



Jack Rabbit II chlorine dispersion modelling and other recent work at HSL

Group of Experts on Mitigation Systems (GEMS) 19th Annual Meeting

Defence Academy of the United Kingdom, Shrivenham, 1 February 2018

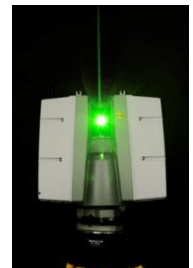
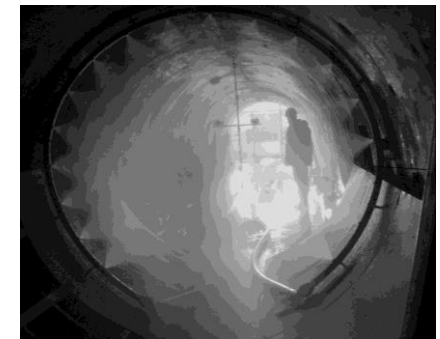
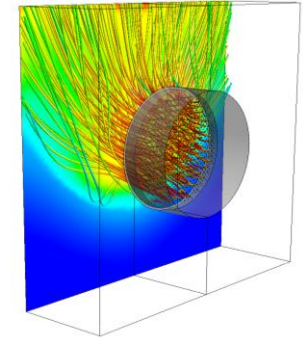
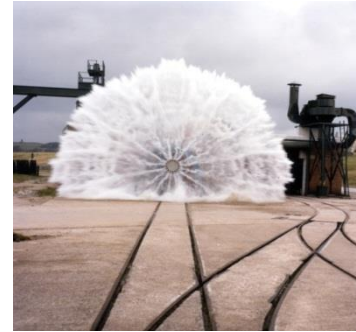
Simon Gant, Fluid Dynamics Team

Outline

- Introduction to HSL
- Jack Rabbit II chlorine releases
 - Background
 - Experiments
 - Modelling
- Other recent projects

Brief Introduction to HSL

- HSE's multi-disciplinary laboratory
 - Exposure control
 - Toxicology
 - Fire and process safety
 - Human factors etc.
- Approx. 400 staff
- 550 acre test site
- Fire galleries and burn hall
- Impact track and drop tower
- Anechoic chamber
- Thermal test chamber
- Explosives Notified Body



Jack Rabbit II: Background

- Mid-2000s, US Congress concerns about risks to public from accidents or terrorist attacks on railcars containing chlorine and other Toxic Inhalation Hazard (TIH) chemicals passing through metropolitan areas¹
- 4 million tons of chlorine transported by railcar annually in the US²
- Previous incidents, e.g. Graniteville (2005): railcar collision, 9 fatalities, 554 injured, 5400 evacuated³

Significant Chlorine Rail Incidents

- Alberton, MT – 04/11/96
- Minot, ND – 01/18/02
- Festus, MO – 08/14/02
- Macdonia, TX – 06/28/04
- Graniteville, SC – 01/05/05
- New Haven, CT – 04/17/08



Festus, MO – 08/14/02




Chlorine release in Festus, Missouri, about 30 miles south of St. Louis.
Caused by unloading line corrosion and poor maintenance of emergency shutdown equipment.

Highest Priority TIHs – 2009 Gap Analysis

The most widely-shipped toxic inhalation hazard (TIH) chemicals in US, by route.

Chemical	Road	Rail	Water	Total	% of Total
Ammonia (NH ₃)	5,793,000	3,470,592	1,718,974	10,982,566	52.8%
Chlorine (Cl ₂)	724,000	3,750,372	137,202	4,611,574	22.2% ~75%
Sulfuric Acid (H ₂ SO ₄)	257,000	207,560	2,057,721	2,522,281	12.1%
Acrylonitrile (C ₃ H ₃ N)	29,000	277,200	671,474	977,674	4.7%
Ethylene Oxide (C ₂ H ₄ O)	106,000	671,260	1,132	778,392	3.7% ~95%
Hydrogen Fluoride (HF)	29,000	264,560		293,560	1.4%
Sulfur Dioxide (SO ₂)	72,000	172,480	361	244,841	1.2%
Hydrogen Chloride (HCl)	2,000	8,400	166,027	176,427	0.8%
Hydrogen Cyanide (HCN)	33,000	31,600		64,600	0.3% ~99%
Bromine (Br ₂)	61,000			61,000	0.3%
Nitric Acid (HNO ₃)	3,000	35,800	44	38,844	0.2%



- Ammonia and chlorine dominate volume shipped
- Consideration of chlorine's much greater toxicity: Chlorine is TIH of greatest concern in transport

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NEWS

World Africa Asia Australia Europe Latin America Middle East US & Canada

Syria conflict: Aleppo 'chlorine gas attack' investigated

MPs offered 'deal or no deal' Brexit vote

Barrow defends Trump comments

RAF escorts Pakistani plane to Stansted

Over the wall

¹ <https://www.dhs.gov/science-and-technology/csac>

² <http://clorosur.org/seminar2016/presentation/18/04-DHS-CSAC.pdf>

³ Source: Chlorine Institute

Jack Rabbit II: Motivation

- In 2008, scientific papers published on evaluation of six commonly-used dense gas dispersion models for three large chlorine incidents
- All models significantly over-predicted the hazard
 - Predicted AEGL-3 (life threatening) > several km
 - No casualties in the incidents beyond around 100 m
- Concerns raised about accuracy of models
- Uncertainties:
 - Source terms: release rates
 - Dispersion
 - Terrain effects (vapour “hold up”?)
 - Deposition and chemical reactions
 - Infiltration into buildings/vehicles
 - Toxic effects

AIChE

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

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12th Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 2008

GAPS IN TOXIC INDUSTRIAL CHEMICAL (TIC) MODEL SYSTEMS

Steven Hanna¹ and Joseph Chang²

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Abstract: There are concerns regarding the hazards to the public due to the releases of toxic industrial chemicals (TICs) to the atmosphere as a result of accidents or intentional acts. For recent chlorine railcar accidents, where 30 to 60 tons of pressurized liquefied chlorine were released in rural areas, the number of casualties estimated by several widely-used model systems far exceeded the number of casualties observed, raising concerns by decision makers about the accuracy of the model systems. The

Jack Rabbit I Trials (2010)

Aims

- Measure source behaviour for model development
- Characterize the vapour/aerosol cloud movement
- Evaluate chemical reactivity with soil
- Compare ammonia and chlorine releases
- Evaluate field instrumentation
- Develop methodology for future larger tests



(© CSAC, DHS)

Experiments

- Undertaken at US Army Dugway Proving Ground, Utah, USA
- 1 – 2 ton releases of chlorine and ammonia: downward impinging jets
- Releases took place within a 50 m wide, 2 m deep circular depression
- Main findings: modelling of vapour “hold up” in shallow depression in light winds, Rapid Phase Transitions (RPTs) from porous desert playa after release finished and significant losses of chlorine from reactivity with soil

Jack Rabbit II Trials (2015 – 2016)

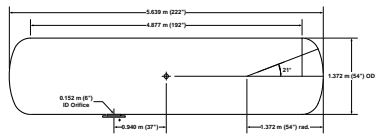
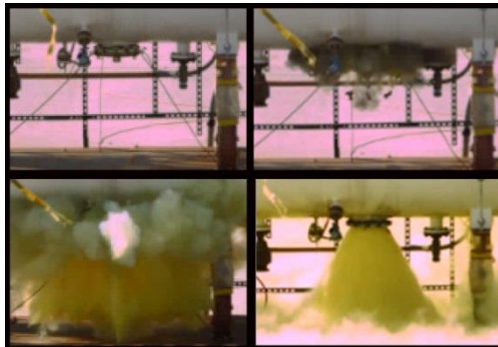
Aims

- Larger-scale chlorine release experiments
- 5 – 20 ton pressurized chlorine releases
- Mock urban array of obstacles
- Different release orientations
- Dispersion measurements to 11 km
- Infiltration into buildings and vehicles
- Measure key source terms parameters
- Assess chlorine reactivity with soil etc.
- Emergency-responders' equipment



(© CSAC, DHS)

Jack Rabbit II: Experiments

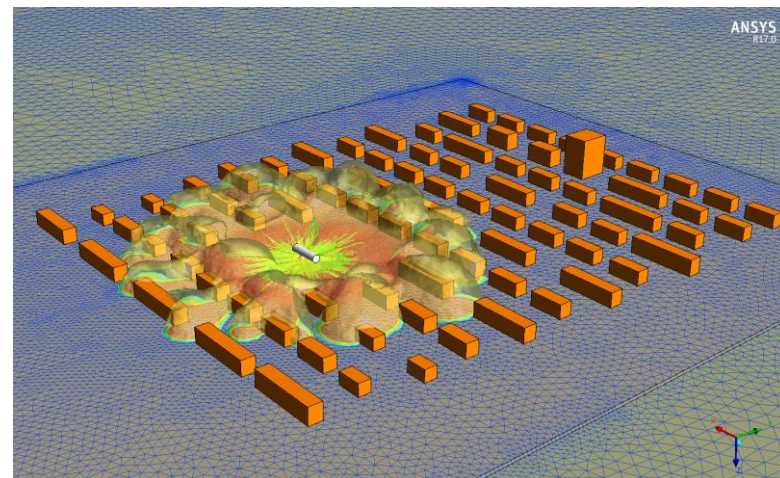


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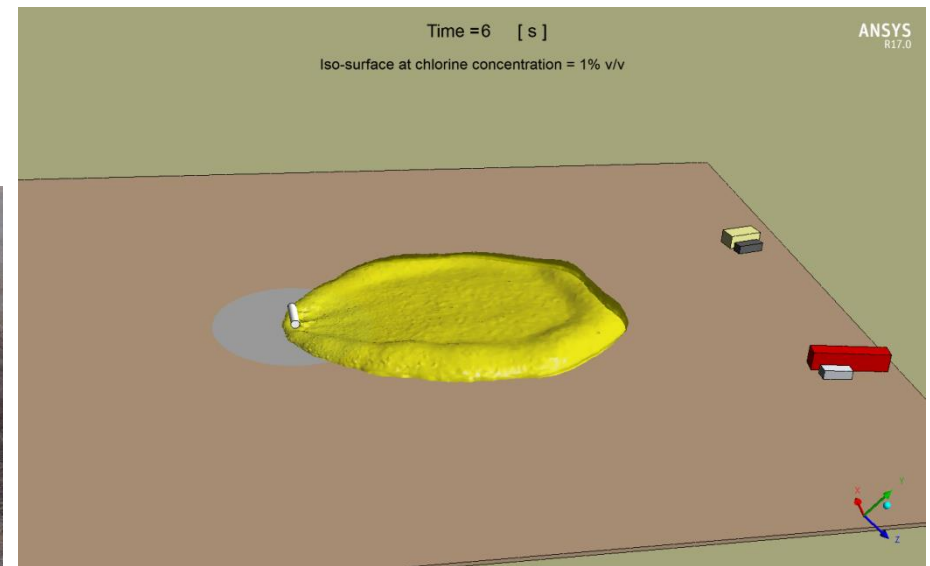
Jack Rabbit II: HSL Involvement

Aims

- Before the experiments
 - To provide dispersion model predictions to help position sensors
- After the experiments
 - To help interpret measurement data
 - To validate the DRIFT dispersion model that HSE uses for regulatory purposes
 - To assess the PHAST dispersion model used by chemical industry consultants
 - To use CFD to investigate the near-field dispersion behaviour
- To collaborate with other experts in the Modelers' Working Group and share findings



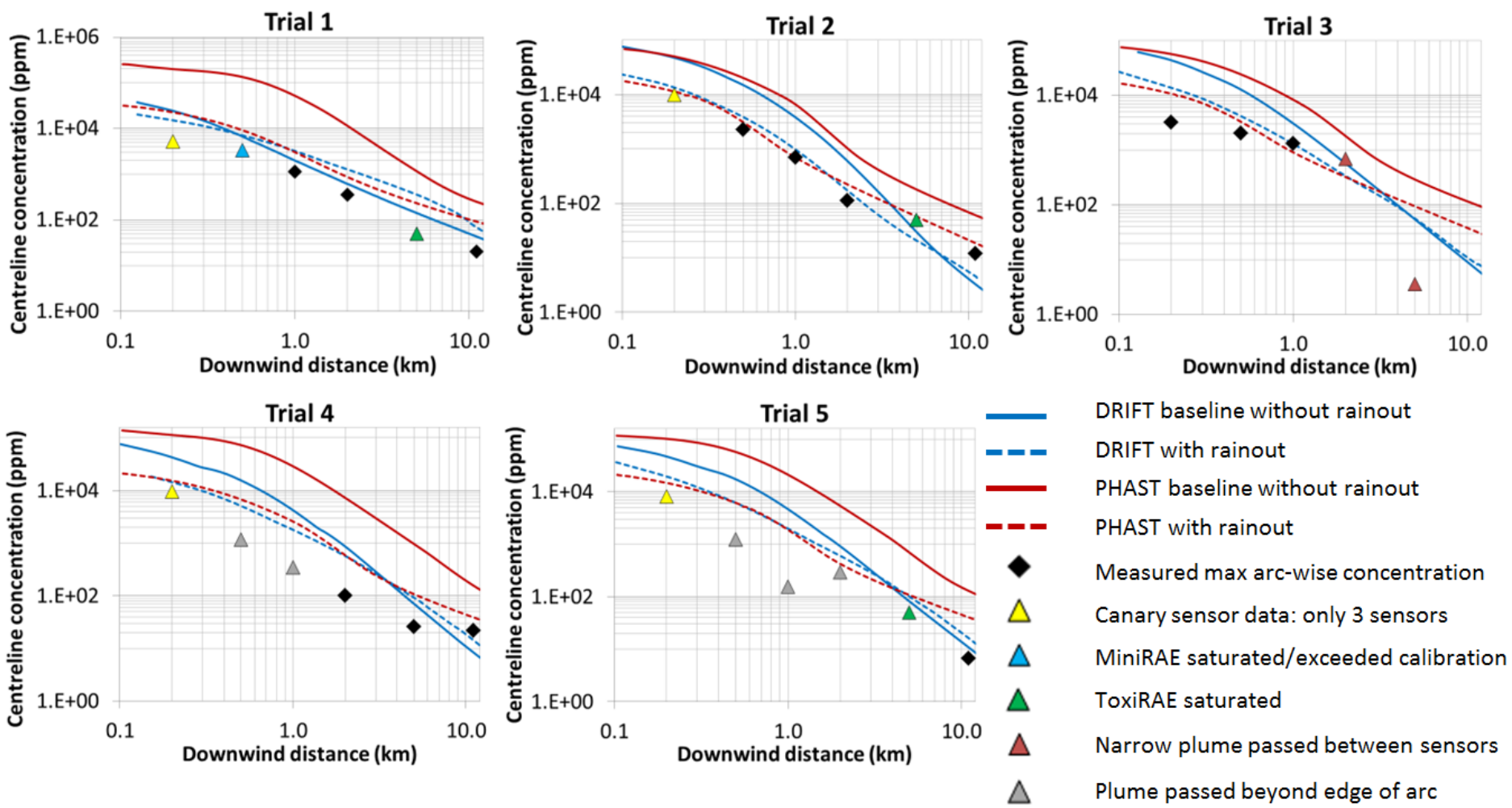
Jack Rabbit II



Play Videos

<http://www.uvu.edu/esa/jackrabbit/>

Jack Rabbit II: DRIFT/PHAST Models



Other recent projects at HSL

Recent and Ongoing Projects

- Vapour Cloud Explosions: Buncefield and other similar incidents
- Carbon capture and storage: CO₂ experiments and modelling
- Liquefied Natural Gas (LNG) spills: experiments and modelling
- Storage of ANFO in mines: Autodyn modelling
- “Cook-off” in explosives (Diamond light source, LANL, Manchester University)
- Fires in ventilated compartments (OECD PRISME project)
- Flammability of oil mists



Buncefield (2005)



Jaipur (2009)



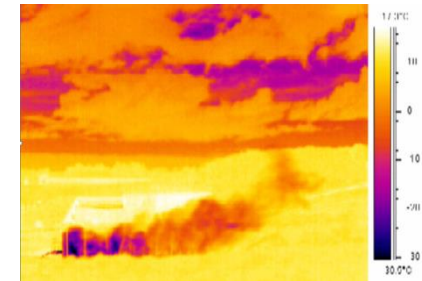
Puerto Rico (2009)



Amuay (2012)

Recent and Ongoing Projects

- Hydrogen safety
 - Hydrogen in natural gas network (NaturalHy, HyDeploy, H21)
 - Hydrogen refuelling stations (HyApproval)
 - Stationary hydrogen and fuel cell applications (HyPER, H2FC)
 - Indoor hydrogen leaks (HyIndoor)
 - Hydrogen release, dispersion, fire and explosion modelling (Susana)
 - Fire testing on composite hydrogen cylinders (FireComp)
 - Flame-out and re-ignition of hydrogen-powered gas turbines (ETI High Hydrogen)
 - Cryogenic liquid hydrogen spill experiments



Recent and Ongoing Projects



Acknowledgements



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Data from the Jack Rabbit II test program is available on request (email: Jack.Rabbit@st.dhs.gov)

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