Literature review on incidents and pollutants behaviour

Developing the Evidence Base around Gaseous and Volatile HNS Hazards and Incident Response

FINAL REPORT

CRCE Wales,
Public Health England

Co-funded by the European Union Civil Protection

Photographs courtesy Public Health England

ACKNOWLEDGEMENT

The work described in this report was supported by the Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG-ECHO) of the European Union through the Grant Agreement number 101004912 - MANIFESTS – UCPM-2020-PP-AG, corresponding to the Call objective “Enhancing prevention and protection from the effects of maritime disasters” under priority 1: “Developing response capacity for marine pollution”.

Contents

Project Acronym	**MANIFESTS**
Project Full Title	**MAN**aging risks and **I**mpacts **F**rom **E**vaporating and gaseous **S**ubstances To population **S**afety
Gant Agreement Nr.	**101004912**
Project Website	**https://www.manifests-project.eu/**

Deliverable Nr.	**D3.1**
Status (Final/Draft/Revised)	**Final**
Work Package	**3**
Task Number	**3.1**
Responsible Institute	**CETMAR**
Author/s	**Public Health England**
Recommended Citation	
Dissemination Level	**Open Source**

Document History			
Version	**Date**	**Modification Introduced**	
		Modification Reason	**Modified by**
0.1 Draft	20-07-2021	NA	NA
1.0 Final	23-09-21	Final Version	PHE

EXECUTIVE SUMMARY

- Maritime transport of hazardous and noxious substances (HNS) continues to rise, with greater numbers and types of chemicals carried, and a growing fleet of larger ships.
- Despite extensive regulation, accidents do occur often with significant consequences to human health and the environment. Furthermore, incidents are often associated with ships in port or near to shore, increasing the risk to coastal populations particularly when involving gaseous or volatile HNS due to their ability to produce toxic and flammable clouds which may disperse well beyond the site of the accident/incident.
- A review of existing literature for such incidents, their impacts and available actions to protect the safety and health of local populations has been undertaken to better understand the evidence around these types of incidents and inform proposed guidance and decision-making procedures for planners and responders.
- Results indicate that while incidents involving gas and volatile HNS are thankfully not prolific, representing less than 1% to 3% of all maritime incidents, and between 10 to 15% for fires, they do occur, with many occurring in ports or near the shore.
- Evidence from published scientific studies identify a number of hazardous gases and volatile HNS commonly associated with such incidents most notably; Ammonia, Chlorine, Hydrogen Sulphide, Liquified Petroleum Gas (LPG), Acrylonitrile, and numerous volatile hydrocarbons, while dense gas clouds are most commonly associated with releases. Reactive HNS such as fumigants in shipping containers may also present potential risks to crew and the general public.
- Considerable evidence exists regarding the actual and potential impacts of incidents, with historic cases such as The *Grandcamp* (US), *Cason* (Spain), Mumbai Port (India) and more recent examples of Birling Gap (UK), Tianjin port (China) and Beirut (Lebanon) illustrating the impacts these can cause. However there appears little if any evidence around decision making for protection of communities during such incidents.
- Based on the literature review, the evidence for selecting protective actions with respect to maritime incidents involving gas clouds and large fires near populations is limited and that development of guidance to aid decision making would help to address this potential gap in incident planning and management. It is further recommended that guidance gives due regard to the key HNS identified from this review as well as communication, victim follow-up and responder training strategies.

Co-funded by the European Union Civil Protection

1. Introduction

Responding to maritime accidents can be especially challenging when involving Hazardous and Noxious Substances (HNS) that behave as gases or evaporators. Due to their potential to form toxic or combustible clouds, evidence-based decisions are needed to protect the crew, responders, the coastal population and the environment.

To better understand the current state of the art around response to gas and volatile HNS incidents a review of existing evidence of such incidents, their impacts and available actions to protect the safety and health of local populations was proposed.

This work represents Deliverable D3.1 of Work Package 3 of the MANIFESTS project and was undertaken by CRCE Wales with support from the consortium.

1.1. Background

Maritime transport is often described as "the backbone of globalized trade and the manufacturing supply chain" (Helcom, 2021).

Data indicate that approximately 90% of European Union external trade is by sea with estimates indicating up to 50,000 hazardous and noxious substances (HNS) carried by sea, and around 2000 carried on a regular basis. Quantities of chemicals shipped are rising with annual bulk trade world-wide estimated at 215 million tonnes in 2015 (Harold, 2014).

HNS can be defined as *"Any substance other than oil, which, if introduced into the marine environment is likely to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea"* (IMO, 2000). Oils are however also included as HNS in other international convention definitions. In either case the fundamental issue is that the substances have the ability to cause harm to health or the environment.

In order to meet increased demand of trade, ships are getting bigger and fleets are becoming more numerous. For example, the new generation of container ships are far larger at 12,000 twenty-foot equivalent units (TEU) than their predecessors (Purnell, 2009). Statistics for 2020 suggest there were around 62,100 vessels in the world trading fleet and by deadweight tonnage, the world fleet has doubled in size since 2005 (DfT, 2021). Breakdown of the fleet indicates this includes 5,360 container ships, 5,914 chemical tankers and 2,035 gas tankers (Statista, 2021). With such projections of increased shipping of chemicals and an expanding range of HNS being transported, some increase in incidents involving HNS may be expected (Purnell, 2009).

Despite the high degree of regulation for transport and handling of such substances incidents do occur and whilst there are few studies on the actual public health impacts of maritime HNS spills, there are many examples where significant impact was possible from exposure to gases and vapours (Dhar, 2012). For example, the *Cason*, caught fire and ran aground 100 m off the Galician coast, Spain in 1987 carrying 1100 tonnes of mixed HNS including xylenes, butanol and phosphoric acid. The resulting plume of smoke and gases resulted in 15,000 people being evacuated from the surrounding area overnight as a precaution against potential airborne exposure to harmful chemicals. More recently in 2004 The *Coral Arcropora* released 600 kg of Vinyl Chloride at its Berth on Manchester Ship Canal with 33 workers and public exposed and requiring to shelter in nearby buildings. Modelling suggested low risk of toxicity but potential ignition risks within 50 m of the vessel (Appendix 1).

Many gases and volatile HNS are flammable and present a fire and explosion risk when released into the environment. The *Halifax Nova Scotia* incident in 1917 (McAlister 2017) was the largest man-made explosion prior to the atomic bomb with almost 2000 fatalities while *The Grandcamp* Port explosion in Texas, 1947, resulted in 600 fatalities and evacuation of a small city (Appendix 1). More recently, the explosion in the port of Tianjin (2015) caused 165 fatalities (Dong 2021) while the 2020 explosion in the port of Beirut resulted in 200 fatalities and 300,000 people displaced from their homes (International Red Cross, 2020).

Seaborne venting and releases of gases and vapours can also have impacts on local populations. Uncontrolled migrating gases and vapours can result in odours, irritation of eyes and airways and distress to those affected. In 2017, several beaches in and around Birling Gap on the south coast of England were evacuated following some form of chemical exposure. While the exact source of the gas cloud remains unknown, most evidence points to some form of uncontrolled gas release at sea from either a ship or its cargo. Over 200 people sought medical treatment for eye, nose and throat irritation (Appendix 1). In 2008, the *Happy Lady*, a gas carrier anchored off Spurn Head in the Humber estuary, requested permission to vent 40 tonnes of ethylene in order to carry out repairs. The ship could not move further offshore due to a fracture of the hull. Risk assessment and atmospheric modelling were undertaken and ensured operations did not lead to unacceptable risks to local coastal communities.

In all such incidents there is a need for responders and incident managers, to be able to make decisions on actions required to protect local communities that may be affected. In such circumstances evidence-based guidance can substantially aid these decisions. This need for evidence to inform guidance and decision making was used to define the scope of the literature review undertaken.

1.2. Aims and Objectives of the Study

The aim of this review was to establish the current evidence around maritime and port incidents involving gaseous or volatile HNS, and/or fire and explosions and their potential for impact to the safety and health of wider communities. Specific objectives were defined to identify evidence detailing:

- hazards associated with transport and storage of gaseous / volatile HNS,
- the types and frequency of incidents,
- the types of HNS involved,
- the impacts / outcomes of incidents on wider communities,
- protective actions undertaken for public health and safety,
- any processes proposed or used around decision making for such actions.

2. Methodology

2.1. Incident Database Review

A range of international maritime accident databases were identified (Table 1).

Table 1: Industry and Regulatory Database Sources Accessed for Review

Source	Description	Link
International Maritime Organisation (IMO)	Database of Global Annual Maritime Accident Statistics	https://www.imo.org/en/OurWork/MSAS/Pages/Casualties.aspx
European Maritime Safety Agency (EMSA)	Database of EU Annual Maritime Accident Statistics and trends	https://data.europa.eu/euodp/en/data/dataset/accident-investigation-emcip
UK Maritime Coast Guard Agency (MCGA ACOPs)	Annual UK maritime incident reports	https://www.acops.org.uk/activities/annual-marine-pollution-survey-reports/
Centre of Documentation, Research and Experimentation on Accidental Water Pollution (CEDRE)	Global maritime incident statistics and case studies	https://wwz.cedre.fr/en/Resources/Spills
National Oceanic and Atmospheric Administration (NOAA)	Database of maritime and transport incidents primarily in USA	https://incidentnews.noaa.gov/raw/index
US Coastguard	Marine Casualty & Pollution Data for Researchers	https://www.dco.uscg.mil/Our-Organization/Assistant-Commandant-for-Prevention-Policy-CG-5P/Inspections-Compliance-CG-5PC-/Office-of-Investigations-Casualty-Analysis/Marine-Casualty-and-Pollution-Data-for-Researchers/
International Tanker Operators Federation (ITOPF)	Global Oil spill incident statistics	https://www.itopf.org/knowledge-resources/data-statistics/statistics/
International Oil Producer Convention (IOPC)	Global accidents where convention funds applied	https://iopcfunds.org/incidents/incident-map/
Allianz (insurers)	Global incident statistics	https://www.agcs.allianz.com/news-and-insights/reports/shipping-safety.html
UK Health and Safety Executive (HSE)	Annual UK Offshore platform statistics	https://www.hse.gov.uk/offshore/statistics/index.htm
Public Health England Database (CIRIS)	Chemical incident database for UK and ROI	In-house access only
Industry Bulletins and Newsletters		https://www.maritimebulletin.net/ https://www.fleetmon.com/maritime-news/?year=2020&category=incidents https://safety4sea.com/23073-maritime-casualties-and-incidents-reported-in-2019/ https://spillcontrol.org/

Databases were chosen to encompass representative international and national maritime regulators, industry and responders.

Historical accident statistics were reviewed for a period from 2000 up to the present day where available, in order to provide sufficient temporal coverage to assess incident trends and patterns and also to be aligned with relevant current safety regulations and legislative controls for accident reporting.

Databases were reviewed to assess the total incidents reported annually and searched for key words and phrases relevant to the study, namely; gas, vapour (vapor), fire, explosion, and a range of specific HNS and combustion products, namely; ammonia, chlorine, benzene, LNG, LPG, carbon monoxide, hydrogen sulphide.

Resulting incidents were assessed for trends over time, incident type, chemicals involved and incident location, as well as for localised and wider impact, incident response and any protective actions employed at the scene and for wider communities.

Results of the search are presented in section 3.1

2.1.1. Media Monitoring and Technical Journals

In addition to historic accident statistics, the study also included review of media sources using Google Alerts (Google.co.uk) and a number of maritime industry newsletters (Table 1) over several months in order to identify any relevant incidents occurring in real-time.

For Google alerts this again involved applying similar key words and search terms as listed in 2.1 as a Boolean search string as well as including some additional vernacular phrases such as disaster, catastrophe.

Again, results were used to identify numbers, types and locations of incidents, HNS involved, impact and relevant response actions. Results are presented in section 3.1.1

2.2. Scientific Literature Review

A systematic literature review of relevant published scientific papers was undertaken with the assistance of PHE Library Services. The search comprised a series of defined steps. Again, the search was defined for the period from 2000 up to the present day, in order to capture studies aligned with current safety regulations and practises and reflective of current legislation.

An initial Annotated Bibliography search was undertaken using a defined search question and keywords as below:

Studies in respect of shipping accidents involving gas or vapour clouds, fire and explosions, and resulting in evacuation or sheltering actions for the general public.

What types of information are you looking for?:	Primary Research
Relevant concepts:	Communities near ports and harbours, shelter and evacuation Fatalities / health impacts from exposure public health follow up Trends / lessons learned
Keywords :	"Maritime, ship, port, harbour, coastal, shore; incident, accident, disaster; cargo, gas, vapour, cloud, explosion, fire, smoke; casualties, health effects, shelter*, evacuation"

(Full details of this process and a link to all abstracts are available from the MANIFESTS website [MANIFESTS - Home (manifests-project.eu)](manifests-project.eu))

Returned abstracts were screened for:

- Relevance to the scope of the study (Section 2.1)
- Age of the paper (excluding papers older than 20 years)
- Availability of the full paper in English
- Availability of the paper as open source or as part of PHE library subscription

The final screened papers were divided amongst the PHE project team and reviewed against an appraisal template (Table 2) to ensure a consistent approach.

As an additional quality control / consistency measure, selected papers were further subjected to second (peer) review and the findings compared and revised where necessary.

In addition to the above any additional references of interest found within the papers were also reviewed where it was felt that they may contribute to the evidence base.

Results of the review are presented in Section 3.2.

Table 2: Paper Assessment Template

Details of Paper	
Title	
EndNote Number	
First Author	
Year	
Publication	
Volume	
Pages	
Peer Reviewed	

Reviewer Name	

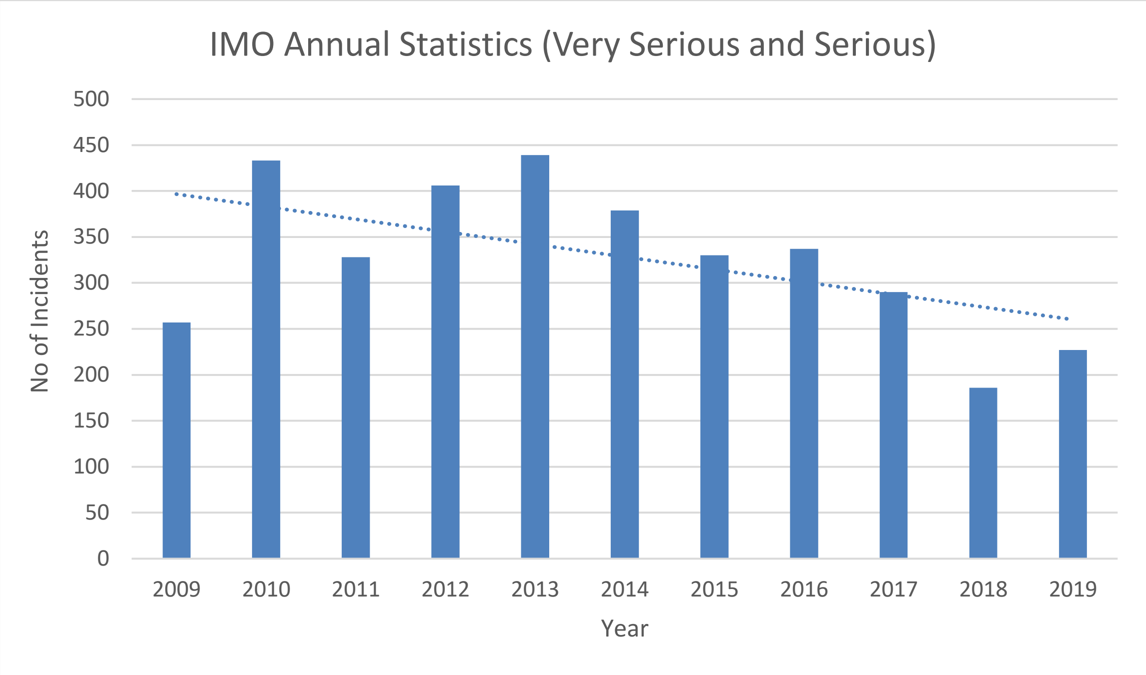
Date of Review	
Should paper be included in the review?	
If excluded, please state reason(s) i.e. Paper is not relevant to review if it does not consider one or more of the following • Volatile and gaseous chemicals and / or Fires, explosions • Transport, maritime, port settings • Hazard and Risk to Safety and Health	
Type of Study e.g. • Review • Analysis • Case Study • Follow-up Study • Novel Technology	
Target Audience • Emergency Planning / Response • Public Health / Medical • Industry / Occupational	
• **Time Period of Study**	
• **Geographical Area Studied**	
Paper Review Questions **Is the study specific to maritime or port incidents involving gases, vapours or explosion events? Y/N** **Does the study apply to emergency planning preparedness and response to such incidents? Y/N** **Are examples (case-studies) of incidents presented? Y/N** **Are specific chemicals detailed? Y/N** **Are potential protective actions / contingencies detailed? Y/N** **Are outcomes of contingency actions presented? Y/N** **Are recommendations to improve contingency actions presented? Y/N** **What would be your overall Conclusion of the Study**	

3. Result and discussion

3.1. Database Review

Of the databases reviewed, the IMO database probably provided the most extensive list of maritime incidents, recording hundreds of incidents every year and classifying these according to seriousness. In this classification a "Serious" casualty relates to an incident involving fire or explosion, damage to vessel, collision, grounding or harm to environment. "Very Serious" applies the same criteria but is where a vessel is lost or the incident has fatal consequences or results in severe damage to the environment. Other databases were less comprehensive being focussed on more specific criteria such as regional areas, incidents where specific conventions applied, incidents where a responder was requested to attend, offshore platform incidents.

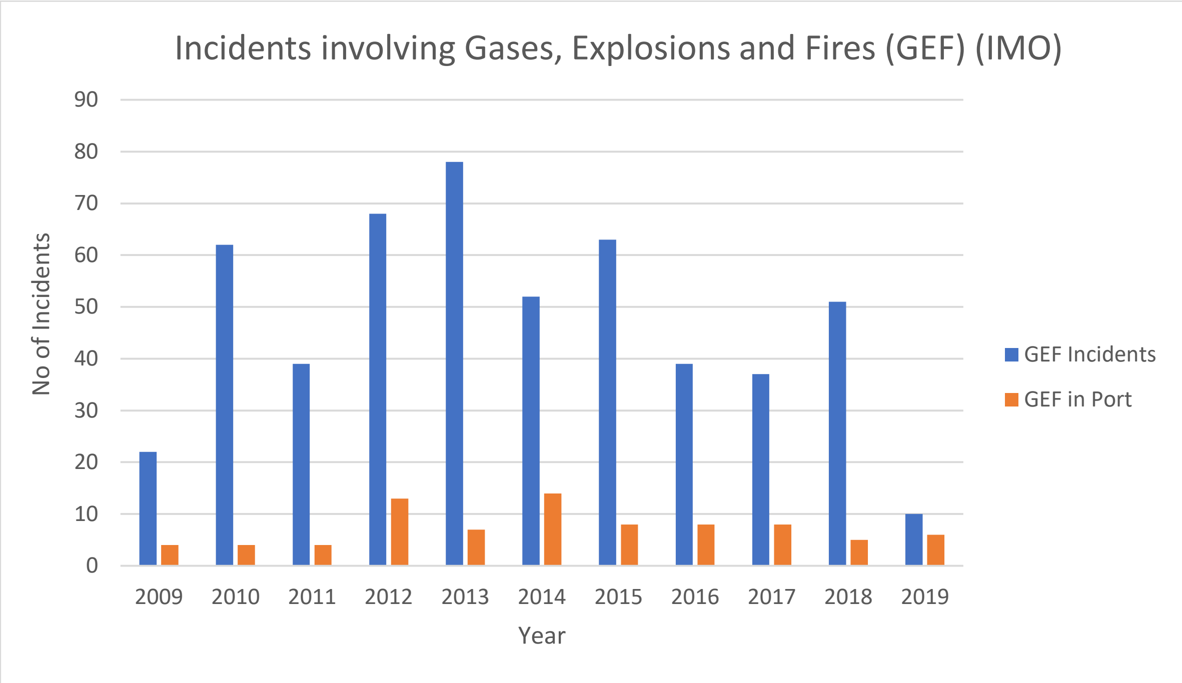
Our analysis confirms that maritime incidents are common, with IMO indicating around 200 to 400 very serious and serious incidents annually. Numbers of incidents reported by IMO is relatively consistent year on year although there is some suggestion of a gradual decline in numbers over time, possibly due to improved regulation and technologies.



Incident detail tended to be limited to summaries in most databases and focussed mainly on the immediate impact to vessels and crew. However, some databases such as CEDRE provided associated cases studies for more notable recent and historic events. Representative case studies are provided in Appendix 1 of this report.

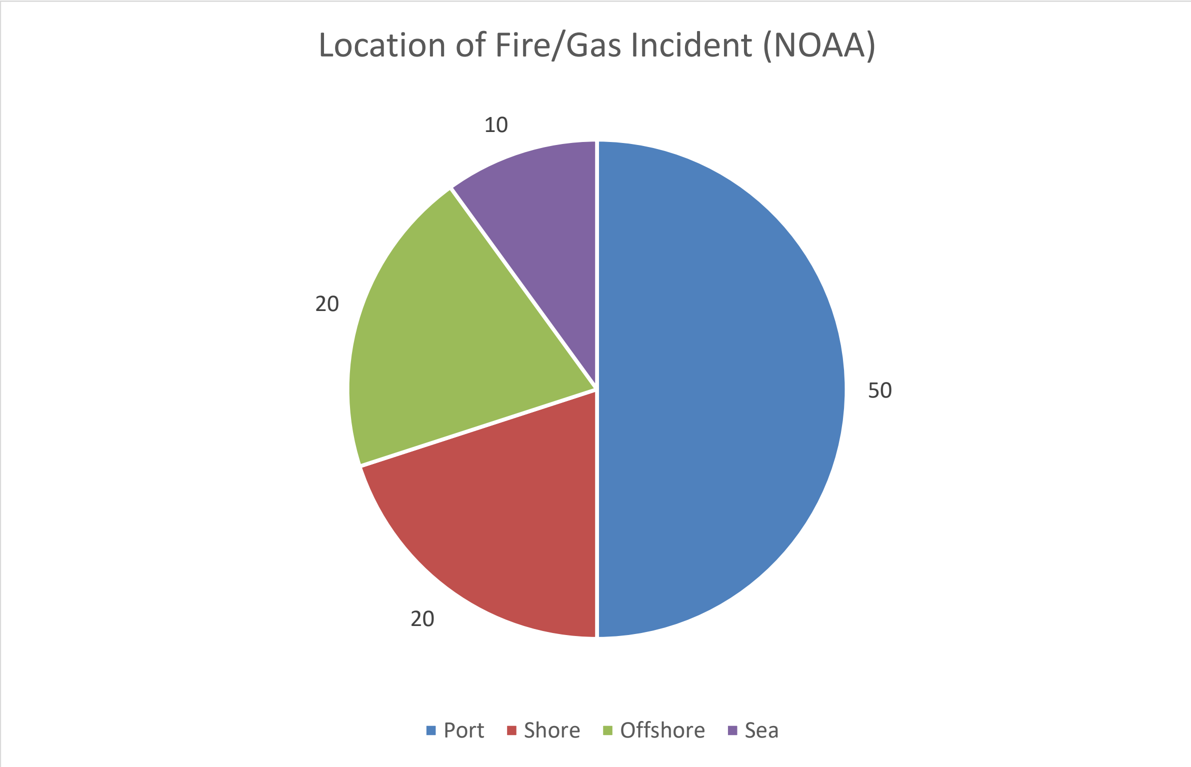
Incidents recorded by IMO suggest, between 10 to 15% related to fires and or gas releases with a wide variety of incident types ranging from major explosions and gas releases during loading, unloading and ship transfers, to localised exposure to fumigants as well as regular smaller scale fires, spills and venting.

The US Coastguard database indicated 230 incidents over 15 years involving gas carrier vessels (<1% of total incidents recorded), with 30 resulting in a release of gases or other hazardous materials and 5 resulting in fire or explosion. While this is only a small percent of total incidents it does demonstrate that accidents occur regularly with potentially catastrophic impacts.



While the IMO reports indicate generally less than 20% of serious and very serious GEF incidents occurring in ports, other databases such as the NOAA database suggested up to half of all gas / fire incidents occurred in ports, possibly reflecting inclusion of incidents in port facilities which may not have directly involved a ship or may not have met the serious / very serious criteria and thus may not be captured by IMO statistics. Similar trends were also reported in previous studies where around 50% of incidents in ports related to fires, explosions and gas releases (Darbra, 2004). The NOAA database also reported a further 10 to 20% of GEF incidents near or at the shoreline.

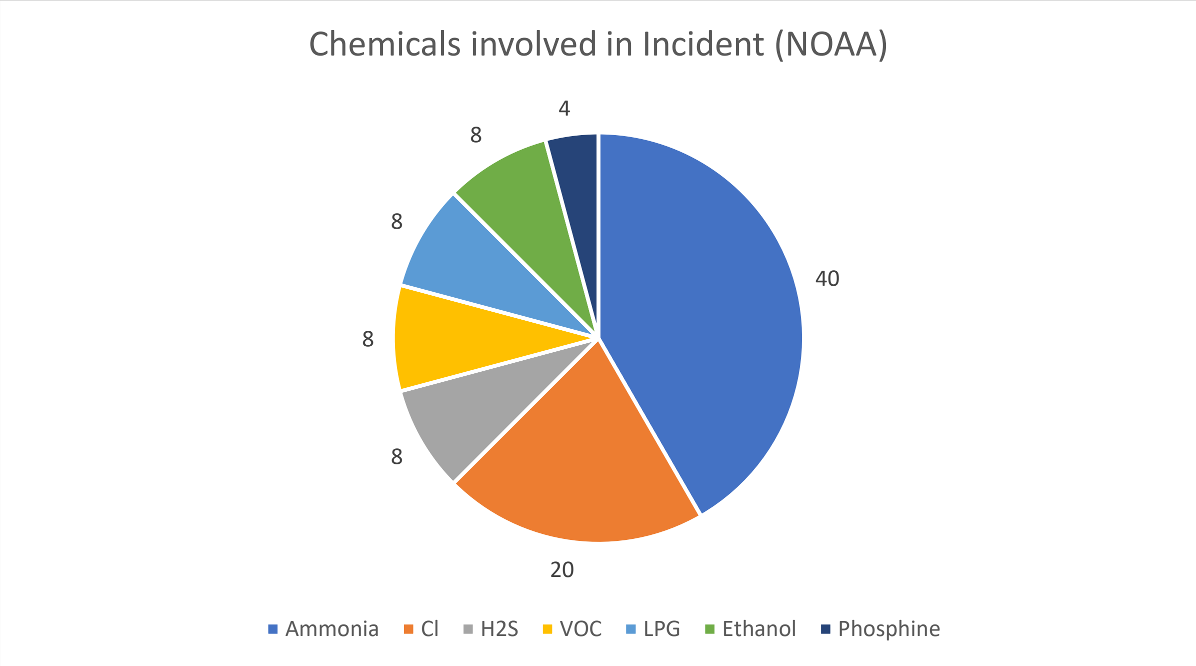
In all cases this demonstrates that many of these incidents have the potential for wider risks and impact to local communities.



Data were limited on the chemicals involved in gas and fire incidents with most information coming from industry / responder sources such as NOAA and PHE (Table 1).

While available data are limited, our analysis indicates that ammonia is the most common chemical involved with many incidents relating to refrigeration processes. Chlorine, hydrogen sulphide, volatile hydrocarbons (benzene, toluene, xylenes, alkanes), carbon monoxide, phosphine and alcohols, have also been involved in a number of incidents. LNG and LPG were identified in relation to gas incidents, principally in respect of the type of ships involved i.e. gas carriers, although in most cases the actual incidents had little to do with the cargo (see comments above regarding the US Coastguard data).

A similar group of chemicals were identified in previous studies of accidents in ports, using the FACTS (Failure and ACcidents Technical information System) accident database (www.factsonline.nl) (Hakkinnen, 2015). However, data on chemicals involved was also limited and may not be wholly reflective of the global pattern of incidents. This may indicate a limitation of the data collected by marine and port incident investigation processes.



Finally, there was little data on wider protective actions taken in response to incidents, with responder databases once more providing the best evidence. Where reported, around 30 to 40% of incidents resulted in protective actions for workers or wider populations, principally involving evacuation as illustrated in selected case studies (Appendix 1).

Evacuation tended to be targeted at specific groups such as crews, or workers in the vicinity of the incident. In the UK, PHE recorded two cases where people were evacuated from public beaches which were affected by unknown airborne chemicals.

Evidence of advice given to people to shelter and stay indoors is limited and principally related to PHEs incident database where it was issued for wider populations as a precaution, during a prolonged wood chip fire where immediate risks did not warrant evacuation, but where some impact was possible. It was also considered for a number of controlled venting operations from ships in port following fires.

3.1.1. Media Review

A total of 107 articles were identified by Google Alerts, over a 6 week period (22/03/21 - 02/05/21). The majority of returns concentrated on high profile media stories such as the *Evergiven* cargo ship blocking the Suez Canal, military attacks in the Gulf and the sinking of an Indonesian submarine. No articles related to gaseous or volatile HNS incidents. Similar low occurrence was indicated from reviews of industry newsletters with no gas incidents identified over a 3 month period, while 8 vessel fires were noted in the same period. The results tend to corroborate the low frequency of such incidents.

While this short review of media and industry newsletters provided limited returns regards incidents, these platforms do report incidents. This is particularly true for larger events and those where the public have been involved, for example the explosion at Ulsan Port Korea in 2019 https://www.bbc.co.uk/news/av/world-asia-49863955 and Birling Gap in 2017 https://www.bbc.co.uk/news/uk-england-sussex-41070002 . As such media sources and especially social media can potentially offer a useful source of information both during and after an incident as was found by studies previously undertaken by PHE (Hazrunoff, 2019).

3.2. Scientific Literature Review

A total of 289 abstracts were returned from the initial search undertaken by PHE Library Services.

Literature sources and returns are presented in Table 3, while Table 4 illustrates the topic groups returned.

Table 3: Summary of Results and Sources

Source	No. of results*
Embase	80
Global Health	1
Grey literature	7
Medline	15
Web of Science	186

Table 4: Summary of Results by Topic

Topic	No. of results*
Evacuation	115
Analysis / Investigation	38
Disaster Preparedness	28
Risk Assessment	52
Explosions	38
Spills	14
Other Maritime Incidents	4

Initial screening of abstracts based on the protocol detailed in section 2.2 reduced the number of viable papers to 40 (Table 5) which were then subject to detailed review and analysis.

Table 5: List of Papers Selected for Detailed Review

Author	Year	Title
Y. Zhang;	2020	Systems approach for the safety and security of hazardous chemicals

S. Sultana;	2019	Hazard analysis: Application of STPA to ship-to-ship transfer of LNG
T. Iannaccone;	2019	Inherent safety assessment of alternative technologies for LNG ships bunkering
C. N. McAlister;	2017	The 1917 Halifax Explosion: the first coordinated local civilian medical response to disaster in Canada
E. J. Scholtens	2013	Container incidents, a serious problem or a media hype
U. Svedberg;	2008	Hazardous off-gassing of carbon monoxide and oxygen depletion during ocean transportation of wood pellets
M. Hightower;	2005	Safety implications of a large LNG tanker spill over water
J. Liu;	2019	A three-dimensional risk management model of port logistics for hazardous goods
J. Weng;	2015	Investigation of shipping accident injury severity and mortality
R. K. Sharma;	2010	Chlorine leak on Mumbai Port Trust's Sewri yard: A case study
R. M. Darbra;	2004	Historical analysis of accidents in seaports
A. Galierikova;	2017	Threats and risks during transportation of LNG on EU inland waterways
R. Lovreglio;	2016	A dynamic approach for the impact of a toxic gas dispersion hazard considering human behaviour and dispersion modelling
S. M. Godoy;	2007	STRRAP system - A software for hazardous materials risk assessment and safe distances calculation
T. C. Nwaoha;	2020	Risk-based Analysis of Pressurized Vessel on LNG Carriers in Harbor
X. Li;	2019	Structural risk analysis model of damaged membrane LNG carriers after grounding based on Bayesian belief networks
T. Abramowicz-Gerigk;	2018	Human and operational factors in the risk assessment of ship-to-ship operations
V. Torretta;	2017	Decision support systems for assessing risks involved in transporting hazardous materials: A review
Fuentes-Bargues;	2017	Risk Analysis of a Fuel Storage Terminal Using HAZOP and FTA
M. Perkovic;	2012	Nautical Risk Assessment for LNG Operations at the Port of Koper
C. Gasparotti;	2012	METHODS FOR THE RISK ASSESSMENT IN MARITIME TRANSPORTATION IN THE BLACK SEA BASIN
R. Bubbico;	2009	Preliminary risk analysis for LNG tankers approaching a maritime terminal
W. Dong;	2021	Analysis of Emergency Medical Rescue in the 8-12" Tianjin Port Heavy Fire Explosion Accident"
M. D. Landry;	2020	The 2020 blast in the port of Beirut: can the Lebanese health system build back better"?"
Red Cross / Red Crescent Societies	2020	Case study: Chemical explosion Beirut Port: Technological and Biological (CBRN) Hazards
H. A. Lin;	2019	Patients' survival rates and their correlated factors in the prehospital setting of a dust explosion incident
J. J. Zhang;	2018	Medical Response to the Tianjin Explosions: Lessons Learned
J. E. Vinnem	2018	FPSO Cidade de Sao Mateus gas explosion - Lessons learned
P. L. Carter	2018	The Halifax Explosion a century later: Lessons for our time
J. T. Granslo;	2017	A follow-up study of airway symptoms and lung function among residents and workers 5.5years after an oil tank explosion
O. Ugurlu	2016	Analysis of fire and explosion accidents occurring in tankers transporting hazardous cargoes
G. Fu;	2016	Anatomy of Tianjin Port fire and explosion: Process and causes
B. Inanloo;	2015	Explosion impacts during transport of hazardous cargo: GIS-based characterization of overpressure impacts and delineation of flammable zones for ammonia

A. Ronza;	2007	Using transportation accident databases to investigate ignition and explosion probabilities of flammable spills
I. M. Shaluf; F.	2003	Fire and explosion at mutual major hazard installations: review of a case history
A. M. Middlebrook;	2012	Air quality implications of the Deepwater Horizon oil spill
A. Luketa-Hanlin	2006	A review of large-scale LNG spills: Experiments and modeling
J. A. Fay	2003	Model of spills and fires from LNG and oil tankers
N Fukuchi	2005	Risk assessment for fire safety considering characteristic evacuees and smoke movement in marine fires
A. Karakavuz	2020	Risk assessment of commonly transported chemicals in the Port of Houston

All selected papers were evaluated against a series of defined parameters, the aim being to establish the current evidence around maritime and port incidents involving gaseous / volatile releases, and/or explosions and their potential for impact to the safety and health of wider communities.

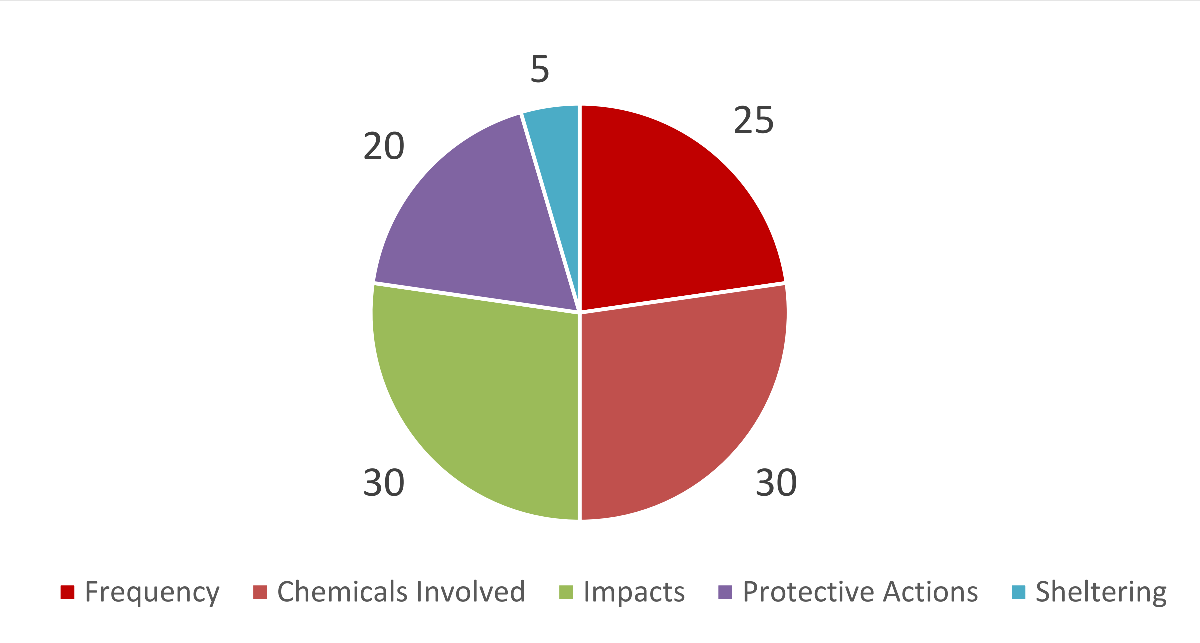
Specifically, the review aimed to identify papers detailing evidence around the hazards associated with transport and storage of gaseous / volatile HNS, the types and frequency of incidents, the HNS involved, the impacts / outcomes of incidents on wider communities, protective actions undertaken for public health and safety, and any processes proposed or used around decision making for such actions.

The papers reviewed covered a variety of topics ranging from tools for risk assessment, data collection for dispersion modelling, case studies for accident investigation techniques and post incident reviews and appraisals.

Approximately 25% of the papers reviewed presented incident frequency statistics, while around 30% included information on the types of HNS involved in incidents. In terms of both incidents and types of HNS, most papers were focussed on flammable substances such as LNG and hydrocarbons and events involving fires or explosions.

There was limited information on incidents involving releases of toxic gases. Similarly, only a minority of the papers (30%) provided detail of the health impacts such as fatalities and / or injuries and most of these related to fire and explosion events.

In terms of mitigation measures taken, the most common cited proactive action was evacuation which was noted in 20% of the papers reviewed. Only a small number of papers (5%) discussed sheltering as an option.



This contrasts with land-based incidents where considerable studies have been undertaken to review the outcomes of protective actions during incidents and where shelter in place is typically viewed as the primary option for protection of the public (Stewart-Evans, 2016).

There are also numerous studies of response to actual land-based incidents where protective actions for public health were required. One such study was undertaken following the Graniteville rail incident in South Carolina in 2005, where a chlorine release from a derailed rail tank resulted in 72 casualties, 9 fatalities and raised a number of questions around selection of shelter versus evacuation and the need for rapid information, (Dunning, 2007).

These studies for land-based incidents have also considered the decision-making process evaluating the benefits and limitations of each option when selecting protective actions (Mannan, 2000), (Glickman, 1990).

None of the papers from this current review discussed decision making when selecting the most appropriate protective action, although a number did outline safety distances for specific toxic and flammable risks and the issues around siting of terminals / ports close to population centres with the potential for increased risks to the wider community.

While the literature review returned limited information with regard to protective actions and decision making, a number of useful papers, discussed in more detail below, were identified which were able to inform the evidence base around accident statistics, types of gaseous and volatile HNS involved in incidents and the subsequent impacts of events. Several additional papers were also identified from references and were included in the review (Table 5a).

Table 5a: Additional References identified from original search

Author	Year	Title
Zhang et al	2012	Characteristics of hazardous chemical accidents in China: A statistical Investigation. Zhang et al 2012
Hakkinen	2015	Port Accidents Involving Hazardous Substances Based on FACTS Database Analysis
Viichez et al	1994	Historical analysis of accidents in chemical plants and in the transportation of hazardous materials
Ellis	2010	Analysis of accidents and incidents occurring during transport of packaged dangerous goods by sea

3.2.1. Key Studies for Manifests Review

A number of individual papers reviewed provided useful evidence and examples applicable to the work being developed by MANIFESTS.

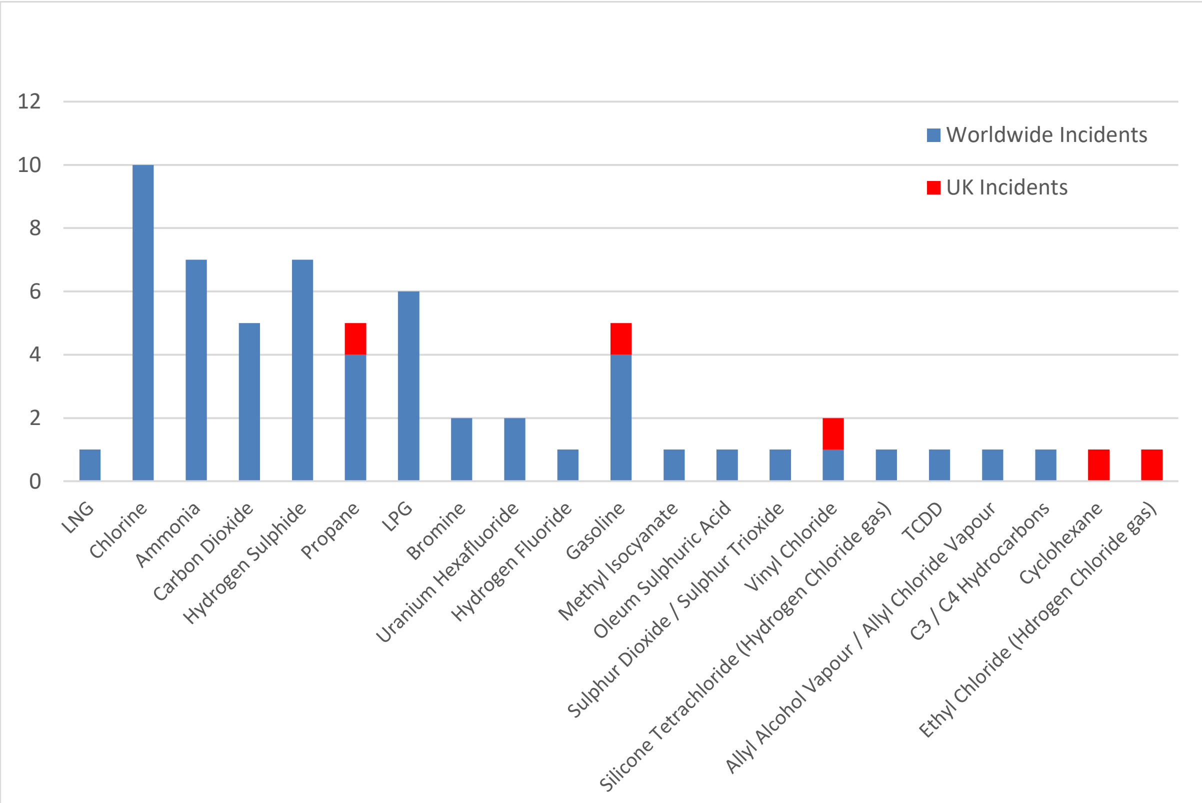
Darbra analysed 471 accidents in seaports (Darbra, 2004) between the beginning of the twentieth century and October 2002 using a database called MHIDAS (Major Hazard Incident Data Service available as a CD-ROM from British Library). Results showed a significant increase in the frequency of accidents over time with a 59% increase in the decade up to 2000. The increases may have been related to improved reporting over time, while industry databases now generally show a reduction in incidents in the last 20 or so years. The study showed few incidents related to gas clouds (3%), while fires and explosions accounted for a higher percentage (30%). Analysis further revealed around 60% of accidents involved oils and 10% chemicals.

A similar study used the FACTS database (Hakkinen, 2015), a subscription source maintained by the TNO organisation, to review 960 incidents related to harbours, ports and docks over the past 90 years to 2013. Results suggested 40% involved oils, 40% chemicals and 16% multiple substances. Where single chemicals were involved, the most common chemicals were ammonia (28%), LPG (41%), volatile aromatics (BTEX) (31%), chlorine (11%), acrylonitrile (11%) and styrene (8%).

An analysis of accidents in chemical plants and transportation using the MHIDAS database (Viichez, 1995) reported that gas clouds attributed to 12% of incidents and fires and explosions to around 45%. Of the incidents involving gas clouds the majority involved dense gases i.e. gases heavier than air that stay close to ground level (352 incidents) compared to 7 for buoyant clouds (lighter than air) and 4 for neutral density clouds. This is not surprising as the majority of hazardous and flammable gaseous and volatile chemicals used in industrial processes are heavier than air. LNG (methane) and hydrogen are probably the 2 main exceptions to this, although studies also show that LNG releases from tanks often will behave as a dense gas at source due to its low temperature (Hanlin, 2005). In contrast high temperatures from fires will often make chemicals more buoyant at the source of the incident.

The UK Health and Safety Executive (HSE) have undertaken a recent study on dense gas cloud incidents indicating the most frequent gases involved were chlorine, ammonia, hydrogen sulphide, LPG, carbon dioxide, propane and gasoline (HSE, 2021). It should be noted however that this study is not specific to maritime events.

Figure illustrating Incidents involving Dense gases (HSE, 2021)



Darbra (2004) further looked at activities resulting in accidents with more than half occurring during loading/unloading operations. Storage and process plants also made a large contribution to the total. Darbra (2004) also suggested around 50% accidents led to fatalities with about 1% resulting in more than 100 fatalities. It is not clear if the fatalities related to workers or the wider population. As previously mentioned, data on protective measures were limited and indicates that evacuation was rare. However, where evacuation did occur about 10% involved the evacuation of over 1000 people.

A review of 1,600 hazardous chemical incidents in China (Zhang, 2012) suggested 22% of incidents involved evacuation compared to around 10% elsewhere in developed countries. These data are not specific to maritime incidents, however.

In addition to accident statistics a number of papers analysed the impacts and health effects arising from specific incidents or scenarios involving volatile HNS and fires.

A case study on the Deepwater Horizon oil spill considered in depth the emissions released during the incident and the associated dispersal and atmospheric transformations (Middlebrook, 2012). A wide range of gas and aerosol species were measured from aircraft and ships in the vicinity while the oil slick was burning. Aerosol particles of respirable sizes were found on occasions to pose a significant air quality issue for populated areas along the Gulf Coast, while evaporating hydrocarbons from the oil and NOx emissions from the recovery and clean-up operations produced ozone. The paper concluded that quantitative assessment findings can be used to estimate the effects on air quality for similar events.

Another study (Hightower, 2005) summarised the risks from LNG spills and identified several incident management measures. Several scenarios were considered including the risks to public safety from spills, vapour clouds and a fire. The paper highlighted the need for clear guidance for mitigating risk from LNG spills including the use of safety zones of 500 metres and 1600 metres downwind of any spill or fire, evacuation areas and community education programmes (Hightower, 2005).

Similarly, the impact of a release of nitrogen dioxide from a fire involving ammonium nitrate was modelled (Lovreglio, 2016). In this scenario, the resulting gas cloud was predicted to disperse over a crowd at an outdoor music festival and the author used this scenario to assess the effectiveness of evacuating people from the festival. The results suggested that in this scenario, people told to stay in place were more likely to have a higher exposure to nitrogen dioxide than those evacuated. However, this study did not look at the effectiveness of sheltering indoors. The importance of incorporating dispersion modelling into contingency planning was noted.

The impacts of a significant chlorine release were demonstrated in a study of an incident in the port of Mumbai in 2007 (Sharma, 2010). In this incident, the incorrect storage of chlorine cylinders led to a large release of chlorine that affected 120 people including the emergency services, local residents and workers at the port. Seventy people suffered critical injuries. The study highlighted a number of gaps in the response and, consistent with the study of LNG releases (Hightower, 2005), demonstrated the need for better guidance and awareness among emergency responders and local communities about the risks from airborne releases in and around ports. Recommendations included the need for dispersion modelling, evacuation distances, hazardous materials training and exercising and better community engagement so that people better understood what to do in the event of an emergency. Many of these recommendations should already be in local, regional and national contingency plans.

Longer term health impacts were reported on a cohort study of residents and workers potentially exposed to air pollution following an oil tank explosion in a harbour in Western Norway (Granslo, 2017). No air monitoring was undertaken during the incident, but air monitoring several weeks afterward still detected the presence of potentially hazardous gases such as mercaptans. This cohort of people were shown to have a high rate of persistent airways effects five years after the incident and it was suggested that that air pollution from the incident contributed to the observed respiratory effects.

Several studies illustrated the potential impact of HNS reactions to produce gaseous or volatile products. These included the potential for harmful gases resulting from fumigants used in containers reacting with moisture (Scholtens, 2013) and risks from inadequately packaged materials resulting in self ignition or off-gassing (Ellis, 2010).

The risks from hazardous off-gassing of HNS such as carbon monoxide from wood pellets (Svedberg, 2008) and self-combusting of cargo such as nitro-cellulose at the Tianjin Port incident, China (Fu, 2016) were also identified by studies.

A number of papers (Table 4) reviewed the impact of the explosions at the ports of Tianjin and Beirut which were both due to incorrect and unsafe storage of combustible materials. The latter is also the subject of ongoing study to appraise the potential post incident effects on the local population in terms of both health and socio-economic impact.

4. Conclusions and recommendations

Public Health England have undertaken a review of the evidence around maritime incidents involving gaseous and volatile HNS as part of Work Package 3 of the MANIFESTS project. Sources consulted for the review included regulatory and industry incident databases, case studies and media reports, together with a systematic review of published scientific literature.

Our review has identified that while shipping of chemicals and ship sizes are increasing, incidents generally appear to be reducing in frequency, and incidents involving gaseous and volatile releases are rare (less than 1% to 3% of all) while fire and explosion (10 to 15%) also represents only a small fraction of the total recorded. However, although relatively infrequent, such incidents do occur and can result in major consequences, particularly when located near to coasts or in ports or harbours.

Our analysis has identified a number of hazardous gases and volatile HNS that are most commonly associated with incidents. These include ammonia, chlorine, hydrogen sulphide, LPG, acrylonitrile, and numerous volatile hydrocarbons (BTEX, Styrene, Gasoline, propane) while dense gas clouds appear from studies to be most commonly associated with releases. LNG may also represent an increasing risk as it becomes more commonly transported at sea and used as a fuel.

There is a growing evidence base describing the actual and potential impacts of incidents with papers describing the severe health and socio-economic damage from such events for example those describing the after-effects of Beirut (International Red Cross, 2020). Many published studies highlight the importance of management controls and planning to prevent incidents.

In contrast, apart from descriptions of some notable mass evacuations, there was little evidence on decision making for protection of communities during maritime based incidents, with little to no evidence of the consideration of shelter in place despite evidence from land-based incidents of its potential beneficial role particularly with regard to vulnerable people (Ozaki, 2018) and its consideration in planning for industrial installations (VROM, 2005).

Maritime guidance for response to gaseous releases developed for the Mediterranean by REMPEC (Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea) and published in 2018 (REMPEC, 2018) includes reference to options for protective action during response. Again, however the examples provided in this document are principally for evacuation suggesting shelter in place currently has limited application to maritime incidents.

Based upon the findings from this review it is concluded that the evidence base to aid decision making around protective actions with respect to maritime incidents involving gas clouds and large fires near populations is limited. As such it is recommended that development of guidance similar to land-based approaches would be helpful to address this gap in current contingency planning and incident management.

It is further recommended that this work focusses on the main HNS identified within the review and the behaviour of dense gas clouds with due acknowledgement of these in modelling and monitoring strategies.

Communication for responders and the public should also form part of an overall strategy to ensure appropriate information is provided during an incident and for effective follow-up of those potentially affected by an incident both in terms of health and socio-economic factors.

In this respect it may be beneficial for future marine and port incident investigation processes to consider collecting and collating data on chemicals involved in gas cloud / flammable incidents and what protective actions were taken.

Finally, it is recommended that training and exercising for planners and responders forms a pivotal role in the use of any developed guidance

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APPENDIX 1: Illustrative Case Studies

Date	Name	Type	Location	Impact	Link
1947	Grandcamp Fertiliser explosion Texas City US	Explosion	Port	600 fatalities City evacuated	http://wwz.cedre.fr/en/Resources/Spills/Spills/Grandcamp
1987	Cason HNS (organics and sodium) Spain	Explosion / Fire	Coastal waters	23 crew fatalities 15000 evacuated in 5km radius	http://wwz.cedre.fr/en/Resources/Spills/Spills/Cason
2004	AnneMasse France. Benzene	Gas cloud	River	Ecological 500 evacuated	http://wwz.cedre.fr/en/Resources/Spills/Spills/Annemasse
2008	Happy Lady. UK	Gas Venting	Estuary	Risk assessment and dispersion modelling	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/203559/14_HPA_CHaPR_Apr_2009.pdf pages 11 to 14
2012	MSC Flaminia Atlantic	Explosion	at sea	2 crew fatalities exclusion zone	http://wwz.cedre.fr/en/Resources/Spills/Spills/MSC-Flaminia
2014	Coral Arcropora UK	Vinyl Chloride release	Berth	33 persons exposed	https://admlc.files.wordpress.com/2021/06/pe06527_admlc_dgd_review_final.pdf pages 75 and 76
2017	Birling Gap UK (unknown gas)	Unknown Gas Cloud	Shore	Public evacuation of beaches. Multiple complaints of irritation	http://data.parliament.uk/DepositedPapers/Files/DEP2018-0080/Annex_A_Birling_Gap_science_report.pdf

Co-funded by the European Union Civil Protection