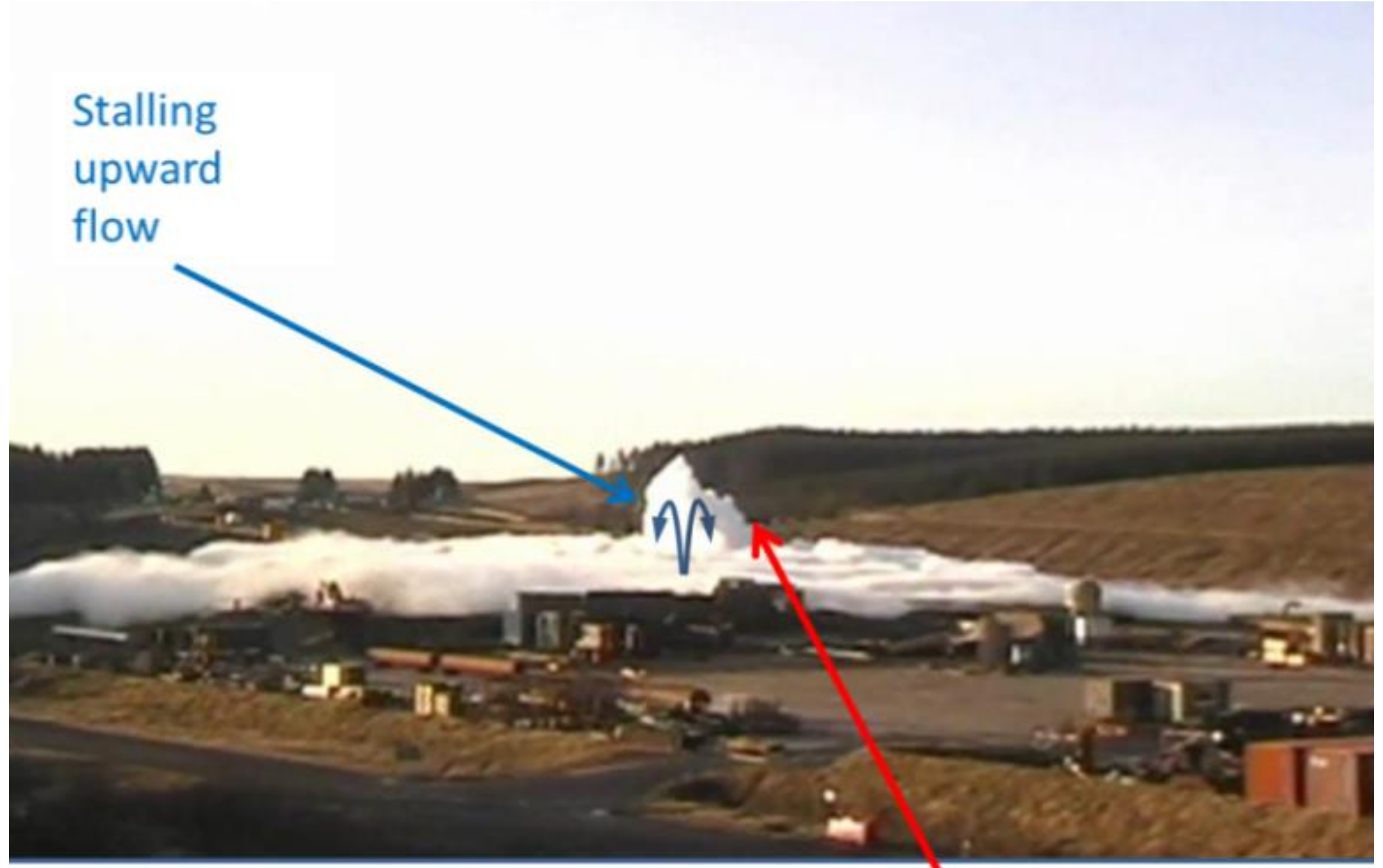
Julian Barnett
National Grid
Solihull, UK

Crater size and its influence on releases of CO2 from buried pipelines

by Philip Cleaver[1], Ann Halford[1], Karen Warhurst[1], and Julian Barnett[2]
1 GL Noble Denton, Loughborough, UK
2 National Grid Carbon, Warwick, UK

4th International Forum on the Transportation of CO2 by Pipeline

Hilton Gateshead-Newcastle Hotel, Gateshead, UK
19-20 June, 2013



Crater is covered by vapour blanket – mixture released previously is drawn into flow

Fresh air entrainment possible around plume base

COSHER Joint Industry Project

International Journal of Greenhouse Gas Control 37 (2015) 340–353

COSHER joint industry project: Large scale pipeline rupture tests to study CO_2 release and dispersion

Mohammad Ahmad[a,*], Barbara Lowesmith[a], Gelein De Koeijer[b], Sandra Nilsen[b], Henri Tonda[c], Carlo Spinelli[d], Russell Cooper[e], Sigmund Clausen[f], Renato Mendes[g], Onno Florisson[a]

http://dx.doi.org/10.1016/j.ijggc.2015.04.001

[a] DNV GL, The Netherlands
[b] STATOIL, Norway
[c] TOTAL, France
[d] ENI, Italy
[e] National Grid, UK
[f] GASSCO, Norway
[g] PETROBRAS, Brazil

219 mm (8.6 inch) diameter pipeline ruptured

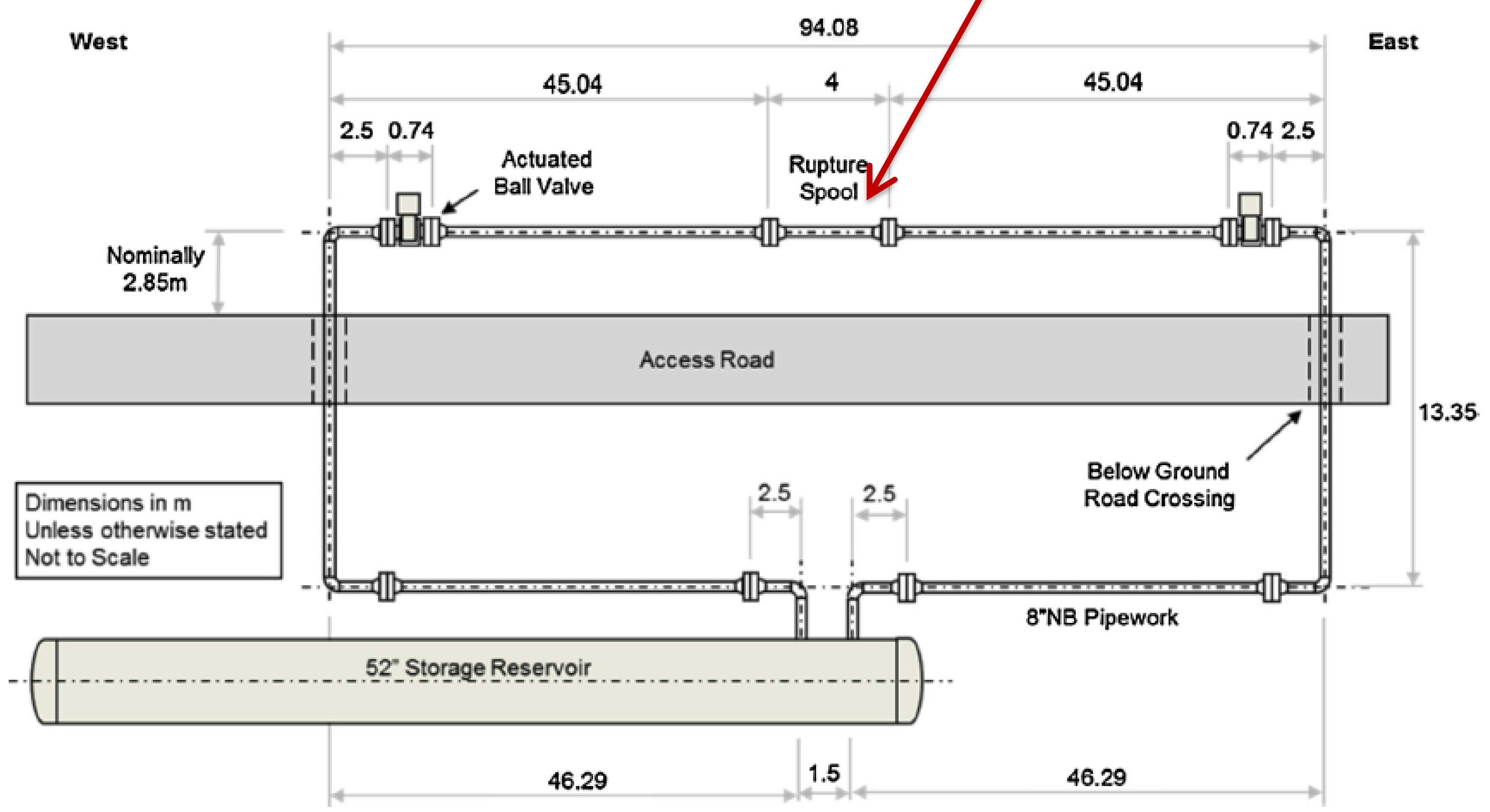


Fig. 1. The pipeline loop (plan view).

Table 2
Summary of the test conditions prior to rupture.

Rig conditions	Test
Overall average gage pressure (MPa)	15.08
Average fluid temperature in reservoir (°C)	13.1
Average wall temperature of reservoir (°C)	14.2
Estimated inventory (tons)	146.8
Atmospheric conditions	
Wind direction (degrees relative to grid N)	261
Wind speed (m s^{-1})	1.9
Ambient temperature (°C)	17.4
Atmospheric pressure (Pa)	99700
Relative humidity (%)	71.5

Max cloud height approx. 60 m

Max visible cloud spread distance approx. 400 m

Fig. 4. The visible cloud at 10 s (top), 30 s and 120 s (bottom) after the rupture.