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Analysis of hazardous material releases due to natural hazards in the United States

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Natural hazards were the cause of approximately 16,600 hazardous material (hazmat) releases reported to the National Response Center (NRC) between 1990 and 2008—three per cent of all reported hazmat releases. Rain-induced releases were most numerous (26 per cent of the total), followed by those associated with hurricanes (20 per cent), many of which resulted from major episodes in 2005 and 2008. Winds, storms or other weather-related phenomena were responsible for another 25 per cent of hazmat releases. Large releases were most frequently due to major natural disasters. For instance, hurricane-induced releases of petroleum from storage tanks account for a large fraction of the total volume of petroleum released during 'natechs' (understood here as a natural hazard and the hazardous materials release that results). Among the most commonly released chemicals were nitrogen oxides, benzene, and polychlorinated biphenyls. Three deaths, 52 injuries, and the evacuation of at least 5,000 persons were recorded as a consequence of natech events. Overall, results suggest that the number of natechs increased over the study period (1990–2008) with potential for serious human and environmental impacts.

Keywords: chemical release, earthquake, hazardous material, natech (a natural hazard and the hazardous materials release that results), hurricane, natural hazard, oil spill

Introduction

There is growing evidence that hazardous material (hazmat) releases triggered by natural hazards can pose significant risks to regions that are unprepared for such events. Hazmat releases caused by earthquakes have been studied for some time in the United States (see, for example, Reitherman, 1982), with increased interest after the Loma Prieta (Perkins and Wyatt, 1990) and Northridge, California, earthquakes (Lindell and Perry, 1996a, 1996b, 1998) of 17 October 1989 and 17 January 1994, respectively. Showalter and Myers (1992, 1994) used a survey of State Emergency Management Agencies (SEMAs) to document hazmat releases due to natural disasters in the US from 1980–89 and coined the term 'natech' (understood here as a natural hazard and the hazardous materials release that results) to describe these events. Natechs have been documented and analysed by researchers in the US and worldwide (see, for example, Rasmussen, 1995; Malhotra, 2001; Steinberg et al., 2004; Young, Balluz and Malilay, 2004; Fendler, 2008; Cozzani et al., 2010; Krausmann, Cruz and Affeltranger, 2010).

Several themes have emerged from research on natechs. One is that catastrophic natech risk is the product of a mixture of factors, including the presence of facilities

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handling hazmat, high population density, and natural hazard risk. Many regions in the US are prone to one or more serious natural hazards (Abbott, 2004), and combined with growth in these areas (see, for example, Van der Vink et al., 1998), the result is a trend towards greater losses due to natural hazards such as floods (see, for example, Zeng and Kelly, 1997) and hurricanes (Pielke et al., 2008). Increased population and industry in hazard-prone areas also leads to greater potential threats from natechs. This was highlighted dramatically by Hurricanes Katrina and Ike in August 2005 and September 2008, respectively, which led to many hazmat releases. Although contaminated floodwater during Hurricane Katrina proved to be a limited hazard (see, for example, Reible et al., 2006), one well-publicised release from an above-ground crude oil storage tank contaminated approximately 1,800 homes in a residential community (Associated Press, 2007). Off-site fatalities, among members of the general public, due to natechs have not been reported in the US, but they can occur. More than 100 people were killed in Durunqa, Egypt, in November 1994, for instance, when floodwaters destroyed a petroleum storage facility and carried burning oil into the town (Smith, 2001). In addition, it has been estimated that hazardous air pollutants released from an oil refinery in a populated area due to a hurricane or an earthquake could threaten residents in a wide radius around the facility (see, for example, Cruz, Steinberg and Luna, 2001; Steinberg et al., 2004).

A second theme from the natech literature is that response presents unique challenges in comparison to other hazmat releases. A single natural hazard event may affect a large area and many industries, initiating multiple releases simultaneously. The response to a natural disaster itself also may divert resources that otherwise would be available for hazmat response. What is more, conditions caused by natural disasters may restrict site access and interrupt lifeline resources (see, for example, Lindell and Perry, 1996a; Steinberg and Cruz, 2004), further slowing the hazmat response and increasing the risk to exposed populations. These conditions have been well documented during earthquakes, but they may manifest themselves as well during other natural hazards, particularly hurricanes, which can similarly generate widespread disruption. Nevertheless, few regulations directly address natech risks in the US or elsewhere around the world. Mitigation requirements that do exist appear largely in general programmes for hazmat management (Cruz and Okada, 2008; Steinberg, Sengul and Cruz, 2008). The special challenges posed by natechs and the limited efforts aimed at their control make the quantification of natech risk a particularly important topic.

This research extends the effort of Showalter and Myers (1992, 1994) by characterising natech events between 1990 and 2008 in the US. Natechs were identified using the National Response Center (NRC) database of hazmat releases, similar to the approach of Young (2002). Unlike some previous studies, all hazmat releases owing to atmospheric or geological phenomena (henceforth referred to as natechs) are considered rather than only those due to severe natural disasters. Thus, the number of natech events in this study, over the same period, is almost six times that considered by Young (2002), thereby painting a more complete picture of natech risk. The analysis presented here contributes to a better understanding of the nature, frequency, and geographic distribution of natech events and serves as a starting point to help guide policy and response planning.

Methodology

The primary source used to identify natechs was the NRC's Incident Reporting Information System (IRIS) database. Under the 1977 Clean Water Act and the 1980 Comprehensive Environmental Response, Compensation, and Liability Act, the NRC must be notified of releases of hazardous chemicals above reportable quantities (RQ), varying from 1 to 5,000 pounds (lbs), as soon as practical. Reporting of petroleum products that violate federal water quality standards, create sheen or deposit sludge within a water body also is required under the Clean Water Act, and the NRC receives reports of incidents involving hazmats regulated by the Department of Transportation under the 1975 Hazardous Materials Transportation Act. For the years 1990–99, release reports also were obtained from the US Environmental Protection Agency (EPA)'s Emergency Response Notification System (ERNS). This data largely duplicates records found in IRIS yet it does contain a small number of events (335), caused by natural hazards, not recorded by IRIS.

Previous studies utilising NRC data have pinpointed a number of limitations in terms of its data quality, including: inconsistencies with records present in other databases; a lack of identification of root causes; incomplete reports; insertion of many records where casualties were not related to hazmat; duplicate reports; and the inclusion of many low severity releases (Binder, 1989; CSB, 1999; Mary Kay O'Connor Process Safety Center, 2002). Some of these limitations were addressed using the analysis methods described below but others are inherent limitations of the data. One must remember that reports represent the state of knowledge soon after the release—for instance, approximately one-third of reports do not record the quantity of material involved. In addition, other databases, such at the Center for Disease Controls' Hazardous Substances Emergency Events Surveillance System (HSEES), have been shown to record a greater number of releases than IRIS (see, for example, Wendt et al., 1996). However, the IRIS database is better suited to the purposes of this study since it covers the entire US, has maintained fairly uniform data specifications over the past two decades, and records releases of both hazardous chemicals and petroleum. Based on the regulatory framework, it is expected that a majority of larger releases with potential to generate serious environmental or human impacts are captured in the database created from IRIS and ERNS; although small releases are under-recorded. This was confirmed by several comparisons with other sources of information about natechs described in the annex.

Releases from the IRIS and ERNS databases were filtered to remove events not involving a release, planned continuous releases, and reports describing drills. Events caused by various natural phenomena were then identified through the use of the 'incident cause' field and keyword searches of written descriptions. Some keywords found within event descriptions, such as earthquake or hurricane, have a clear meaning; others such as rain, storm, weather, and wind may be interchangeable and only provide a general indication of the hazard involved. Event descriptions were reviewed manually to ensure a high degree of confidence in the natech records identified. A small number of natural events caused by spontaneous combustion, animal damage, and corrosion were excluded by this process. Records also were reviewed by location and time of release in order to spot duplicate reports of the same event; if duplicates were found, only the most complete report was retained.

In this process, more than 588,000 records were examined by electronic or manual methods and 16,600 were retained as natech events. A new field was created for these records, merging the existing 'incident type' field with information from the 'fixed facility type' field and keyword searches of the event descriptions. This corrected for changes in the NRC's data collection methodology over time—for instance, the value 'storage tank' for the 'incident type' field was introduced to the database in 1999 (for events in prior years such records were identified and labelled to allow for a consistent and more detailed analysis of the facilities involved). Releases also were characterised by the type of material involved. All releases of oil, or processed liquid fuels (such as diesel, gasoline, jet fuel, and kerosene) were classified as petroleum whereas the majority of other releases were classified as hazardous chemicals. Small numbers of releases were classified separately as natural gas, aqueous waste (such as low-concentration waste water, salt water, sewage, water with trace oil), or bulk material (such as coal, iron oxide, soil, tyres), all of which often were released in extremely large quantities. Reported losses of aid to navigation (ATON) batteries also were classified separately.

To provide an estimate of the population of industrial facilities from which many of these releases originate, several sources were used. Data from the national Risk Management Plan (RMP) programme highlights facilities that handle large quantities of hazardous substances. The Toxic Release Inventory (TRI) database was used to identify manufacturing facilities, petroleum bulk storage terminals, power generation plants, and federal facilities reporting to the programme over the study period. The EPA's Facility Registry System was employed to distinguish oil and gas production facilities (standard industrial code (SIC) 1311). Although it is expected that during the 19-year period covered by this study there will have been changes in the population of these facilities, recent versions of these databases (dating from 2005–07) are assumed to represent adequately industry over the entire period.

Information was supplemented by documents from the Lexis-Nexis Academic Database, government reports, and company press releases. Furthermore, following the example of Showalter and Myers (1992, 1994), a written survey, followed as necessary by two reminders, was distributed to contacts at all 50 SEMAs to procure additional information on natech events and prevention and emergency response activities. Responses were obtained from seven states (14 per cent response rate), of which only one could supply a list of natech events.

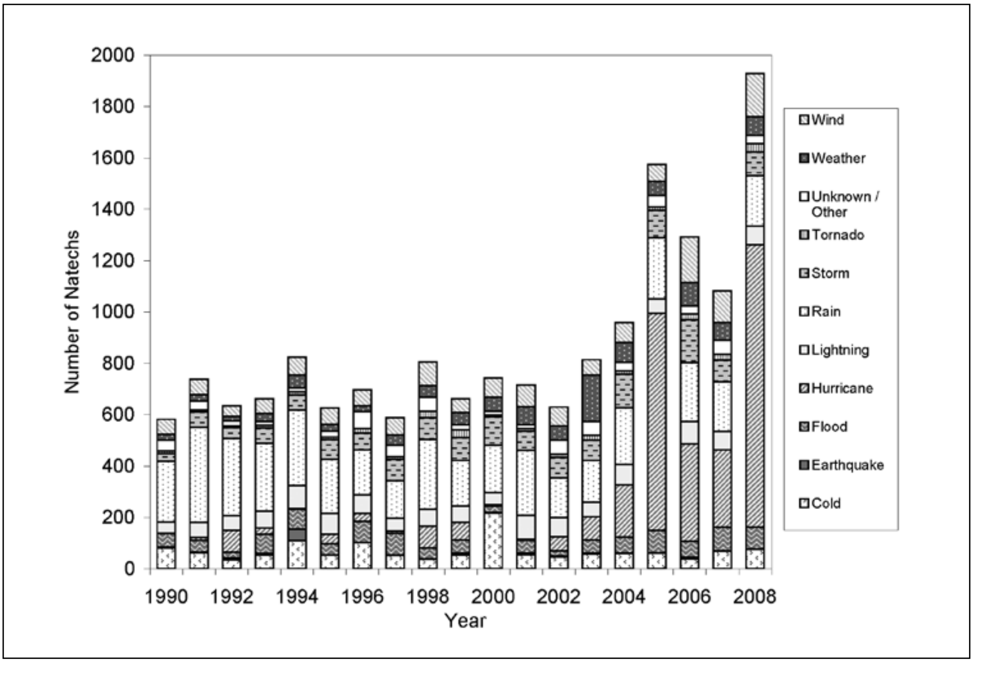
Database results

Number, facility or equipment type and cause of natech events

Natechs reported to the NRC totalled more than 16,600 between 1990 and 2008. These events comprised three per cent of all hazmat releases over this period and made up between one and seven per cent of the total in each year. Rain caused the largest number of natech releases, 26 per cent of the total, whereas hurricanes were responsible for 20 per cent, and an additional 25 per cent were attributable to storms, winds, and other unspecified types of weather. Hazards commonly resulting in natural disasters (earthquakes, floods, hurricanes, tornadoes) were the cause of only one-third of natechs, although these types of events make up 75 per cent of FEMA (Federal Emergency Management Agency)-declared disasters. Similar observations were made by Rasmussen (1995) who examined data from US and European accident databases and found that between one and five per cent of hazmat releases were attributable to natural causes, 80 per cent of which were due to various atmospheric phenomena. These results differ markedly from those of Showalter and Myers (1992, 1994) who observed that earthquakes were the origin of the majority of natechs. This presumably reflects Showalter and Myers' exclusive focus on natural disasters, the possibility of reporting bias in their data due to the voluntary nature of the survey, and variations in the occurrence of natural hazards between the two study periods.

Figure 1 illustrates the frequency of natechs caused by various natural phenomena from 1990–2008. The number of all hazmat releases reported to the NRC, on average 29,000 per year, remained stable during this period. Hurricane-related events

Figure 1. Number of releases associated with various natural phenomena

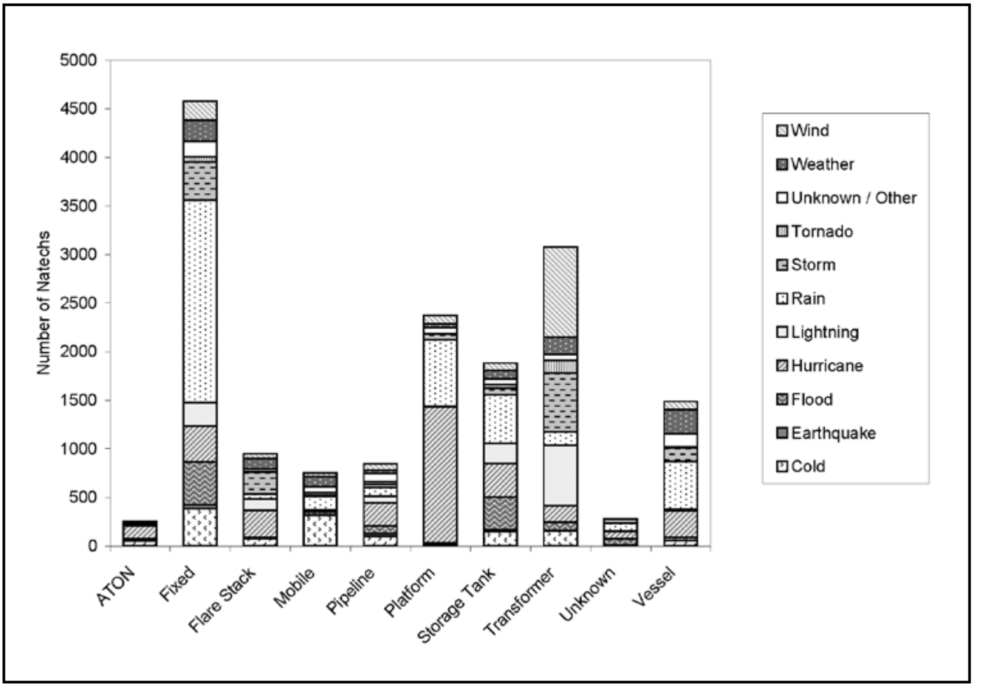


increased 15-fold in the period from 2005 because of releases during Hurricanes Katrina and Rita in August and September 2005, respectively, and Hurricanes Gustav and Ike in August and September 2008, respectively. Hurricane natechs remained high in 2006 and 2007 owing to offshore releases during clean-up and recovery following Hurricanes Katrina and Rita.[2] A rise in cold weather-related natechs also was observed during the unusually bitter winters of 1994 and 2000. Wind-related releases doubled suddenly after 2006 as a consequence of an increased number of reports of downed transformers, and they are presumed to be an artefact of changes in reporting by electrical utilities rather than an increase in the actual incidence of releases. Steady changes were observed in the number of releases attributed to several other natural phenomena. Linear regressions indicate that, on average, weather- and storm-related releases have risen by approximately four per year (eight and five per cent, respectively) whereas events due to tornadoes have increased by one per year (five per cent). Rain-related events, in contrast, have decreased on average by five per year (two per cent). While these shifts were statistically significant, and were observed across all types of facilities, they should still be interpreted with caution as they could be influenced by changes in the language used in reporting to the NRC over time. Releases caused by other natural phenomena, including cold, floods, and lightning, demonstrated no statistically significant trend over time.

The recent dramatic rise in hurricane-related natechs, as well as smaller increases in the frequency of natechs due to weather, storms, and tornadoes, raises the question as to whether natech risk is mounting. The expansion of population and assets in vulnerable areas is accepted as a primary explanation for greater natural hazard risk (see, for example, Zeng and Kelly, 1997; Van der Vink et al., 1998; Pielke et al., 2008) and these same factors would suggest that industry exposure to natural hazards should also increase. In addition, a number of studies have addressed the possibility that changes in climate may boost the frequency or severity of natural hazards. Although the literature on climate and natural hazards is complex and beyond the scope of this study, recent reviews suggest that there is evidence of a greater frequency of flooding and extreme rain events, more frequent and intense hurricanes, and changes in other phenomena that might affect natech occurrence (National Assessment Synthesis Team, 2001; Nicholls and Alexander, 2007; Trenberth et al., 2007; Mills, 2009). Potential clearly exists for a rise in natural hazard risk in the future, whether due to more development in hazardous areas, anthropogenic climate change, or natural variation. Without adaptation, natechs may continue to become more frequent. Understanding natech occurrence is therefore an important first step towards attempting to control the risk posed.

To comprehend natech occurrence, it is helpful to identify the type of facilities or equipment from which natechs originate and the mechanism by which they occur. This process can help to pinpoint the industries and equipment where greater effort to mitigate natech risk would be well placed. Natechs tabulated by natural phenomena and facility or equipment type are summarised in Figure 2. While storage tanks,

Figure 2. Natechs by facility/equipment type and natural hazard



flare stacks, and transformers represent specific types of equipment rather than facilities, they have been separated out and tabulated because they each make up a significant fraction of total natechs and because they have distinct release mechanisms and consequences. Natech events at fixed facilities, excluding storage tanks, flares, and transformers, were most numerous, representing 26 per cent of the total. The specific type of fixed facility where the releases occurred could be identified in only one-third of events. Of those, manufacturing facilities were the most common (26 per cent of the total), followed by refineries (22 per cent), chemical plants (12 per cent), oil and gas wells (12 per cent), various military sites (8 per cent), water and wastewater treatment plants (7 per cent), and power plants (6 per cent). Almost one-half of these releases resulted from rain, followed by floods, cold weather, hurricanes, and storms. Releases from electrical transformers were the second most numerous (19 per cent of the total) and largely were due to lightning, storms, and wind. Oil and gas production platforms account for another 14 per cent of natechs, mostly owing to hurricanes and to a lesser extent to rain. Storage tank releases make up 11 per cent of all natech releases and result most often from rain, hurricanes, and floods. Releases from vessels also were numerous at nine per cent of the total whereas releases from flare stacks, mobile sources (largely trucks with some railroad cars), and pipelines all account for between five and six per cent. One should note that, while the majority of pipeline releases are from onshore or offshore transportation pipelines, a small fraction are on-site pipeline failures at various facilities.

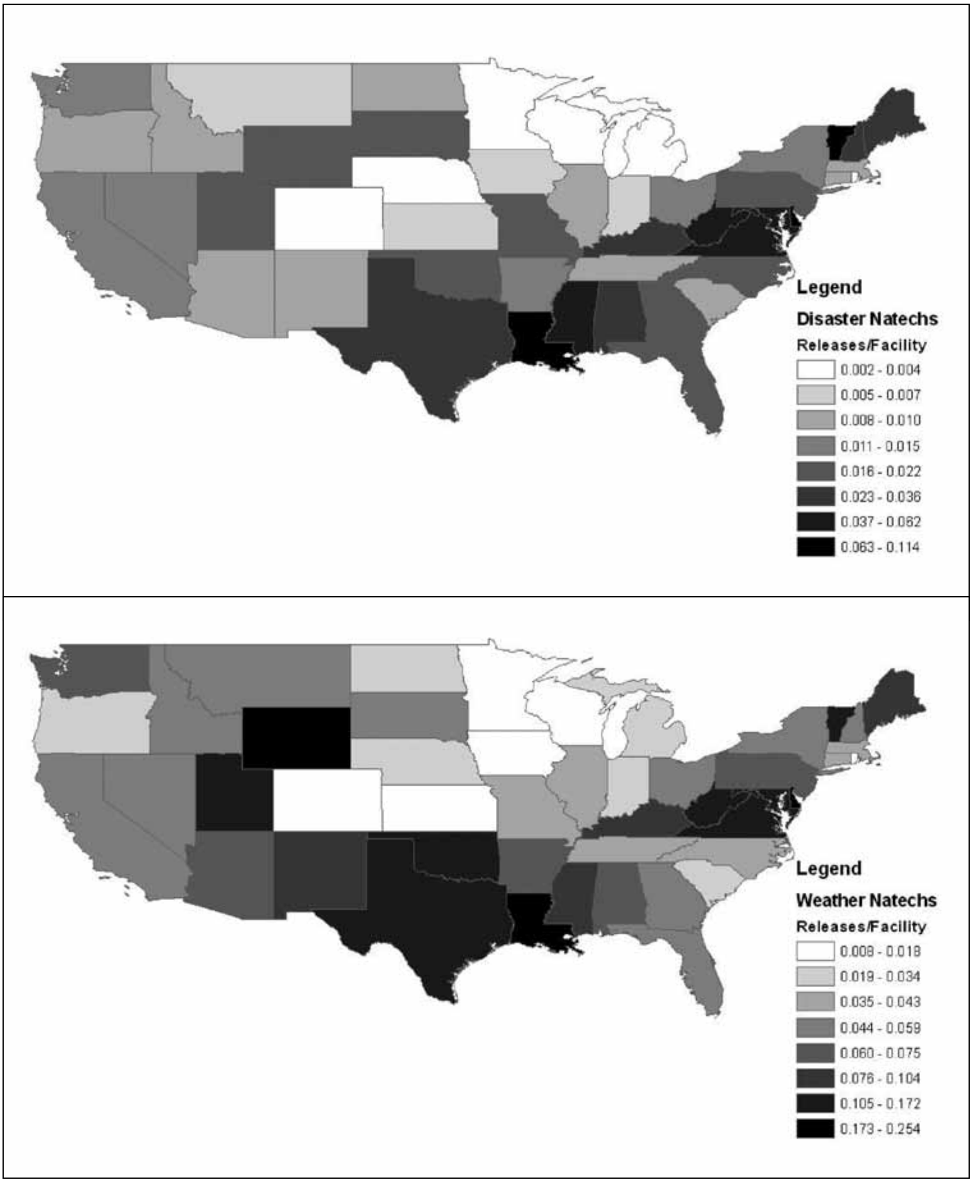
The mechanism by which these releases occurred varies with the facility or equipment type and natural phenomena involved. A number of general patterns emerge from inspection of text descriptions of these events. Rain-related events at most locations were largely due to overflows of different types of containment washing the materials, most often petroleum products, into the environment. The ultimate cause of these overflows appeared to be insufficient systems for dealing with storm water, as contributing equipment failures, such as of pumps, were mentioned infrequently. An exception is the relatively small number of rain-related releases from flare stacks, which generally derive from equipment failures, such as shorted out compressors. Hurricane-related releases were more often the result of physical damage to equipment, including storage tanks, pipelines, and valves. Wind was mentioned less frequently as a cause of hurricane damage as compared to storm surge and flooding. One common mechanism for releases from storage tanks during hurricanes, as well as floods, was the flotation of tanks, producing a rupture of the tank or associated piping, or the creation of orphaned containers in the case of smaller vessels. Overflow of containment also was a relatively common cause of hurricane-related releases at fixed facilities. The majority of hurricane-related releases from flare stacks were the consequence of shutdown prior to, or start-up after, a hurricane. While flare stack releases often are part of deliberate and controlled safety measures, only rarely generating human impacts, they can release sizable quantities of hazardous materials with potential for environmental damage. The majority of cold weather releases were from freezing-related damage to pipelines or valves, with the exception of releases from mobile sources, which generally were due to vehicular accidents caused by icy road conditions. Storm- and weather-related releases from fixed facilities were almost equally divided between overflows because of precipitation and power outages, whereas releases from transformers and vessels were largely due to physical damage. Wind-related releases also were dominated by physical damage whereas those from floods were split between overflows of material from containment and physical damage. The majority of releases cased by lightning were due to direct damage to equipment, but those occurring at fixed facilities, and from flares, often were due to lightning-induced power losses.

Geographical distribution of natechs

The greatest number of recorded natechs occurred in Texas, Louisiana and California, resulting from a combination of a large population of industries within each of these states and high exposure to various natural hazards. More than one-half of natechs in Louisiana and one-quarter of those in Texas were hurricane-related. In California rain, wind and storms were the dominant causes.

To control for the density of industry, the number of TRI, RMP, and SIC 1311 industrial sites in each state was tabulated along with natechs from all fixed facilities, including those from flare stacks and storage tanks. The total numbers of industrial sites and facility natechs for each state were moderately and significantly correlated ($r^2=0.40$), with a 95 per cent confidence level ($p<0.05$), suggesting that 40 per cent of the variation in the number of natechs is explained by the number of facilities in a state. The other 60 per cent presumably is due to the level of natural hazard risk, the characteristics of facilities in each state, and random variation owing to the limited time span of the data set. All of the facility natechs were divided into 'disaster natechs' that had causes often associated with natural disasters (earthquakes, floods, hurricanes, tornadoes) and 'weather natechs' that were due to all other natural phenomena.

Figure 3. Rate per facility of 'disaster' natechs due to earthquakes, hurricanes, tornadoes, and floods and 'weather' natechs resulting from all other phenomena



Source: authors.

For each state, rates of natech occurrence per facility were calculated for natural disaster and weather natechs, by dividing the number of natechs by the total number of facilities. This provides a quantitative indication of the rate of natech occurrence in each state controlling for density of industry. However, correction for industry density is not perfect, as some releases may have taken place at facilities other than the types tabulated.

Figure 3 shows disaster and weather natech rates per facility for each state. By way of comparison, across the entire US during this period, there were an average of 0.03 disaster natechs and 0.09 weather natechs per facility. Figure 3 indicates that when accounting for density of industry, some states still have a much higher than average frequency of natech occurrence. Louisiana, Mississippi, and Virginia have high rates of natechs primarily due to hurricanes; West Virginia, Vermont, and Delaware have a high rate of flood natechs; Louisiana, West Virginia, and Delaware have the highest rates of weather natechs, primarily caused by rain; and Wyoming has a high rate of weather natechs due to both cold weather and rain. Although Texas and California have the second and third highest total number of natechs, they have less dramatically elevated natech rates when one takes into account their large number of industrial facilities. A similar geographic distribution is observed between disaster natechs and those from other natural phenomena. For instance, natechs caused by both rain and hurricanes happen with greater frequency along the Gulf coast and to a lesser extent along the Atlantic coast.

Type of materials released during natechs

The properties of the materials released during natechs are important with regard to the possible effects on humans and the environment. Petroleum was released during 60 per cent of natechs whereas various chemical releases made up another 30 per cent, aqueous materials comprised five per cent of releases, and natural gas constituted three per cent of releases. Crude oil was the most common form of petroleum both in frequency (28 per cent of the total) and quantity (41 per cent), much of which was released due to hurricanes. Transformer and mineral oil releases were the next most common (together equalling 31 per cent of petroleum releases), but they were only three per cent of the total volume of petroleum. Releases of diesel fuel also were fairly common (six per cent) but not very large (three per cent of volume). Natural gas condensate, in contrast, was released in a relatively small number of events (one per cent), but because of several large releases caused by hurricanes it made up seven per cent of the volume of all petroleum releases.

The most common hazardous chemicals released during natech events are tabulated in Table 1. Nitrogen oxides (NOx) and benzene, the two most common, resulted primarily from flare stack emissions. One reason for large numbers of reports of these compounds is their relatively small RQs of 4.5 kilograms (kg) (10 lb). Although numerous, NOx releases from flares generally do not necessitate an emergency response so to reduce the reporting burden on industry in 2006 the RQ for nitrogen oxides was increased to 453.6 kg (1,000 lb) for combustion-related sources, such as flares

Table 1. Most common and largest quantity hazardous chemicals released during natechs

Material	Releases (number/ % total)		Volume (litres/% total)		Weight (kg/% total)	
NITROGEN OXIDE	414	13	–	–	294,998	4.4
BENZENE	246	8	5,155	0.1	76,445	1.1
POLYCHLORINATED BIPHENYLS	172	5	17,994	0.5	57	0.0
SULFUR DIOXIDE	152	5	–	–	725,514	10.8
NITRIC OXIDE	146	5	1,590	0.0	126,496	1.9
HYDROGEN SULFIDE	139	4	–	–	28,397	0.4
BUTADIENE	164	5	–	–	80,095	1.2
AMMONIA, ANHYDROUS	125	4	52,536	1.5	186,200	2.8
NITROGEN DIOXIDE	95	3	–	–	42,266	0.6
ETHYLENE GLYCOL	59	2	334,128	9.3	46,110	0.7
ASBESTOS	47	1	–	–	6,724	0.1
SODIUM HYDROXIDE	16	0.5	542,182	15.0	–	–
COPPER SULFATE (IC)	9	0.3	227,100	6.3	7,249	0.1
AMMONIUM NITRATE	5	0.2	–	–	3,104,824	46.4
SODIUM CARBONATE	1	0.0	–	–	272,154	4.1
TOTAL	**1,790**	**56**	**1,180,685**	**32.7**	**4,997,529**	**74.6%**

(EPA, 2006). This led to a decline of more than 40 per cent in the total number of hazardous chemical-related reports to the NRC and a 10-fold decrease in the number of reported natechs involving NOx. Anhydrous ammonia stands out as the most commonly released material with a source other than flares; in this case, many natechs represent damage to refrigeration systems at storage tanks and other fixed facilities. Although released in only a few events, ammonium nitrate made up almost one-half of all natech releases by weight, principally due to two large releases after fertiliser warehouses were washed away during floods.

Releases of aqueous materials (such as sewage and waste water with low concentrations of hazardous materials) were considered separately from petroleum or hazardous chemicals because the reported volumes of these releases, including water, are sometime very large, in the range of millions of litres, and would otherwise distort any account of the quantities of material releases. The large volumes involved also make containment or treatment of the release particularly difficult. Such releases present a limited acute health risk but they may cause environmental damage. Approximately 36 per cent of these releases are oil-contaminated water, 16 per cent are releases of sewage, and the remainder is various, often unspecified, hazardous chemicals at low levels.

Quantity of material released by natechs

The quantity of material released during natechs varies widely (such as from drops to millions of litres of oil). Even in the case of natural disasters such as floods or hurricanes, many (35–55 per cent) reported releases were small (less than 45 kg or 379 litres). Figure 4 illustrates the size distribution of natech releases of petroleum and hazardous chemicals. Chemical release size was approximately log normally distributed whereas the distribution of petroleum releases was skewed towards smaller volumes. Reporting requirements probably account for much of this difference; few chemicals require reporting when released in small quantities, whereas petroleum releases to water (80 per cent of petroleum releases) must be reported regardless of size. In contrast, small releases of petroleum on land are likely to be under-reported. One indication of this is that smaller petroleum spills (less than 379 litres) were much more often reported to water than to land, at a ratio of 10:1, whereas larger spills (more than 37,850 litres) were also more often reported to water but at a reduced ratio of 2:1.

Given the wide variation in the size of releases, the quantity of material released due to natural hazards may offer a better indication of more vulnerable components of infrastructure than the number of releases alone. Figure 5 illustrates the quantity of petroleum released from various facilities and equipment due to each natural phenomenon. ATON releases and releases with an unknown source generally did not include information on the quantity of material released so are not tabulated. The volume released often is highly dependent on a few large releases. For instance, a single incident in 1992—when 757,000 litres of liquid asphalt leaked from a storage tank due to damaged piping—accounted for most of the petroleum released by tornadoes. Similarly, most of the petroleum released by earthquakes was from one release of 556,395 litres of crude oil owing to damage at a tank farm during the Northridge earthquake. The total volume of petroleum released during natechs (approximately 29 million litres between 1990 and 2008) comprises three per cent of the volume of all petroleum releases reported to the NRC over that time period as well as three per cent of their total number, indicating that, on average, these natechs were similar in size to other petroleum releases reported to the NRC.

Figure 4. Size distribution of petroleum and hazardous chemical natechs

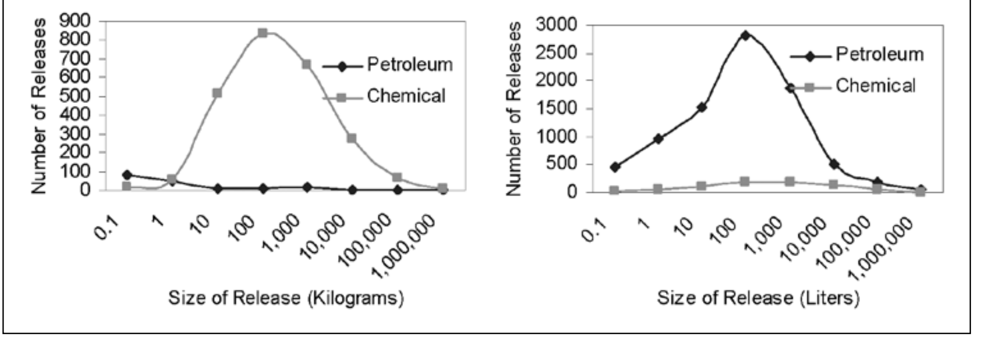
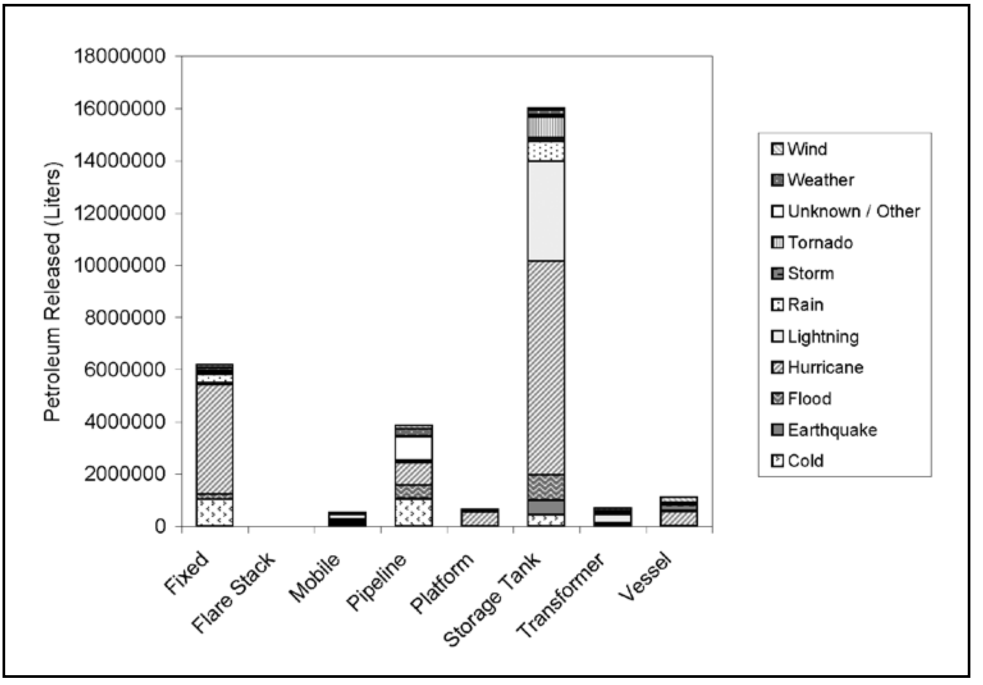


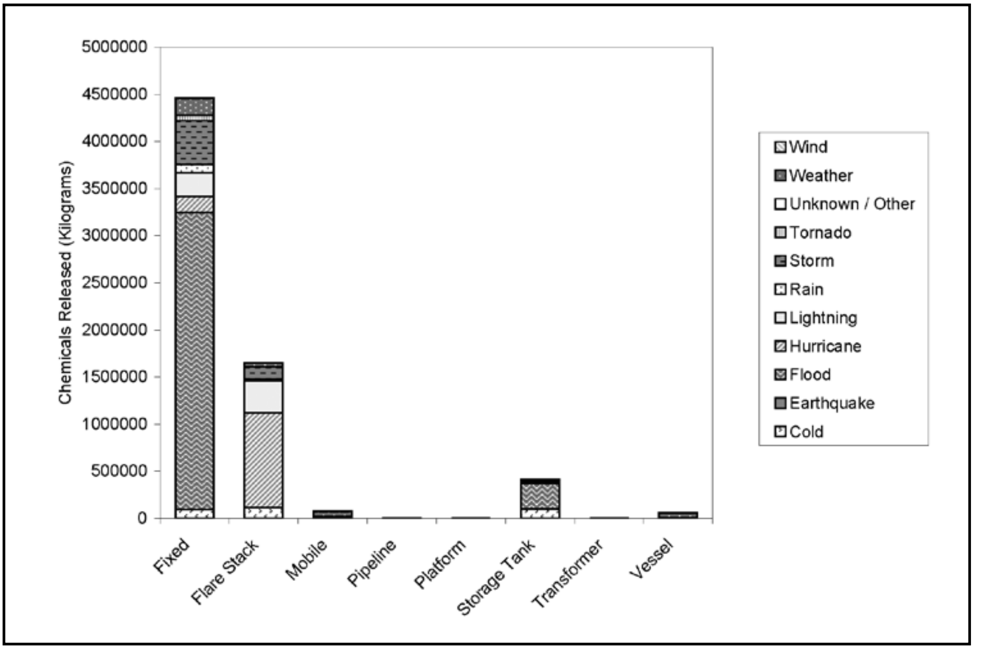
Figure 5. Volume of petroleum released by Natechs, 1990–2008



Hurricane-induced releases of petroleum from storage tanks, primarily during Hurricanes Katrina and Ike, account for a large fraction of the total volume of petroleum released. Releases from other fixed facilities, excluding flares, also were sizable. In 2005 and 2008, because of these large releases, natechs made up 31 and 27 per cent respectively of the total petroleum releases reported to the NRC in those years. Consequently, the threat of hurricane-induced oil spills has gained increased recognition and there is interest among regulatory authorities in the Gulf coast region in managing better large storage tanks at risk from hurricanes (see, for example, Baccigalopi, 2009). Large releases also were caused by lightning strikes on storage tanks, frequently resulting in fires or explosions—77 fires and 18 explosions reported. Persson and Lönnermark (2004) highlight the gravity of lighting risk to storage tanks, observing that 150 (31 per cent) large fuel-tank fires from 1951–2003 resulted from lighting strikes. In contrast, rain-related natechs, although common, were small for the most part, making up only four per cent of the total volume of petroleum released by natechs. Likewise, releases from pole- or ground-mounted electrical transformers were numerous, but they comprise only two per cent of the total of petroleum released. While the total quantities of petroleum released by some events, such as earthquakes or floods, also were low, this represents the total of a very small number of events, some of which were quite large in size.

Hazardous chemical releases reported by weight make up 73 per cent of chemical releases of known quantity. Figure 6 illustrates the weight of chemicals released from each facility or equipment type. Flood-related releases from fixed facilities were the

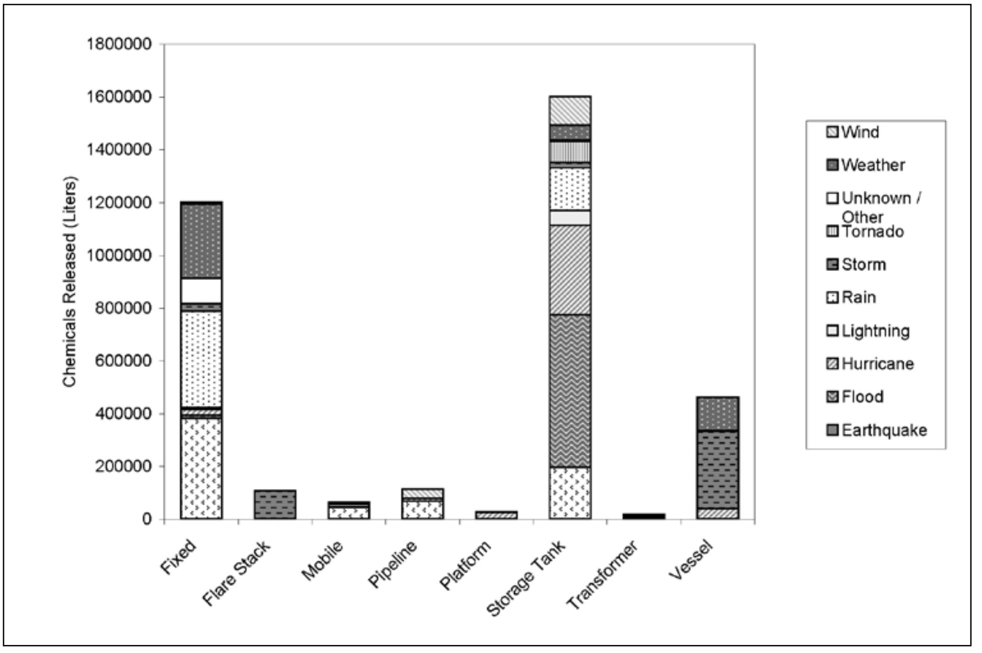
Figure 6. Mass of chemicals released by natechs, 1990–2008



largest single category because of two very large ammonium nitrate releases (also mentioned in the section above) in 1993 and 1994. Despite the size of these releases, natechs made up only 14 and 7 per cent of the total releases of chemicals by weight reported to the NRC in those years. Hurricane-related losses from flare stacks were the second largest source of emissions. Flaring releases were particularly large for Hurricane Rita in 2005 when 0.5 million kg were released with 71 releases greater than 1,000 kg from approximately 25 different sites. Such releases also were large during Hurricane Ike in 2008; 0.3 million kg were released with 20 releases greater than 1,000 kg at 10 different sites. These releases accounted for only a few percentage points of the total mass of chemicals reported to the NRC in those years. Lightning-induced releases also were sizable, with more than one-half (53 per cent) due to flaring from lightning-induced power loss. Overall, natech releases of hazardous chemicals by weight totalled 0.5 per cent of all chemical releases reported to the NRC and made up 1.7 per cent of the total number of all such releases, suggesting that natech releases of chemicals by weight were smaller on average than other non-natech releases reported to the NRC.

Chemical releases are less often reported by volume than by weight. Figure 7 illustrates the volumes of chemicals released by natural phenomena. Releases occurring at storage tanks or other fixed facilities account for most of this volume. Somewhat surprisingly, cold weather was the natural phenomena responsible for the largest volume of releases due to half-a-dozen large releases during the unusually cold winters of 1994 and 2004. Flood-related releases also were large because of a single 537,528-litre release owing to flood damage to a storage tank containing sodium hydroxide

Figure 7. Volume of chemicals released by natechs, 1990–2008



solution in 2003. Hurricanes, rain, storms, and weather also were significant sources of releases, with the last two standing out as the causes of a sizable volume of releases from vessels.

Natech events with human impacts

The IRIS database records acute human impacts but this information can be treated only as an estimate given that it may not have been complete at the time of reporting. Some known human impacts were not recorded within IRIS, such as the exposure of two coastguard personnel to toxic fumes after Hurricane Ike (Dean, 2008). However, the fraction of natechs with injuries or fatalities remained roughly constant in each year of the 19-year record, suggesting that the presence of human health consequences were recorded consistently, if imperfectly. Natech events account for 0.4, 0.8, and 1.6 per cent of all releases within IRIS with fatalities, injuries, or evacuation, respectively. Considering that natechs make up three per cent of all IRIS reports, those in the US in the last 19 years have been less likely to generate human impacts than other hazmat releases reported to the NRC. Nonetheless, natechs have resulted in a significant number of serious human impacts.

Removing from consideration human impacts caused by the accident or natural hazard itself (such as death in vehicular accidents caused by weather or tornadoes), only two fatal natech events were recorded in the US during this period. One was a 1995 incident in which two firefighters were killed while responding to a tank fire caused by a lightning strike (Smith, 1997), and the other was a 1990 incident in which a contractor was killed by inhalation of propane released from a valve that froze open in cold weather.

There were 33 events that resulted in a total of 52 injuries, of which one-half required hospitalisation. Lighting was responsible for 37 per cent of these events, cold 31 per cent, and flooding 6 per cent. Lighting resulted in many events with multiple injuries, accounting for one-half of the total number of injured. No injuries were recorded from releases due to hurricanes, tornadoes, or earthquakes. Natural gas, mostly from pipelines, was involved in 40 per cent of events with injuries, while 15 per cent involved petroleum, and hazardous chemicals accounted for the remaining 45 per cent.

Some 5,000 individuals were evacuated during 102 natechs, with an equal division between employees and members of the public. As with injuries, lightening caused 35 per cent of these events and a larger fraction of the total number evacuated. Only 15 per cent of evacuations were related to earthquake, hurricane, tornado, and flood events. Releases at fixed facilities (excluding storage tanks and flares) caused 35 per cent of evacuations, storage tanks 30 per cent, and pipelines 20 per cent. Approximately 25 per cent of evacuation events involved natural gas releases (about one-half of which were pipelines), 21 per cent involved the release of petroleum, divided between storage tanks and other fixed facilities, and the remainder was due to hazardous chemicals.

Keeping these events in perspective, many were related to lightning strikes that resulted in fires and releases from storage tanks or buildings. Such fires could be considered as a 'routine' emergency for which many communities are well prepared. It is only when severe releases occur under circumstances that may prevent a normal emergency response that natechs present an increased threat to the public as compared to other hazmat releases. The natech record presented here does not cover a sufficiently long period of time to record very low probability natech events that might have severe human consequences. However, the possibility of severe human consequences is hinted at by the significant number of natech events resulting in evacuations, particularly of the public. For instance, 40 people were evacuated after flooding damaged a natural gas pipeline crossing a river in 1996; 300 residents were evacuated after a tornado damaged an ammonia storage tank in 1992; and 12 employees were evacuated after an ammonia leak during the 2001 Nisqually (Washington) earthquake. In addition, a serious human impact not generally recorded in the database is damage or destruction of homes due to natech releases. Notably, hundreds of homes were contaminated with oil after the 2007 flood in Coffeyville, Kansas (Wichita Eagle, 2007), and almost 2,000 after Hurricane Katrina owing to the spill at the Murphy Oil refinery (Associated Press, 2007). Although natechs have not yet resulted in catastrophic effects in the US, the impacts described above, combined with severe experiences of natechs globally (see, for example, Malhotra, 2001; Steinberg and Cruz, 2004), indicate that additional consideration of natech risk in industrial facility design and emergency planning may be warranted.

Conclusion

This paper presents a comprehensive assessment of the prevalence of natechs within the US from 1990–2008. It observes that natechs occur frequently in the country and make up three per cent of all releases reported to the NRC. The largest number of natech events was caused by rain, but the total quantities of material released in these events usually were small. Hurricane-related releases, in contrast, comprise a disproportionately large volume of petroleum releases due to natural hazards. Although the largest numbers of natech petroleum releases have happened at fixed facilities (excluding storage tanks), the greatest quantities of petroleum were released from storage tanks by hurricanes and lightning. Releases due to hurricanes also have increased 15-fold in the period since 2005, and together these results suggest that the security of storage tanks (against hurricane damage) is an important area for improvement. However, large natechs have been observed during all types of natural phenomena, indicating that planning for common hazards, such as heavy rains, should not be neglected, particularly in geographic areas with a high natural hazard risk.

Natech events are the cause of a small fraction of human impacts in the IRIS database: 0.4 per cent of fatalities, 0.8 per cent of injuries, and 1.6 per cent of evacuations, as compared to the three per cent of all hazmat releases represented by natechs. While this indicates that recent natechs in the US were less likely to trigger human consequences than other types of hazmat accidents, these events still accounted for a significant number of injuries and evacuations as well as several deaths during the time period of interest. Although this study is not sufficient to predict the health hazards or the environmental ramifications of future natechs, it is an important first step towards understanding natech risks in the US. Further investigation is needed to inform the effective mitigation of natech risk. With more detailed analysis, the data presented here can indicate the nature and causes of natech releases at many types of facilities. Use of more sophisticated data analysis methods, such as data mining and Bayesian statistics, which have been applied already to the NRC accident database, might contribute to these efforts (see, for example, Anand et al., 2006; Meel et al., 2007). Improvements in the IRIS database, such as consistent updating of records and the collection of more detailed information on the causes, consequences, and actions taken in response to releases, would also improve its utility. Study of natechs remains an important topic as a full understanding of the mechanism, fluctuations in frequency over time, and their consequences is necessary in deciding how and where to invest in prevention whether through legislation, construction standards, engineered defences, or changes in operating procedure.

Annex: evaluation of the completeness of the IRIS–ERNS natech record

This study could have underestimated natech frequency because the regulatory framework that drives reporting to the NRC does not require the reporting of smaller releases of hazardous substances or of petroleum products that do not threaten a water body. However, regulators encourage industry to report all releases that may require an emergency response. Small releases also may be reported to the NRC as a precautionary measure by companies when it is unknown if the release meets RQ criteria, by concerned members of the public, or by local authorities responding to an incident. As such, it is expected that the vast majority of larger releases caused by natural hazards with potential to generate serious environmental or human impacts were included in the IRIS–ERNS record.

Several comparisons with other sources of information on natechs were conducted to test this assumption. Hazmat releases caused by the Northridge earthquake from IRIS (34 incidents) were compared with the 139 incidents reported from site inspections by the Los Angeles County Fire Department (LACFD, 1994). Lindell and Perry (1996b) note that the earthquake was characterised by a dozen large incidents, all but one of which are recorded in IRIS, and many smaller incidents. Only two of these smaller releases, one of 5,678 litres of fuel oil from a city facility and another of 5,678 litres of plating solution, might have required reporting to the NRC depending on the circumstances. Earthquakes may be more likely to result in releases not reported to the NRC as compared to other natural hazards because releases that remain fully contained within a building, common in earthquakes, do not require reporting.

A comparison also was made between records of releases within the State of Louisiana from IRIS and the Hazardous Substances Emergency Events Surveillance System (HSEES) during Hurricane Katrina (Ruckart et al., 2008). Releases not legally requiring reporting to the NRC often are reported to the state and hence to the HSEES, but the HSEES does not record releases of only petroleum. More releases, excluding petroleum, were reported to the HSEES (25 records) as compared to IRIS (17 records). Five of the releases only found within the HSEES were small, but three represent significant emissions that might have required reporting to the NRC. IRIS data also significantly underestimate the quantity of petroleum released during Hurricane Katrina—only six million litres—as compared to known releases of more than 30 million litres (LHRR), because records of several large releases did not include quantity of material. However, during Hurricane Ike, the size of large releases of petroleum was accurately recorded within IRIS. In general, it is believed that the total quantities reported released within IRIS only should be relied on as an approximation of the true value.

Lastly, the record used in this study was compared to a list of natechs provided by the Delaware SEMA. The latter identified 19 events due to floods, hurricanes, and storms between 1992 and 2003, most of which occurred during declared natural disasters. IRIS–ERNS recorded 39 natechs within the State of Delaware over the same period. Only 10 events were shared between the two data sets. Most of the 11 releases reported by SEMA but not found in IRIS were small, and none appeared to require reporting to the NRC. All of these comparisons indicate that the largest and most hazardous natechs were very likely to be recorded in the data used for this study whereas intermediate-sized spills may be somewhat under-reported and small spills were probably significantly under-reported.

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[2] See Cruz and Krausmann (2009) for further analysis of these releases.

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