Natech Disasters: A Review of Practices, Lessons Learned and Future Research Needs

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Abstract: There is heightened awareness of the danger posed by potential conjoint natural and technological (natech) disasters. The inclusion of a session on natechs at the recent World Conference on Disaster Reduction (Kobe, January 2005) serves as an example. However, there is still not sufficient reflection of this in laws of individual countries. For example, country laws generally refer to natech hazards only indirectly as “external” threats, and provisions to prevent or respond to simultaneous disasters from single or multiple sources concurrent with the natural disaster are usually not present. In this paper natech risk management practices in the United States, the state of California, Turkey, Japan and several European countries, as well as at the European Community level are discussed. The paper highlights some natech risk reduction initiatives undertaken by individual countries, as well as gaps in current regulatory requirements.

Key words: natural and technological disasters; natechs; risk management, hazardous materials, chemical accidents

1. Introduction

It is well known that natural disasters can trigger secondary disasters such as toxic air releases, spill of hazardous materials, and fires or explosions. These secondary technological disasters triggered by a natural disaster event are termed “natechs”. In this paper we are concerned with natechs in the form of hazardous materials releases from their containment vessels (including releases from pipeline) and damage to lifeline systems that are needed to contain these releases.

There is heightened concern of the danger posed by these conjoint natural and technological disasters; the inclusion of a session on natechs at the recent United Nations’ World Conference on Disaster Reduction in Kobe, Japan, in January 2005, serves as an example. Nevertheless there is still not sufficient reflection of this in laws of individual countries. For example, country laws generally refer to natech hazards only indirectly as “external” threats, and provisions to prevent or respond to simultaneous disasters from single or multiple sources concurrent with the natural disaster are usually not present. In this paper natech risk management practices in the United States, the state of California, Turkey, Japan and several European countries, as well as at the European Community level are discussed. The paper highlights some natech risk reduction initiatives undertaken by individual countries, as well as gaps in current regulatory requirements.

2. Natech Disasters

Research in the last two decades indicates an increase in the number of natech events in the United States. Sengul, Steinberg, and Cruz [1], based on chemical accident data from the National Response Center and Emergency Response Notification System databases kept by the U. S. Coast Guard and the U. S.

Environmental Protection Agency respectively, found an increase in natechs in the United States in last 15 years. Lindell and Perry [2] found that there were almost three times more natech events during the Northridge earthquake in 1994 than in the Loma Prieta earthquake in 1989. Showalter and Myers [3] found a clear trend towards an increasing number of natechs between 1980 and 1989 in the United States.

Natechs are not limited to the United States, of course, but can occur anywhere where natural hazards and technological hazards co-exist. In Europe, a few examples of natech incidents among Seveso II industrial facilities were identified from data from the Major Accidents Reporting Systems (MARS) database of the Joint Research Centre [4]. Cruz *et al.* [4] report on average at least one natech incident per year since 1985. Unfortunately, most countries do not have measures in place to systematically record natech events. Even in cases where systematic recording of chemical accidents and hazardous materials releases exists, the identification of natech incidents is often difficult or not possible because the external triggering natural hazards are not recorded.

Nevertheless, individual reports of natechs abound. The recent Asian tsunami on 26 December 2004 is an example. The tsunami caused extensive damage to several industrial plants triggering hazardous materials releases. In Banda Aceh, the Pertamina oil depot in Kreung Raya Bay reportedly leaked about 8,000 kilolitres of oil [5]. The Kocaeli earthquake in Turkey in 1999 is another example, and served as a warning signal. The magnitude 7.4 earthquake triggered unprecedented hazardous materials releases resulting in off-site consequences to the population. More than 6 million kilograms of toxic acrylonitrile were released into air, water and soil from an acrylic fiber plant. Six simultaneous fires were triggered by the earthquake in the crude unit, naphtha tank farm, and chemical warehouse of one of Turkey's largest oil refineries. In addition, thousands of kiloliters of oil were spilled into Izmit Bay; and more than 30 kiloliters of liquefied petroleum gas were released into the atmosphere, among other releases from the refinery [6, 7]. Steinberg and Cruz [6] documented more than 21 hazardous materials releases during the Kocaeli earthquake. Their investigation revealed that the hazardous materials incidents resulted in the evacuation of residents in several municipalities, the abandonment of search and rescue of earthquake victims, and the abandonment of posts by fire fighters. As a result, the hazardous materials fires went uncontrolled requiring four days to bring under control; and an unknown number of earthquake victims were left behind still trapped in collapsed buildings and under debris.

3. Natech Risk Management: Country Practices

Although most countries have taken steps towards chemical accident prevention, and have taken steps to protect their infrastructure against natural hazard forces these actions may not provide adequate protection if the particular conditions associated with conjoint events have not been factored in.

The conditions brought about by natech events are particularly problematic for a number of reasons [8]. Cruz[8] noted several important issues including: a) more than one release may occur nearly simultaneously as the natural disaster will have a forcing effect over hazardous material storage throughout a stricken zone; b) many of the utilities expected to be available (e.g. water, power, and communications) may not be available, chemical safety personnel are likely to be preoccupied, and mitigation measures (e.g. containment dikes or foam systems) may not function as anticipated due to upset from the natural hazard; c) there will be need to simultaneously attend to the technological disaster as well as the triggering natural disaster; and d) the response to the technological disaster(s) will inevitably complicate the response to the natural disaster using up much needed resources, creating confusion among government officials, emergency personnel and citizens, and potentially reducing the capabilities of the natural hazard response effort. Furthermore, emergency protective actions such as shelter in place or evacuation may not be feasible if buildings are no longer safe or roads are inundated. These unique aspects of risk management and emergency response planning for natural disasters in conjunction with technological disasters have been largely ignored.

In this paper, a summary of industrial risk management and emergency response regulatory requirements for natech disaster prevention in the United States, the state of California, the European Community, Italy, Bulgaria, France, Germany, Portugal, Sweden, Japan and Turkey are presented. For each country, the laws and regulations for chemical accident prevention, and laws and regulations specific for natural hazard risk reduction were evaluated.

The assessment included identifying whether specific items related to natech risk reduction are specified in the regulations. Specific natech risk reduction items might include requirements to consider external hazards in the hazard assessments, to carry out a seismic risk assessment for prevention of chemical accident during earthquakes (in earthquake prone regions), or requiring facilities to adopt flood control measures (e.g., elevation of storage tanks above flood plain level, having emergency plans that include removal of water-reactive chemicals to safer grounds, securing of storage tanks so that they do not float off) to prevent chemical releases during floods (in flood prone areas). The assessment included determining whether accidental hazardous materials releases have to be reported to the competent authorities, and whether or not countries are systematically tracking and recording natechs. Furthermore, it was noted whether countries have developed natech hazard maps, or are using land use planning for natech hazard risk reduction. Finally, the general concern/awareness about natech risk in each country was noted, as well as future natech risk reduction initiatives. The following sections present a summary of findings for each country.

3.1 United States

Several Federal programs in the United States are in place for hazardous materials risk management and emergency response planning. The Process Safety Management (PSM) plan rule under the Occupational Safety and Health Administration (OSHA) requires facilities to carry out process safety and risk management planning to protect workers from potential chemical accidents. The Risk Management Plan (RMP) rule under the Environmental Protection Agency (EPA) requires facilities to develop a risk management and emergency plan to insure the protection of the public from accidental chemical releases. The requirements of these regulations are usually met by industrial facilities through the creation and implementation of a risk management plan which includes three components: a hazard assessment, a prevention program, and an emergency response program [8].

The hazard assessment specifically addresses the potential effects of an accidental hazardous material release. The prevention program includes process safety analysis; process safety information; evaluation of mitigation measures; standard operating procedures; training; maintenance; external events analysis; prestart-up review; management of change; safety audits; and accident investigations [9]. The emergency response program incorporates measures taken to protect human health and the environment in response to an accidental release. The emergency program also requires establishing procedures for notifying the public and local agencies; procedures for the use of emergency equipment, inspection, testing and maintenance; emergency health care;

and employee training.

However, none of the Federal regulations explicitly calls for the analysis of external hazards in the hazard assessment, nor do they address the potential for a natural disaster-triggered hazardous material release. None of the Federal regulations require analyzing, preparing for, or mitigating conjoint natech events or multiple, simultaneous releases concurrent with natural disasters. Furthermore, there are no provisions in the PSM or the RMP to prevent domino effects or for land use planning.

Natechs are somewhat addressed indirectly through the adoption of building codes for new construction, land use planning to guide new development, construction of preventive infrastructure (e.g., break walls, levees), or education and awareness campaigns, among others. Nonetheless, in many cases the problem remains, particularly for older industrial plants (e.g., built before the adoption of stricter building codes, or on known flood plains, built before the adoption of land use restrictions).

In the United States, releases of certain regulated hazardous chemicals, when these exceed a predetermined threshold quantity is required by law. Currently, all reportable releases must be called-in to the National Response Center (NRC) (local and state governments may have additional reporting requirements) which maintains a comprehensive database of chemical accidents throughout the fifty states since the end of 1982. Nevertheless, specific tracking of natech releases has not been under taken. In addition, changes in formats and reporting criteria make it difficult to identify natechs and trends on natech incidence. There is an effort underway however to estimate the incidence of natechs in the United States and to construct natech probabilistic hazard maps based on an extensive review of the NRC database and other data sources [8].

There has been awareness of the danger posed by natechs in the United States, particularly in the state of California due to the high seismic risk. In fact most natech research has been undertaken with respect to California (see for example ABAG [10], Reitherman [11], Kiremidjian *et al.* [12], Tierney and Eguchi [13], Werner, Boutwell and Varner [14], Lindell and Perry [2, 16], Steinberg *et al.* [16]). The following section describes the regulatory requirements in California with respect to natech risk management.

3.2 California

In California, risk management planning for chemical accident prevention falls under the California Accidental Release Prevention (CalARP) Program regulation. Due to the high risk of earthquakes in California, CalARP calls specifically for a risk assessment of potential releases due to an earthquake [17]. Even under CalARP, however, there are gaps in the risk management planning process. For example, only processes that handle regulated hazardous materials must be analyzed under CalARP. Thus, structures adjacent to the covered processes whose structural failure or excessive displacement could result in the failure of adjacent covered processes would not be included in the seismic analysis [6]. Seismic analysis of on-site utility systems which would be required to operate following an earthquake for emergency response or to maintain the facility in safe condition is not called for under CalARP. Furthermore, response planning under CalARP is not required to consider the possibility of more than one release occurring simultaneously. However, recent natech research [6, 8, 18] shows that an earthquake can act as a common triggering mechanism for a number of releases at a single or multiple plants simultaneously. As with the Federal requirements, CalARP has no provisions for domino effects or land use planning.

3.3 European Community: EC level practices

At the European Community (EC) level, chemical accident prevention is regulated by the Seveso II Directive. Under the Seveso II Directive industrial facilities that store, use or handle dangerous substances are required to set out a major-accident prevention policy, write and submit a safety report, and establish emergency plans in the case of an accidental chemical release [4]. As with the United States regulations, the Seveso II requirements are usually met by an industrial facility through the creation and implementation of the safety report, which typically includes identification of hazards, implementation of adequate safety measures to prevent chemical accidents, and establishing emergency response plans.

Although the Seveso II Directive does not have any specific requirements for natech risk management, it does call for the analysis of external events. This means that establishments must consider the potential threat of natural hazards in the hazard analysis, carry out preventive measures to reduce the likelihood of an accident, and establish preparedness measures in case an accident does occur. The Directive however does not specify methodologies or actions that can be taken to achieve these requirements; therefore the levels of preparedness vary among countries.

Two items are different in the Seveso II Directive compared to the chemical accident prevention regulations in the United States. The Directive calls for the analysis of potential domino effects and the establishment of land use policies [4]. These two items are of particular importance when addressing natech risk reduction. Several researchers have noted that domino effects may be more likely during natural disasters than during normal plant operation, particularly earthquakes [15, 18, 19]. The likelihood of domino effects will depend among other factors on the proximity of vulnerable units containing hazardous substances within or at a neighboring establishment [20], and the consequences will undoubtedly increase with the proximity of residential areas.

The EC has published guidelines (see Papadakis and Amendola [21], Mitchison and Porter [22], and Christou and Porter [23]) to help member states fulfil the requirements of this Directive. The guidelines specifically recommend analysing the potential effects of external hazards in the hazard analysis; however they do not provide specific actions or methodologies that can be taken to prevent, mitigate or respond to natech events. Therefore the particular problems associated with natechs such as loss of emergency water, prolonged power shortages, and other non-structural related problems might be overlooked [4]. In addition, the Seveso II Directive does not require the analysis of potential for multiple simultaneous releases.

The Joint Research Centre (JRC) of the EC maintains records of major chemical accidents in the Major Accidents Reporting Systems (MARS) database of the Major Accident Hazards Bureau (MAHB). Unfortunately, changes in the reporting system criteria, and the fact that more countries are now reporting chemical accidents makes it difficult to identify natechs and natech trends in this database. Efforts are underway to improve reporting and streamline reporting criteria across member states.

At the EC level there has been increased concern and growing awareness of the dangers posed by natechs, particularly following extensive flooding and a natech incident in the Czech Republic in the summer of 2002. In the fall of 2003, the JRC in collaboration with the United Nations' International Strategy for Disaster Reduction organized the International Workshop on Natech Risk Management with participation of representatives from more than 14 countries. The following section presents a summary analysis of the country reports prepared for this meeting as well as review of the literature.

3.4. European Community: Individual Country Practices

Although more than fourteen countries participated in the natechs workshop, only six submitted reports on country practices including Italy, Bulgaria, France, Germany, Portugal, and Sweden. An analysis of the country reports indicates that all of the countries have specific regulations in place for chemical accident prevention, and to protect its citizens from the impacts of natural hazards. None of the countries have specific natech risk and emergency management programs in place, although all of them have recognized the special problems and challenges in preventing and preparing for this type of threat. Cruz [8] underlines that having risk management and emergency response measures in place for chemical accident prevention during day-to-day plant operation will not guarantee protection against natural disaster forces unless these are explicitly considered and prepared for. The Seveso II Directive, which was being implemented by a number of countries (Bulgaria, France, Germany, Italy, Portugal and Sweden) requires the analysis of external hazards such as floods, consideration of potential domino effects and calls for land use planning to protect citizens. However, the Directive only provides general rules and does not specify specific actions that can be taken. This leaves room for large variations in actual practice [4]. All of the countries reported having systems in place for recording of chemical accidents, but not for natechs specifically. All the countries have maps of natural hazards and may keep an inventory of hazardous installations, however none reported having natech hazard maps.

All of the countries have indicated a growing awareness of the particular problems associated with natech disasters and natech risk reduction, with some countries taking steps to implement specific natech disaster prevention measures. In Italy, the Department of Civil Protection has taken steps to prevent flood-triggered releases. France has modified its Environmental Law to reflect lessons from natech incidents in the south of France in 2002. Germany, following the floods in August 2002, is studying the risk of unusual dangers (such as natechs) and other hazardous situations in order to adopt the appropriate safety precautions. Portugal is finding ways of incorporating lessons learned after suffering a near-miss natech incident involving the flood-erosion and exposure of one of the country's major gas pipelines, which threatened a nearby population.

The following section presents a preliminary analysis of the situation in Japan. Japan is a country subject to all kinds of risk factors such as high population density, mixed land use including industrial, agricultural and residential, and high susceptibility to natural hazards.

3.5 Japan

In Japan, chemical accident prevention and safety management is regulated by a myriad of laws including: (1) the High Pressure Gas Control (HPGC) Law; (2) the Labor Safety and Hygiene (LSH) Law; (3) the Petroleum Complex Disaster Prevention (PCDP) Law; and (4) the Fire Service (FS) Law. Under these laws industrial facilities that handle high pressure gases, and other regulated substances are required to establish maintenance programs to insure chemical accident prevention, protection of workers, and public safety [24].

There are no specific laws for natechs. However, natech risk reduction may be addressed indirectly through the adoption strict seismic design codes, land use planning ordinances, and construction of preventive infrastructure. In most cases the laws are triggered when changes in processes occur, new equipment is introduced or there is new construction. In the case of the HPGC law for example, industrial facilities must notify the controlling agency of any changes incurred, but they need not submit written reports of process safety actions or other risk management information. Thus, older industrial establishments may not be adequately protected. The HPGC law does not explicitly call for a process hazard assessment for existing equipment, nor does it specifically require analyzing offsite impacts to the public of an accidental release. Nonetheless, the law calls for a process safety inspection in the case of changes or modifications, or the construction of new plants.

Damage incurred by petroleum refineries during past earthquakes has prompted the adoption of a broad range of earthquake hazard reduction measures. The PCDP stipulates detailed restrictions concerning the layout of processing facilities in order to maintain the safety of people and property in a petrochemical industrial zone. For example the law may require builders to set aside passageways of six to twelve meters, and set-back areas of three to five meters for use by firefighters [25]. The PCDP law however, applies only to the petroleum industry, other sectors that handle highly hazardous substances may be at higher risk.

The LSH law is concerned with industrial accident prevention (not necessarily chemical accidents) and worker safety. It calls for the adoption of measures to prevent industrial accidents, provision of education and training of workers and provision of their overall health and well-being.

The FS law states the responsibility of industrial facilities for ensuring safety, and calls for actions on the part of corporations to make the necessary arrangements for ensuring safety, implement measures to identify risks and mitigate possible damage, and disclose information necessary for smooth fire-fighting activities.

In Japan, the new law "Concerning Reporting, etc. of Releases to the Environment of Specific Chemical Substances and Promoting Improvements in Their Management"[26] requires industrial establishments to report releases of hazardous materials into the environment and to provide technical information on the properties and handling of such substances. The information is reported to the Prefectural governors and the reports are then submitted to and collected by the Ministry of Economy Trade and Industry and the Ministry of the Environment. The information is available to the public upon request.

Japan has carried out hazard mapping with regard to earthquakes, tsunamis, volcanic eruptions, tidal waves, and flooding, some of them have been made available to the public on the internet or through prefecture and municipal offices [27]. The author is not aware of any efforts to track natechs nor are there any publicly available natech hazard maps.

3.6 Turkey

In Turkey the Environmental Law of 1983 regulates the storage, processing, and disposal of hazardous chemicals and flammable substances. These environmental regulations require facilities to report inventories of hazardous materials on-site and to report any accidental hazardous materials releases and air emissions [6]. The implementation of safety and mitigation measures to reduce the risk of accidental hazardous materials releases, and the establishment of emergency management plans for hazardous materials releases, are both mandatory under the Environmental Law. However, the law does not call for the analysis of external hazards such as earthquakes or flooding. Additionally, chemical accident prevention laws do not require the consideration of the potential for domino effects, nor do they require any land use planning requirements.

The Turkish government has taken steps to protect its infrastructure from the impact of earthquakes through the adoption of seismic building codes; the most recent codes were updated in 1997 [7]. Nevertheless, as the large number of building collapse during the Marmara earthquake in 1999 demonstrated, there has been lax enforcement by government officials. Furthermore, although most of Turkey is at high risk for seismic activity, there is no law requiring the development of emergency management plans that specifically prepare facilities to prevent, prepare for or respond to chemical accidents during an earthquake.

Although there have not been any major changes in the chemical accident prevention laws, a study by Cruz and Steinberg [7] found a significant improvement in the adoption of mitigation measures specific for earthquake-triggered releases by industrial plants in the Kocaeli area after the earthquake. The authors reported that two years after the earthquake, more than 50% (as compared to less than 25% prior to the earthquake) of industrial plants had adopted seismic design codes or retrofitting for earthquakes, were using anchoring mechanisms for equipment and chemical storage tanks, and had emergency response plans for hazmat accidents. The author is not aware of any national efforts to track natechs or to develop natech hazard maps.

4. Conclusions

All of the countries studied have laws and regulations in place for chemical accident prevention, and have adopted measures to protect against natural hazard forces. However, only a few countries have taken steps to prevent or prepare for natech disasters. Most notably in the United States the state of California requires a seismic assessment as part of the CalAPR rule. Italy is looking at ways to prevent chemical releases and to reduce potential losses caused by flooding. France has modified its environmental law to reflect lessons learnt from past flood-triggered chemical releases and other industrial losses. Industrial plant owners and managers in Kocaeli, Turkey, as well as local government officials are well aware of the need to improve risk management practices to prevent natech disasters in the future.

At present the author continues to work and collect data in Japan to better understand current industrial natech risk management practices. Some Prefectures have additional regulatory requirements that might include provisions for natech risk reduction. An analysis of case studies will help identify innovative practices and lessons learnt.

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