**Role of Natural Disasters in Process Safety Incidents**

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**Introduction**

 Natural disasters are unforgiving forces of nature which occur both seasonally and without warning. These severe weather events can destroy critical infrastructure, cause lasting economic disruption to communities and business sectors, or lead to serious personnel injury or death. Natural disasters can also play a role in process safety incidents both directly and indirectly as the harsh weather conditions interact with and amplify the existing hazards present at the facility. Research was conducted to compile a database of these natural disaster-based process safety events shown in *Table 1* below. The incident information was found through a multitude of process safety journals, natural disaster reports, and other research papers provided in the *References* sections of this report. *Table 1* consists of forty-four natural disaster-based process safety incidents with the incident title, location & date, contributing natural disaster, and resulting consequences provided.

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#### Table 1: Database of Process Safety Incidents from Natural Disasters

|  |  |  |  |
| --- | --- | --- | --- |
| **Incident** | **Location & Date** | **Associated Natural Disaster** | **Consequence** |
| Lightning Strike Fuel Depot19  | Egypt: 1994 | Lightning | Fuel flowed into village and killed 400 people |
| Pembroke Refinery Lightning19 | United Kingdom: 1994 | Lightning | Downtime of 4.5 months; Loss of 10% of the total refining capacity in the United Kingdom |
| Oil & Gas Pipeline Release29 | San Jacinto River USA: 1994 | Flood | Eight pipelines ruptured; 36,000 barrels of crude oil and 200 million m^3 of natural gas released; 545 injuries |
| Waste Site29 | Honduras: 1998 | Hurricane | Agricultural chemicals released into environment |
| Turkey Oil Refinery Tank Farm12 | Turkey: 1999 | Earthquake/Tsunami | Fire in naphtha tanks; Fire spread causing explosions at adjacent chemical tanks |
| Gold Mine Settling Pond29 | Romania: 2000 | Flood | Pond dam breached; Cyanide and toxic metals released into river system; Ecosystem destruction |
| Naphtha Tank Lightning Strike19 | Germany: 2001 | Lightning | Fire started in storage area |
| Chemical Factory Release5 | Central Europe: 2002 | Flood | Severe chemical release into River Elbe and riverbank |
| France Chemical Plant7 | France: 2002 | Freeze | 1200 tonnes of cyclohexane released |
| Taylor Energy Oil Platform8,9 | Louisiana: 2004 | Hurricane | Wells leaked oil & gas into Gulf of Mexico for 15 years+ |
| Deepwater Nautilus Oil Platform1 | Gulf of Mexico: 2005 | Hurricane\* | Rig pushed 80 miles offshore; Tore 4 others loose and capsized a fifth |
| Ocean Warwick Platform1 | Gulf of Mexico: 2005 | Hurricane | Rig completely destroyed |
| Bass Enterprises South26 | Louisiana: 2005 | Hurricane | Oil spilled into Mississippi River; Leak from rig drifted & contaminated St. Plaquemines Parish  |
| Shell Pilot Town20 | Louisiana: 2005 | Hurricane | Approximately 10,000 barrels estimated to have been leaked in Pilottown |
| Murphy Oil6,27 | Louisiana: 2005 | Hurricane | Release of approximately 25,110 barrels of oil impacting 1700 homes in an adjacent residential neighborhood; Several canals were also impacted |
| Chevron Empire Facility10 | Louisiana: 2005 | Hurricane | Approximately 24,000 barrels of crude oil were lost - most reported to be contained on-site |
| Chevron Port Fourchon Terminal14 | Louisiana: 2005 | Hurricane | Quantifiable oil spill |
| Sundown East23 | Louisiana: 2005 | Hurricane | 1,885 barrels of oil spilled from tanks |
| Dynegy Venice20 | Louisiana: 2005 | Hurricane  | Six-month downtime from tank damage |
| Chalmette Refinery20 | Louisiana: 2005 | Hurricane | Breach in the tank's side wall released up to 25,110 barrels |
| Chevron Pascagoula Refinery20 | Mississippi: 2005 | Hurricane | Flood waters caused rail cars to float off tracks and damage refinery docks; Jet fuel leak |
| Crompton Chemical Production20 | Louisiana: 2005 | Hurricane | 12,800 lb n-hexane flaring during shutdown |

\*All hurricanes occurring in 2005 are related to Hurricane Katrina except when indicated by (\*\*)

\*\*Related to Hurricane Rita

#### Table 1: Database of Process Safety Incidents from Natural Disasters (Continued)

|  |  |  |  |
| --- | --- | --- | --- |
| **Incident** | **Location & Date** | **Associated Natural Disaster** | **Consequence** |
| Aqua Pool Co20 | Mississippi: 2005 | Hurricane | 3,000 lb calcium hypochlorite, dichlor and trichlor, hydrochloric acid released from a warehouse  |
| Entergy New Orleans Inc.20 | Louisiana: 2005 | Hurricane | 1,010 ft^3 asbestos released from piping and duct work |
| Lone Star Industries Inc.20 | Louisiana: 2005 | Hurricane | 1,220-gal lubricating oil & grease, gasoline and diesel fuel released from 5 small, overturned storage tanks  |
| Tomah Reserve Inc.20  | Louisiana: 2005 | Hurricane | 316 lb ethylene oxide released  |
| Weyerhaeuser Co.20  | Mississippi: 2005 | Hurricane | 100,120 lb H2S and methyl mercaptan released from loss of power |
| Mississippi Phosphate20  | Mississippi: 2005 | Hurricane | Anhydrous ammonia, sulfuric acid released from storage tanks |
| Chevron Typhoon Rig1 | Louisiana: 2005 | Hurricane\*\* | Rig capsized; Production of 40,000 barrels of oil per day stopped  |
| Royal Dutch Shell Mars Rig21 | Gulf of Mexico: 2005 | Hurricane | Complete destruction of rig |
| BP Thunder Horse Platform1 | Gulf of Mexico: 2005 | Hurricane | Rig hull partially submerged and filled with water |
| Praxair Gas Repacking Site2 | Missouri: 2005 | Heat | Fire in storage area; Cylinder explosions impacting surrounding homes |
| Valero McKee Refinery18 | Texas: 2007 | Freeze | 4 workers injured; Total shutdown/evacuation of plant from propane fire |
| Leaf River Agronomy Facility25 | Minnesota: 2010 | Tornado | 6,800 gallons of anhydrous ammonia and water released |
| Fukushima Nuclear16,30  | Japan: 2011 | Earthquake/Tsunami | 100,000 people evacuated; Damage to backup generators and loss of power caused cooling system failure; Reactor cores overheated & melted – radiation released |
| Japan Oil Refinery29 | Japan: 2011 | Earthquake/Tsunami | Structural damage of refinery; Fire in storage tanks; Explosion of toxic gas cloud; Community evacuation |
| Con Edison Electrical Substation8 | New York: 2012 | Hurricane | Substation explosion |
| Motiva Refinery8 | New Jersey: 2012 | Hurricane | Diesel spill into Woodbridge creek from storage tank damage |
| Kinder Morgan Terminal8 | New Jersey: 2012 | Hurricane | Biodiesel spill in petroleum terminals – shipping/receiving at facility delayed |
| Phillips 66 Refinery8 | New Jersey: 2012 | Hurricane | Salt water flooded into facility, small fuel oil leak – curtailed production for weeks |
| Fort McMurray Wildfires: Suncor Energy Inc., Syncrude28 | Canada: 2016 | Wildfire | 8,000+ workers evacuated; Prolonged shutdown - cut production 1 million/day |
| Arkema3 | Crosby, TX: 2017 | Hurricane | Severe flooding and loss of cooling for ethylene oxide storage vessels; 21 people exposed to fumes initially; 350,000 lbs peroxide combusted; 200 residents evacuated |
| Rio Tinto Kennecott's Refinery25 | Utah: 2020 | Earthquake | 8,200 gallons of hydrochloric acid leaked from 12,000-gallon container; Refinery closed for 30 hours after incident |
| CP Chem Sweeny | Texas: 2021 | Freeze | Furnace blowout resulting in curtailed production |

**Analysis**

The distribution of natural disaster-based process safety incidents from Table 1 is shown in *Figure 1*. Hurricanes contribute to a majority of the database at 62% of the forty-five incidents identified. Hurricane Mitch, Hurricane Matthew, Hurricane Katrina, Hurricane Rita, and Hurricane Sandy are included in this disaster category with all but one of the 2005 hurricanes relating to Katrina. The hurricanes were all category 5 except for Hurricane Sandy sitting at a category 3. Category 5 hurricanes experience winds at or above 157 miles per hour (mph) while category 3 hurricanes experience winds ranging from 111 to 129 mph. The other natural disasters included in the study include earthquake/tsunamis, freezes, flooding, wildfires, lightning, heat waves, and tornadoes, with the first two making up the next largest fraction – each 9%.

#### Figure 1: Process Safety Event Associated with Natural Disaster Pie Chart

After further analysis of the incidents in Table 1, three main root causes were found to be associated with the natural disaster-based process safety events. Some incidents in the database held a combination of these root causes which is accounted for in the pie and pareto charts below. The root causes of these process safety incidents ranged from:

- lack of proper catastrophic planning for the facility (e.g., Suncor Energy & Syncrude had emergency plans in place to clear vegetation and have gravel & an industrial firefighting service on site; however, there was no plan for catastrophic advancement of the fire),

- insufficient safety systems in place (e.g., Pembroke Refinery did not have the proper safety systems in place to control lightning strikes), as well as

- constructing equipment with design flaws and insufficiencies to handle the magnitude of a natural disaster (e.g., Chevron Typhoon’s rig had design flaws in the floating platform – specifically in the tensioned tendons which secured to the moorings on the ocean bottom. The moorings were not designed to withstand forces from Hurricane Rita).

The distribution of root causes in the database are shown in *Figure 2* below. Many of the process safety incidents - (62%) - were found to have a root cause relating to the lack of proper emergency or catastrophic planning for the facility. In many of the incident analyses studied, this specific root cause was often referred to as a lack of planning for the “100-year storm”. Since the number of hurricanes included in the database may introduce bias to this analysis, a pareto chart for each root cause is also displayed below as *Figure 3*, *Figure 4*, and *Figure 5*. For the figure relating to lack of proper catastrophic planning, hurricanes still lead by a large majority – (80%) – while earthquakes/tsunamis and floods follow at ~10-13%. The subsequent figure – insufficient safety systems in place - shows that lack of properly safety systems mainly effects hurricanes, freezes, and lightning strikes; however, earthquakes/tsunamis and floods did not have any root causes in this area. The final pareto showcases the construction/equipment design flaws which are highest in hurricanes and even across earthquakes/tsunamis, freezes, and heat waves.

14% (7)

25% (13)

61% (31)

#### Figure 2: Root Causes/Safety Elements Lacking Pie Chart



#### Figure 3: Root Causes/Safety Elements Lacking – Lack of Proper Catastrophic Planning



#### Figure 4: Root Causes/Safety Elements Lacking – Insufficient Safety Systems in Place



#### Figure 5: Root Causes/Safety Elements Lacking – Construction/Equipment Design Flaws

 After analysis of each root cause and the associated natural disaster, it is evident that a lack of catastrophic and emergency planning is the leading cause. This conclusion directly correlates to the definition of natural disasters as they typically occur suddenly and with fatal force – making it difficult to plan for and defend against. However, this evaluation should act as an admonition to industry to not only plan for but expect the “100-year storm” to happen and perform the proper hazard analyses, safety preparations, and mitigative efforts. These findings also suggest that companies should consider the implications of more than a “100-year storm” in order to respect the true magnitude and potential destruction of these natural disasters. A company should plan to invest as much money as necessary to allow for continued production and complete personnel safety during an event that is beyond a 100-year storm.

 An additional factor analyzed in this research includes the consequence of each natural disaster-based process safety incident. The list of consequences includes environmental or community damage, complete destruction of the facilities, minimal damage or small release within the facility, curtailed production, and lives lost. Many of the incidents had multiple consequences which were documented in more than one category below in *Figure 6*.

#### Figure 6: Consequences of Natural Disaster-based Process Safety Incident

The comparison shows that natural disaster-based process safety events do not yield as many lives lost as many other process safety incidents – presumably due to the predictive nature of natural disaster and time for prior personnel evacuation. Natural disasters incidents can lead to more extensive structural damage and harmful releases to the environment or surrounding community. The extensive structural damage also leads to longer downtimes and curtailed production at the facilities.

 The equipment related consequences of the natural disaster-based process safety incidents were also analyzed with fallen or damaged structures as the leading factor at 54% as seen in *Figure 7* below. This conclusion showcases the need to focus on equipment and structure reinforcement and protection against the aggressive weather conditions associated with natural disasters. Water damage from flooded facilities was an additional consequence along with tanks/tank farms catching fire from tank releases finding ignition sources. Electrical shortages and power outages yielding equipment failure were also found to be equipment related consequences.

#### Figure 7: Consequences of Natural Disaster-based Process Safety Incident

**Conclusions**

 Forty-four natural disaster-based process safety incidents were compiled into a database to discover similarities and bring awareness to the results found. Natural disasters are severe weather occurrences which bring about news reports worldwide; however, the associated process safety incidents tend to go unnoticed as they are overshadowed by the “big event”. These process safety incidents are just as important to analyze as key findings may avoid or reduce the severity of future consequences. The main conclusions drawn from this research include that the majority of natural disaster process safety incidents stem from hurricanes, with earthquakes/tsunamis and freezes following behind. These incidents have root causes mainly attributed to the lack of proper catastrophic or emergency planning. This may be attributed to a lack of understanding and judgement for the severity of natural disasters or the lack of concern for the possibility of them. The main consequences of these incidents are environmental and community damage due to prior site evacuations. Similarly, the highest percentage of equipment related consequence is fallen or damaged structures from wind, lightning, water, etc. resulting in environmental releases and community damage. These conclusions help provide new insight to the causes, severity levels, and specific consequences of natural disaster-based process safety incidents.

**Path Forward**

The path forward for this research project may include expanding upon the database of natural disaster-based process safety events and developing further analysis on the root causes and consequences of these events. Although there are current regulations and design practices in place for natural disaster process safety – e.g., Occupational Safety and Health Administration (OSHA) mandates companies have written emergency actions plans (EAPs) that outline procedures for emergency evacuations, these requirements / actions can be expanded upon by companies based on the research findings. Suggestions may also be created to help reduce the potential of future process safety incidents from natural disasters.

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