Challenges in Natech Risk Reduction

Desafíos en la reducción de riesgos Natech

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Key words
Natech, industry, chemical accidents, risk management, risk governance.

Abstract
Natech refers to a conjoint natural and technological hazard or accident. This paper is concerned with Natechs involving hazards arising from the handling, processing and/or storage of hazardous materials, as well as the transportation of oil and gas by pipeline. Risk management of chemical accident hazards has generally been carried out using industrial risk management regulations and practices, engineering safety codes and standards, environmental regulations, and land use planning. However, there is evidence that existing regulations and practices may not be sufficient if the particular conditions associated with Natechs have not been factored in. Awareness of the need to better address Natech risk has been on the rise; nevertheless, this is not reflected sufficiently in the laws and regulations of individual countries, and a general framework for the governance of Natech risk is lacking. This paper provides an overview of Natechs, their characteristics, and the problems associated with Natech risk management.

Palabras claves
Natech, industria, accidentes químicos, gestión de riesgos, gobernanza de riegos.

Resumen
Natech se refiere a una asociación entre los peligros naturales y los peligros o accidentes industriales. Este documento se ocupa de Natechs que involucran peligros derivados de la manipulación, procesamiento y/o almacenamiento de materiales peligrosos, así como del transporte del petróleo y el gas por oleoductos o gasoductos, respectivamente. En general la gestión de riesgos de accidentes químicos se ha hecho a través de normas y prácticas de gestión de riesgos industriales, códigos de ingeniería y estándares de seguridad, regulaciones ambientales y planificación del uso de la tierra. Sin embargo, hay evidencia que la existencia de regulaciones y prácticas seguras no son suficientes si las condiciones específicas asociadas a Natechs, no se tienen en cuenta. La conciencia de abordar mejor el riesgo Natech ha ido en aumento; no obstante, esto no se ha reflejado lo suficiente en las normas y regulaciones de cada país y en general hay una ausencia de un marco general para la gobernanza del riesgo Natech. Este artículo propone una visión general de los riegos Natech, sus características y los problemas asociados con su manejo.

Introduction

Natural disasters can trigger secondary disasters such as chemical accidents in the form of toxic air releases, spillage of hazardous materials, and fires or explosions. These secondary technological accidents triggered by natural disasters are known as “Natechs”.

Some prominent examples of Natech accidents include:

- More than 200 hazardous materials (hazmat) releases from fixed industrial facilities and over 400 oil and gas releases from offshore platforms with harmful impacts on the surrounding communities and the environment triggered by Hurricanes Katrina and Rita in the United States (US)’ Gulf Coast in 2005 [9]; [28]. The oil spills and chemical releases required the activation of a special spill cleanup task force, resulted in huge losses to the oil and gas industry, triggered shortages of much needed fuel for emergency response and cleanup activities, and had economic repercussions in the United States and abroad [8-9]. Furthermore, the oil spills affected more than 1800 homes and resulted in a class action settlement for US $330 million.
- The Great East Japan earthquake of magnitude Mw 9.0 on 11 March 2011

and the tsunami it triggered— resulted in hundreds of chemical releases and oils spills, including several large refinery fires in the cities of Chiba and Sendai. In one case, the earthquake forces resulted in multiple fires and explosions which completely destroyed 17 liquefied petroleum gas (LPG) storage tanks, triggered domino chemical accidents at neighboring industrial plants, and caused damage to other parts of the refinery, residential buildings, roads and vehicles. The economic losses to industry due to property and production capacity losses were huge and have had repercussions worldwide through supply chain effects [19].

- The Great East Japan earthquake and tsunami also triggered the worst nuclear power accident in Japan's history. The Dai-ichi nuclear power plant (NPP) in Fukushima was inundated by a 15 m tsunami wave, which caused loss of power leading to disruption of controls and the power plant's cooling system shortly after the earthquake. Radionuclide contaminants were released into the air and water due to venting of gases, hydrogen explosions, and a fire in a spent fuel pond in one of the plant's units [4] The social and economic impacts of the Fukushima disaster have been huge, with policy repercussions concerning nuclear energy production affecting the whole world.

Globalization and interconnected infrastructure, both soft and hard, mean that disaster impacts on industry in one part of the world can result in impacts in other areas through the supply chain. The floods in Thailand in 2011 resulted in damage and losses worth more than US$ 45.7 billion [34]; most of these losses were due to flooding of large industrial manufacturing areas [24]. The disruption of the manufacturing supply chains affected many industrial sectors and caused global shortages of some computer parts [14], [24].

Natech accidents can exacerbate the impacts of natural disasters and vice-versa. The Natech accidents triggered by the Great East Japan earthquake and tsunami have represented an enormous additional social, environmental and economic burden on the people of Japan and the world. Damage to oil refineries and petrochemical companies resulted in fuel shortages at a time when fuel was most needed not only for emergency response and relief efforts, but also to compensate for the energy shortage caused by the nuclear accident.

The nuclear accident alone has had tremendous impacts on risk governance of the nuclear power industry in Japan. One of the main outcomes of the disaster has been a decision to set up a new independent nuclear regulatory agency under the Environmental Ministry. The agency will be responsible for regulating nuclear power generation, and it will be separate from the previous agency that was in charge of promoting it. The Fukushima disaster has also resulted in comprehensive safety reviews, which have led to regulatory changes that may slow or even eliminate plans for expansions of and investments in nuclear power in many countries. The most drastic public policy changes due to the strong public reactions have occurred in Japan, Germany, Italy, and Switzerland [35].

Although awareness of the need to better address Natech risk has been on the rise, this is not, as yet, reflected the laws and regulations of individual countries, and a general framework for the governance of Natech risk is lacking. This paper provides an overview of Natechs, their characteristics, and the problems associated with Natech risk management. The paper highlights some Natech risk reduction initiatives undertaken by individual countries, as well as gaps in governance of Natech risks. A call for a comprehensive analysis approach to the risk management of Natechs is called for as well as the need to address Natech risks as a territorial risk governance issue.

General background

Natechs can occur in areas where there is overlapping of natural, environmental and technological hazards. Unfortunately, rapid urbanization and industrialization in areas subject to natural hazards have resulted in more people and property being at risk from potential Natech accidents. Of particular concern are low-lying coastal areas, and areas that are likely to experience more frequent extreme weather events [33],[25]. Some of these areas are already home to densely populated cities as well as some of the largest chemical and petrochemical industrial areas in the world [10]. To illustrate this, higher incidence of Natechs have been reported in the states of Louisiana, Texas, and California in the United States, which are densely populated, heavily industrialized and subject to earthquake, hurricane and flood hazards [29].

Frequency of Natechs

Natech accidents have occurred in both wealthy and less wealthy countries [21]; [37]; [1-2]; [30]; [12]; [31,27]; [20]. Most research indicates that the frequency of Natechs is increasing.

Meteorological Related Natechs

Recently, [29] found an increase of eight and five per cent per year in the number of weather- and storm-related hazmat releases, respectively, reported to the United States (US) Federal National Response Center (NRC) between 1990 and 2008; events due to tornadoes had significantly increased by five per cent per year. Weather related Natechs in the US accounted for over 80 % of all Natech accidents reported to the NRC. Similar results were reported by Rasmussen (1995), who studied data from US and European accident databases. He reported between 1 – 5 % of hazmat releases were caused by natural events, 80 per cent of these were weather related.

Conditional probabilities of Natechs at industrial plants regulated by various US Federal regulatory requirements have been estimated [28]. In [28] found that during hurricanes, a higher probability of releases was observed due to storm surge compared to category 1–2 hurricane and areas inundated during flood events had a probability of 1.1 releases per 100 facilities. Nonetheless, the authors found widely varying Natech occurrence during individual flood events; factors not quantified in their study such as flood depth and speed are considered important predictors of flood Natechs. Climate change and increased urbanization, particularly in coastal areas, may result in a higher frequency of extreme weather events with an accompanying increase in the number of Natechs.

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Earthquake and Tsunami Related Natechs

Natech accidents have been documented during major earthquakes (magnitude 7.0 and higher) affecting urbanized areas: Kocaeli Earthquake, Turkey, 1999[12]; Gujarat earthquake in India in 2001 [37] Great Indian Ocean earthquake and tsunami 2004 [32] Wenchuan earthquake in China in 2008 [20], and the Great East Japan Earthquake and tsunami in 2011 [19] serve as examples.

Estimating the likelihood of Natech accidents during earthquakes has been an important research topic. [21] found that hazmat releases during the Northridge earthquake in Los Angeles County in 1994 had likely occurred from 19% of the industrial facilities in the county (where the Modified Mercalli Index (MMI) values were VIII -IX). [28] found that the probability of Natechs at industrial facilities during earthquakes increased from 0.1 releases per 100 facilities at MMI V to 21.4 releases per 100 facilities at MMI IX. [12] reported that hazmat releases during the Kocaeli earthquake of 1999, occurred in 8% of the industrial facilities that handle hazardous chemicals. Furthermore, [12] found that larger industrial plants, as well as older facilities that handle hazmats were significantly more likely to suffer damage and result in hazmat releases during the Kocaeli earthquake.

There is limited or no data on the incidence of Natechs during tsunami. This is an area that requires more research.

Factors Contributing to Natechs

Overall, the likelihood of experiencing a Natech accident will not only depend on the type of natural hazard trigger and its magnitude or severity, but also on other factors including the extent of exposure, the type of chemical, quantity, type of storage tank and storage conditions (pressure and temperature), structural integrity of the vessel containing the material, its design, age, maintenance schemes, safety management culture, proximity to other structures, etc. Atmospheric storage tanks, pressurized tanks and pipelines have been affected most often during past earthquakes and flood events [3].

As compared to other types of industrial accidents, Natechs present the following characteristics [31]: a) multiple releases may occur simultaneously; b) safety and mitigation measures may not work properly due to the natural event; c) emergency response personnel and resources may not be available as they may be attending to the victims of the natural disaster; d) emergency response to the chemical release may be hampered by the natural disaster, or the natural disaster may exacerbate its effects, and; e) recovery from the hazmat release may be significantly slowed by impacts from the natural disaster or, vice-versa, recovery from the natural disaster may be slowed by the hazmat release.

The likelihood of multiple simultaneous chemical accidents from one or more sources may be higher during a natural disaster. The natural hazard forces can impact large areas and similar structures simultaneously often causing common-cause failures [30]; [13]; [31] such as elephant foot buckling, liquid sloshing, and fires during earthquakes; and floating off of tanks and damage to pipelines during floods [3] to name a few examples. Using probabilistic risk assessment, [3] found that individual risk increased by an order of magnitude for accidental scenarios triggered by earthquakes as compared to accidental scenarios triggered by internal system failures. The authors found similar effects for flood-triggered accidents [3].

Natural disasters generally impact large areas, thus many industrial facilities may be affected simultaneously resulting in a high number of hazmat releases which may overwhelm emergency response personnel. Furthermore, mitigation measures may not work properly as the natural disaster may have damaged them or they may be inoperable due to loss of plant utilities, or damage to critical equipment. The possibility of cascading events also exists, as mitigation measures fail and one release triggers another. The liquid petroleum gas (LPG) storage tank fires at an oil refinery after the Great East Japan Earthquake serve as an example. Fire impingement from the initial fire on other LPG tanks lead to the explosion of other tanks in a chain of events that destroyed all 17 LPG tanks at the refinery.

Response personnel, equipment and emergency materials such as water and foam for firefighting may not be available due to damage caused by the natural disaster, or because the disaster has overwhelmed response capacity. In addition to the possible need to respond to a large number of simultaneous releases, response personnel and their equipment may be called to respond to the problems caused by the natural disaster, especially search and rescue operations of natural disaster victims. Other personnel may be unavailable as they may wish to stay close to their families, or because they themselves have been hurt.

The natural disaster may hinder response to the chemical release and/ or exacerbate its effects. Transportation routes may be blocked or impassable to response vehicles and flooding may prevent responders from reaching the release site, or areas where response equipment is stored may be flooded. People may be trapped in buildings or in other areas from which they cannot escape, subjecting themselves to the effects of the released chemicals. Conflicts may arise between the need to ''shelter-in place,'' and the need to evacuate (Steinberg et al. 2008). Recovery from the Natech accident may be significantly slowed by impacts from the natural disaster, and vice-versa, recovery from the natural disaster may be hampered due to contamination or pollution from the release [31].

The particular conditions of Natech accidents require special consideration in terms of risk governance. Natech risk governance should involve many players and stakeholders including the industrial facility owners/ operators and its contractors, suppliers, etc., but also government officials in charge of chemical accident prevention, first responders, neighboring industrial facilities, and residents, among others.

Natech Risk Management

Industrial risk management generally calls for a risk assessment including hazard identification and risk analysis of certain regulated processes in order to quantify the probability of occurrence and the expected consequences of the identified hazards; a prevention program including adoption of safety and mitigation measures; and an emergency response program which should include emergency response procedures and training.

A Natech specific risk assessment will require a detailed analysis of the natural hazard (frequency and severity), potential impacts of the natural events on vulnerable target equipment (probability of failure and damage state given the natural hazard), as well as the analysis of the consequences of any chemical accident given the natural hazard event context [5]; [18].

A few countries have provisions that address Natechs in their chemical accident prevention rules. Some examples include the California Accidental Release Prevention (CalARP) program in the US, which specifically calls for a risk assessment of potential releases due to an earthquake [30]; and the Law on the Prevention of Disasters in Petroleum Industrial Complexes and Other Petroleum Facilities (PDPC) amended after the Tokaichi-oki earthquake in Hokkaido, Japan in September 2003, which triggered fires at a refinery [11]. In the European Union, the Seveso II Directive requires industrial establishments to consider external hazards in the hazard analysis, but does not specify methodologies or actions that can be taken to achieve these requirements leading to unequal levels of preparedness among countries [13];[17]. Furthermore, there are still limited risk assessment methods and tools for Natech risk evaluation, and only limited guidance is available on what industry and government authorities can do to assess Natech risk.

Risk management for Natechs should not only include a risk assessment of potential impacts of natural hazards to an industrial facility, but should also consider the potential impacts of the natural hazard forces on neighboring industrial plants and other infrastructure in a territory such as utilities, roads, etc., and nearby communities. Based on this comprehensive risk assessment, risk-reduction alternatives should be evaluated and adopted not only for the industrial facility, but also for the industrial zone or territory at risk, which in many cases includes residential areas and other infrastructure.

In most countries industrial risk management practices for chemical accident prevention fall short when it comes to the application of a more comprehensive risk assessment [13]; [11]; [17]; [18] particularly because most regulations do not require the analysis of Natech risk in a territory. Most risk management rules and regulations around the world concern individual facilities, with the exception of Japan, which enforces the PDPC rule described above.

There is growing awareness of Natech issues. Several countries are taking a second look at their risk management practices to include Natechs. France recently passed a new regulation (Decrees 210-1254 and 2010-1255, dated October 22nd 2010), which introduced a new zoning for seismic activity. According to the new regulation, industrial establishments may be considered under “normal risk” or “special risk”. “Special risk” classified sites are pieces of equipment in low and upper-tier Seveso establishments that may lead, in case of an earthquake, to one or more dangerous phenomena with lethal offsite consequences (Ministerial Order, 24 January 2011) [39]. In Germany, concern over a possible increase of hazards by precipitation and floods due to climate change, has lead the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety to pass the new Technical Rule for Plant Safety 310 in 2012. This Technical Rule requires industrial establishments with major chemical accident potential to assess the risk of flood triggered accidents at their installations, including the consideration of potential impacts due to climate change, and requires establishments to take necessary risk reduction measures.

In Japan, concerns about a powerful earthquake (magnitude > 8.0) with a 95% probability in the next 50 years along the Tokai, To-nankai, and Nankai regions, has resulted in the passing of the Large-Scale Earthquake Countermeasures Special (LSECS) Act. This Act has prompted national, regional, and local governments in these potentially affected areas to take special disaster-prevention measures. The LSECS Act has also resulted in amendments to the Japanese High Pressure Gas Safety (HPGS) Law specifically requiring industrial establishments to take any additional measures necessary to reduce the risk of accidents, to protect its workers and the public from any accidental releases caused by severe ground motion or earthquake triggered tsunami (High Pressure Gas Safety Law). In addition, Japan uses performance-based building codes, so buildings and structures must satisfy performance criteria (e.g., remain operational) with regards to materials, equipment, and structural methods (Japan External Trade Organization 2005). For example, hazardous industrial establishments will be subject to strict building design codes that would permit withstanding the 1 in 800–1500 year event, depending on particular fault characteristics, distance to the fault, soil type, etc, [36] The relatively low damage to buildings and industry due to the 9.0 magnitude Great East Japan earthquake pays tribute to the effectiveness of Japan's earthquake mitigation efforts [23].

Risk management for Natechs still poses many challenges including lack of data on past accidents and lessons learned; limited availability of industrial equipment vulnerability relationships for natural hazards—only some data exists for earthquakes and limited data for floods and other natural hazards—and over confidence of industrial personnel and engineers, and government officials in risk management practices designed for day-to-day chemical accident prevention, which they believe provide sufficient protection against natural events.

Risk Reduction Measures

The risk to people, property and the environment from chemical accidents triggered by natural disasters can be reduced through both structural and non-structural risk reduction measures. These prevention and mitigation measures to reduce the risk of chemical accidents triggered by natural hazards will vary depending on the type of natural hazards present in a territory and their potential magnitude or severity and frequency. Generally, these may include natural hazard design codes and standards, protective infrastructure (e.g., break walls, levees), combined natural hazard and chemical process safeguards, land-use planning that takes into account natural hazards in the territory, adequate safety management systems and trained personnel aware of the additional burden a natural disaster may pose, natural hazard warning systems, disaster mitigation and response planning, and contingency planning for recovery and reconstruction that has carefully considered the possible natural hazard scenarios and its impacts to the facility, neighboring facilities, lifeline infrastructure and community.

Emergency Response for Natechs

Natech accidents will require special planning in terms of emergency management because the natural disaster may impact large areas triggering multiple, simultaneous chemical accidents, and may impact safety and mitigation measures and emergency response capacity to deal with the Natech accidents. Furthermore, a natural disaster can contribute to the escalation of a chemical accident, often resulting in more severe consequences and complicating emergency response [30]; [3].

Industrial emergency response plans are generally developed for single accidents that might occur during normal day-to-day plant operation. Thus, emergency response may be insufficient. In addition, safety and mitigation measures may not be available due to impacts from the natural disaster, and standard emergency operation procedures may be inadequate under the natural disaster conditions. Furthermore, external emergency responders (e.g., public fire departments) may be unavailable as they may be busy attending to natural disaster victims, residential fires, etc.

Natech accidents may hamper emergency response to the natural disaster victims, or may even make the situation worse. Following the Wenchuan earthquake, one ammonia release resulted in the evacuation of 6000 earthquake victims, and another ammonia release was believed to have affected survivors of the earthquake—some still trapped under the debris in a village—killing some of them [20].Evacuation of search and rescue teams and remaining residents following the Kocaeli earthquake in Turkey due to an acrylonitrile release resulted in the abandonment of earthquake survivors still trapped in damaged buildings [30].

There is a need for careful consideration of conflicting emergency-management objectives during a Natech accident. The examples above highlight the importance of careful evaluation and planning to prepare for and respond to threats involving the impact of natural hazards on chemical industry, particularly if these are located in industrialized, urbanized areas that can result in potentially high death tolls, damage to property and environmental pollution. Because natural hazards may impact large areas, thus exposing a high number of facilities and communities, the need to address Natech risk reduction as a territorial risk governance issue is of utmost importance. Natech risk reduction cannot be tackled as a problem of an individual facility, but through a comprehensive and integrated risk governance approach.

Natech Risk Governance

Natech risk governance requires a comprehensive analysis approach. As the area impacted by a natural disaster is often large, e.g., the area impacted by a hurricane, earthquake or flood can be hundreds of square kilometers, affecting everything in its path. The natural disaster can cause major disruptions not only to industrial areas, but also to other infrastructure (e.g., electric power stations and power transmission lines, communications, transportation, emergency services). The interdependencies of industrial and other infrastructure systems can lead to cascading events which may cross regional, national and international boundaries [10]. The huge losses inflicted by the Great East Japan earthquake in 2011, hurricanes Katrina and Rita in 2005, and the floods in Thailand in 2011 have pointed out the need to better understand infrastructure failure interdependencies and their societal significance. Menoni noted the need to incorporate both parameters of the physical environment such as lifelines, industrial facilities and building stock as well as organizational, social and systemic factors into the analysis of natural hazard risk.

The growing body of research and lessons learned from past Natech accidents indicate that they require special attention in terms of risk governance. Natech risk will involve bringing to the table many players and stakeholders including the industrial facility owners/operators and its contractors, suppliers, etc. but also government officials in charge of chemical accident prevention, first responders, neighboring industrial facilities, and residents, among others. Risk governance provides an excellent framework for the identification, assessment, management and communication of Natech risks in a territory.

Risk governance for the prevention of major chemical accidents has generally been delegated to one agency or a couple of agencies in charge of worker safety, hygiene and security, and another (or the same) in charge of environmental issues. The risk from natural hazards has generally been the responsibility of civil protection authorities or specific emergency management departments. However, in most cases, government agencies in charge of natural disaster prevention, preparedness and response generally work separately from those in charge of chemical accident prevention resulting in gaps in terms of risk governance.

Given the specific characteristics of Natechs, the various steps—assessment, prevention, preparedness and response, and recovery and reconstruction—to reduce their risks require special governance arrangements, and coordination and planning to insure that all possible hazards and consequences in a territory are identified, adequately addressed, and the vulnerability minimized. Thus, only by bringing all players and stakeholders together, can the full picture of possible interactions and failure modes be anticipated, and their impacts reduced or mitigated.

As mentioned above, the governance of Natech risks requires bringing together industry owners/operators, professionals from differing backgrounds including engineers, flood hazard specialists, hydrologists, meteorologists, earthquake engineers, industrial equipment manufacturers, etc., officials from government agencies in charge of industrial risk management, public health and environmental pollution control, regional and city planners, civil protection officials and first responders, and policy-makers as well as potentially affected communities [7]. The protection of hazardous industrial facilities, their associated systems and neighboring communities and infrastructure, requires that they be analyzed not as independent entities, but as a part of a much larger, connected system. Disaster consequences may be greatly reduced with a collective effort to understand and prevent ripple effects from Natech type failures [10]. Reducing Natech risk should be a collective decision making process.

Conclusions

Current practices for industrial risk management have worked quite well, particularly in wealthier countries. Nevertheless, the Great East Japan earthquake and tsunami, among other examples above, show that there have been failures even in the rich world. These recent events point to the need for a more careful assessment of potential impacts of natural hazards on hazardous facilities. They also show that the potential impacts of Natechs may be widespread and could exacerbate the natural disaster. The human and economic, financial and environmental costs of Natech accidents can be very high.

Major accidents may have real and profound impacts on risk perception and tolerability, and in the past have often forced authorities to make changes to regulations. These changes often result in additional technical and economic burden to industry. The Fukushima nuclear power accident is an extreme case of a Natech with major social, environmental and economic impacts for Japan and the world.

In the face of a possible increase in the number of severe weather related events due to climate change, and growing urban populations and industrialization in areas subject to high natural hazard risk, governments should take heed in addressing the risk of Natechs not only to avoid natural disaster caused losses in industry, but also to avoid or reduce possible health, environmental, and economic impacts.

A comprehensive approach to Natech risk governance should be adopted that considers Natechs as a territorial issue integrating structural and nonstructural risk reduction measures at individual facilities and across industrial areas, strengthens the capacity of local communities to make their own informed Natech risk management choices, and promotes the participation of all stakeholders, in particular natural hazard specialists, disaster managers, land use planners, engineers, industry and professional associations, community groups, non-governmental organizations (NGO) and municipal governments, in all stages of Natech risk reduction.

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