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Identification of knowledge gaps for future testing in Jack Rabbit III: a European perspective

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Outline

- Aims
- Survey of knowledge gaps and research priorities
  - Survey methodology
  - Top five research topics identified
  - Specific research questions
- Brief reviews of:
  - Relevant previous experiments
  - Ammonia incidents
- Summary
- Tentative proposal for some future work

Aims

- To conduct a survey amongst European experts of knowledge gaps in atmospheric dispersion of acute toxic hazards
- To help prioritise the key topics to study in the future Jack Rabbit III experiments

Jack Rabbit III

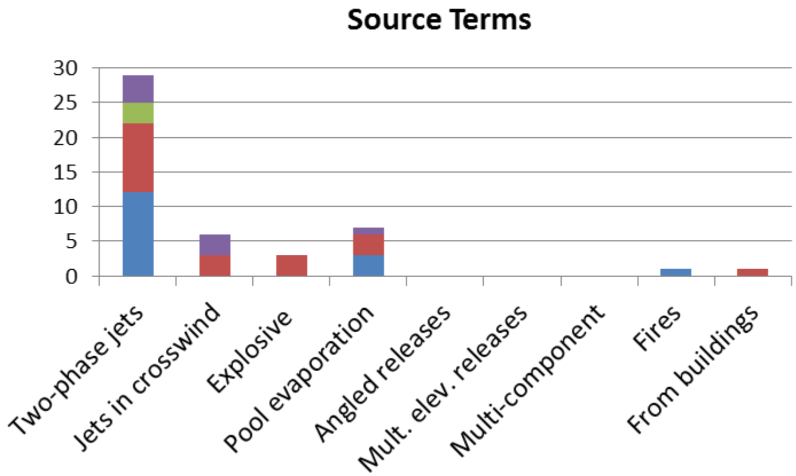
- Focus on anhydrous ammonia

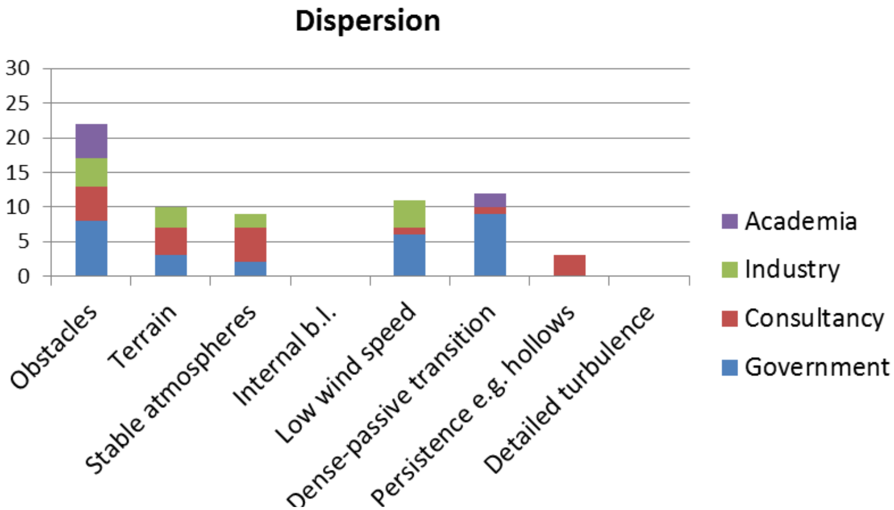
Knowledge Gaps Methodology

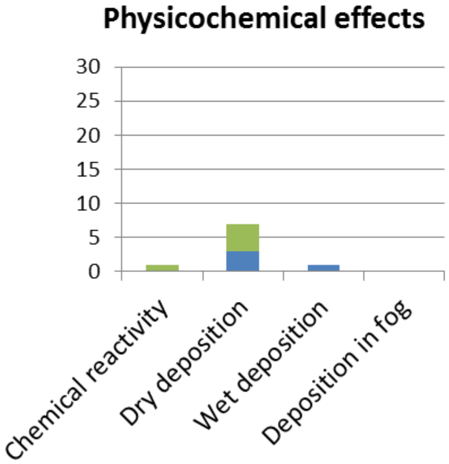
Staged approach:

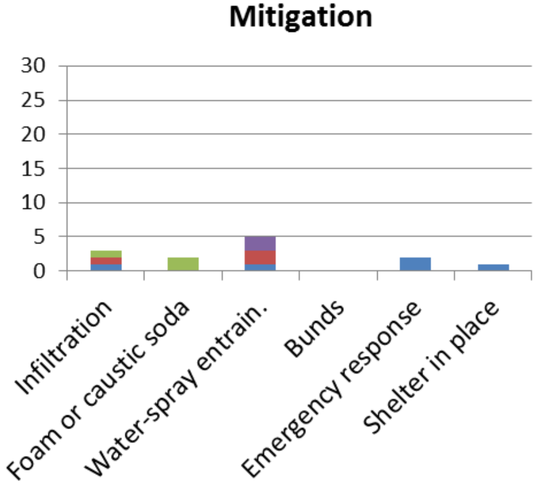
1. Pose open questions to gather information
2. Group common issues identified in the responses into topics and sub-topics
3. Contributors vote on their top three sub-topics
4. Collate responses from all contributors

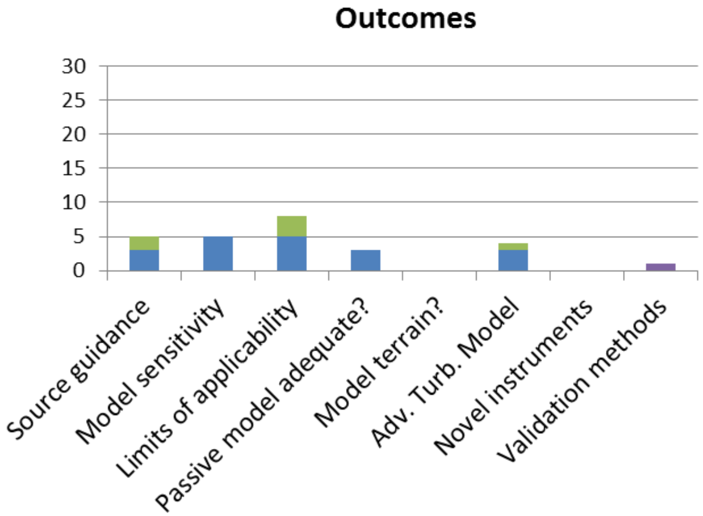
Knowledge Gaps: Results from votes



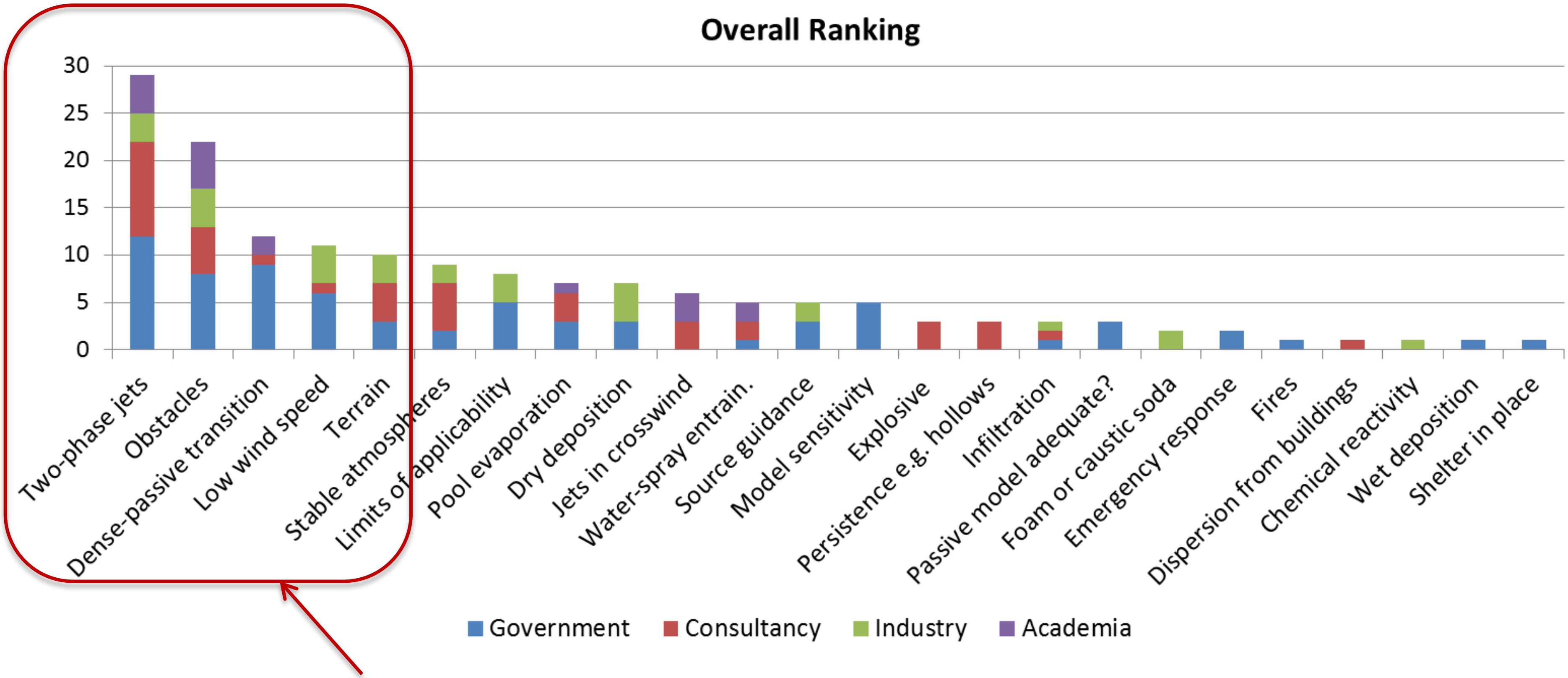








Knowledge Gaps: Results from votes



Next slides focus on top five sub-topics

1. Two-phase jets

- Critical issue studied in several previous projects (see later review)
- Lack of data for partitioning between airborne aerosol and liquid pool (i.e. rainout fraction)
- Validity of rainout approaches in operational models is uncertain
- Rainout fraction can have significant influence on dispersion, particularly in the near field
- Rainout is scale-specific: depends on geometry and release size
- Useful to consider range of conditions: hole sizes, release orientations, impinging, short releases (e.g. catastrophic vessel failure), long duration releases (e.g. pipeline)
- Uncertainty in post-expansion source conditions: jet velocity and liquid fraction (metastable or homogeneous equilibrium) – could be studied in laboratory-scale tests?
- Uncertainty in behaviour inside vessel (champagne effect)

2. Obstacles

- Limited field-scale data available for dense-gas dispersion with realistic obstacles
- At what size do obstacles become important such that they need to be taken account of in modelling?
- Are dense gas dispersion models for flat and rough terrain still applicable to built-up environments?
- Which is better: a building-resolved passive model or a dense gas model with surface roughness?
- How much do isolated or small obstacles affect dispersion?
- What is the impact of obstacles on persistence of the cloud?
- How effective are vapour barriers for mitigation?
- Do wakes from isolated tall buildings in city environments have a significant affect? Is it important to model them?

3. Transition from dense-gas to passive dispersion

- When is it necessary to use a dense-gas model instead of a passive model?
    - Is the current rule of thumb that says a dense-gas model should be used for releases of 1 ton or more accurate?
- Can testing determine if there is a threshold release size when a passive model is adequate?
- How rapid is the mixing between the dense cloud and the atmosphere that produces a passive cloud?
- Does near-field dense gas behaviour matter far downwind?
- How does the transition from dense to passive affect turbulence levels and toxic dose (non-linear toxic response to concentration)?
- What are the implications for infiltration into buildings, e.g. draining of dense clouds into basements?

4. Dispersion in low/zero wind speeds

- Lack of experimental data for large dense-gas releases in low/zero wind speeds
  - But there are examples of several severe incidents involving flammable dense-gas releases in low/zero wind, e.g. Buncefield and San Juan fuel storage depots
- How do obstacles and terrain influence the dispersion behaviour when the wind speed approaches zero?
- What are the implications of low/zero wind speeds for emergency response?
  - ERG provides protective action distance in downwind direction
  - ERG for ammonia has three wind speeds (low, moderate, high) for (<10 km/h, 10-20 km/h, >20 km/h)
  - What is the advice for very low or zero wind? Which direction is downwind? Are the ERG distances still valid?

5. Terrain effects

- Lack of experimental data for large dense-gas releases with terrain
  - Indications from incidents that even moderate slopes could have significant effect in low/zero wind
- At what scale does terrain become important for dispersion?
- What is the combined effect of the wind, the release direction and terrain on dense-gas releases?
  - Useful to have range of tests: e.g. releases upslope, downslope and cross-winds for a range of release sizes and slopes
  - Also elevated releases, e.g. for rooftop-mounted ammonia refrigeration tanks

Brief review of previous experiments

Brief Review of Previous Experiments

The next slides examine experimental data for the top five priorities:

1. Two-phase jets (only ammonia)
2. Obstacles
3. Transition from dense-gas to passive
4. Low/zero wind speed
5. Terrain

References to papers/reports cited in these slides are provided at the end of the presentation

1. Previous ammonia two-phase jet experiments

	Instantaneous	Continuous	Flashing jet	Evaporating Pool	Gas source	Unobstructed	Obstructions	Topography	Nil/low wind/stable	Concentration measured	Ingress	Mitigation
Desert Tortoise		●	●			●				●		
Ecole des Mines d'Ales		●	●	●						●		●
FLADIS		●	●		●	●				●		
ICI	●	●	●	●			●					●
INERIS		●	●	●	●	●	●			●		●
Jack Rabbit I		●	●	●		●		●	●	●		
Landskrona		●			●	●						
Resplandy		●	●		●	●	●		●		●	●
University van Kunstmest bv			●	●								

1. Example: Two-phase jet ammonia trials

- **INERIS, 1996-1997**
  - CEA/CESTA test site near Bordeaux, France
  - 15 ammonia releases of 2-3 tonnes with discharge rates of 3-4 kg/s
  - Release orientations: horizontal, vertically-down, annular, with/without impingement
  - Six types of ammonia sensors on 150 masts at different heights on arcs from 20 m to 1700 m
  - Atmosphere: stable to neutral
  - Mitigation: effect of water sprays
  - Data used to validate Phast model
  - Bouet (1999)

Images © INERIS
Source: Bouet (1999)

2. Obstacles: previous experiments

	Substance	Field	Wind tunnel	Instantaneous	Continuous	Flashing jet	Topography	Nil/low wind/stable	Concentration measured	Ingress	Mitigation
AGA	LNG	•		•							•
BA Hamburg	SF_6		•	•	•		•		•		•
BA TNO	SF_6		•	•	•				•		•
BMT	Argon/Freon		•		•				•		
Bureau of Mines	LNG	•			•						
CHRC	CO_2		•		•				•		•
COOLTRANS	CO_2	•			•		•	•	•	•	
Eagle	Nitrogen Tetroxide	•			•				•		•
EMU-ENFLO	Unknown		•		•		•		•		
Falcon	LNG	•			•				•		•
FLIE	LPG	•			•	•					
Guldemond	Argon		•		•		•		•		
Hall et al.	BCF, argon		•	•	•			•	•		•
Hoot et al.	Freon/air mix		•		•			•	•		

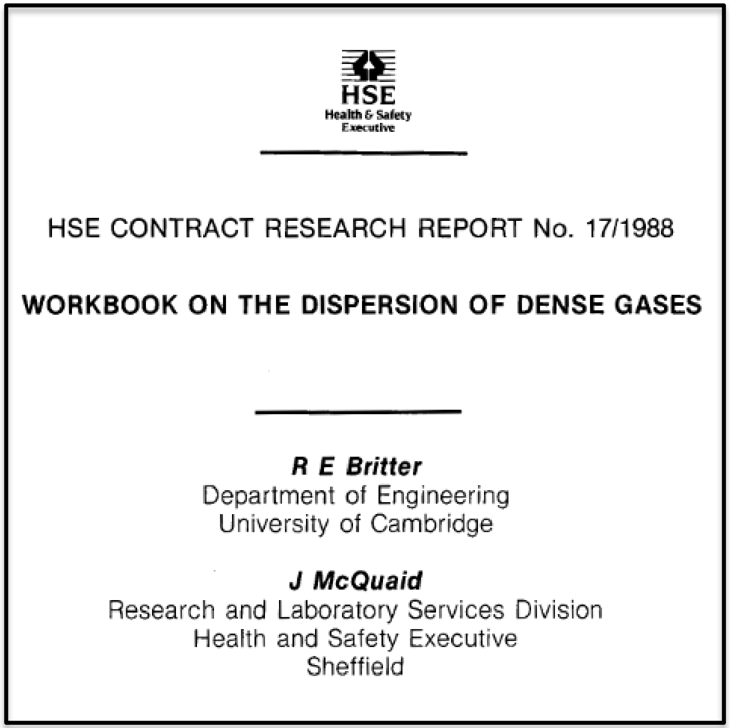
2. Obstacles: previous experiments

	Substance	Field	Wind tunnel	Instantaneous	Continuous	Flashing jet	Topography	Nil/low wind/stable	Concentration measured	Ingress	Mitigation
CHMAP	HF	•	•		•	•	•		•		•
ICI	Ammonia	•		•	•	•					•
INERIS	Ammonia	•			•	•			•		•
Jack Rabbit II	Chlorine	•			•	•		•	•	•	
JGA	LNG	•			•						
Kit Fox	CO_2	•		•	•			•	•		
Lathen / BA Propane	Propane	•		•	•	•		•	•		
MODITIC	CO_2		•		•				•		
Petersen and Ratcliff	TBC		•		•				•		
Resplandy	Ammonia	•			•	•		•		•	•
Schatzmann et al	SF_6/CO_2 mixture		•		•				•		
Texas A&M	LNG	•			•				•		•
Thorney Island	Freon-12/N_2	•		•	•			•	•		

- ICI & Resplandy – no concentration measurements

3. Transition from dense to passive

- Transition from dense to passive dispersion studied previously in FLADIS and INERIS ammonia field-scale experiments



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HSE CONTRACT RESEARCH REPORT No. 17/1988

WORKBOOK ON THE DISPERSION OF DENSE GASES

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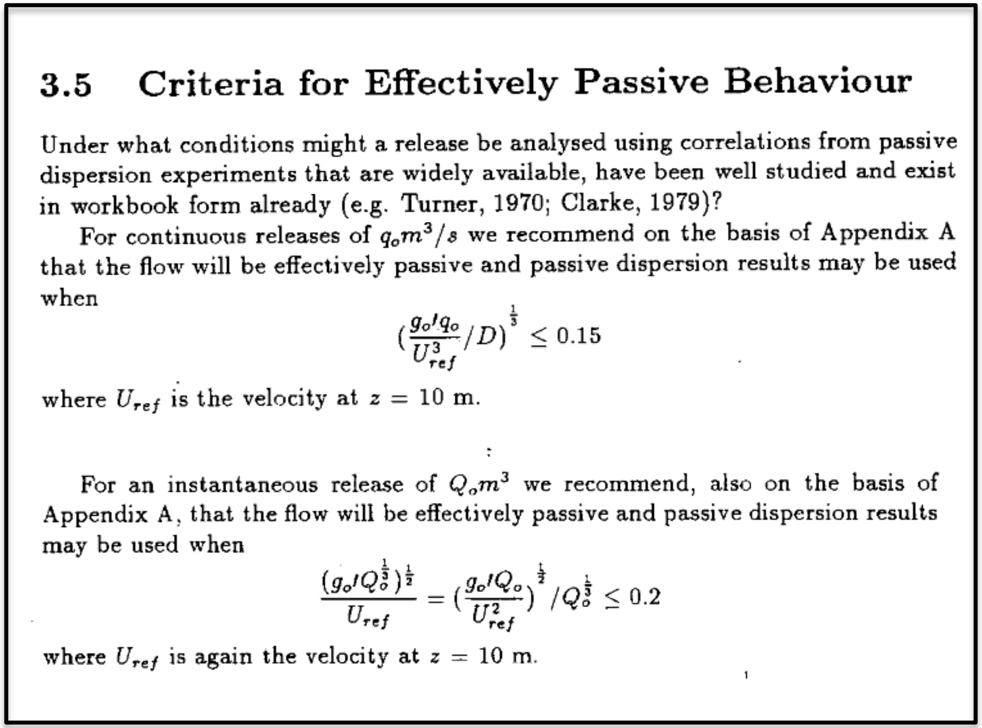

3.5 Criteria for Effectively Passive Behaviour

Under what conditions might a release be analysed using correlations from passive dispersion experiments that are widely available, have been well studied and exist in workbook form already (e.g. Turner, 1970; Clarke, 1979)?

For continuous releases of $q_o m^3/s$ we recommend on the basis of Appendix A that the flow will be effectively passive and passive dispersion results may be used when

$$\left(\frac{g_o' q_o}{U_{ref}^3}/D\right)^{\frac{1}{3}} \le 0.15$$

where U_{ref} is the velocity at $z = 10$ m.

For an instantaneous release of $Q_o m^3$ we recommend, also on the basis of Appendix A, that the flow will be effectively passive and passive dispersion results may be used when

$$\frac{(g_o' Q_o^{\frac{1}{3}})^{\frac{1}{2}}}{U_{ref}} = \left(\frac{g_o' Q_o}{U_{ref}^2}\right)^{\frac{1}{2}} / Q_o^{\frac{1}{3}} \le 0.2$$

where U_{ref} is again the velocity at $z = 10$ m.

4. Low/zero wind speeds: previous experiments

	Substance	Field	Wind tunnel/indoor	Instantaneous	Continuous	Flashing jet	Obstructions	Topography	Concentration measured	Ingress	Mitigation
Burro 8	LNG	●			●			●	●		
COOLTRANS	CO_2	●			●		●	●	●	●	
ENFLO 2000	CO_2, krypton		●		●				●		
Hall et al.	BCF, argon		●	●	●		●		●		●
Hoot et al.	Freon/air mix		●		●		●		●		
HSE 1985	CO_2	●			●				●		●
Jack Rabbit I	Chlorine, ammonia	●			●	●		●	●		
Kit Fox	CO_2	●		●	●		●		●		
Lathen / BA Propane	Propane	●		●	●	●	●		●		
Maplin Sands	LNG/LPG	●		●	●	●			●		
Porton Down	Freon-12	●		●				●			
Thorney Island	Freon-12/nitrogen mixture	●		●	●		●		●		
URAHFREP	HF, HF/isobutane mix	●	●		●				●		
Wannberg et al	Propylene	●			●				●		

4. Example: Low wind speed ammonia trials

Images from Bauer (2013)

Ammonia Pilot Test at 5 sec © CSAC, DHS

Ammonia Pilot Test at 3 min © CSAC, DHS

- Jack Rabbit I
- 905 kg ammonia cloud released over 76 s
- Surface wind speeds < 1ms^{-1}
- Cloud persisted in the crater for more than 30 minutes

5. Terrain effects: previous experiments

	Substance	Field	Wind tunnel	Instantaneous	Continuous	Flashing jet	Obstructions	Nil/low wind/stable	Concentration measured	Ingress	Mitigation
BA Hamburg	SF_6		•	•	•		•		•		•
Burro	LNG	•			•			•	•		
China Lake (Meroney WT)	Argon, Freon-12		•				•		•		
COOLTRANS	CO_2	•			•		•	•	•	•	
EMU-ENFLO	Krypton		•		•		•		•		
Guldemond	Argon		•		•		•		•		
Jack Rabbit I	Chlorine, ammonia	•			•	•		•	•		
Muller	SF_6		•					•	•		
Porton Down	Freon-12	•		•				•			

Field-scale tests all have limitations:

- Burro: complex evaporating pool source
- COOLTRANS: data not yet fully available, terrain not mapped
- Jack Rabbit I: rainout/absorption into desert playa, only 2 m dip
- Porton Down: no concentration data, just dose

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Brief review of ammonia incidents

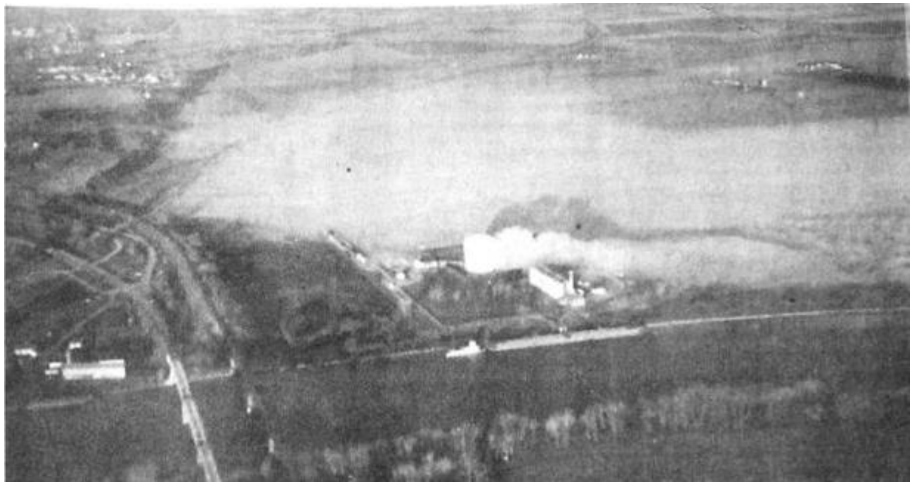
Ammonia incidents

Location	Description	Deaths	Instantaneous	Continuous	Obstructions	Nil/low wind/stable	Mitigation	Previous model comparison	Potential use for model comparison?
Blair, Nebraska	Tank overfilling			•	•	•	•		•
Potchefstroom, South Africa	Partial tank failure and railcar failure	•	•			•	•	•	
McPherson, Kansas	Failed valve closed in pipeline leading to pressure build up			•			•		
Houston, Texas	Tanker fell off freeway	•	•		•	•		•	
Jonova, Lithuania	Liquid ammonia spill, quickly set alight	•		•		•	•		•
Dakar, Senegal	Road tanker overfilled causing vessel failure	•	•				•		
Theodore, Alabama	12" suction pipe fail			•			•		•
Lake County, Illinois	Farm tractor failure, 2 m^3 of liquid ammonia released				•	•	•		•

Also Larvik, Norway (2002): overfilled ammonia tank on farm, 1 death, 10 injured, 130 cattle killed, details limited

Ammonia Incidents

Blair, Nebraska, 1970



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Beach Park, Illinois, 2019

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https://www.chicagotribune.com/suburbs/lake-county-news-sun/ct-lns-ammonia-spill-no-charges-st-0626-20190625-ikztowsrhfhwhgym3lryjk4v2m-story.html

With thanks to Sun McMasters (CSAC) for the information

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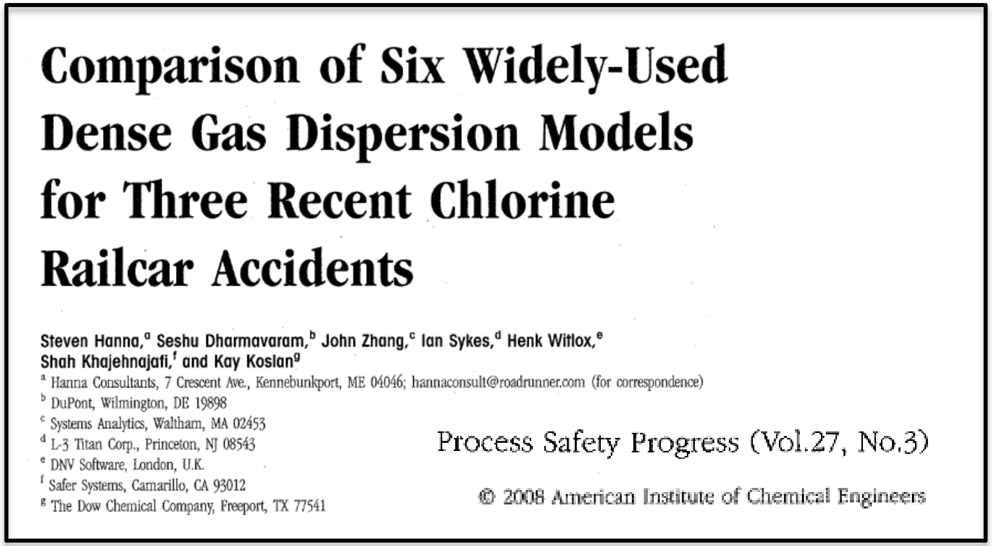
Summary of knowledge gaps exercise for JRIII

European Interests and Support for Jack Rabbit III

- Survey of 27 European organisations: government agencies, industry, consultants, academia
- Top five research priorities were:
  1. Two-phase flashing jets
  2. Obstacles (buildings, equipment, vegetation etc.)
  3. Transition from dense-gas to passive dispersion
  4. Low/zero wind speed dispersion
  5. Terrain effects
- Briefly reviewed specific questions, previous experiments and incidents
- More than a dozen organisations keen to provide in-kind support to JRIII trials, e.g. modelling, analysis of data

Tentative Proposal for Some Future Work

- **Proposal**: simulate previous ammonia incidents using different models, similar to the previous analysis of Graniteville, Festus, Macdona chlorine incidents by Hanna *et al*. (2008)
- **Aims**:
  - To develop experience in modelling ammonia releases
  - To examine common factors in ammonia incidents
  - To see if we get similar over-prediction of casualties to that seen before in the chlorine study



Comparison of Six Widely-Used Dense Gas Dispersion Models for Three Recent Chlorine Railcar Accidents

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Any questions?

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