2011

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Journal of Homeland Security and Emergency Management

Volume 8, *Issue* 1 | 2011 | *Article* 53

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Recommended Citation:
Santella, Nicholas and Steinberg, Laura J. (2011) "Accidental Releases of Hazardous Materials and Relevance to Terrorist Threats at Industrial Facilities," *Journal of Homeland Security and Emergency Management*: Vol. 8: Iss. 1, Article 53.
DOI: 10.2202/1547-7355.1809
Available at: http://www.bepress.com/jhsem/vol8/iss1/53

Accidental Releases of Hazardous Materials and Relevance to Terrorist Threats at Industrial Facilities

Nicholas Santella and Laura J. Steinberg

Abstract

Hazardous material releases, some with serious consequences, are a common occurrence in the U.S. Of late, the hazards posed by releases caused by terrorist attacks or natural disasters have been of particular concern. Although terrorism directed at hazardous material handling industries within the U.S. has not yet resulted in a significant incident, there is much recent experience with serious accidental releases resulting from natural disasters. Case studies are developed from a number of recent natural disasters and severe weather events that resulted in large releases of hazardous materials. These case studies are used to illustrate parallels between the risks posed by hazardous material releases resulting from terrorism and natural disasters; examples include the presence of a dominant mechanism for physical damage, difficult-to-control and unforeseen scenarios of releases, limited specific regulation of the risks, and a complex and difficult response environment. Hence, lessons learned from previous experience with releases during natural disasters can be used to increase the resilience of industrial facilities and to improve the planning for hazardous material response in the face of terror threats. Routes to improve hazardous material industry preparedness for terror attack and natural disasters include physical hardening of facilities and equipment, utilization of passive safety devices, greater consideration of facility layout and siting, application of inherently safer design principles, and additional legislation at local, state or federal levels.

KEYWORDS: natech, chemical facilites, terrorism, natural disaster, hazardous material

Author Notes: This work was supported through NSF grant #0302194. We thank Hatice Sengul for her contribution to early phases of this work, and Rochelle Brittingham for comments on this manuscript.

Introduction:

The terrorism threat to hazardous chemical (hazmat) handling industries within the US has not yet resulted in a significant attack on hazmat facilities (Kosal 2007), and hence mitigation/response plans for such an event have not been tested in real-world situations. In this study, we address this lack of first-hand experience with terrorist-triggered chemical releases by analyzing the large amount of empirical data available from accidental releases of hazmats due to natural hazards. Given the similarity in the health risks posed by chemical releases due to terrorism and natural hazards, as well as the similarity of the challenges in response, releases caused by natural hazards can offer valuable lessons for risk management of terrorist-triggered releases. Accidental chemical releases triggered by natural hazards, sometimes referred to as natechs (Showalter and Myers 1994), are especially relevant to terrorism for a number of reasons:

- Applicable regulatory requirements which serve to mitigate natech risk are largely through programs that apply generally to hazmat management, with little specific consideration of the role played by natural hazards as an initiating event[1] (Cruz and Okada 2008). As a result, although many vulnerable facilities plan for natural hazards in general (e.g. a hurricane plan), fewer facilities perform detailed analysis of natech risk (e.g. inclusion in a Process Safety Management Hazard Assessment). Hence, natech failures can often occur in unforeseen ways. Likewise, terrorism-caused failures are not considered in typical process safety analyses, and process design does not typically include anti-terrorism provisions (Whiteley and Wagner 2004). Thus, like natechs, terrorist-triggered releases can more easily result in releases that have not been planned or prepared for.
- By definition, natechs are associated with a coincident natural hazard event, so resources must be shared between responses for both events. Hazmat response is also compromised because site access and supportive infrastructure are limited by the effects of a large natural disaster (see Lindell and Perry 1996, Steinberg and Cruz 2004 for discussion of effects of earthquakes, and Cruz et al. 2001, Santella et al. 2010 for effects from hurricanes). Response may also be complicated by uncertainty as to whether new releases or physical hazards are imminent, e.g., from earthquake aftershocks. Likewise, a well-coordinated terrorist attack may seek to destroy or inhibit response mechanisms, mechanical or human, so that the

[1] In the US, a prominent exception is the hazmat risk posed by earthquakes in California. For example, the California Accidental Release Prevention (CalARP) program requires industrial plants that handle highly hazardous materials to perform a detailed seismic risk assessment.

effects of the attack are maximized.[2] This may take the form of multiple simultaneous attacks or secondary attacks targeting first responders, and such an act, or its threat, may significantly hinder emergency response. The possibility also exists that terrorists may launch an attack on the heels of a pre-existing catastrophe, like a land-falling hurricane, in order to maximize impact.

- Because natechs take place in the midst of a natural disaster, the community's level of concern regarding the chemical release is compounded by the stresses resulting from the natural disaster. This may lead to an increased level of social disruption and mental health issues than might occur under either set of circumstances individually. Similarly, the impact on the community of a terrorist-caused chemical release would likely be exacerbated by the knowledge of its source. This combination might increase the psychological burden on the threatened population and contribute to counterproductive behavior, such as attempting evacuation against official instructions (e.g., Boscarino et al. 2003) or seeking unneeded medical treatment (e.g., Stone 2007).

This work uses a variety of data sources to develop case studies of recent natural disasters and severe weather that resulted in large releases of hazmats. The goal is to highlight the challenges presented by these events and demonstrate their salience to the work of emergency managers and homeland security practitioners. Case studies illustrate the factors leading to serious natech events and their impacts on industrial facilities and nearby communities. The case studies also illustrate steps that can be taken by industry as well as local and state emergency managers to reduce the risks posed by both natechs and terrorist attacks on industrial facilities through changes in procedures and equipment investment.

Methodology

Case studies were developed for a selection of serious natechs. To sample a broad range of events, releases were identified from reports to the U.S. Coast Guard's National Response Center (NRC). The NRC is the national point of contact for reporting discharges into the environment and over 25,000 releases are reported annually. Although some radiological releases are reported through the NRC this work focuses on chemical hazmat releases. The record of hazmat releases provided by the NRC is the most extensive in the US. However a number of limitations exist in the quality of this data. These include inconsistencies with

[2] For example, both the timing and location of the 9/11 attacks in NYC served to destroy and disrupt response capabilities

records present in other state or federal hazmat release databases, lack of identification of the root cause of events, incomplete reports, inclusion of many records where casualties were not related to hazmat, duplicate reports, and the inclusion of many low severity releases. Some of these limitations, were addressed by the analyisis methods described below, but it must be rememberd that reports represent the state of knowledge soon after the release, for example approximately one third of reports do not record the quantity of material involved.

NRC data for 1990 through 2008 was first downloaded and records were filtered to remove events not involving a release, planned continuous releases, and reports describing drills. Events caused by natural hazards were then identified both by selection of events where the event cause was coded as "natural phenomena" and a series of keyword searches of written descriptions of the events for phrases indicative of various natural hazards. Over 16,000 releases caused by natural hazards were identified, many of them minor. Although this selection is sizeable, and should record most of the more serious events, this represents only a subset of the total number of natchs occurring in the US.

This pool of potential events for case studies was distilled based on several fields in the NRC database indicative of event severity including the quantity and type of material released, consequences such as contamination of water bodies, and level of media interest. The several hundred releases identified through these criteria were researched further, and a single natural hazard event, sometimes involving numerous releases, was selected to represent earthquakes, lightning, rainstorms, tornadoes, floods, and hurricanes. Selection of the case study for each hazard was based on both the event's inherent interest and how well the releases would represent the larger body of similar events in the IRIS record. However, events were selected by a partially subjective process and are not intended as a representative sample of serious natechs.

To provide more detailed information for each event than available from the preliminary reports to the NRC media reports available through the Lexis-Nexis Academic Database, government reports, and company press releases were used. In some cases this was supplemented with information gathered from phone interviews with federal, state, and local agencies. This analysis focuses only on events in the US, thereby excluding many more catastrophic examples in other countries. However, these events have many common factors with international events with serious consequences, such as 1994 flooding in Durunqa, Egypt (Smith 2001), the 1999 Izmit earthquake in Turkey (Steinberg and Cruz 2004) and most recently the 2011 Tohoku earthquake and tsunami in Japan which resulted in a number of serious chemical as well as radiological releases.

Results

Earthquake, Nisqually Valley WA, February 28, 2001

The 6.8 magnitude earthquake that occurred near Olympia WA in 2001 is the most recent major earthquake to impact a large US metropolitan area. Although there was significant damage, with initial estimates by FEMA of $2 billion, ground motion was weak compared to the earthquake's magnitude due to the depth of the earthquake (McDonough 2002). Despite the relatively weak ground motion, the earthquake caused a number of hazmat releases. One release, a leak and subsequent explosion of a natural gas line, resulted in a fire at Cedar Creek Correctional Center and injured two workers (WDGER 2008). Numerous other natural gas leaks as well as several hazmat releases including asbestos, metal plating solution, and petroleum were also reported, but with no injuries (McDonough 2002). One of the gas leaks resulted in the evacuation 50 nearby mobile homes (WDGER 2008). An ammonia release required evacuation of eighteen employees when refrigerant pipes at Rainier Cold storage in Seattle ruptured (IRIS). It is suspected that liquefaction of the fill material underlying the storage facility contributed to the release. The affected building and several others nearby were severely damaged and subsequently abandoned (Port of Seattle 2004).

Although both the number and the size of releases from the Nisqually earthquake were relatively small, they were similar in mechanism to the numerous releases observed during the more destructive 6.9 magnitude Loma Prieta and 6.7 magnitude Northridge earthquakes in California. In all three cases, failure of pipelines, damage to asbestos-containing insulation, and releases from sloshing of open vessels occurred. Similar releases are also occasionally reported to IRIS during smaller US earthquakes, but generally with only one or two incidents resulting from each quake. Hazmat releases during earthquakes in the US have generally not had severe consequences, probably in part because of adherence to seismic building codes, particularly for large storage tanks. However, the number and circumstances of releases, as revealed in empirical data collected from large US earthquakes, indicate that the next high magnitude earthquake may result in many releases, some potentially dangerous, for which industry and emergency responders are likely to be unprepared.

Lightning, Sonoma TX, November 2000

A lighting strike on November 5, 2000 resulted in escalation of a small fire into a serious release through a set of cascading events. Two drums of flammable material at a Multi-Chem warehouse and storage area were ignited by lightning.

Despite efforts of local fire fighters, flaming liquid from the drums spread and ignited a wooden utility pole, which subsequently fell, rupturing the natural gas pipeline supplying the site. The natural gas was ignited by electrical arcing from the downed lines and resulted in a fire that destroyed the warehouse and ignited most of the product stored on site and a fire engine. Approximately 200 nearby residents were evacuated from within a 0.5 mile radius (IRIS), and two residents were treated for smoke inhalation. All residents except those within a two block radius of the site were permitted to return home when the fire was extinguished three hours later (AP 2000). Two days later, 15 nearby residents had still not returned to their homes (EPA 2000). Cleanup after the fire was overseen by the Texas Natural Resource Conservation Commission (TNRCC), assisted by EPA. Nearby waterways were temporarily dammed to contain contaminated rain and fire fighting water, and 63,000 gallons were collected for testing and disposal (IRIS).

Lightning is a common natural phenomenon that results in a substantial number of deaths and injuries as well as property damage in the US (e.g., Curran et al. 2000). Lightening also results in hazmat releases relatively frequently with over 1,200 releases related to lightning strikes recorded in IRIS, approximately 3% of which resulted in releases greater than 10,000 gallons or pounds. Lightning strikes on petroleum storage tanks, which totaled 143 in IRIS, can be particularly dangerous. Emphasizing the threat posed by lighting induced releases, Persson and Lönnermark (2004) reviewed 480 large fuel tank fires worldwide and found that 150 (31%) resulted from lightning strikes.

Rain, Lake Charles LA, June 19- 21 2006

Although rain, apart from flooding, is not generally considered a serious natural hazard, serious hazmat releases can occur due to heavy rains. This was the case during heavy rains over several days in Lake Charles, LA when as much as 12” of rain fell in a 24 hour period (NWS 2006). The volume of runoff resulted in the overflow of two large holding tanks containing rainwater and waste oil from the CITGO refineries drain system. Approximately 100,000 barrels of petroleum were released from the tanks. Secondary containment berms around the tanks subsequently leaked through a drainage pipe, releasing the oil to a lagoon. Approximately 25,000 barrels reached the Calcasieu River (AP 2006a). Initial attempts to contain the spill with booms failed, resulting in contamination of miles of river. The same facility also reported two other less serious releases due to the same rain event: unburned hydrocarbons to a flare and 100 lb of sulfur dioxide from a sulfur recovery unit (IRIS). Four nearby facilities also reported releases to the river as a result of overflow of storm water collection systems or secondary containment. Materials released included crude oil, coke fines, and hexachlorobutadien (IRIS). As a result of the CITGO release, the Calcasieu river ship channel was closed for more than a week, reducing production at a number of refineries. Cleanup required more than 1,000 personnel with costs exceeding $10 million (AP 2006b). Because CITGO had been aware that the storm water retention system was under-capacity and an excessive quantity of petroleum was present in the tanks at the time of the release, the company was fined $13 million dollars (AP 2008). The spill also resulted in the filing of over 200 lawsuits.

The CITGO release was unusual in its size and consequences, however heavy rains are the cause of many hazmat releases with over 4,200 recorded in IRIS. Although the majority of these releases are small, sometimes as little as a few drops of oil resulting in a sheen on a water body, a number were substantial. Seven releases of more than 10,000 gallons of petroleum and eight releases of more than 10,000 lb of hazardous chemicals have been reported.

Tornado, Greensburg KS, May 4, 2007

Hazmat releases can add to the inherent physical hazard associated with tornadoes as occurred during the catastrophic Greensburg, KS tornado. Ten people were killed and a warning 20 minutes before the tornado struck is credited with preventing greater fatalities (FEMA 2007). A national disaster was declared on May 6 and estimates of insured losses were over $153 million (KID 2007). Natural gas was released from damaged homes, necessitating a shutdown of gas supply to the town by Kansas Gas Service and several rail cars of petroleum condensate were overturned (IRIS). On May 7, during cleanup, a valve failed on a 30,000 gallon anhydrous ammonia rail car tank damaged by the tornado. A 6 block radius was evacuated around the leaking tank (EPA 2007) while a replacement valve for the rail car was located and installed (Wichita Eagle 2007).

Cleanup of hazmats in Greensburg was an extended process with input from a number of responding agencies. EPA Region 7 personnel with a mobile command post arrived the day after the tornado. EPA Superfund Technical Assistance Response Team (START) contractors were also brought in to assess damaged electrical transformers for potential PCB contamination, and 106 transformers were collected for disposal (EPA 2007). EPA was given responsibility by FEMA for initial separation and collection of household hazardous waste (HHW) and white goods from other debris. By the end of EPA involvement, 36,728 pieces of HHW and white goods had been collected including various chemicals, paint, propane, and compressed gases. A state hazmat response team also was called into operation during the recovery. The team demobilized on May 21, transferring responsibility to EPA personnel who turned responsibility over to the Kansas Department of Health & Environment on June 9.

Tornadoes which hit populated d areas have serious consequences in terms of both fatalities and property damage (Brooks and Doswell 2001). Hazmat releases caused by tornadoes are, however, relatively infrequent, with just under 300 recorded in the IRIS record. The infrequent nature of releases, despite the high frequency of tornadoes, is in large part due to the small footprint of individual tornadoes which may not overlap with locations of industrial facilities. However, given the powerful winds generated by tornados and the reluctance of owners to build to withstand such extreme events, the possibility exists for catastrophic release upon the intersection of a major tornado and a hazmat handling facility.

Flood, Coffeyville KS, July 1 2007

Heavy rains over several days led to flooding on the Verdigris River and the evacuation of over 2,500 residents from Coffeyville KS (Reuters 2007) with a national disaster declared July 2. The Coffeyville Resources Refinery performed a rushed emergency shut down due to flooding and several hours later an oil spill was discovered at the site (NewsInferno 2007). The refinery was flooded by up to 6 feet of water, shifting storage tanks (EPA 2007a) but the Kansas Department of Health and Environment attributed the release of over 71,000 gallons of crude oil to a valve left open (Wichita Eagle 7, 29, 07). Additionally 4,200 gallons of petroleum was released due to flooding of the refinery's sewer system (IRIS). Spread by the flood waters, oil contaminated over 300 homes and businesses and traveled down the Verdigris River. Overflights observed sheen 10 miles downstream causing fear that Oologah Lake and water supply intakes might become contaminated. Later in July, benzene and hydrogen sulfide emissions were reported from flare stacks at the refinery during the recovery process (IRIS). The Coffeyville Resources Nitrogen plant adjacent to the refinery, but at a higher elevation, also shut down, releasing 100 lb of anhydrous ammonia and an unknown amount of ammonia due to loss of power (IRIS).

Cleanup after the flood involved federal and state responders as well as private contractors. EPA on-scene coordinators inspected the refinery site the day the release was discovered. Personnel from EPA Regions 6 and 7 as well as START contractors conducted tests in Coffeyville, along the Verdigris River and in Lake Oologah near drinking water intakes. None of the tests indicated health risks (EPA 2007b). EPA also assisted state authorities with collection and disposal of household hazardous waste and orphaned containers of hazmats dispersed by the flooding. Several private remediation companies were hired by the refinery to respond to the release including O'Brien's Group who were involved in the response to the Murphy Oil spill resulting from Hurricane Katrina (Coffeyville Resources Jul 7 2007). Coffeyville Resources conducted a buyout of affected residences and 313 homes were purchased and demolished. In 2008, a $4.39 million lawsuit was filed against the company by those affected by spill (Wichita Eagle 8, 21 08).

Flooding is a common and costly natural hazard. Releases of hazmat caused by floods are also relatively common with over 1,100 identified in the IRIS record. Releases from small orphaned containers, which are rarely reported to IRIS, are likely to be much more frequent. There were 350 reports in which flooding resulted in releases of chemical or petroleum products from storage tanks. In approximately 30 of these cases, releases are known to be over 1,000 gallons, with many additional reports in which the size of the release was not reported.

Hurricane Ike, September 13, 2008

Hurricane Ike made landfall in Galveston, TX September 13 as a large Category 2 hurricane. Federal emergencies were declared in Florida on Sept 7, Texas on Sept 10, and Louisiana on Sept 11 prior to landfall in order to authorize mobilization of federal emergency response resources. In the days prior to landfall, many chemical and petroleum facilities began shutdown procedures, sometimes resulting in releases to flare systems, and put hurricane ride-out crews in place. Due to flooding and high winds, a federal disaster was declared for parts of Texas, Louisiana, Alabama Arkansas, Ohio and Kentucky. The effects of Hurricane Ike resulted in a large number of hazmat releases with over 3,000 reported to state and federal agencies according to news reports (Associated Press 2008) and almost 500 reports to the NRC. The largest release, approximately 900,000 gallons of distillates, occurred at a Magellan Midstream Partners terminal in Galena Park, Texas just outside of Houston on the shipping channel. This release required the booming off of parts of the facility and shipping channel and ultimately. Most of the material from this release was recovered (IRIS).

Another large spill occurred on Goat Island, Texas where storm surge flooded the St. Mary Land and Exploration Co. plant, damaging secondary containment dikes, valves, and piping attached to eight storage tanks holding crude oil and produced water (IRIS). Approximately 266,000 gallons of oil were spilled, almost all of which was dispersed by the hurricane. Due to conditions after Ike, company responders took 24 hours to arrive by boat (Associated Press 2008). The third largest release was in Texas City, Texas where a NuStar Energy terminal sustained approximately $18 million in damage (NuStar 2008) and reported a release of 33,474 gallons of a 30% sodium methylate and 70% methanol mixture (IRIS). In addition to larger releases, over 76,000 orphaned containers varying from small containers to larger storage tanks were collected, sorted and disposed of (EPA 2009 a,b). The scale of the releases required EPA, Coast Guard, and a variety of state agency and private contractors to participate in the cleanup under a unified command structure with cleanup continuing for over 3 months. In one incident early in the response, six coast guard personnel were hospitalized after coming into contact with displaced chemical tanks in the Houston shipping channel (Dean 2008).

Hurricanes account for the most costly natural disasters in the US because of the very large areas they impact with strong winds, storm surge and flooding. For the same reason, they are also the natural disaster most often associated with releases of hazmat in the IRIS record with over 3,300 releases recorded. At least 53 releases were petroleum releases greater than 10,000 gallons and 36 were hazmat releases over 10,000 lb. Many of these releases occurred as a result of recent hurricanes including Katrina and Rita in 2005 and Ike and Gustav in 2008 but other large hurricanes such as Floyd in 1999, Isabelle in 2003 and Ivan in 2004 also resulted in over 70 reported onshore releases each. Releases are reported to IRIS during almost all hurricanes which make landfall in the US.

Discussion

Natech releases in the US sometimes have serious consequences, although they have so far resulted in very few fatalities and limited injuries. Consequences observed in this study include direct injuries, threatened contamination of drinking water supplies, shutdown of transportation routes, and significant expenses from response, compensation and fines. These case studies confirm that natural hazards that cause destructive natechs tend to be: sudden in onset, severe, geographically diffuse, and disruptive of resources normally available for the operation of safety devices and support of emergency response (e.g., power, water, communication).

Many of the attributes of natural hazards that lead to serious natech incidents also characterize typical scenarios of terrorist attacks against industries using and storing hazmats. Commonalities provide insight into mitigation, preparedness, response, and recovery activities relevant to both threats. In the following discussion, these similarities are used as the basis for applying the sizable and expanding body of experience with natechs to the threat posed by terrorism to the chemical industry.

One common characteristic of natural hazards and terrorist attacks is the predominance of a single major mechanism of direct damage. Damage to equipment, particularly tanks, valves, and piping, accounts for most large releases during natechs. Similarly, previous experience with terrorism suggests that direct attack with explosives on a plant's physical facilities is the most likely threat to hazmat handling industries (Kosal 2007). These observations suggest that hardening of vulnerable plant elements may be an appropriate response to mitigate both threats. Examples of this include installation of stabilizing tie downs and heightening of fluid detention facilities around storage tanks; construction of barriers to protect valves and piping from flood, air-born debris from explosions or storms, and deliberate vehicular impacts; and flexible joints and bracing for pipes that serve to limit seismic or indirect blast damage.

In addition, the external nature of both terror and natural hazard threats as well as their sometimes sudden and unexpected onset, may make resulting releases harder to control than typical accidents. As a result, an even greater focus on mitigation measures such as facility location, layout, and process design can be helpful in addressing both threats (Whiteley and Wagner 2004, Moore and Kellogg 2006). Some have even argued that the threats posed to the public and the chemical industry by terrorism and natural disasters require a fundamental rethinking of US hazmat risk management policy, with a greater emphasis on inherently safer technologies (e.g., Malloy 2008). In the context of terrorism threats, it has been suggested that the Department of Homeland Security should support research and development to foster inherently safer chemical processes (NRC 2006). Indeed, adoption of safer alternative processes with the potential to deter terrorist use of hazmats has already been documented in some industries (Orum 2006).

Technological controls, intended to mitigate release severity, are also applicable to both types of threats. Safeguards requiring human intervention may not be reliable during either a natural disaster or a terrorist attack, as operator action may not be possible for a variety of reasons, including site evacuation or unsafe conditions. For example, standard industry practice includes the confinement of hurricane ride-out crews during periods of high winds. Similarly, Whiteley and Wagner (2004) observe that procedural safeguards requiring specific actions by personnel cannot be relied upon in the case of terror attacks. Hence, passive or automated safety devices, such as flow restrictors, automated cutoffs, heat-actuated foam systems and automated scrubbers, may be more successful at limiting the severity of a release should damage to systems occur during a natural disaster or deliberate attack.

Inadequate preparedness efforts can also contribute to the consequences of both types of threats. For instance, negligent practices by industry, including improper maintenance of pipes and tanks and poor operational practices, significantly contribute to the severity of natech events. Similarly, inadequate site security increases terrorism risk. Attention to basic procedures, such as routine inspection, maintenance, and site security, is critical for managing both types of threats. Given limited resources, appropriate plans for risk-based operation, maintenance, and security can reduce the potential for negligence to contribute to the likelihood or severity of a release.

Moreover, similarities between response and recovery from natechs and from terrorist attacks on hazmat handling industries can provide guidance on appropriate actions for impact reduction. Industries in areas vulnerable to natural disasters must plan to respond to releases and undertake recovery under severe conditions where much of the infrastructure of the surrounding area is unavailable and site access is limited (e.g., Moor and Kellogg 2007). The scale of damage and disruption from a terrorist attack on an industrial facility is unlikely to match that of a hurricane. However, terrorist acts may be planned to maximize disruption and public fear, for example by shutting down critical energy or transportation infrastructure. In such a case, response may be hindered by limited availability of transportation, resources, or lifelines as was the case after 9/11 (EPA 2002). In addition, first responders' site access may be limited due to security concerns. Under such conditions, on-site response capabilities and plans for coordination of off-site response are likely to be overwhelmed. It is clear that preplanning for a complex large-scale response, considering in particular limited availability of resources such as backup water, power, and communication, is critical for both kinds of threats.

Responding effectively to the environmental contamination resulting from either natechs or terrorist attack on industry is also a challenge. Because of the large area potentially affected by natural hazards, environmental remediation efforts for natech releases can be geographically widespread, long term, and complex. Examples of this can be seen in the extensive efforts after floods and hurricanes, often extending for months, to clean up petroleum spills on waterways, locate and recover orphan containers, and remediate contaminated soil. Such cleanup efforts often involve multiple jurisdictions; numerous federal, state and local responding agencies; private contractors; and stakeholders including private citizens, regulators, and affected companies (e.g., Santella et al. 2010). Responses to terrorist attacks are likely to be just as difficult and complex. Indeed, responses of unprecedented complexity by multiple agencies and with many stakeholders were typical of the remediation efforts at the World Trade Center and anthrax contaminated sites in 2001 (EPA 2002, GAO 2003).

Furthermore, the risks posed by natech or terrorist threats, as well as available measures to identify and counter vulnerabilities, may or may not have been given sufficient consideration by facilities. Some companies in the chemical and petroleum industries have been proactive in addressing natural hazard risks, particularly after the experiences of Hurricane Katrina. Likewise, many hazmat handling industries have taken voluntary measures to reduce vulnerability to terrorist attack, and high risk facilities must comply with federal Chemical Facilities Anti-Terrorism Standards. On the other hand, it has been shown that company size is a determinant of the level of disaster preparedness efforts generally (e.g., Dahlhamer and D'Souza 1997, Webb et al. 2000) and for the implementation of natech mitigation measures specifically (Cruz and Steinberg 2005). Hence, smaller companies with fewer resources and limited experience with the complexities of natural hazards and terrorism may be less likely or able to fully evaluate the potential risk posed to their operations and to the public. Similarly, the benefits of changes to infrastructure, equipment, or operating procedures intended to limit the damage and reduce the risk of releases may be less apparent to smaller companies.

Where an internal motivation for risk mitigation does not exist within industry, regulatory input in the form of federal, state, or local laws can serve to encourage effective planning, mitigation, and operation by industry. For example, on a local level, flood-vulnerable jurisdictions might incorporate into their land development regulations the National Fire Protection (NFP) standard 30 4.3.2.6 for storage tanks in flood zones. Nationally, legislation encouraging the adoption of inherently safer technologies has been proposed, for example the Chemical Facility Anti-Terrorism Act of 2009 (H.R. 2868), and such measures continue to be debated. Legislative efforts can never eliminate terrorism risk to industry. Nevertheless, if precautionary steps are widely implemented, they may significantly reduce the risk of releases with catastrophic consequences. Likewise, while minor natechs are likely to continue on a regular basis, the risk of events with significant human health or environmental impacts can also be reduced.

Conclusion

These case studies suggest that the threat of natechs may require further consideration by industry, public emergency managers, and regulators in regions where industry is subject to severe natural hazards. Likewise, a terrorist attack on hazmat handling industries has the potential for serious public health risks that are not comprehensively addressed by mitigation efforts or response planning. Existing building codes, response capabilities, and regulations may be sufficient to protect the public from undue risk in the case of hazmat releases caused by minor natural hazards although such releases may still be costly. On the other hand, major natural disasters, such as earthquakes, hurricanes and large floods, or terrorism are likely to result in potentially dangerous releases which may overextend local, state, and even federal resources, delaying remediation and leading to greater risk to human health and the environment.

Parallels between natech and terrorist threats to hazmat handling industries include prominence of an external mechanism causing physical damage; difficult-to-control and unforeseen scenarios of facility damage and releases; limited specific regulation of the risks; and a complex and difficult response environment. Hence, lessons learned from previous experience with natechs can be used to both reduce the vulnerability of industrial facilities to terrorist-triggered releases and to improve hazmat response under the extreme and complex conditions which characterize terrorist attacks. Examples of methods to improve industry preparedness for terror attacks on hazmat handling facilities include physical hardening of facilities and equipment, use of passive safety devices, greater consideration of facility layout and siting, and wider application of inherently safer design principles. In the case of both threats, additional legislation at local, state, or federal levels may be necessary to promote these types of risk reduction measures.

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