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26

Case Studies and Lessons Learned in Chemical Emergencies Related to Hurricanes

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1. Introduction

The 2005 hurricane season in the United States was one of the most active seasons documented. Hurricane Dennis, the first major hurricane of the season, weakened to Category 3 strength before making landfall over the western Florida Panhandle on July 10, 2005. Hurricane Dennis caused considerable damage across the western Florida Panhandle, including widespread utility and communications outages and storm surge-related damage far to the east of the landfall location (National Oceanic and Atmospheric Administration, 2005a).

Hurricane Katrina entered southern Florida on August 25, 2005 as a Category 1 hurricane before rapidly gaining strength in the Gulf of Mexico. The storm made its second landfall in south eastern Louisiana on August 29, 2005, as a Category 3 hurricane (Knabb et al., 2005a). Due to levy failures in the New Orleans area, Hurricane Katrina was one of the worst natural disasters to ever strike the United States. Katrina resulted in an estimated 1,464 deaths in Louisiana, numerous illnesses and injuries, and substantial infrastructure damage (Centers for Disease Control and Prevention, 2005e; Knabb et al., 2005a; Louisiana Department of Health and Hospitals 2006).

Hurricane Rita was also classified as a Category 3 hurricane when it struck the Louisiana-Texas border on September 24, 2005 (Knabb et al., 2005b). Although the impact from Hurricane Rita was not as severe as that from Hurricane Katrina, the approach of Hurricane Rita generated one of the largest evacuations in United States history; estimates exceed 2 million evacuees in Texas (Knabb et al., 2005b).

Hurricane Wilma, another Category 3 hurricane, struck the southwest coast of Florida on October 24, 2005 (Taylor et al., 2007). Hurricane Wilma caused extensive damage to homes and power lines and also temporarily displaced thousands of residents (Centers for Disease Control and Prevention, 2006b).

Much of the public health response to the hurricanes was focused on assessing health-related needs and surveillance of injuries, infectious diseases, and other illnesses (Centers for Disease Control and Prevention, 2005b; Centers for Disease Control and Prevention, 2005c; Centers for Disease Control and Prevention, 2005e; Knabb et al., 2005a; Knabb et al., 2005b; Tayor et al., 2007; Todd, 2006). However, the hurricanes also resulted in unintended

chemical releases in the affected states. When natural disasters, such as hurricanes, trigger technological disasters, the resulting event is called a natural-technologic or "natech" event. Natech events may involve releases of household chemicals or large industrial releases, such as an oil leak from a severed pipeline (Young et al., 2004). Industrial natech releases can involve the release of extremely toxic substances and have the potential to expose large numbers of people. Hurricane Katrina resulted in small- and large-scale natech events. There were unintentional chemical releases with widespread health implications for affected populations (Picou, 2009).

This chapter summarizes chemical incident surveillance data associated with the 2005 hurricanes from three states participating in the Hazardous Substances Emergency Events Surveillance (HSEES) system at the time (Florida, Louisiana, and Texas). Additionally, case studies and lessons learned from hurricanes developed as part of a chemical emergencies workgroup are presented to give more detailed insight into the types and causes of the hurricane natech releases, and their environmental public health impact.

2. Methods

2.1 HSEES data analysis

HSEES was an active multi-state web-based surveillance system maintained by the United States Agency for Toxic Substances and Disease Registry (ATSDR) from 1990-2009. HSEES collected information on uncontrolled or unpermitted acute releases of hazardous substances meeting specific pre-established criteria. The surveillance system enabled identification of factors related to the public health impact of these acute events and activities to lessen the impact of and potential for future events. Events involving petroleum only were excluded because of the Petroleum Exclusion clause of the Comprehensive Environmental Response, Compensation, and Liability Act which prohibits ATSDR from becoming involved with incidents where any form of petroleum was released that had not been refined to the point of becoming a specific chemical product, such as pure xylene (CERCLA/SARA). HSEES collected data on all other hazardous substance incidents, including ones with petroleum where another hazardous substance is present (ATSDR, 2005a). HSEES was a surveillance system for a wide range of hazardous materials incidents and therefore is not specifically designed to collect data on hurricane chemical emergencies.

State health department personnel used a variety of sources (e.g., records and oral reports of state environmental agencies, police and fire departments, and hospitals) to collect information about the acute hazardous substances events. Information collected for each event included the location and industry involved in the event, hazardous substances released, number of victims, evacuations, and contributing causal factors for the event. The HSEES system collected data on the primary contributing factor and the secondary contributing factors related to an event. Information on contributing causal factors was either reported by the notification source or determined by the state HSEES coordinator using various reports. Data were entered into a Web-based application that enabled ATSDR to access the data.

A victim was defined as a person experiencing at least one documented adverse health effect (such as respiratory irritation or chemical burns) that was likely associated with the event and occurred within 24 hours after the release (ATSDR, 2005a). Hazardous substances

released were grouped into 13 categories: acids, ammonia, bases, chlorine, hetero-organics, hydrocarbons, mixture across categories, carbon monoxide, pesticides, polymers, volatile organic compounds, other inorganic substances, and other substances. Mixtures across categories consisted of hazardous substances that were mixed before release, including hazardous substances from more than one of the other 12 categories used. The category "other inorganic substances" comprised all inorganic substances—except for acids, bases, ammonia, and chlorine—and includes hazardous substances such as nitrogen oxide and hydrogen sulfide. The "other" category consisted of hazardous substances, such as asbestos, that could not be classified into any of the other 12 categories.

For this analysis, data from the three participating states affected by the hurricanes (Florida, Louisiana, and Texas) were analyzed to describe the characteristics of hazardous substances releases associated with the 2005 hurricanes. Events were identified as hurricane-related based on the date of the incident and state reports. Descriptive statistics are presented including contributing causal factors, hazardous substances and industries/locations involved in the releases, victim information, and event scenarios, with emphasis on those events with actual or potential public health impact.

2.2 Case study derivation

Case studies and lessons learned about chemical emergencies during hurricanes were derived from a review of the literature on three prominent hazardous materials incidents relating to the hurricanes. Only one of the three case studies was captured by HSEES; the other two did not qualify for HSEES because they were either petroleum–related or were a chronic release. The case study of the incident captured by HSEES is based on details from the literature as these were more extensive that the information captured by HSEES.

The three case studies were originally prepared for the Agency for Toxic Substances and Disease Registry Chemical Emergencies workgroup of the National Conversation on Public Health and Environmental Exposures and have been modified for this chapter. These case studies are reviews and interpretations of the current literature concerning these incidents and are presented to give a broader perspective on hurricane-related hazardous substance issues than HSEES data alone can provide.

3. Results

3.1 Data from HSEES

In 2005, 245 hurricane-related chemical events were reported to HSEES from the coastal states of Florida, Louisiana, and Texas. Figure 1 is a timeline of the four hurricanes with information on category, area where they made landfall, and number of HSEES events. Of the 245 events, 133 occurred in Texas, 68 occurred in Florida, and 44 occurred in Louisiana. These events represented 7% of all HSEES events combined in Florida, Louisiana, and Texas in 2005 (ATSDR, 2005a). Fifty-four percent of the events were related to Hurricane Rita, 24% were related to Wilma, 19% were related to Katrina, and 3% were related to Dennis.

The two most frequently reported industries/locations involved in hurricane-related events were manufacturing (159, 65%) and private households (48, 20%) (Table 1). Chemical manufacturing (n=115) and petroleum and coal manufacturing (n=42) accounted for 99% of the manufacturing events.

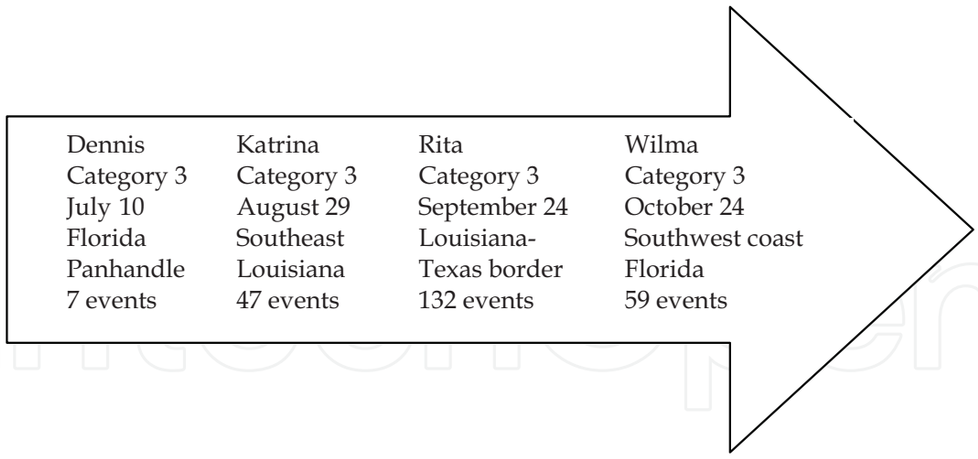


Fig. 1. Timeline of 2005 Atlantic Hurricane and HSEES incidents.

Industry/location	Number of events	Percent
All manufacturing	159	65
Private households	48	20
Mining	11	4
Unknown	11	4
Utilities	4	2
Wholesale or retail trade	6	2
Other	6	2
Total	245	99

Table 1. Industry/location of hurricane-related events, Hazardous Substances Emergency Events Surveillance (HSEES) System, 2005.

3.2 HSEES events involving evacuation, response, and nearby areas

Activities conducted to protect public health during hurricane-related events included health advisories (n=14) and environmental sampling (n=10). One building was evacuated because of a hurricane-related hazardous substances event; the evacuation lasted 2 hours. No response personnel were involved in 80 of the events; multiple types of responders responded to the remaining 165 events.

Personnel most frequently responding to hurricane-related events included company response teams (n=128) and hospitals or poison control centers (n=22). Other responders included fire departments (n=8), law enforcement officials (n=7), certified HazMat teams (n=5), third-party clean-up contractors (n=5), emergency medical services (n=4), environmental agencies (n=2), and departments of public works (n=1).

Most events (n=220) were contained inside the facility or within 200 feet of the release. The area impacted was missing for 19 events. In six events, the chemical extended beyond the facility and affected greater than 200 feet beyond the release. All of these events were in Louisiana, in predominately industrial areas with little or no residences, schools, daycare facilities, nursing homes, hospitals, or recreational parks within ¼ mile of the release. Descriptions of these 6 incidents are as follows:

Event 1- Approximately 980 pounds of ammonia were released with 490 pounds of nitrogen oxides after a power failure caused by Hurricane Katrina at a nitrogen fertilizer manufacturer. The power failure resulted in a loss of refrigeration to the ammonia storage tanks. This caused an emergency release of ammonia to a flare. The ammonia was only partially combusted by the flare and thus formed the nitrogen oxides.
Event 2- Seven hundred fifty nine pounds of zinc bromide were released from storage tanks that were washed away from an oil and gas support operation during Hurricane Katrina.
Event 3- Ten pounds of nitrogen oxide and 500 pounds of sulfur dioxide were released when a petroleum refinery shut down its plant in preparation for Hurricane Katrina and there was a release to the stack.
Event 4- A chemical product and preparation manufacturer released 270 pounds of ammonia and 75 pounds of nitrogen oxides when the ammonia storage tank routed to the flare after the compressors were shut down in preparation for Hurricane Katrina, thus causing a release of nitrogen oxides as a combustion product.
Event 5- Seven hundred eighty pounds of ammonia were released from a nitrogen fertilizer manufacturer when a power outage caused the loss of key monitoring equipment. The flare on the ammonia tank was blown out by the high winds sustained during Hurricane Rita.
Events 1-5 occurred in industrial areas with no nearby residences, nursing homes, schools, or daycare facilities.
Event 6- One thousand eighty two pounds of chlorine were released from an alkali and chlorine manufacturing plant when a power failure due to Hurricane Rita caused excess pressure in the chlorine tank. The tank had to be manually vented to reduce pressure and protect the tank integrity. Approximately 493 persons lived within ¼ mile, and a licensed daycare center was within ¼ mile of the release; no information was available about whether people were in the homes or daycare center when the release occurred.

3.3 HSEES causal factors

Bad weather conditions (n=165, 67%) were the most frequent primary causal factor contributing to hurricane-related events. Other primary causal factors were human error (n=61, 25%), equipment failure (n=11, 4%), and intentional release (n=8, 3%). Of the 225 (92%) events where a secondary causal factor was also reported, the most frequently reported were system start-up or shut down (n=120, 53%) and power failure (n=70, 31%). Other secondary causal factors included equipment failure (n=19, 8%), system/process upset (n=7, 3%), and fire (n=4, 2%). Of the 120 events where system start-up or shut down was a contributing causal factor, 6 (5%) were shutdowns in preparation for Hurricane Katrina, 59 (49%) were shutdowns in preparation for Hurricane Rita, and 55 (46%) were start-ups after Hurricane Rita.

3.4 HSEES incidents hazardous substances involved

A total of 283 hazardous substances were released in the 245 hurricane-related events. The number of hazardous substances released per event ranged from 1 to 8. Most events were air releases (88%), 9% were spills, 1% were fires, 1% were threatened releases, and <1% involved an air release with a fire.
The categories of hazardous substances most frequently released in these events were mixture across categories (34%), carbon monoxide (21%), volatile organic compounds (16%), and other inorganic substances (15%) (Table 2). The most frequently released individual

hazardous substances were carbon monoxide (n=59, 21%), oxides of nitrogen (includes nitrogen oxide and nitrogen dioxide) (n=16, 6%), a mixture of carbon monoxide/nitrogen dioxide/propylene (n=8, 3%), and ammonia (n=8, 3%).

Substance Category	Frequency	Percent
Mixture across categories	97	34
Carbon monoxide	59	21
Volatile organic compounds	45	16
Other inorganic substances	42	15
Other	10	4
Ammonia	8	3
Acids	7	2
Hydrocarbons	4	1
Pesticides	4	1
Bases	2	1
Chlorine	2	1
Polymers	2	1
Hetero-organics	1	<1
Total	283	

Table 2. Substance categories released in hurricane-related events, Hazardous Substances Emergency Events Surveillance (HSEES) System, 2005.

3.5 HSEES victims

There were 160 victims in 62 hurricane-related events (25% of all hurricane-related events). Florida reported 116 of the victims, Louisiana reported 7, and Texas reported 37. Ninety-nine additional people in 49 events were observed at a medical facility but did not require treatment, so are not counted as victims.

Although manufacturing events accounted for 65% of the hurricane-related events, less than 1% of the events in this industry category resulted in victims. Most of the victims were injured in carbon monoxide events in private households (n=103, 64%). All 59 of the carbon monoxide events were in Florida and all had victims. A bus accident and fire involving nursing home residents and their oxygen tanks in Texas resulted in 36 (23%) victims. The industry/location was unknown for 18 (11%) victims, and there was 1 victim each in retail, manufacturing and the postal service. Most (n=139, 87%) victims were members of the general public, followed by employees (n=11, 7%). However there were also 10 (6%) responder victims as follows:

1. Six career firefighters suffered carbon monoxide-related symptoms while helping with post-Katrina recovery efforts. Generator exhaust fumes from a nearby motor home entered the camper in which they were sleeping.
2. One responder was injured when a barrel containing a mixture of hydrocarbon, hydrogen sulfide, and water leaked during post-Katrina orphan drum recovery operations.
3. Three fire rescue responders were among six people injured by carbon monoxide exposure as a result of improper generator use in a power outage after hurricane Wilma. One non-responder in this event died.

The ratio of male to female victims was approximately 50/50. The victims ranged in age from less than 1 year old to 100 years old, but most victims were 20-44 years old (41%) (median age was 34 years). The most frequent injuries/symptoms were dizziness/central nervous system effects (38%), headache (22%), gastrointestinal problems (15%), and thermal burns (11%) (Table 3).

Injury/Illness	Number of victims	Percent
Dizziness/central nervous system symptoms	81	38
Headache	48	22
Gastrointestinal problems	32	15
Thermal burns	24	11
Respiratory irritation	12	6
Trauma	7	3
Eye irritation	4	2
Shortness of breath	4	2
Heart Problems	3	1
Total	215	100

Table 3. Injuries/illnesses sustained in hurricane-related events, Hazardous Substances Emergency Events Surveillance (HSEES) System, 2005.

Twenty-nine persons died on scene or after arrival at a hospital. Treatment information was available for 115 of the remaining 131 victims. These victims were treated at a hospital and released (n=62), admitted to a hospital (n=19), received first aid only (n=4), or were observed at the hospital (n=1). Only one victim was decontaminated.

Two victims wore personal protective equipment. One wore Level C personal protective equipment which requires a full-face or half-mask, air-purifying respirator and chemical resistant hooded clothing, inner and outer gloves, and steel toe boots. The other wore Level D personal protective equipment which is the lowest level of protection and requires coveralls and safety shoes/boots. Personal protective equipment levels are determined by the U.S. Occupational Safety and Health Administration's Standard (29 Code of Federal Regulations 1910.120 (q)).

3.6 HSEES events with fatalities

Twenty-three nursing home residents died from thermal burns in a charter bus fire and medical oxygen tank explosion in Texas during an evacuation in anticipation of Hurricane Rita.

There were six deaths among members of the general public in five events in Florida from carbon monoxide exposure. One event occured in July after Hurricane Dennis, one in August after Hurricane Katrina, and three in October after Hurricane Wilma. Five events were due to generator misuse and one event was due to charcoal grill misuse because of hurricane-related power loss.

4. Case studies

4.1 Case study background

HSEES collected a broad array of incidents and was not specifically tailored to collect data on chemical emergencies during hurricanes or other natural disasters. Therefore, the case

study section reviews the literature on three incidents of chemical emergencies during hurricanes for issues that were broader than the typical HSEES data to elucidate lessons learned. These case studies were chosen to bring up issues that HSEES does not focus data collection on, including vulnerable populations, petroleum emergency clean-up, and chemical waste disposal issues. These were three very prominent cases that arose from the 2005 hurricane season.

4.2 Case study 1

On September 23, 2005, at 3 p.m. a nursing home began evacuating prior to Hurricane Rita. A charter bus was secured when the regular bus was unavailable. The nursing home did not have time to carefully select a bus and had to take the first available bus. The bus was carrying 44 nursing home residents and nursing staff from Bellaire, Texas to Dallas, Texas. Although the bus had originally been going to a much closer shelter, the shelter was full and they had to go to a much farther one. Early the next morning, a motorist alerted the bus driver that the right-rear tire hub was glowing red. Upon stopping the bus, the driver and nursing staff observed flames emanating from the right-rear wheel well and they began to evacuate the bus.

The bus was quickly engulfed in flames when the residents' oxygen tanks exploded and further fueled the fire. Twenty-three passengers died, 2 passengers were seriously injured and 19 received minor injuries. The bus driver also received minor injuries (National Transportation Safety Board, 2007). This incident was also contained in the HSEES database.

Contributing factors for this event were the charter bus company's failure to conduct proper vehicle maintenance, failure to do pre-trip inspections, and previous violations of several United States safety regulations pertaining to its drivers and vehicles; the lack of fire retardant construction materials on the bus exterior and adjacent to the wheel well; and no guidance for emergency transportation of medical oxygen cylinders on a bus. Release valves on the cylinders were designed to release during a fire only if they were fully pressurized. Therefore, cylinders that were in use and partially pressurized exploded and became dangerous projectiles during the fire. Additionally, emergency responders had difficulty rescuing passengers because of window height and top-hinge design window exits that are not optimally designed for elderly or children; the latches are difficult to open and the drop to the ground was too far (National Transportation Safety Board, 2007).

4.3 Case study 2

Storm surge from Hurricane Katrina placed an oil tank facility and surrounding neighborhoods in St. Bernard Parish, Louisiana under water for several days. When the water receded, it was discovered that the hurricane had dislodged a 250,000 barrel above-ground storage tank containing about 65,000 barrels of mixed crude oil (Agency for Toxic Substances and Disease Registry, 2005b). Approximately 25,110 barrels (slightly over a million gallons) of oil spilled from the ruptured tank.

The initial response was delayed because of high water, debris, barricades by the National Guard or local police, downed telephone lines, and lack of satellite phones. When the area was accessible, the United States Environmental Protection Agency on-scene commander directed the facility to secure the tank, identify the extent of the release, and begin recovery operations. The facility immediately began pumping out the containment canals and recovered approximately 72% of the oil.

In October 2005, long-term remediation was initiated with oversight by the United States Environmental Protection Agency and the Louisiana Department of Environmental Quality, including clean up on land, residential areas, and non-commercial waterways. Approximately 1,800 affected properties in an area of about one square mile were identified through a house-to-house visual survey conducted from the street. The Environmental Protection Agency classified contamination on 114 properties as heavy (more than 50% of the yard, sidewalks, and home were covered with oil), 286 properties as medium (about 50% of the yard and sidewalks were covered in oil), and the balance as light to oil line only (small percent of oil was visible on horizontal surfaces or a "bathtub ring" of visible product band approximately 3 to 6 inches wide was seen on the residence, with no visible oil on the yard, sidewalks, and home (Agency for Toxic Substances and Disease Registry, 2005c). However, some affected properties may have been missed because properties that were not visible from the street or public sidewalk were not surveyed due to legal access requirements. The more heavily affected areas were immediately to the west of the facility.

The 25 month long clean-up of the contaminated properties within the impacted area began with the facility removing oil-stained sediment and soil. After removal, the remaining soil was analyzed to ensure that the Louisiana Department of Environmental Quality risk evaluation/corrective action program residential soil standards for High Public Use Areas were met. If the standards were not met, additional soil was removed and the process was repeated.

Residential clean-up was complex and involved two phases. In Phase 1, property owners requested clean-up from the facility and granted them access to the property, and the facility obtained wipe and sediment samples (10% of the samples were split with the Environmental Protection Agency) and washed home exteriors. In Phase 2, the homeowner was responsible for gutting the house to the studs, and the facility removed the oiled part of the debris and transported it to an industrial landfill. The homeowner then requested an interior cleaning from the facility and granted them a second access to the property which involved the facility power washing the home's interior and exterior and replacing the yard. Reoccupation of the property was determined by the parish based on results of a final air sample (U.S. Environmental Protection Agency Region 6, 2006).

Several factors impeded residential clean-up, including class actions lawsuits filed against the facility that restricted homeowner contact with the facility and therefore barred remediation by the facility; temporary or permanent relocation of many residents after the spill; and lack of funds to complete the clean-up because the facility was only responsible for the oil-damaged part of the cleanup. This resulted in a less efficient clean-up and an "island effect" where oiled homes were next to cleaned homes because crews could not clean up whole contiguous blocks of neighborhoods (U.S. Environmental Protection Agency Region 6, 2006).

The Environmental Protection Agency shared the results of more than 800 sediment/soil samples collected from properties between September 19 and November 8, 2005 with the Agency for Toxic Substances and Disease Registry and requested an assessment of potential health hazards posed by the contamination. In December 2005, the Agency for Toxic Substances and Disease Registry released a health consult for the site which concluded that for the properties sampled, there were no short or long term risks from oil-related chemicals in sediment and soil for most properties. Recommendations were made that properties should be evaluated and remediated if necessary for other potential health hazards, such as indoor mold and structural damage, prior to re-occupancy. The recommendation was also made that properties which exceeded recommended soil standards should be remediated to

be protective of public health for re-occupancy. Additionally, the health consult recommended that residents avoid bare skin contact with sediment, soil, and indoor surfaces with visible oil contamination and that homes with visible indoor oil contamination or noticeable petroleum odors be tested to determine if concentrations of chemicals in indoor air were of health concern prior to re-occupancy (Agency for Toxic Substances and Disease Registry, 2005b).

Oil companies were not required to plan to withstand storm surges that resulted from Hurricane Katrina. However, in 2007, a buyout program to create a buffer around the facility was approved to minimize the threat of future spills. In August 2009, the Louisiana Department of Environmental Quality determined that the area's shallow groundwater was unaffected by the spill and concluded that the area impacted by the spill had been remediated to acceptable levels.

Recovery and response related to this spill were complicated by competing priorities (local, state, and federal) and high background levels of contamination in that area of Louisiana which interfered with the sampling. Communication issues were also a major barrier and included delays in the public receiving information about contaminant levels which was often on a website that was not accessible to the affected population; difficulties in interpreting data and comparing it with general drinking water or ambient air quality standards which were not appropriate for an acute exposure event; and adequately conveying re-occupancy policies because federal agencies had a different opinion than the parish who ultimately made the decision (Manuel, 2006; Johnson, et al. 2005).

4.4 Case study 3

As a result of Hurricane Katrina, the city of New Orleans needed to quickly find a disposal site for the approximately 55 million cubic yards of hurricane-related debris and waste contaminated with hazardous substances that were created. In response, the Mayor of New Orleans issued an executive decree which reopened three closed landfills and granted a conditional permit to urgently convert the Chef Menteur site from a light industrial zone to a landfill. The Chef Menteur landfill began accepting waste in April 2006 (Choi et al., 2006).

The approximately 100 acre Chef Menteur site was created about 40 years ago by construction companies for use as a local source of sand for building. In July 1994, an application for a permit to begin construction of a landfill at this site was submitted to the Louisiana Department of Environmental Quality. Because of extensive resistance and pressure from the local community and the proximity of the site to the nation's largest urban wildlife refuge, the city council denied the permit in March 1997 (Choi et al., 2006).

The Chef Menteur Landfill is located in the Versailles neighborhood and is next to the 23,000 acre Bayou Sauvage Wildlife Refuge. It is less than a mile from the center of a mostly Vietnamese- and African-American community of approximately 15,000 residents (Choi et al., 2006). The unlined landfill has a large storage capacity and was approved to accept 6.5 million cubic yards (about 2.6 million tons) of construction and demolition debris (Louisiana Department of Environmental Quality, 2006). Besides trees and sheetrock, the site also accepted asbestos-containing materials and the moldy contents of gutted homes, including household pesticides, electronics, personal-care products, cleaning solutions, paint, and bleach.

Although the landfill lacked the liners required to stop leachate from leaking into the water table and contaminating surface water and groundwater, the state department of

environmental quality stated that the landfill had a 10 foot clay bed, which they maintained was enough to stop leachate from reaching the community and wildlife refuge. Opponents of the landfill argued that this was not the industry standard, nor the environmental standard, which calls for multiple layers of both composite and clay (Colby, 2008). Other environmental and public health concerns included that landfill leachate would affect the watering source for the community gardens and locally caught seafood, as well as exposure to air pollution from the over 1,000 trash carrying trucks per day that drove along the main road leading into the community (Colby, 2008; Citizens for a Strong New Orleans East, 2006).

The landfill was supposed to be capped with two feet of clay and six inches of topsoil. This type of cap may not be effective in preventing precipitation from entering the landfill, mixing with wastes, and forming leachate, especially in southern Louisiana, which receives approximately 60-80 inches of rain per year (Choi et al., 2006) Additionally, the landfill is surrounded by permeable soil, and much of the site is a wetlands area where the water table is at or near the surface of the ground. Soil borings showed that groundwater is located between 1.6 and approximately 12 feet below the surface (Choi et al., 2006).

Several air and water samples taken by the state department of environmental quality in May and June 2006 shortly after the landfill opened showed that contaminants were below levels of concern (Choi et al., 2006). However, the community is concerned about potential long-term effects. Amid mounting pressure and lawsuits by the community and environmental groups, the Mayor of New Orleans did not renew the landfill's permit, and the landfill was closed in August 2006.

5. Discussion

5.1 HSEES incident distribution

HSEES recorded 245 hurricane-related events in 2005. All of the Hurricane Dennis and Hurricane Wilma events were reported by Florida because this was the only U.S. state affected by these hurricanes. Texas did not have any Hurricane Katrina-related events because of the path of the hurricane. Texas reported most of the Hurricane Rita-related events because Beaumont and Port Arthur, as well as several other areas in the state, shut down their plants in preparation for Hurricane Rita. Louisiana reported fewer events from Hurricane Rita because of the path of the hurricane and many of their plants were still not operating when Hurricane Rita struck. Florida did not report any events associated with Hurricane Rita, likely because of the mandatory evacuation orders for the Florida keys and because the Florida Panhandle escaped most of the land effects from the hurricane (National Oceanic and Atmospheric Administration, 2005b).

5.2 HSEES limitations

The HSEES system had several limitations. As in any disaster, local and state public health and emergency response infrastructure was severely disrupted by the hurricanes. Because of this some events may not have been reported and some data may not have been captured during follow-up. In Louisiana, agencies were only notified about the most severe releases that resulted from Hurricane Katrina, so some events may not have been included in HSEES. Furthermore, HSEES collected information on acute, not chronic, releases, and

releases of only petroleum were excluded. Lastly, since HSEES is a surveillance system for a variety of hazardous material releases, it is not specifically tailored for hurricanes and therefore does not capture detailed information on these incidents.

Carbon monoxide exposure was traditionally underreported in the HSEES system because of the lack of existing reporting mechanisms. A case review of medical charts and emergency medical services records coded as carbon monoxide poisoning found 41 non-fatal cases from 11 incidents and 10 deaths from 4 incidents in Texas that were not reported to HSEES while analysis of hyperbaric oxygen facilities reports detected 16 non-fatal and 5 fatal cases among Louisiana residents that were not reported to HSEES (Centers for Disease Control and Prevention, 2006b; Centers for Disease Control and Prevention, 2005d). Additionally, after data closeout, Florida identified 31 cases of carbon monoxide exposure through hospitals and medical examiners reports.

5.3 Manufacturing industry

Most events involved the manufacturing industry (65%), however, only one injured person was associated with this industry. This is likely because there were few people in the area to be harmed, most facilities had already shut down and were operating with reduced crews and many residents evacuated the areas before the hurricanes hit (Knabb et al, 2005a; Knabb et al, 2005b). The immediate contributing causal factor in over half of the events was system start-up or shut down. Most releases were air releases (88%), and about a third of the events involved the release of mixtures of chemicals.

About a quarter of the events were caused when complex industrial processes were shut down in preparation for the hurricanes. The shutdowns that occurred while preparing for Hurricanes Katrina and Rita were more massive and involved numerous simultaneous activities and rapidly changing process conditions compared with one process or unit during normal shutdowns. Additionally, these large massive shutdowns had not been done before.

There is a need for different shutdown procedures that involve massive shutdowns of entire plants, such as those that occur during hurricanes. One lesson learned from Hurricanes Katrina and Rita is that it is critical for chemical facilities to better coordinate with state and local emergency preparedness agencies, especially for decisions concerning mandatory evacuation orders which can directly impact plant shutdown sequence and timing (Challener, 2006). The U.S. Environmental Protection Agency advises that all industry sectors review past events associated with shutdowns during hazardous weather conditions and make administrative/procedural, operational/process equipment and hardware/software safety improvements as needed (U. S. Environmental Protection Agency, 2010). Chemical facilities should also establish staff responsibilities and procedures to shut down process operations safely (U. S. Department of Energy, 2008).

Almost a quarter of the events were caused when major industrial processes started up after the hurricanes. The start-ups that occurred following the massive shutdowns in preparation for the hurricanes were also large-scale. Many plants used this opportunity to conduct massive maintenance or repairs on the idled plants, as equipment in some facilities in Texas dates back to the 1940s. The maintenance resulted in releases. Additionally, releases are more likely to occur when processes are shut down for more than one day (U.S. Chemical Safety and Hazard Investigation Board, 2005.)

The U.S. Chemical Safety and Hazard Investigation Board issued a safety bulletin for precautions needed during oil and chemical facility start-up following hurricanes. The Chemical Safety and Hazard Investigation Board recommends that as facilities resume operations, established and up-to-date start-up procedures and checklists should be followed and pre-start-up safety reviews should be carefully performed. Specific recommendations include using appropriate management-of-change processes before making any modifications; having adequate staffing and expertise available before starting up; and evacuating nonessential personnel from nearby process units that are starting up.

The Chemical Safety and Hazard Investigation Board also recommends that equipment, tanks, and instrumentation be thoroughly evaluated for damage. Particular attention should be given to examining large bulk storage tanks and pressure vessels for evidence of floating displacement or damage, and examining sewers, drains, furnace systems, electric motors and drives, switchgear, conduits, electrical boxes, electronic and pneumatic instrumentation, emergency warning systems, emergency equipment, and insulation systems for piping, vessels, and tanks for trapped floodwater and debris-impact damage (U.S. Chemical Safety and Hazard Investigation Board, 2005.)

Industrial releases resulting from power failures may benefit from improved backup power generation (Ruckart et al., 2004). Generators and backup lights should be tested in preparation for a hurricane, extra fuel should be on-hand, and generators should be located in areas of the facility that are not likely to be flooded (U. S. Environmental Protection Agency, 2006). Other efforts include filling all storage tanks to prevent floating or falling during hurricane-force winds, adequately securing equipment and piping to withstand high winds, and properly labeling all chemical bulk storage tanks to aid identification if these items are washed or wind-blown away (U. S. Environmental Protection Agency, 2006).

5.4 Carbon monoxide incidents

Carbon monoxide was the most frequently released single hazardous substance. Carbon monoxide poisoning, particularly from misuse of generators in residences, was the largest source of the morbidity and mortality; over two-thirds of the 160 victims were injured in carbon monoxide–related events. In another study of 27 incidents of carbon monoxide poisoning that resulted in 10 fatal and 78 nonfatal cases in Alabama and Texas after Hurricane Katrina and Rita, the majority of incidents were caused by portable generators. Most of the generators were placed outside but close to the home in order to power window air conditioners or to connect to central electric panels.

Interviews of 18 of the 27 incident households showed that only 6 (33%) had a carbon monoxide detector present, but only one alarm went off. The other 4 had dead batteries and one sent a signal to a remote security system that was unable to alert the household by telephone. The Centers for Disease Control and Prevention recommends that because there has shown to be no safe distance for generator placement, there should be functional carbon monoxide detectors in all households (Centers for Disease Control and Prevention, 2006b). Our data show that responders were injured by carbon monoxide while sleeping in temporary housing (camper). Therefore this recommendation should be expanded to temporary housing as well.

In January 2007, the Consumer Product Safety Commission required manufacturers to place a danger label on all new generators and the generator packaging. The commission began to explore various strategies to reduce consumers' exposure to carbon monoxide including generator engines with substantially reduced carbon monoxide emissions, and interlocking or automatic shutoff devices (Consumer Product Safety Commission, 2009). These measures could potentially reduce harm in the future.

5.5 Case studies

Lessons learned in case study 1 are the importance in the haste of preparing for an oncoming hurricane or responding after one occurs of adhering to important health and safety measures. Almost 25% of the 2005 hurricane victims reported to HSEES were injured in a single bus accident when oxygen tanks exploded on a bus carrying senior citizens who were being evacuated prior to Hurricane Rita. They were placed on a bus that had numerous safety violations in the haste of trying to secure a bus when their dedicated bus was not available. Hospital and nursing home administrators face several challenges during hurricanes, including deciding whether to evacuate or shelter inside their facilities until the outside danger is over.

According to a the National Transportation Safety Bord, the charter bus fire incident showed how ill prepared the United States was to evacuate those who are most vulnerable, particularly the elderly, disabled, and those in hospitals and nursing homes. The loss of life was exacerbated by the frailty of the passengers. This incident highlights the need for special plans to be developed for nursing home residents (as well as other institutionalized residents, such as hospitalized persons or prisoners) because they are not able to quickly escape from hazardous substance events and have special considerations.

Motor coaches were used for this evacuation and will be used again should a similar emergency arise. Following this incident, the National Transportation Safety Board issued several recommendations to other agencies to protect the travelling public that should be urgently implemented (National Transportation Safety Board, 2007). The U.S. National Transportation Safety Board also investigated the risk that medical oxygen tanks posed to rescuers during the fire. Three days after the accident, the Department of Transportation issued "Guidance for the Safe Transportation of Medical Oxygen for Personal Use on Buses and Trains" which recommends that medical oxygen be securely stored upright and be limited to one canister per patient in the passenger compartment (U.S. Department of Transportation, 2006).

There are several lessons learned from case study 2, when an oil spill contaminated a large residential area. One lesson is the need for improved and more rapid identification of environmental hazards and their communication to emergency responders and the public. Another lesson learned is the need during a hurricane and aftermath for greater collaboration among Federal, State, and local officials, as well as an enhanced public communication program. All of these measures could have improved the effectiveness of the Federal response (Manuel, 2006; The White House, 2006)

Case Study 3 highlights that in the haste of rebuilding, proper health and safety measures for handling the hurricane hazardous substance contaminated debris were not followed. The "hub and spoke" method of debris handling is supported by the U.S. Environmental Protection Agency and the Army Corps of Engineers. It involves collecting debris on the

curbside and taking it to temporary staging sites in more central locations in the day time, followed by night-time hauling to permitted landfills outside the city (Citizens for a Strong New Orleans East, 2006). This would have avoided the use of the unpermitted landfill that was not designed properly to handle hazardous waste.

6. Conclusion

Because preventing hurricanes is not possible, increased attention must be focused on preventing and minimizing acute releases of hazardous substances during hurricanes and preplanning in case releases do occur. Because of the urgency of a hurricane, preplanning for those most vulnerable and increased diligence to health and safety during and after a hurricane are called for.

Many of the incidents occurred due to power interruption. Industries, particularly in hurricane prone areas, can take steps to minimize their risks for chemical releases in future power outages. Additionally, public health campaigns that emphasize placement of generators as far away from the home as possible should continue. Since no safe distance has been determined, the use of battery operated, functional carbon monoxide detectors should be stressed for all sleeping quarters, temporary or permanent.

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Recent Hurricane Research - Climate, Dynamics, and Societal Impacts

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This book represents recent research on tropical cyclones and their impact, and a wide range of topics are covered. An updated global climatology is presented, including the global occurrence of tropical cyclones and the terrestrial factors that may contribute to the variability and long-term trends in their occurrence. Research also examines long term trends in tropical cyclone occurrences and intensity as related to solar activity, while other research discusses the impact climate change may have on these storms. The dynamics and structure of tropical cyclones are studied, with traditional diagnostics employed to examine these as well as more modern approaches in examining their thermodynamics. The book aptly demonstrates how new research into short-range forecasting of tropical cyclone tracks and intensities using satellite information has led to significant improvements. In looking at societal and ecological risks, and damage assessment, authors investigate the use of technology for anticipating, and later evaluating, the amount of damage that is done to human society, watersheds, and forests by land-falling storms. The economic and ecological vulnerability of coastal regions are also studied and are supported by case studies which examine the potential hazards related to the evacuation of populated areas, including medical facilities. These studies provide decision makers with a potential basis for developing improved evacuation techniques.

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