RESEARCH AND GUIDANCE FROM HSE

Health, Safety and Security Workshop

2nd Symposium on Ammonia Energy, Université d'Orléans, France, 11-13 July 2023

Simon Gant

Fluid Dynamics Team, Risk and Human Factors Group, HSE Science and Research Centre

Research - HSE funded to provide evidence which underpins its policy and regulatory activities
Guidance - freely available to help people comply with health and safety law

Workshop Objectives

- Learn about recent scientific developments
- Share information about new projects and initiatives
- Raise safety-related issues that need to be addressed
- Ask questions and participate in discussions

- Broad scope:
  - Health, safety and security in ammonia production, transport and use

Outline of this talk

- Review discussions at last year's health and safety workshop
- Provide an update on recent activities at HSE
- Discuss useful recent publications and ongoing research projects

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- Think about a question you would like to put to the room
  - HSE question: where do you seek information on ammonia safety, e.g., when designing a new facility or undertaking a new operation?

Review of Health and Safety Workshop, 3 Sept 2022

- Ammonia has been produced, stored, transported and used generally safely for many years by the fertilizer industry
- In the coming years, to meet Net Zero ambitions, we are likely to see new entrants who may be unfamiliar with the risks
- Novel risks may also emerge due to the use of ammonia in new environments and/or for new applications
- Important that research is undertaken to ensure that these novel risks are identified and appropriately managed
- Discussions focused on four areas:
  - Production, storage, distribution and use of ammonia

Review of Health and Safety Workshop, 3 Sept 2022

- Production
  - Siting of new ammonia facilities near sources of renewable energy
  - Decentralised production?
  - Need for inherently safe designs

- Storage
  - Cryogenic liquid ammonia: lack of experimental data on behaviour of spills
  - Hazard profiles depend on liquid ammonia storage conditions
    - Temperature-liquefied (<-33°C, <5 bar) ← Smaller hazard?
    - Pressure-liquefied (20°C, >8 bar)

Review of Health and Safety Workshop, 3 Sept 2022

Pressure-liquefied (Houston, Texas,1976)

https://www.houstonchronicle.com/news/houston-texas/houston/article/In-1976-an-ammonia-truck-disaster-claimed-the-12906732.php

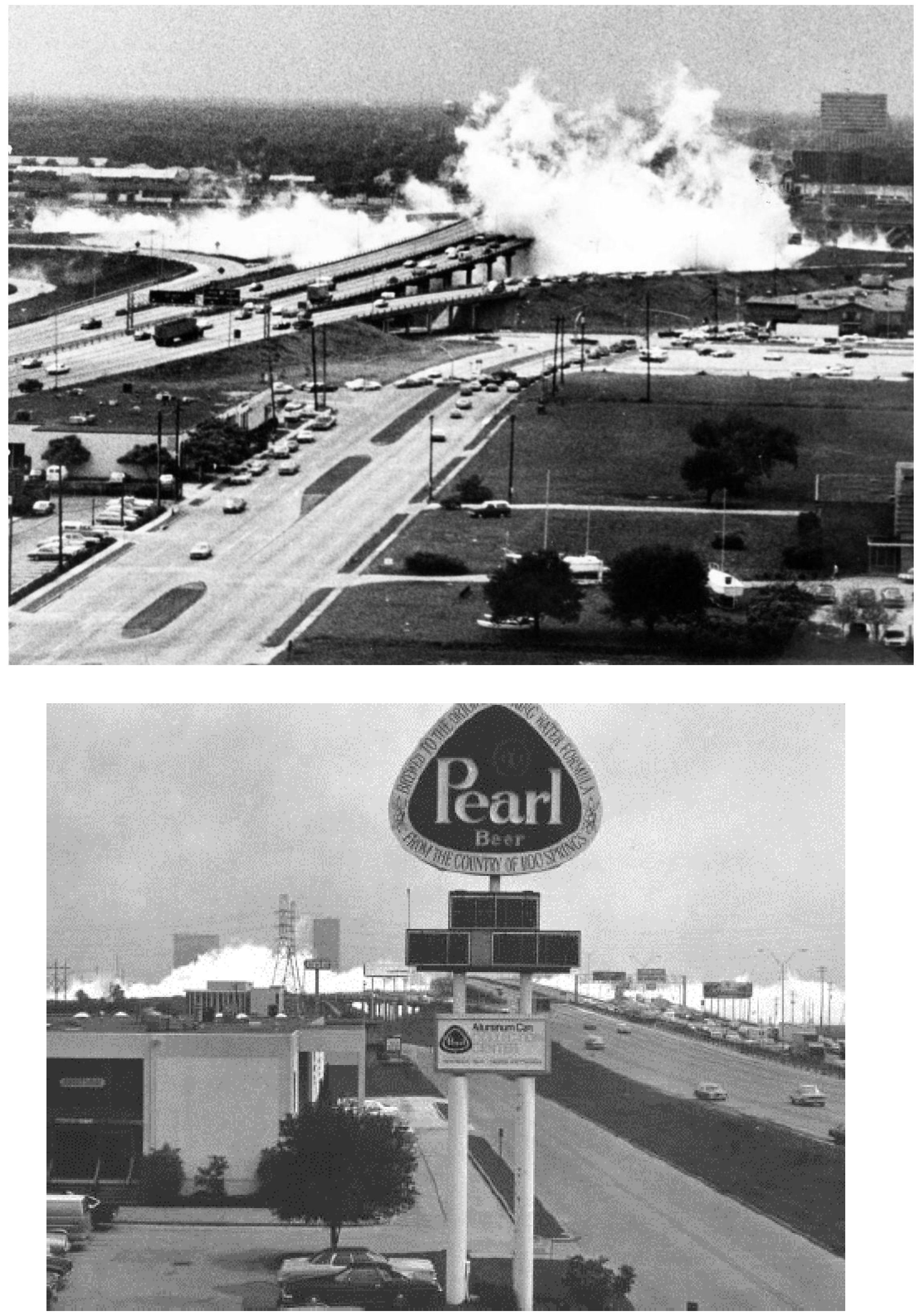


Figure 26 Photography of the Southwest freeway in Houston, Texas taken about one minute after the Houston tanker crash. Photograph taken by Texas Air Control Board (© Texas Commission Environmental Quality copyright 1976).

Temperature-liquefied (Blair, Nebraska, 1970)

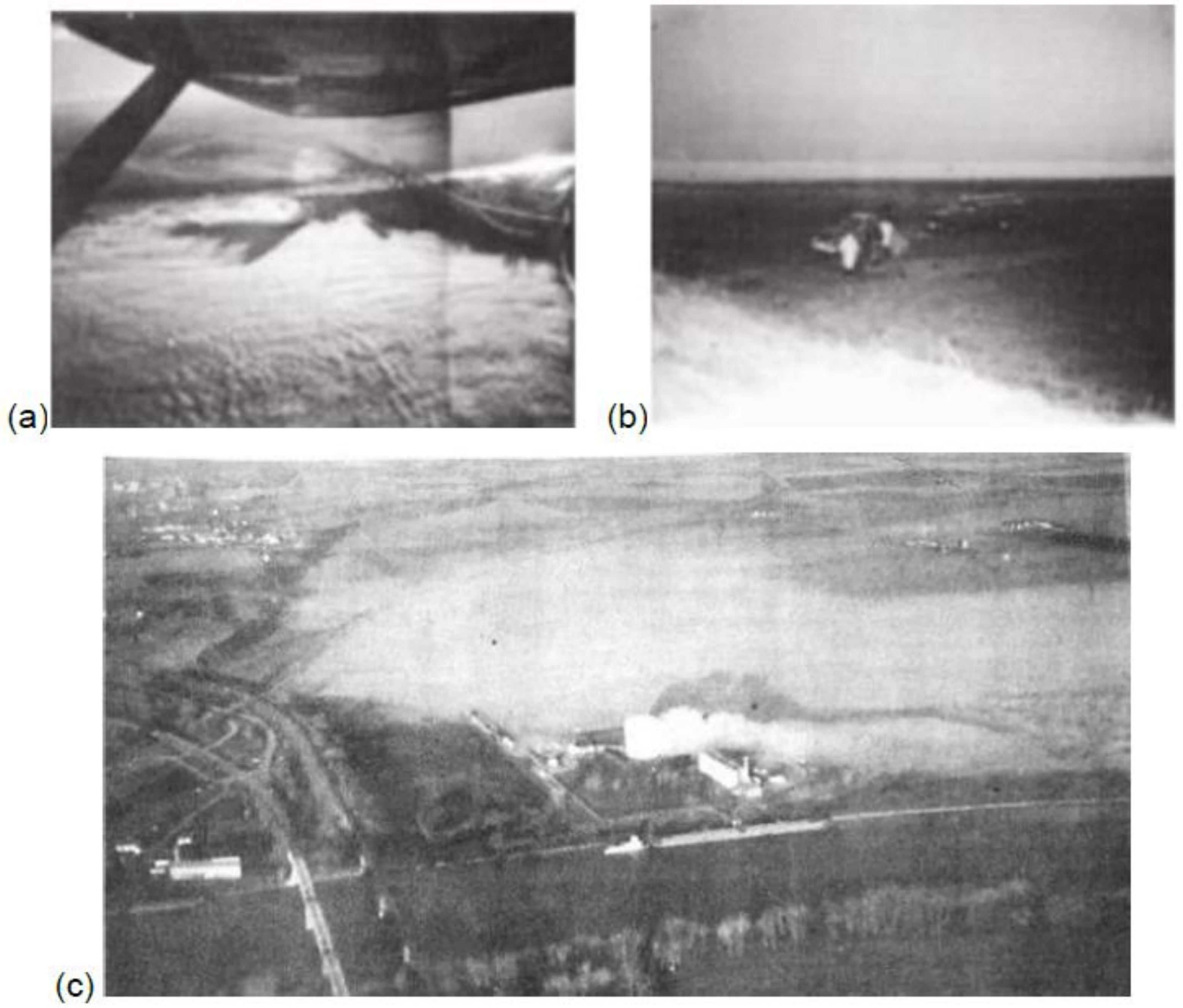
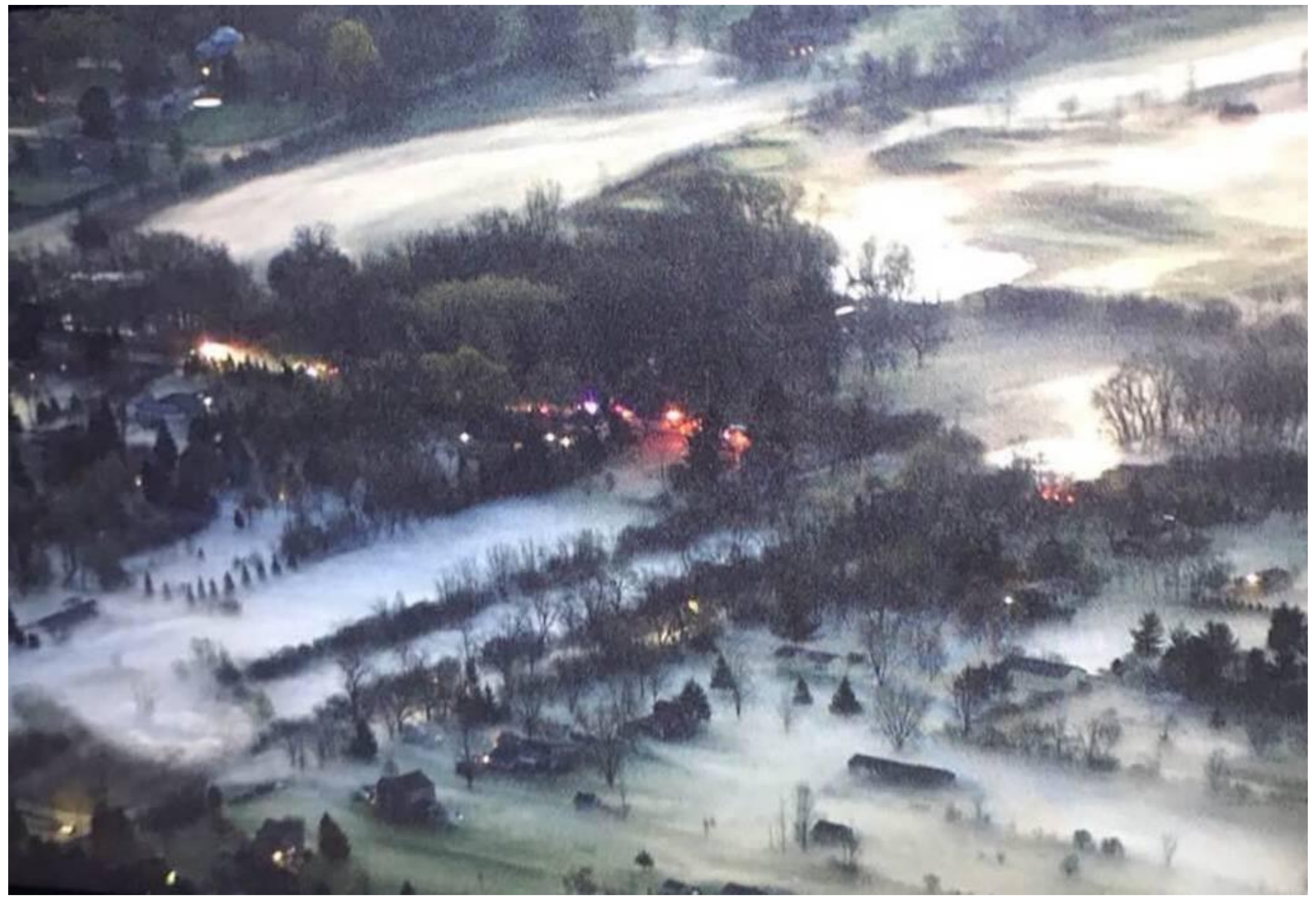


Figure 25 Photos of the ammonia cloud resulting from the release at Blair, Nebraska. (a) Aerial view showing ammonia cloud covering whole of foreground; and (b) ground level view showing relatively shallow cloud depth, (c) Aerial view (© Washington County Enterprise copyright 1970)

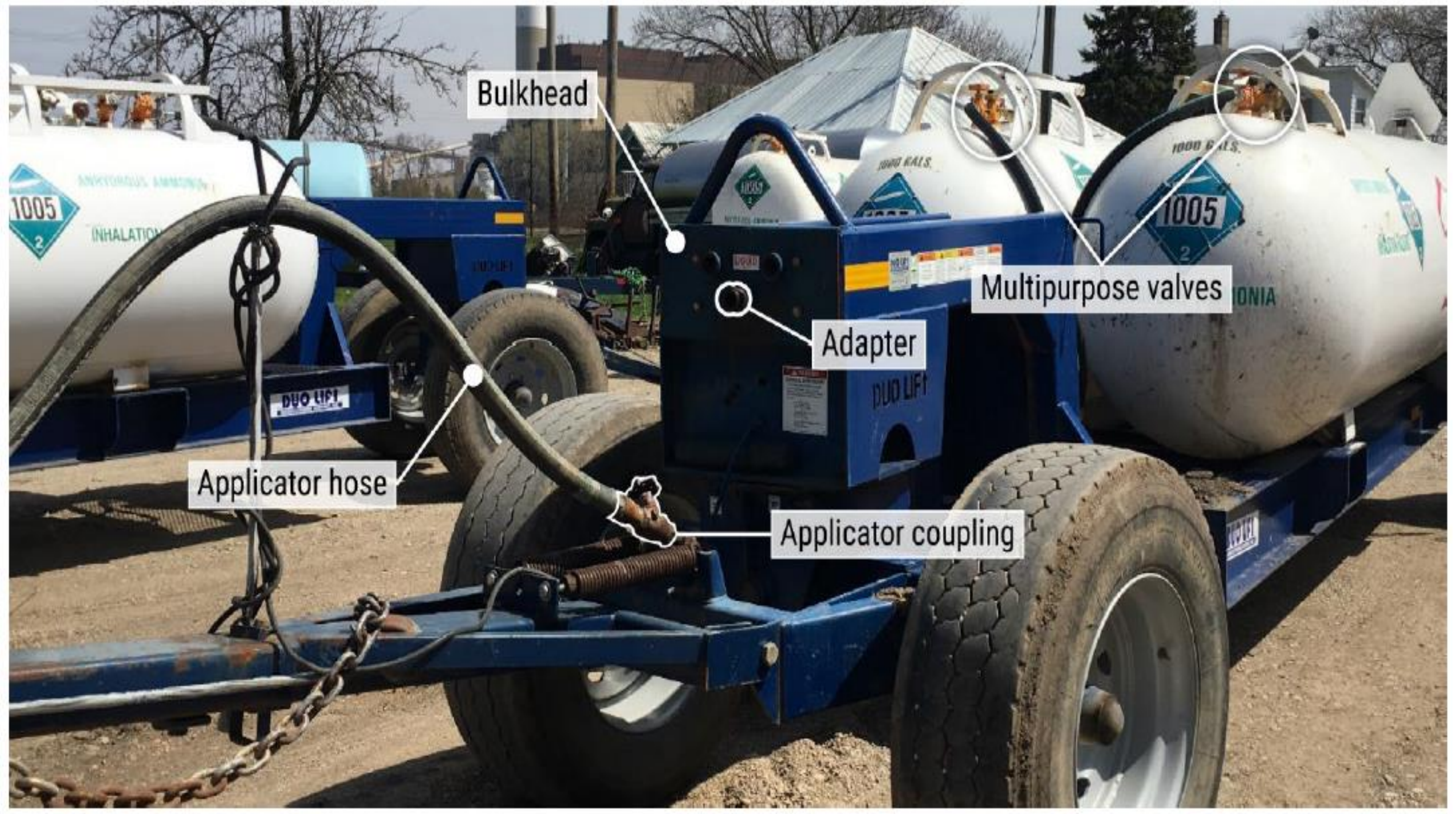
From Batt (2021) "Review of dense-gas dispersion for industrial regulation and emergency preparedness and response" https://admlc.com/publications/

Review of Health and Safety Workshop, 3 Sept 2022

- Production
  - Are incidents more common for pressure-liquefied ammonia because of the frequency of operations, e.g., agricultural fertilizer applications in the USA?
  - Often the source of the leak is failure of a transfer connection or hose



© Beach Park Fire Department
https://www.chicagotribune.com/suburbs/lake-county-news-sun/ct-lns-cdc-report-ammonia-fog-zion-st-0131-20200130-bphoo3jltjffxnsed2u3ftbqqg-story.html



© PHMSA
Source: Hazardous Materials Investigation Report: HZIR-22/01
www.ntsb.gov/investigations/AccidentReports/Reports/HZIR2201.pdf

Review of Health and Safety Workshop, 3 Sept 2022

- Production
  - Important considerations: level of training of operatives involved in filling operations
  - Need for new system designs that completely reduce chances of leaks
  - Standards and guidance: good examples from LPG and industrial gas sector
  - Ammonia guidance often internal fertilizer company documents
  - Useful for this guidance to be shared with new entrants to the ammonia market
  - Efforts to be coordinated by the Energy Institute? The Ammonia Energy Association? AIChE? ASTI?
  - For other toxic chemicals, such as chlorine, there are established groups that help to share safety-related information, e.g., the Chlorine Institute

Review of Health and Safety Workshop, 3 Sept 2022

- Distribution and Utilization
  - Ammonia is an important future clean transportation fuel, mainly in shipping
  - Risk assessments followed by demonstration projects are needed
  - Experience of ammonia in liquefied-gas carriers: useful source of guidance and statutory requirements
  - Toxicity challenges are significant but manageable, adding complexity to ship designs
  - Ammonia likely to be used for deep-sea cargo vessels, rather than passenger or inland-waterway craft
  - Bunkering operations? Still some challenges and unknowns
  - Ship designs: how to reduce risks to crew in case of a leak?
  - Design and layout needs high level of inherent safety: consideration of double-containment, gas detection etc.

Review of Health and Safety Workshop, 3 Sept 2022

- Distribution and Utilization
  - Handling ammonia onboard ships will require new set of skills and safety procedures
  - Need for new regulations, codes and rules development
  - Technical issues to be solved in use of ammonia in combustion engines:
    - Use of pilot fuels
    - Co-firing with hydrogen for improved combustion
    - Corrosion of engine components (seals, bearings etc.)
    - Reactions between ammonia and lubricants producing toxic products
  - Public perception of ammonia risks and benefits of switching from fuel oil

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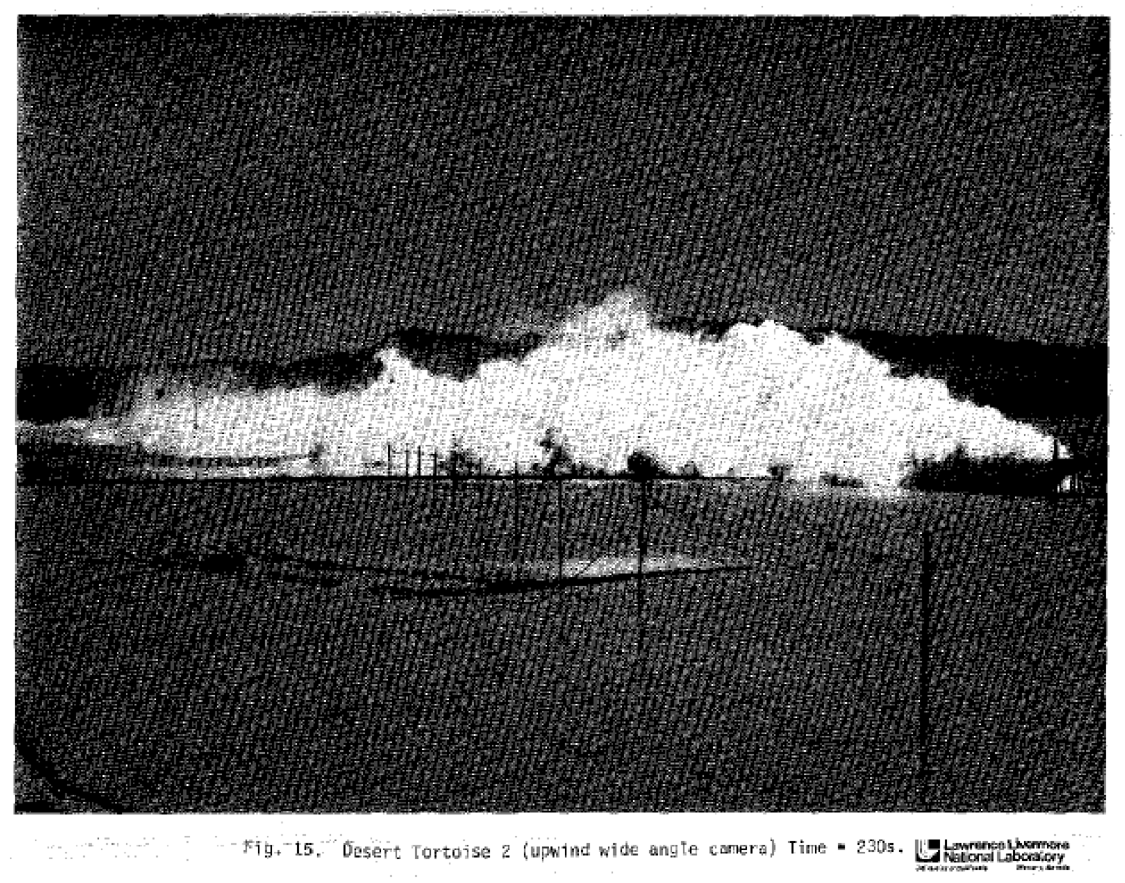
Recent activities at HSE

- Jack Rabbit III https://www.uvu.edu/es/jack-rabbit/
  - Completed (mostly) the model-intercomparison exercise on previous pressure-liquefied ammonia release experiments: Desert Tortoise and FLADIS
  - Three groups still running dispersion models for the exercise:
    - Dave Brown (Argonne National Lab) CASRAM model, also used for developing the PHMSA Emergency Response Guidebook dispersion distances
    - Bob Bradley (Emergency Management Solutions) ALOHA
    - Bjørn Lilleberg (DNV KFX) testing ammonia-specific version of KFX
  - Aiming to write-up full account in September-November 2023 for journal publication



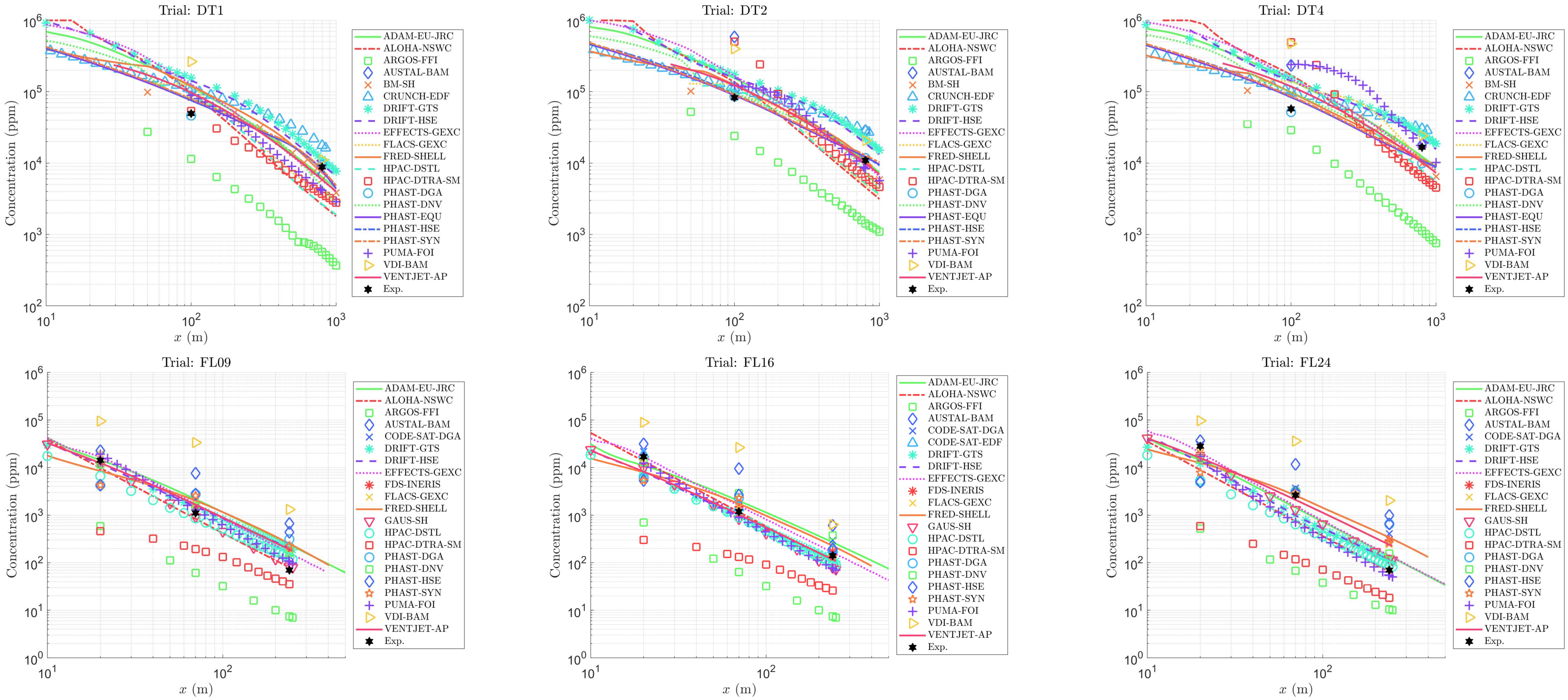
Desert Tortoise © LLNL

FLADIS © Riso

Participants in the JRIII Initial Modeling Exercise

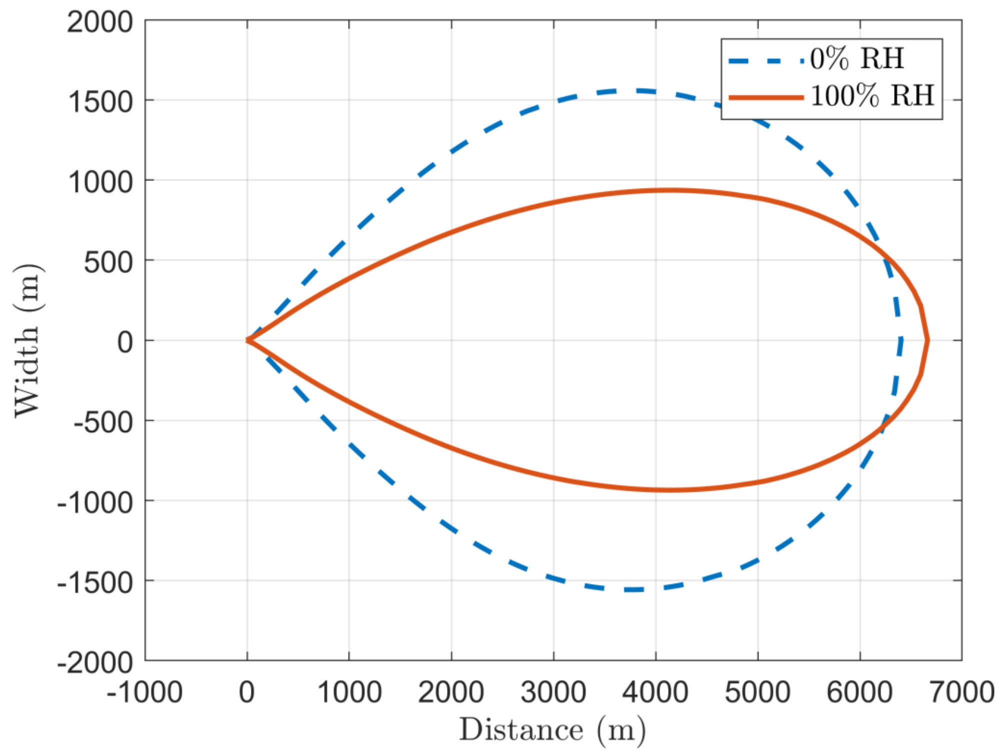
#	Organization	Model	Model Type				Desert Tortoise			FLADIS		
			Empirical nomogram/ Gaussian plume	Integral	Gaussian Puff/ Lagrangian	CFD	1	2	4	9	16	24
1	Air Products, USA	VentJet		■			■	■	■	■	■	■
2	BAM, Germany	AUSTAL			■		■	■	■	■	■	■
3		VDI	■				■	■	■	■	■	■
4	DGA, France	PHAST v8.6		■			■	■	■	■	■	■
5		Code-Saturne v6.0				■				■	■	■
6	DNV, UK	PHAST v8.61		■			■	■	■	■	■	■
7	DSTL, UK	HPAC v6.5			■		■	■	■	■	■	■
8	DTRA, ABQ, USA	HPAC v6.7			■		■	■	■	■	■	■
9	DTRA, Fort Belvoir, USA	HPAC			■		■	■	■	■	■	■
10	EDF/Ecole des Ponts, France	Code-Saturne v7.0				■					■	
11		Crunch v3.1		■			■	■	■			
12	Equinor, Norway	PHAST v8.6		■			■	■	■	■	■	■
13	FFI, Norway	ARGOS v9.10			■		■	■	■	■	■	■
14	FOI, Sweden	PUMA			■		■	■	■	■	■	■
15	Gexcon, Netherlands	EFFECTS v11.4		■			■	■	■	■	■	■
16	Gexcon, Norway	FLACS				■	■	■	■	■	■	■
17	GT Science & Software	DRIFT v3.7.19		■			■	■	■	■	■	■
18	Hanna Consultants, USA	Britter & McQuaid WB	■				■	■	■			
19		Gaussian plume model	■							■	■	■
20	HSE, UK	DRIFT v3.7.12		■			■	■	■	■	■	■
21		PHAST v8.4		■			■	■	■	■	■	■
22	INERIS, France	FDS v6.7				■				■	■	■
23	JRC, Italy	ADAM v3.0		■			■	■	■	■	■	■
24	NSWC, USA	RAILCAR-ALOHA		■			■	■	■	■	■	■
25	Shell, UK	FRED 2022		■			■	■	■	■	■	■
26	Syngenta, UK	PHAST v8.61		■			■	■	■	■	■	■

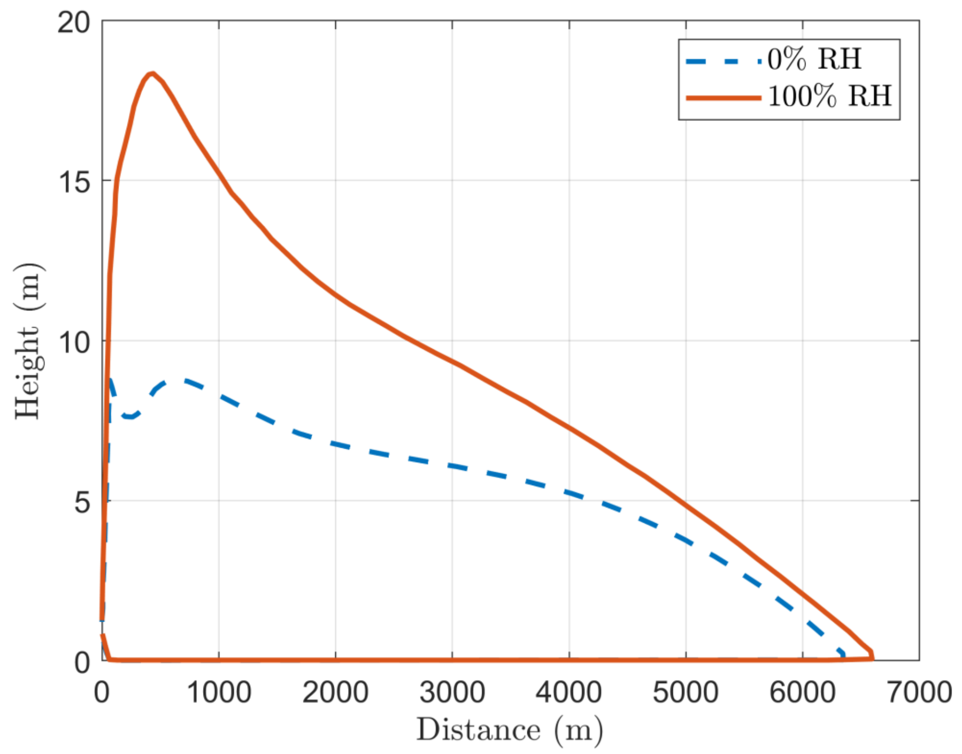
All Model Results

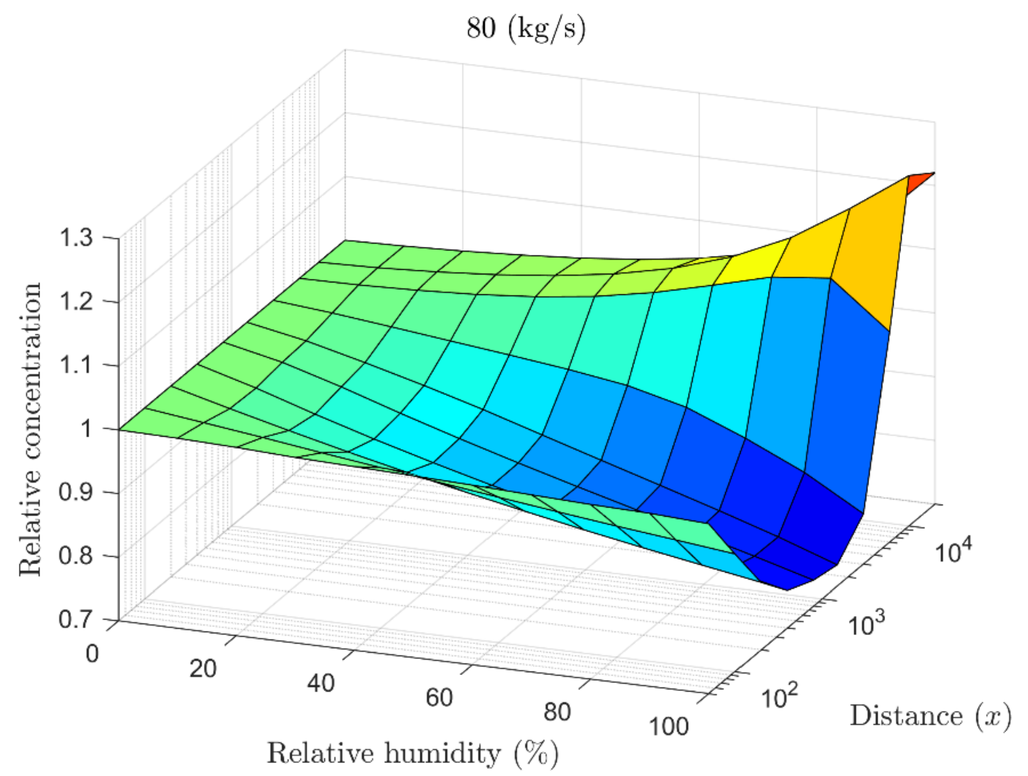


Recent activities at HSE

- Jack Rabbit III
  - How does humidity affect the dispersion behaviour of pressure-liquefied ammonia jet releases?
  - Which release scenarios are most sensitive to humidity?
  - If you vary humidity from 0% to 100% RH, what are the differences in concentrations?
  - Methodology: sensitivity analysis using DRIFT dispersion model that accounts for thermodynamics of ammonia-water reactions
  - Slides from George Mason University (GMU) conference available on request

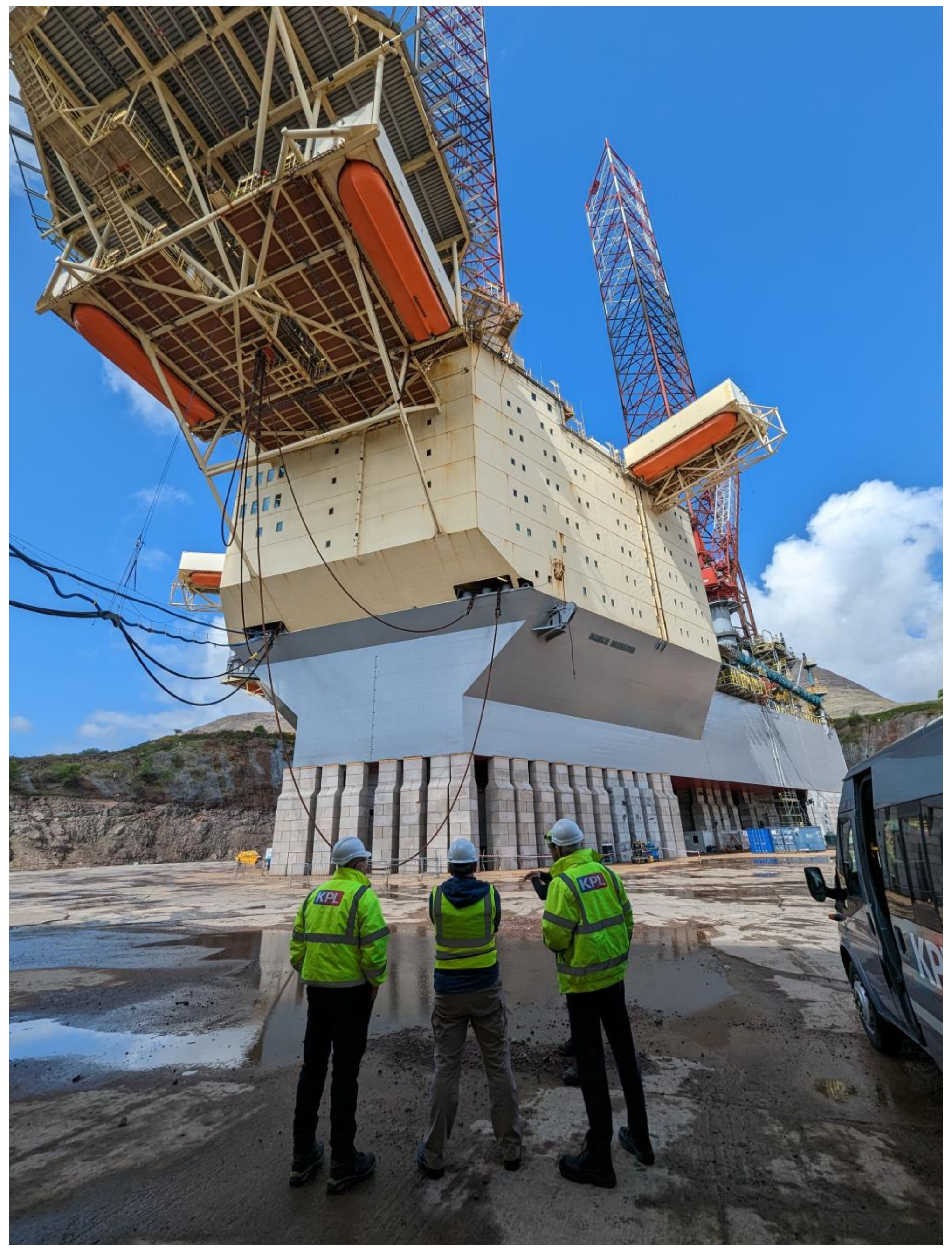






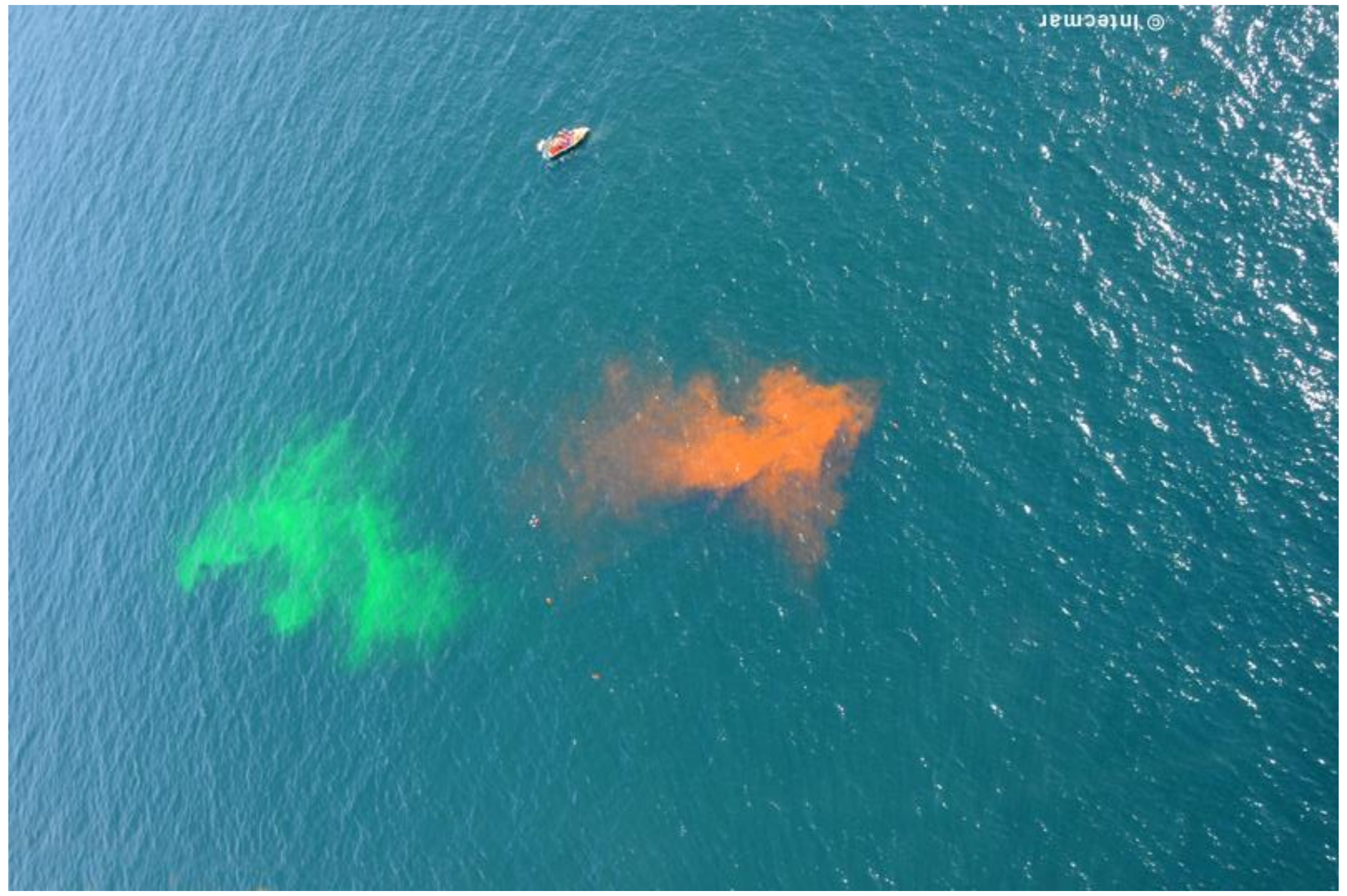
Recent activities at HSE

- Jack Rabbit III
  - Simulations of 2-ton nurse tank releases and short pipeline releases to assist with planning for future JRIII trials
  - Project leads at US Dept of Homeland Security and Dept of Defence are currently visiting USA and international test sites
  - Current timeline:
    - 2026 for small/medium scale ammonia release experiments
    - 2027 for large-scale ammonia release experiments



French JIP on waterborne ammonia spills

- Initiated by Yara Clean Ammonia (contact: Laurent.ruhlmann@yara.com)
- Led by INERIS (contact: olivier.gentilhomme@ineris.fr)
- Current partners: Yara, INERIS, CEDRE, ONERA, RBINS, HSE
- Aim: To improve confidence in the prediction of ammonia spills onto water
- Work packages to include:
  - Scenario definition and risk analysis
  - Sensor technologies for air and water
  - Model development and validation
  - Experiments and data analysis
- Timeline: aiming to conduct tests in 2024/2025



https://wwz.cedre.fr/Projets/2022/IRA-MAR-2022

Energy Institute

- Workshop on “Energy storage network development for hydrogen and liquid derivatives”, Friday 7 July 2023
- Other initiatives on ammonia import/export and ports are ongoing at the Energy Institute
- https://www.energyinst.org/
- Contact: Mark Scanlon

energy institute

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Recent Publications

- Risk studies on marine applications of ammonia:
  - "**Hydrogen and ammonia infrastructure: safety and risk information and guidance**" by Lloyds Register, May 2020 https://static1.squarespace.com/static/5d1c6c223c9d400001e2f407/t/5eb553d755f94d75be877403/1588941832379/Report+D.3+Safety+and+regulations+Lloyds+Register.pdf
  - "**External safety study - bunkering of alternative marine fuel for seagoing vessels, Port of Amsterdam**" by DNV, April 2021 https://sustainableworldports.org/wp-content/uploads/DNV-POA-Final-Report_External-safety-study-bunkering-of-alternative-marine-fuels-for-seagoing-vessels_Rev0_2021-04-19.pdf
  - "**Safety and operational guidelines for piloting ammonia bunkering in Singapore**", DNV-led ammonia safety study for Global Centre for Maritime Decarbonisation (GCMD), April 2023 https://www.gcformd.org/ammoniabunkeringreportdownload
  - "**Ammonia as a marine fuel**", Maritime Energy & Sustainable Development (MESD) and Nanyang Technological University (NTU), October 2022 https://www.ntu.edu.sg/mesd-coe/publications
  - "**Recommendations for design and operation of ammonia-fueled vessels based on multi-disciplinary risk analysis**" by Lloyds Register for Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, June 2023 https://www.zerocarbonshipping.com/publications/recommendations-for-design-and-operation-of-ammonia-fueled-vessels-based-on-multi-disciplinary-risk-analysis/
  - **ITOCHU** Joint Study Framework on Ammonia as an Alternative Marine Fuel – any progress? https://www.itochu.co.jp/en/news/news/2022/220406.html

Recent Publications

- Air Products “Red Squirrel” trials at DNV Spadeadam

Received: 27 February 2023 | Revised: 27 March 2023 | Accepted: 30 March 2023
DOI: 10.1002/prs.12454

ORIGINAL ARTICLE

PROCESS SAFETY PROGRESS

Red Squirrel Tests: Air Products' ammonia field experiments

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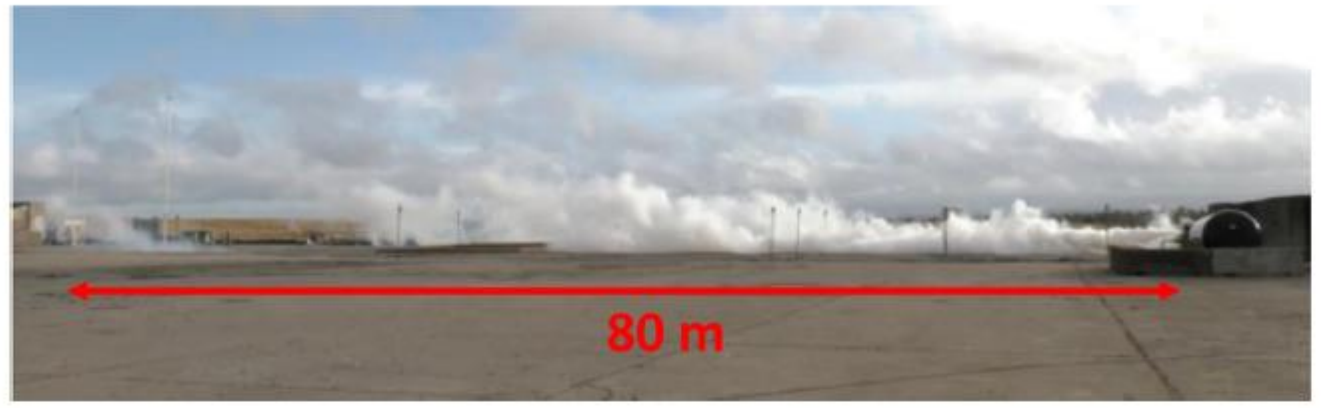
Abstract

The Red Squirrel ammonia field experiments were conducted at the DNV Spadeadam site in the UK in 2022. Field test data currently exists for high-pressure (ambient temperature) two-phase releases of ammonia from Desert Tortoise (1983) and FLADIS (1996) experiments. No field tests have ever been done for cold (refrigerated) ammonia liquid spills on dry land or into water. The handling of liquified ammonia, during storage/processing and transportation, in a cold (refrigerated) state is inherently safer than in a high-pressure (ambient temperature) liquified state. The main objective of the Air Products' Red Squirrel Tests was to determine the source term and dispersion characteristics for high-pressure (ambient temperature) liquified ammonia and low-pressure (cold/refrigerated) liquified ammonia in form of two-phase releases and liquid spills, respectively. Liquid spills on concrete and water were studied, along with the process conditions that led to the transition from liquid spills to two-phase flow regimes based on discharge pressures for cold liquified ammonia. Details on the equipment, instrumentation, secondary containment, and ammonia sensors and their layout are presented. An initial analysis of the source terms and dispersion behavior for two-phase releases and contained liquid spills over a range of weather conditions is also provided.

KEYWORDS
ammonia, field testing, pressurized ammonia, Red Squirrel, refrigerated ammonia, spills on land, spills on water, two-phase releases

FIGURE 8 RS-1F unpressurized/cold ammonia spill on the water in bund with initial puff discharge for 18 s (left) and aqua ammonia pool after release (right). RS, Red Squirrel.

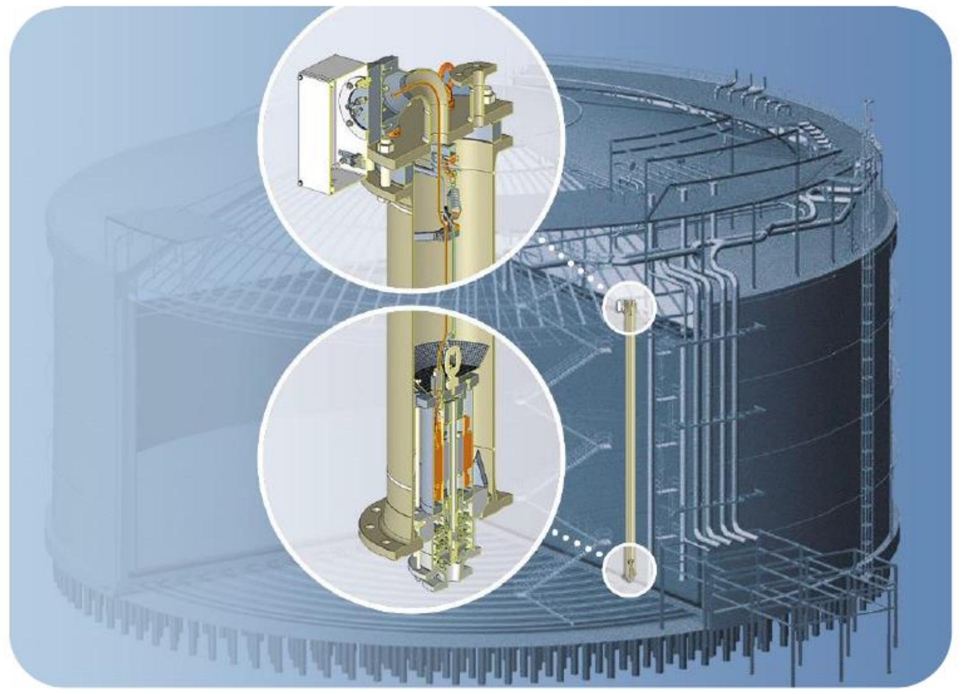
FIGURE 9 RS-2F pressurized ambient temperature ammonia release. RS, Red Squirrel.



http://dx.doi.org/10.1002/prs.12454

Recent Publications

- Ammonia cryogenic storage tank design



Hazards32

SYMPOSIUM SERIES No.169 HAZARDS 32 © 2022 IChemE

Cryogenic Storage of Anhydrous Ammonia

Adrian Wright, Technical Lead Process Safety, TGE Gas Engineering GmbH

Suite 2a, Manchester International Office Centre, Styal Road, M22 5WB Manchester

As well as providing bulk cryogenic storage for LNG and LPG, TGE-Gas is getting an increased number of projects, and project enquiries for large scale cryogenic bulk storage of anhydrous ammonia. Ammonia has long been used in the fertiliser industry, but it now has the potential to be a clean feed for production of hydrogen gas fuelling aviation. This will lead to an increase in the need for cryogenic anhydrous ammonia bulk storage tanks at new locations such as airports.

Hazards 32 delegates will benefit by understanding the properties of anhydrous ammonia that make it very suitable for cryogenic bulk storage at atmospheric pressure and will gain an understanding of how the hazards from liquid ammonia can be successfully managed during commissioning and operation.

Ammonia Storage Terminal Design

A typical modern ammonia storge terminal shown below.

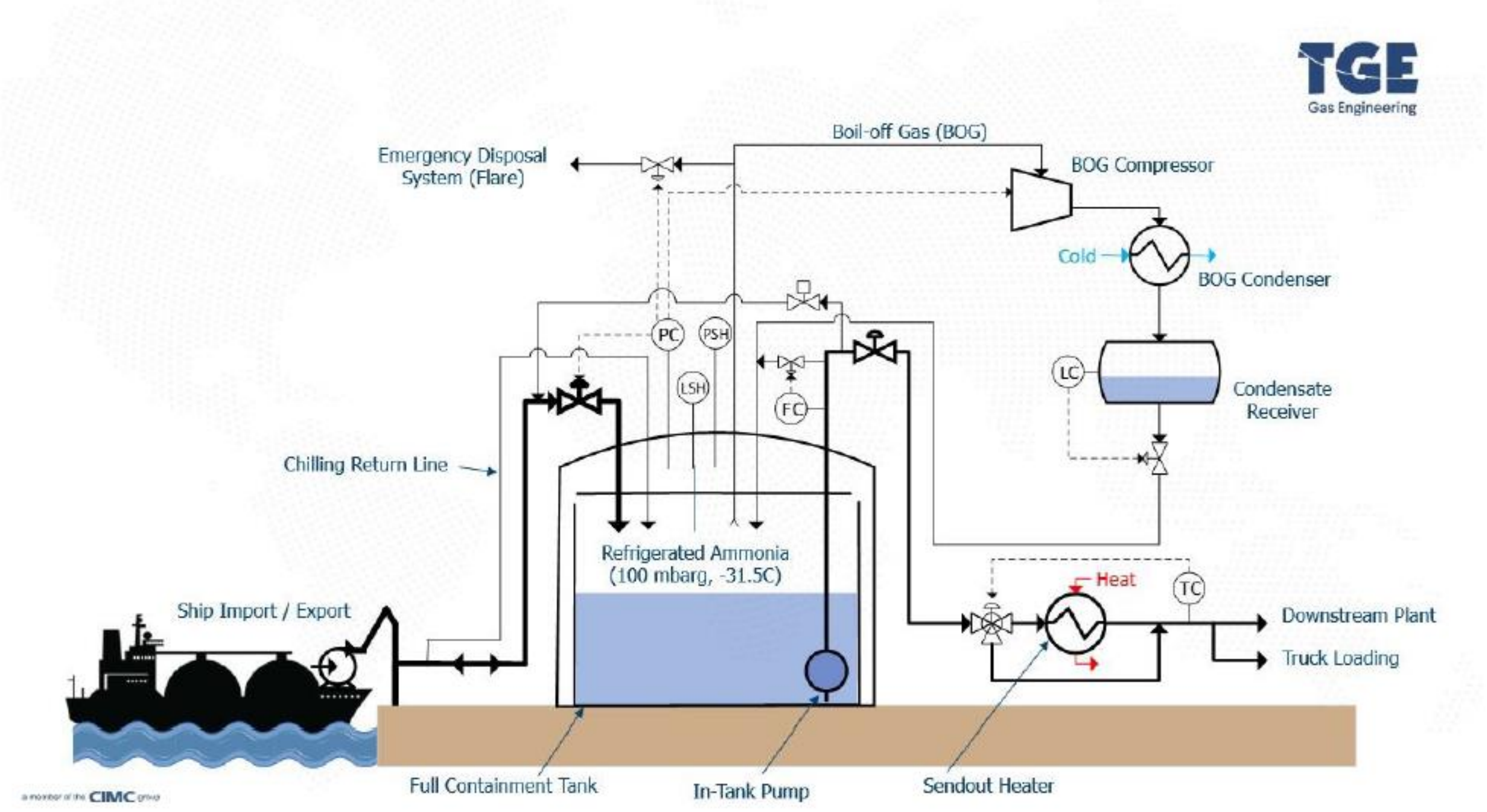


Figure 6. Typical design for an ammonia storage terminal

Ongoing Research Projects

- Norwegian research institute, SINTEF, project MaritimeNH3

MaritimeNH3 – Enabling implementation of ammonia as a maritime fuel

Research Partners

- SINTEF Energy Research
- SINTEF Industry

Industry partners

- Yara International
- Amon Maritime
- ECONNECT Energy
- Ocean Hyway Cluster
- HYEX Safety
- Viridis Bulk Carriers

MaritmeNH3 focuses on developing improved models for safety assessments, methodologies for techno-economic analysis and GHG assessments of the whole NH_3 value chain, and technological advancements for end-use in NH_3-fuelled engines and fuel cells. It will address barriers related to the use of NH_3 as a maritime fuel including production, cost, safety, regulations, end-use technology and understanding of the value chain.

Project duration
2021 - 2024

Aims and objectives

MaritimeNH3's main objective is to develop and disseminate knowledge contributing to the necessary technology advancements in the ammonia (NH_3) value chain in order to enable a safe and cost-efficient implementation of NH_3 as a maritime fuel.

This will be achieved by:

- Improving risk mitigation for NH_3 bunkering installations in a Nordic climate by improving the modelling of NH_3 dispersion at ppm levels between rapidly lethal and detectable odour limits,
- Advancing the technological development of NH_3-fuelled combustion engines and high-temperature fuel cells by evaluating concepts for improving the combustion characteristics of NH_3 and determining the main degradation mechanisms that impact the lifetime of NH_3-fed fuel cells,
- Developing and applying a methodology for a techno-economic analysis and greenhouse gas (GHG) assessment of a Norwegian NH_3-based energy system for maritime transport, and comparing this to alternative H_2-based value chains, and
- Increasing the social acceptance of NH_3 as a maritime fuel, and promoting its uptake and further development.

https://www.sintef.no/en/projects/2021/maritimenh3-enabling-implementation-of-ammonia-as-a-maritime-fuel/aims-and-objectives

Ongoing Research Projects

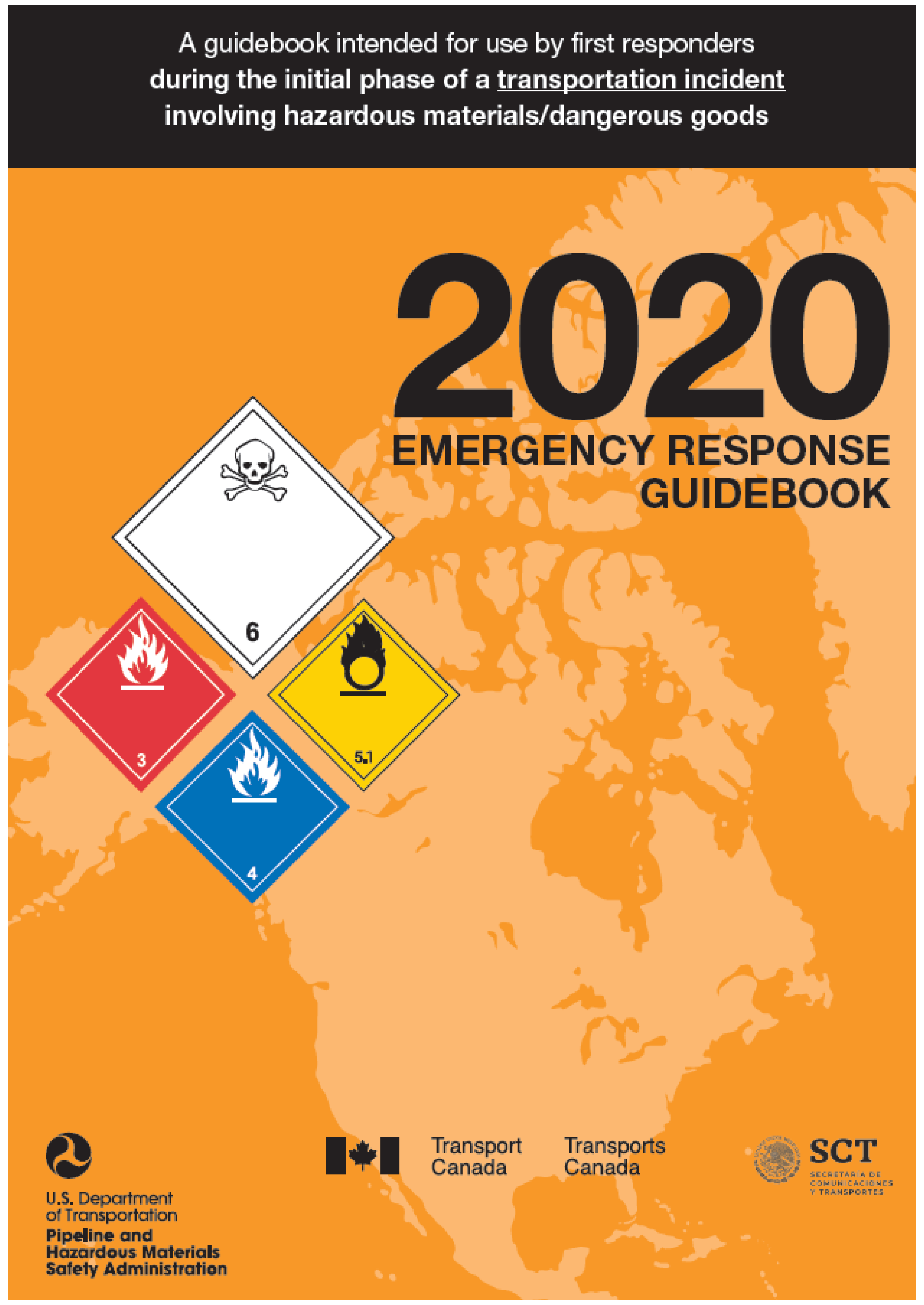
- Project **SafeAm** led by Marta Bucelli, SINTEF
- Small-scale experiments involving ammonia spills on water
- Model development and testing
- Awarded funding by the Research Council of Norway, June 2023

HSE question

- Where do you seek information on ammonia safety, e.g., when designing a new facility or undertaking a new operation?
  - Lloyds Register, DNV and NTU reports cited earlier

Safety-Related Information

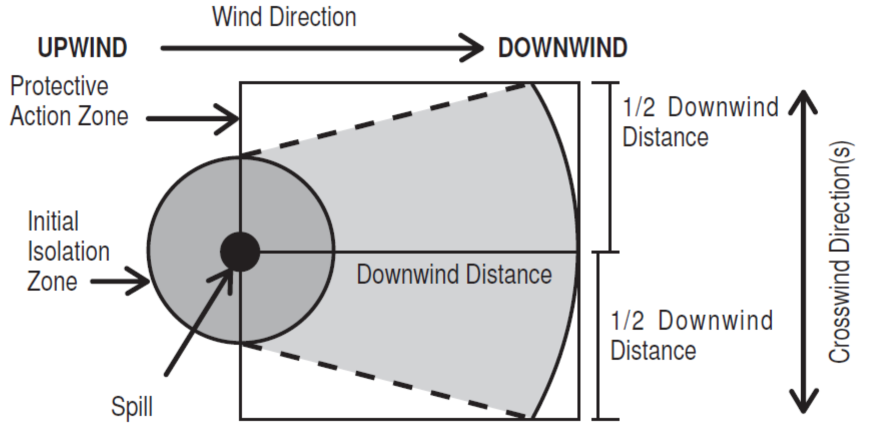
- PHMSA Emergency Response Guidebook (ERG) for hazard distances
  https://www.phmsa.dot.gov/training/hazmat/erg/emergency-response-guidebook-erg
  https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2021-01/ERG2020-WEB.pdf



steps you take to preserve the health and safety of emergency responders and the public. People in this area should be evacuated and/or sheltered-in-place. Consult pages 289-291.

(6) Initiate protective actions beginning with those closest to the spill site and working away in a downwind direction. When a water-reactive TIH (PIH in the US) producing material is spilled into a river or stream, the source of the toxic gas may move with the current or stretch from the spill point downstream for a large distance.

In the figure below, the spill is located at the center of the small black circle. The larger circle represents the initial isolation zone around the spill. The square (the protective action zone) is the area in which you should take protective actions.



Note 1: For factors that may change the protective action distances, see "Introduction to Green Tables" (page 286).

Note 2: When a product in Table 1 has the mention (when spilled in water), you can refer to Table 2 for the list of gases produced when these materials are spilled in water. The TIH gases indicated in Table 2 are for information purposes only.

For more information on the material, safety precautions and mitigation procedures, call the emergency response telephone number listed on the shipping paper or the appropriate response agency as soon as possible.

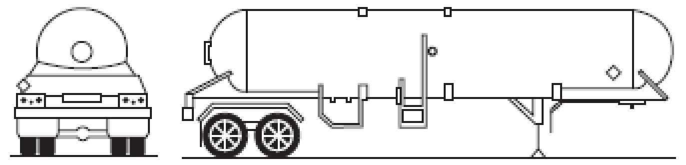
Page 295

TABLE 3 - INITIAL ISOLATION AND PROTECTIVE ACTION DISTANCES FOR LARGE SPILLS FOR DIFFERENT QUANTITIES OF SIX COMMON TIH (PIH in the US) GASES

	First ISOLATE in all Directions		Then PROTECT persons Downwind during													
			DAY						NIGHT					
			Low wind (< 6 mph = < 10 km/h)		Moderate wind (6-12 mph = 10 - 20 km/h)		High wind (> 12 mph = > 20 km/h)		Low wind (< 6 mph = < 10 km/h)		Moderate wind (6-12 mph = 10 - 20 km/h)		High wind (> 12 mph = > 20 km/h)	
	Meters	(Feet)	km	(Miles)	km	(Miles)	km	(Miles)	km	(Miles)	km	(Miles)	km	(Miles)
TRANSPORT CONTAINER	UN1005 Ammonia, anhydrous: Large Spills													
Rail tank car	300	(1000)	1.9	(1.2)	1.5	(0.9)	1.1	(0.6)	4.5	(2.8)	2.5	(1.5)	1.4	(0.9)
Highway tank truck or trailer	150	(500)	0.9	(0.6)	0.5	(0.3)	0.4	(0.3)	2.0	(1.3)	0.8	(0.5)	0.6	(0.4)
Agricultural nurse tank	60	(200)	0.5	(0.3)	0.3	(0.2)	0.3	(0.2)	1.4	(0.9)	0.3	(0.2)	0.3	(0.2)
Multiple small cylinders	30	(100)	0.3	(0.2)	0.2	(0.1)	0.1	(0.1)	0.7	(0.5)	0.3	(0.2)	0.2	(0.1)

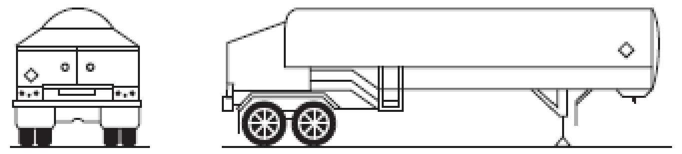
MAWP: Maximum Allowable Working Pressure.

117 MC331, TC331, SCT331



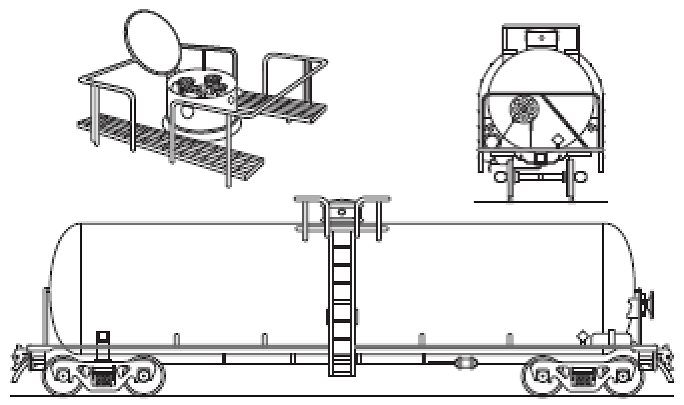
- For liquefied compressed gases (e.g., LPG, ammonia)
- Rounded heads
- Design pressure between 100-500 psi

117 MC338, TC338, SCT338, TC341, CGA341



- For refrigerated liquefied gases (cryogenic liquids)
- Similar to a "giant thermo-bottle"
- Fitting compartments located in a cabinet at the rear of the tank
- MAWP between 25-500 psi

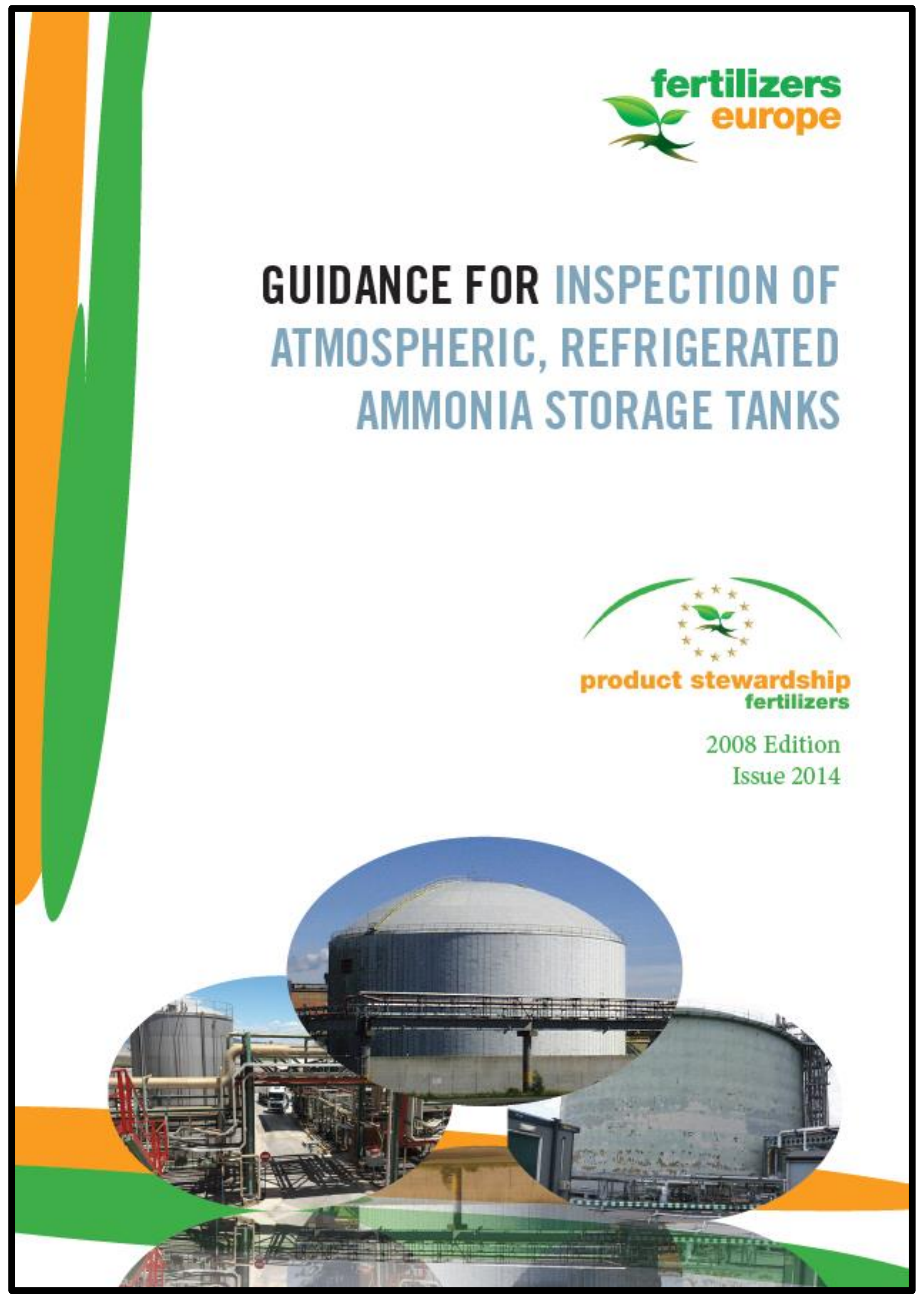
117 Pressure tank car

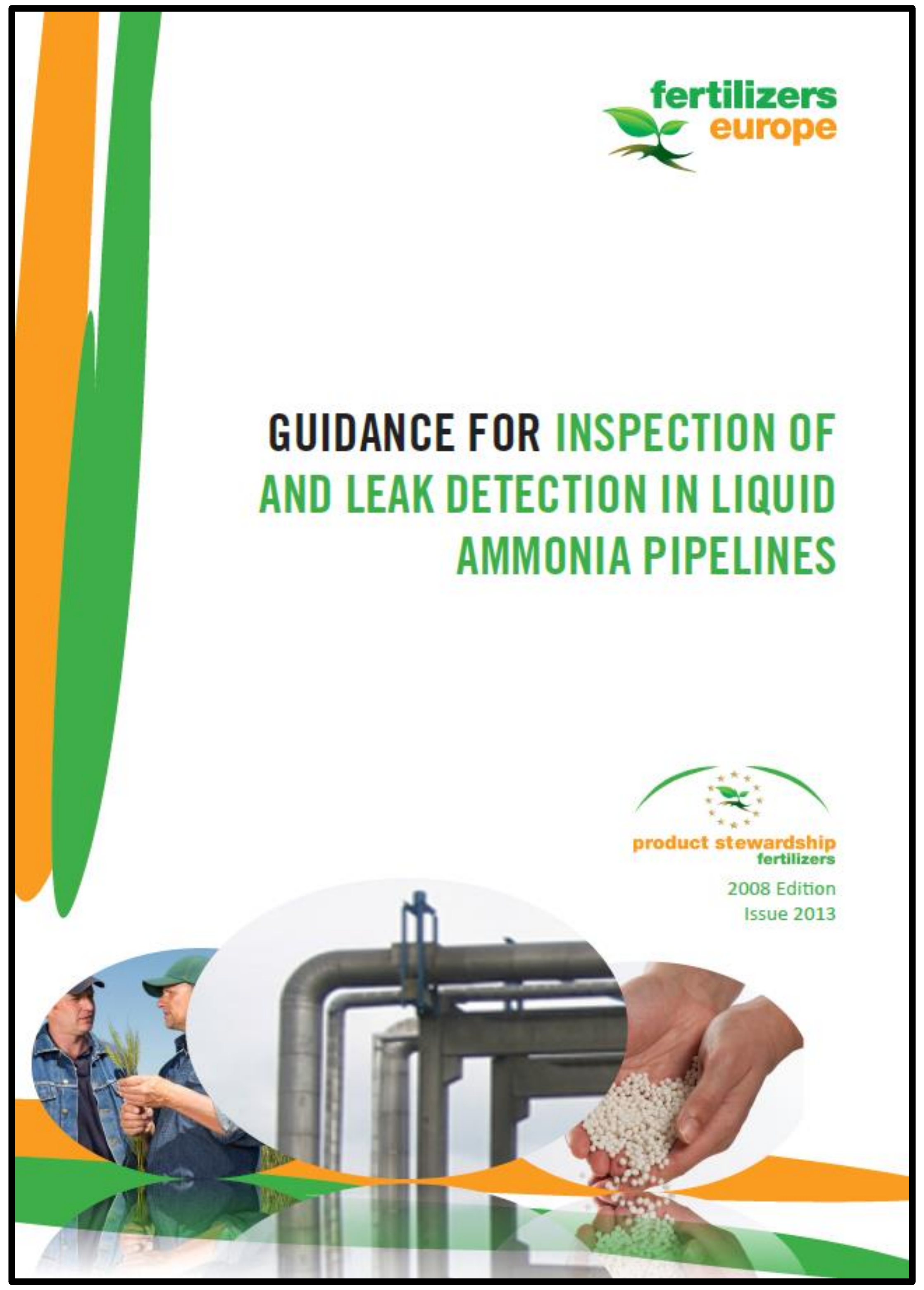


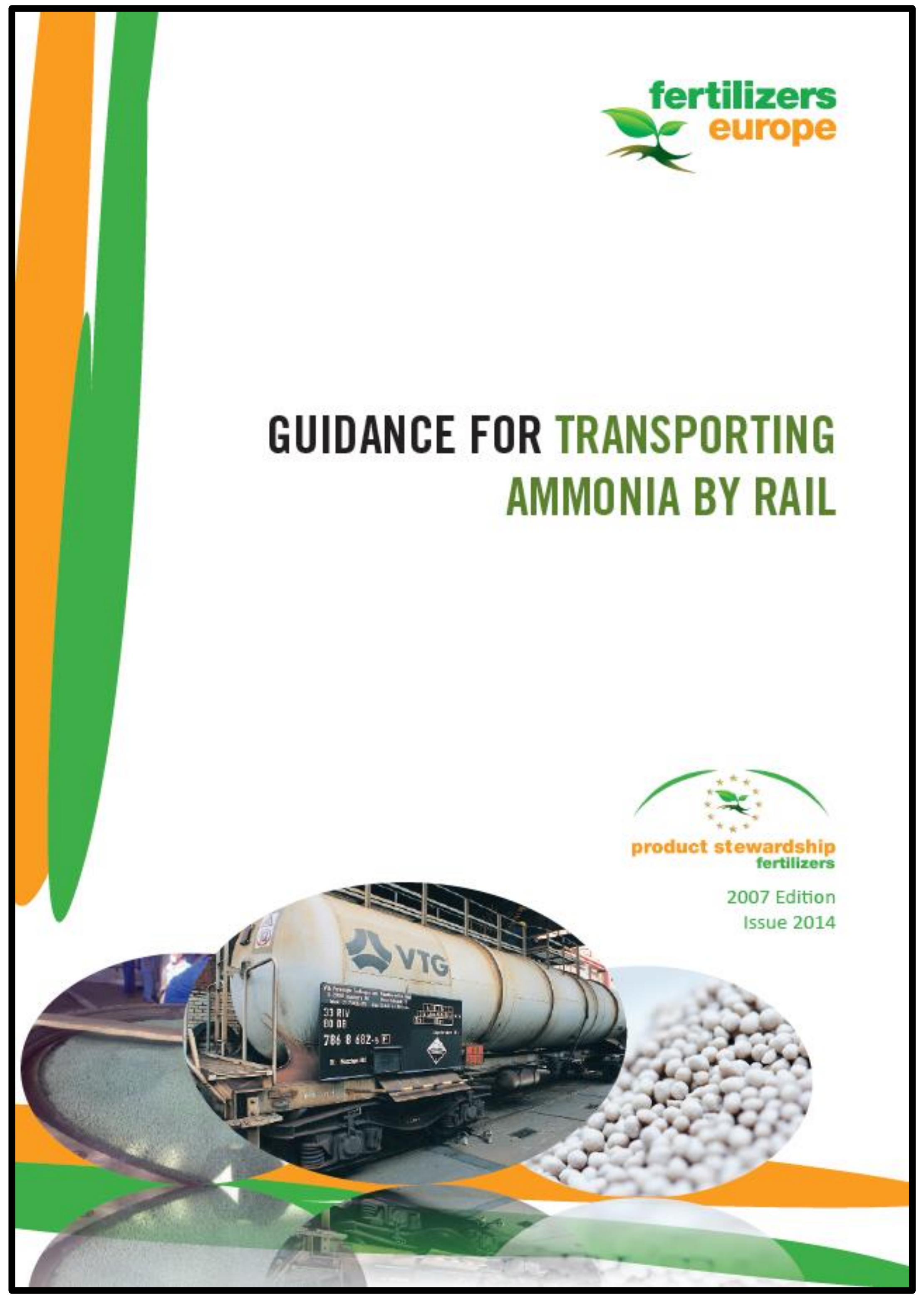
- For flammable, non-flammable, toxic and/or liquefied compressed gases
- Protective housing
- No bottom fittings
- Pressures usually above 40 psi

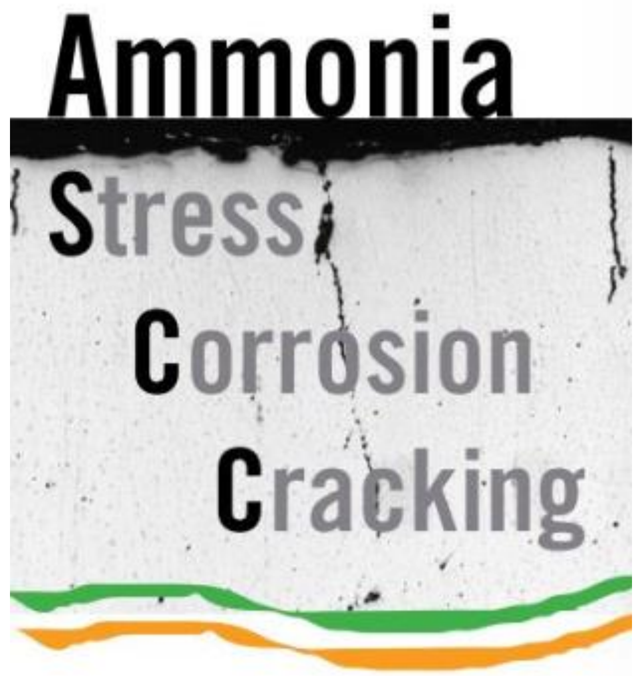
Safety-Related Information

- Fertilizers Europe publications https://www.fertilizerseurope.com/









25 May 2013
Stress Corrosion Cracking

24 April 2013
Safety assessment of ammonia tanks

Safety-Related Information

- Chemical Industries Association (CIA, UK) https://www.cia.org.uk/
- No current publications on ammonia, some historical reports

Guidance for the large scale storage of fully refrigerated anhydrous ammonia in the UK

Second edition - June 1997

ISBN 0 90062 359 4

RC 94 CIA/CISHEC/9706/CP/250/1.6

(First edition printed May 1975)

HS/G 30

Storage of anhydrous ammonia under pressure in the United Kingdom

Storage of anhydrous ammonia under pressure in the United Kingdom

Spherical and cylindrical vessels

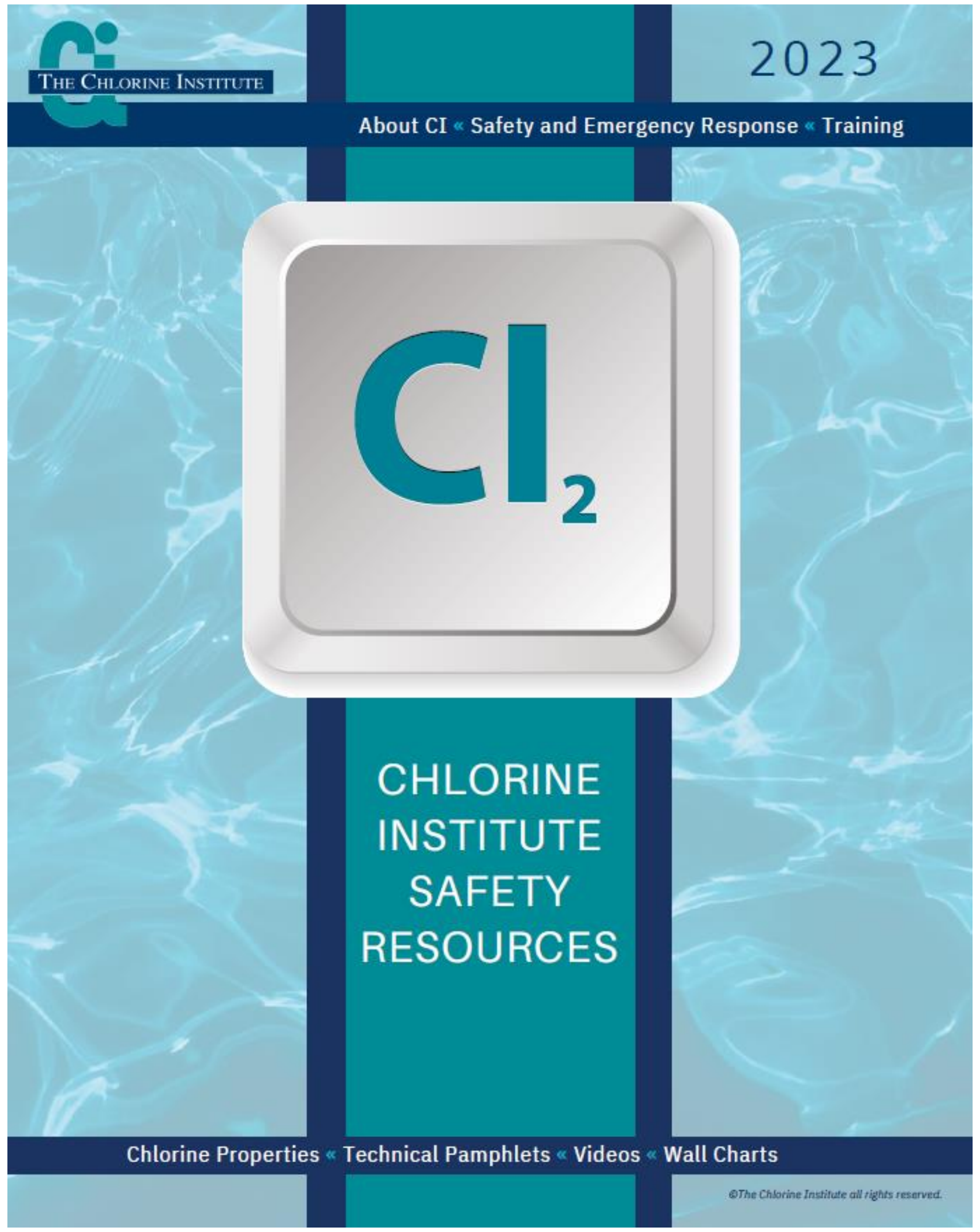
First published 1986

Enquiries regarding this publication should be addressed to area offices of the Health and Safety Executive, or the Enquiry Points
St Hugh's House, Trinity Road,
Bootle, Merseyside L20 3QY, tel: 051-951 4381

Contents

Safety-Related Information

- The Chlorine Institute https://www.chlorineinstitute.org/
- Do we need something like this for ammonia?



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- ONE INDIVIDUAL COMPLIMENTARY meeting registration to the CI meeting of your choice.

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