State of the Art in Natech Risk Management

(NATECH: Natural Hazard Triggering a Technological Disaster)

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ABSTRACT

There is growing evidence that natural disasters can trigger technological disasters, and that these joint events (also known as natechs) may pose tremendous risks to regions which are unprepared for such events. The recent floods across Europe in the summer of 2002 and the multiple hazardous materials releases triggered by the Turkey earthquake of August 1999 were examples which showed the potential danger of a natech disaster occurring near populated areas. However, there is scarce information available on the interactions between natural disasters and simultaneous technological accidents. This report aims to provide an overview of the natech problem, and to present the state of the art in natech risk management. The report identifies the main problems in natech risk management and emergency response, as well as proposes a set of key strategies for natech risk reduction.

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CHAPTER 1. INTRODUCTION

1.1 Introduction

There is growing evidence that natural disasters can trigger multiple and simultaneous chemical accidents, can down electrical power lines leading to blackouts in large areas, can breach dams leading to mudslides and inundation, etc., and that these joint events may pose tremendous risks to regions which are unprepared for such disasters.

Steinberg and Cruz (2004) documented more than 21 incidents of natech (natural hazards triggering technological disasters) events following the August 17, 1999 earthquake in Turkey, with more than 8 of these events resulting in off-site impacts to the surrounding communities. In one example, the earthquake caused the collapse of a concrete stack at an oil refinery and triggered multiple fires in the refinery's naphtha tank farms. The multiple fires burned for four days, necessitated the evacuation of thousands of residents living near the plant and threatened to spread to a nearby fertilizer plant storing more than 13,000 tons of anhydrous ammonia. 200 metric tons of ammonia had to be intentionally released from these liquefied ammonia vessels in order to prevent an explosion. In another major incident resulting from the recent floods in the Czech Republic in August 2002, 400 kilograms of chlorine were released from the Spolana Chemical Works company, situated at the river Labe in Neratovice, north of Prague (European Commission 2002). The chlorine release forced authorities to declare an emergency state in the proximity of the plant, warning the local population to stay inside their houses and to keep doors and windows closed.

The systematic study of the interaction between natural and technological disasters is an area that has attracted growing attention in the last decade. Awareness of natechs as an "emerging systemic risk" has grown in Europe. The collaboration between the JRC-IPSC- and the UN/ISDR to study natech disasters and the social economic consequences of disasters, and between the Italian Ministry of Environment and the OECD[1] on this issue are examples.

However, there is little information available on the actual risk of natechs, or on what local governments and communities are doing to prevent and prepare for these types of events. This lack of information on joint natech disasters may be due to the fact that these events have been rare. In Europe, a few examples of natech incidents among Seveso II industrial facilities can be identified. Data from the Major Accidents Reporting Systems (MARS) database of the Major Accident Hazards Bureau (MAHB) at the JRC reveals on average at least one natech incident per year since 1985 (MAHB, 2003). Unfortunately, changes in the

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[1] The OECD is carrying out pilot studies addressing emerging systemic risks. Italy is one of the partner countries taking part in the initiative, with a project on *floods involving industrial installations*. JRC-IPSC will also collaborate with the OECD with view to the World Conference on Disaster Reduction in Kobe Hyogo, Japan on 18-22 January 2005, where a Technical Session on *Natechs and other Systemic Risks* will be prepared.

reporting system criteria, and the fact that more countries are now reporting chemical accidents makes it difficult to identify trends in this important database.

In addition, a few natech events have been identified after searching the Natural and Environmental Disaster Information Exchange System (NEDIES) database of the JRC, which contains lessons learnt information, in three disaster management phases: prevention/mitigation, preparedness and response, on 78 natural and technological disasters not falling under the Seveso II Directive.

Although natechs have been relatively rare events, there is growing evidence that natechs are on the rise. In the United States an increase in natechs has been reported over the last 20 years (Lindell and Perry, 1997; Showalter and Myers, 1994). For example, the number of natech problems in the Northridge earthquake in California in 1994, tripled those of the Loma Prieta earthquake in 1989. Additionally, natural disasters have increased both in frequency and in dollar losses (United Nations 2002, McCarthy et al. 2001, and Mileti 1999). The United Nations (2002) reports that the number of natural hazard events have almost tripled in the last three decades. McCarthy et al. (2001) in studying climate change report that the frequency of floods and droughts is increasing. Furthermore, they observe, global economic losses from catastrophic events increased 10.3-fold from 3.9 billion US$/yr in the 1950s to 40 billion US$/yr in the 1990s (all in 1999 US$). Mileti estimates that dollar losses from natural disasters in the United States alone have increased from $ 4.5 billion annually in 1970 to $ 6 - $10 billion annually in 1999 (all in 1970 dollars). With the threat of more natural hazard events in the future, the potential for natech disasters increases as well.

This increase in joint natech events is in part due to the fact that there is more at stake. As Mileti states: "Modern cities have more to lose. There is in general a higher population density, more industry and more infra-structure at risk." In fact, one of the reasons the natech events described are particularly disturbing is that the impacted facilities were located in urbanized areas. As a result, the hazardous materials releases threatened the lives and health of large numbers of people.

While safety techniques have been developed and implemented to prevent or contain accidents at industrial facilities and other hazardous installations, they are typically not designed to accommodate releases that are triggered by, and are simultaneous with, natural disasters. Natech disasters are especially problematic for a number of reasons including (Steinberg and Cruz 2004):

> *"Simultaneously, response efforts are likely to be required to attend to the technological disaster as well as the triggering natural disaster."*

More than one technological disaster may occur nearly simultaneously, as the natural disaster will have a forcing effect over hazardous materials containing vessels throughout the stricken zone.

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.

Cascading events are more likely to occur during a natural disaster than during normal plant operation because the natural disaster, particularly earthquakes, increases the likelihood of multiple, simultaneous failures. If not taken into account during the planning process, emergency response needs are likely to overwhelm response capacity.

Human, economic, and environmental losses caused by joint natech disasters could be enormous especially in highly populated industrialized areas. The lack of basic information on the potential impacts of joint natech disasters has resulted in minimal existing mitigation and emergency response practices to respond to these types of events; representing a major gap in the hazards literature and public policy. Recognizing the limited information available on natechs, this report aims to provide an overview of the natech problem, and to present the state of the art in natech risk management. The report identifies the main problems in natech risk management and emergency response, as well as proposes a set of key strategies for natech risk reduction.

The report has five chapters including this introduction. The remainder of the chapter presents a review of the literature and other published information on natech disaster management. Chapter 2 provides an analysis of relevant regulatory requirements at the European Community level which directly or indirectly address natech risk. Chapter 3 presents a summary of six country papers on natech risk management, followed by four case studies of natech events. Chapter 3 also presents the main results of a workshop on natechs sponsored by the JRC/EC, in cooperation with the UN/ISDR held at the JRC in Ispra, Italy, in October of 2003. The workshop explored natech risk management in participating countries. Chapter 4 presents an analysis and conclusions of natech risk management practices at the European Community level and among the individual countries. Chapter 5 delineates future research needs for natech risk reduction.

1.2 Background and Previous Studies

For the purpose of this report a conjoint natural and technological (natech) disaster is defined as a technological disaster triggered by any type of natural disaster. The technological disaster can include damage to industrial facilities housing hazardous materials, gas and oil pipelines, and lifeline systems which results in significant adverse effects to the health of people, property, and/or the environment. Based on this definition there are few studies that address conjoint natech disasters, although there is a wealth of literature on natural disasters (see for example Quarrentelli 1954, 1986, 1987; Barton 1970; Form and Nosow 1958 ; Drabek 1983; Alexander 1990; Sylves and Waugh 1990; Lindell and Perry 1992, 1997; Burby 1998; Godschalk et al. 1999; Mileti 1999; and Waugh 2000) , and technological diasters (e.g. Greenberg and Cramer 1991; Moses and Lindstrom 1993; Donahue 1994; Rogers 1994; Lindell 1995; Papazoglou and Christou 1997; Greenway 1998, and Christou et al. 1999) as separate events.

One of the first studies on the incidence of natech disaster was carried out in the United States by Showalter and Myers (1994). The authors conducted a survey of state emergency management agencies in the 50 United States to determine the number of technological emergencies triggered by natural disasters between 1980 and 1989. The survey results indicated that the majority of natech incidents involved interaction with earthquakes (228 reported incidents), followed by hurricanes (26), floods (16), lightning (15), winds (13) and storms (7). An important finding of their study was a clear trend towards an increasing number of natech events during the period studied. They suggested that methodologies be developed to track, record and analyze natech events in each state. Showalter and Myers (1994) also observed that more first hand data was needed which linked natural disasters to hazmat releases.

Later, following the Northridge earthquake in California in 1994, Lindell and Perry (1997) studied earthquake-initiated hazardous material releases (EIHRs). They reported 139 hazmat releases during the Northridge earthquake, and noted this was almost triple the number of hazmat releases reported during the Loma Prieta earthquake in 1989. The authors found that hazmat releases during the earthquake had likely occurred from 19% of the industrial facilities in the county (where the Modified Mercalli Index values were VIII - IX). Lindell and Perry conclude their study by recommending that regional EIHR assessments be conducted to assess the impacts of EIHR threats in different seismic zones.

In a later study of the Turkey earthquake of August 17, 1999, Steinberg and Cruz (2004) interviewed and visited 19 industrial facilities affected by the earthquake. The authors identified over 21 earthquake-triggered hazmat releases. Steinberg and Cruz found that eight of these natech events resulted in major offsite consequences, requiring the evacuation of thousands of residents in two municipalities and resulting in the abandonment of search and rescue of earthquake victims. Previous natech incidents documented by other researchers had had little or no offsite consequences on the population. The earthquake and natech incidents ensued offered valuable lessons for future natech risk management.

Steinberg and Cruz (2004) note that these events demonstrated that risk management and emergency response planning for accidental hazmat releases during *normal day-to-day plant operation* are not sufficient if they have not taken into account the problems that accompany an earthquake such as the potential for simultaneous failures at single or multiple lo cations and the loss of electrical power and water which hamper the ability of safety and mitigation measures to function properly. In another study, Cruz and Steinberg (2004) found that hazmat releases during the Turkey earthquake occurred in 8% of the industrial facilities that handle hazardous chemicals. Although the percentage of natech events reported for the Turkey earthquake is lower than that reported by Lindell and Perry (1997) (19%) for the Northridge earthquake, the magnitude of the events, and the overall effects on public health and emergency response in Turkey were much greater.

These differences are not clear, but may be due to differences in the magnitude of the natural disaster, industrial facility density in the impacted regions, underreporting of natech events, effectiveness of risk management and emergency response practices, among others. Although more research is needed, in a recent study of industry disaster preparedness for natechs, Cruz and Steinberg (2004) found that the likelihood of earthquake triggered hazmat releases increases with the amount of chemicals stored at a facility. This finding is important in the light that the tendency of industrial firms is to have fewer, but larger plants, thus handling larger volumes of hazmats.

In an attempt to better understand the triggering mechanisms leading to conjoint natural and technological disasters, Cruz, Steinberg and Luna (2001) identified potential hazmat release scenarios from a petroleum refinery subject to five hurricane threats: high winds, tornadoes, storm surge, flooding, and lightning. Their findings showed that these threats (during hurricanes category 3 or higher) could trigger multiple and simultaneous hazmat releases unless these external threats were explicitly factored in as part of prevention and preparedness measures for chemical accidents.

1.2.1 Analysis of Risk Management and Emergency Response Practices for Natechs

The information available on natech risk management and emergency response practices is limited and mostly related to earthquake hazards.

An initial assessment of risk management and emergency response practices for natechs was done by Showalter and Myers in the study of the 50 State Emergency Management Agencies in the US between 1980 and 1989. The authors concluded that states generally did not have specific natech risk management programs in place. They recommended that states perform vulnerability analyses to determine specific regions that are more susceptible to natechs, develop mitigation and emergency response plans specific for natechs, and obtain appropriate legislation to enable implementation of these plans.

The Association of Bay Area Governments (ABAG) (1990a, 1990b) studied natechs following earthquakes in California analyzing their causes and proposing mitigation measures that could be taken to prevent earthquake-triggered releases.

More recently, Steinberg and Cruz (2004) reviewed risk management and emergency response regulatory requirements for natechs in the United States based on previous research and lessons from the Turkey earthquake. The authors note that although the U.S. has a series of laws which requires planning for chemical accidents and mandates the use of seismic-sensitive designs in earthquake-prone areas and construction of buildings to certain design wind loads in areas subject to hurricane threats for example, there are nevertheless gaps in the regulations with respect to conjoint disasters. The authors write (Steinberg and Cruz 2004):

> *"…in order to protect worker safety at industrial facilities, the Occupational Health and Safety Administration mandates that the Process Safety Management (PSM) analysis requires industrial plants to identify and mitigate hazards involved in processes that use hazardous materials. Hazards considered in the analyses are those which would occur under "normal" operating conditions, not those that might be generated by external hazards such as earthquakes or flooding e.g. the catastrophic rupture of a tank due to an earthquake would not normally be considered in a PSM. Also, these analyses assume that most mitigation measures are working properly e.g. there would normally be no provision for a breached containment dike, or for the absence of emergency personnel."*

Steinberg and Cruz (2004) conclude that none of the U.S. Federal regulations explicitly addresses a natural disaster-induced hazmat release, nor does any regulation require analyzing, preparing for, or mitigating a joint natech event. However, the State of California has included specific elements for hazardous materials caused by seismic activity in the final regulations of the California Accidental Release Prevention Program

(California Office of Emergency Services, 1998). CalARP requires that industrial facilities determine the potential for, and impacts of, accidental releases of regulated substances due to earthquakes. CalARP specifically requires industry to analyze seismic events in their risk management plans (particularly Article 3, Article 5, and Article 6) and to maintain an Emergency Response Plan in the event of an accidental hazmat release. However, none of the regulations requires analyzing the consequences or preparedness for multiple and simultaneous hazardous materials releases that are likely during natural disasters.

1.2.2 Prevention of Natural Disaster-Triggered Chemical Accidents

Accidental releases of hazardous materials from their containing vessels pose a substantial threat to human health and the environment. Unfortunately, it is not unusual for industrial facilities that routinely consume or produce hazardous materials to be located in urbanized areas. In these cases, a natech event can endanger not only plant personnel, but also residents of the neighboring community.

At present, little guidance is available on how these conjoint disasters should be prepared for or avoided. Only a few studies, primarily based in California, have been published regarding the mitigation of possible hazmat releases at industrial facilities during earthquakes. Kiremidjian et al. (1985) developed a general methodology for seismic risk evaluation at major industrial facilities. Similarly, Tierney and Eguchi (1989) described a methodology for estimating the risk of post-earthquake hazmat releases of anhydrous ammonia and chlorine in the Greater Los Angeles area. Werner, Boutwell and Varner (1989) identified potential hazmat releases that could occur in Silicon Valley facilities and suggested a methodology for risk evaluation and mitigation. Reitherman (1982) offered some suggestions on engineering approaches to the prevention of earthquake-caused spills after studying releases from a number of smaller earthquakes during the period of 1964-1980.

The Association of Bay Area Governments (ABAG) recommended specific risk management precautions to hazardous materials during earthquakes in its 1990 document "Hazardous Materials Problems in Earthquakes: A Guide to their Cause and Mitigation" (ABAG, 1990). Based on experiences from the Loma Prieta earthquake, ABAG provided a list of the types of failures, which precipitated hazardous materials releases and offered recommendations on how to mitigate releases including the use of seismic restraints, secondary containment structures, and earthquake-resistant structural designs for tanks and pipeline support.

Examples of specific safety and mitigation measures for natural disaster-triggered chemical accidents are presented in Table 1.

Table 1 - Summary of safety and mitigation measures for natural-disaster-triggered chemical accidents and other technological accidents.

Safety and Mitigation	**Type of natech trigger addressed**	**Structural measure**	**Non Structural measure**
Use of structural design codes or retrofitting	Earthquakes Winds and storms Flooding	X	
Containment dikes or walls	Earthquake Winds and storms	X	
Use of structural design codes or retrofitting of walls and dikes	Earthquakes Winds and storms	X	
Anchoring mechanisms of tanks and equipment (e.g. anchor bolts, bracing)	Earthquakes Winds and storms Floods	X	
Bracing of pipes and connections	Earthquakes Winds and storms Floods	X	
Flexible connections for pipes	Earthquakes		X
Restraining straps or chains for barrels or pressure vessels	Earthquakes Winds and storms Floods		X
Strapping and anchoring of emergency equipment	Earthquakes Winds and storms Floods		X
Emergency shut off/safety valves	All		X
Emergency water systems, and foam spraying systems	All		X
Adequate siting of emergency water and foam spraying systems to avoid damage from falling debris	Earthquakes Winds and storms		X
Redundancy in pipeline systems, particularly emergency water	Earthquakes Winds and storms		X
Warning systems	All		X
Emergency power generators designed to maintain critical equipment housing hazadous chemicals in safe condition for extended periods of time	All		X
Routine inspection and maintenance for corrosion and deterioration	All		X
Inventory control (e.g. minimizing the amount of hazardous materials used)	All		X

Strategic placement of substances inside plant in order to avoid chemical incompatibility	Earthquakes Floods Winds and storms		X
Placement of storage tanks with hazmats above the maximum height reachable by water	Floods	X	
Construction of drainage system	Floods	X	
Interruption of production process	All		X
De-inventory of main processing units	Floods Winds and storms		X
Giving transport priority to most dangerous chemicals (those that react violently with water)	Floods Winds and storms Hurricanes		X
Verification of storage tank seals	Floods		X
Hermetic sealing of silos and underground storage tanks	Floods Winds and storms Hurricanes		X
Wrapping of subtances in watertight packing and labeling	Floods Winds and storms Hurricanes		X
Raising of electrical equipment such as motors, pumps and control panels to avoid water damage and system failure	Floods Hurricanes Winds and storms	X	
Maintaining natech emergency response plan	All		X
Construction of retaining walls and levees or dykes	Floods Landslides Avalanches	X	
Drills and Training	All		X
Plan to allow workers to check on family	All		X
Training plan for external responders on management of hazardous chemicals onsite	All		X

1.2.3 Lifeline Disruption during Natural Disasters: Implications for Emergency Response

There are many measures taken to protect lifeline systems such as electrical power grids, water distribution systems, gas and oil pipelines and transportation routes from the impacts of natural disasters. However, the potential for lifeline disruption during natural disasters is evident from recent natural disaster events. For example, electrical power outages were reported during the Taiwan (Business Week 1999) and Kocaeli earthquakes in 1999 (Tang 2000), the Kobe earthquake in 1995 (Erdik 1998), and the Northridge earthquake in 1994 (Lau et al. 1995). The recent power outage in Italy was initiated by a spruce-fur tree which fell under the force of high winds during a storm in Brunnen, Switzerland (see DiGennaro in Vetere Arellano et al.). Power outages have also been reported during floods such as occurred in France in 1999 and 2002 (see Valle in Vetere Arellano et al.).

Lifeline disruption during natural disasters can affect whole cities or almost even entire countries as occurred in the Italy blackout. An after-action report about the Northridge earthquake prepared by the Los Angeles City Administrative Officer (City Administrative Officer 1994) observed, “For the first time in its history, Los Angeles’ entire 466 square miles was plunged into darkness with a total loss of all electrical power [, and] over ten percent of Los Angeles’ 3.5 million people found themselves without running water.” The storms which struck Europe one after the other (Storm Lothar hit Northern France, Southern Germany and Switzerland on 26 December; Storm Martin affected Central and Southern France, Northern Spain, Corsica and Northern Italy on 27 December) at the end of December 1999 are two other examples of natural hazards triggering power outages (SwissRe, 2000). Lothar and Martin destroyed over 200 electricity pylons that were in their path, leaving more than three million households in Europe without electricity for many days. Extensive damage to transportation routes was reported following the Kobe earthquake, which destroyed the city’s main highway, several railroad tracks, and much of its port (Banker 1995). Venancio (see Vetere Arellano et al.) reported exposure and threat to a major gas pipeline during floods along the Mondego River in Portugal in 2000. Lau et al. (1995) reported extensive damage to gas distribution systems during the Northridge earthquake resulting in residential fires.

Damage to lifelines can affect emergency response to hazmat accidents and can be the cause of a hazmat release. Loss of water due to multiple pipeline breaks delayed emergency response to several of the gas-caused fires following the Northridge earthquake (City Administrative Officer 1994) and loss of electrical power during the floods in France in 1999 threatened the cooling system of the cryogenic storage of ammonia. Steinberg and Cruz (2004) reported that loss of water and power outages following the Kocaeli earthquake hampered emergency response to earthquake-triggered hazmat releases. In one of the cases documented, the authors reported that loss of electrical power and water resulted in the inability to promptly operate emergency water pumps and foam sprayers to contain vaporization of more than 6,500,000 kg of liquid acrylonitrile released during the earthquake at an acrylic fiber plant. Table 2 provides some examples of natural disasters that have disrupted lifelines. The table also provides information on lessons learnt from each incident, and corrective risk management measures taken or envisioned.

Table 2 - Natural disasters that have disrupted lifelines, the related lessons learnt and the input into risk management[2].

Date and place of event	Type of triggering natural disaster	Lifelines affected	Brief description of impact to lifelines	Lessons Learnt	Input into Risk Management
26/12/1999, Northern France, Southern Germany and Switzerland (SwissRe, 2000)	Storm (Lothar)	Electricity pylons	Lothar and Martin destroyed over 200 electricity pylons that were in their path, leaving more than three million households in Europe without electricity for many days.	(see French experience below)	(see French experience below)
27/12/1999, Central and Southern France, Northern Spain, Corsica and Northern Italy (SwissRe, 2000)	Storm (Martin)	Electricity pylons		(see French experience below)	(see French experience below)
26-27/12/1999, France (Sauvage in Colombo and Vetere Arellano, 2001)	Storm	Electricity supply, water supply, telecommunication systems, rail and road networks	3.5 million households (which corresponds to about 10 million people) lost their electricity supply; 2.5 million people no longer had access to drinking water; 2/3 of the railway network was damaged by 15 000 fallen objects; hundreds of roads have been interrupted or damaged.	- *For the electricity grid*, power lines must be made able to withstand this kind of event and alternative means of power production (electricity generators) must be made more readily available and a rapid response force set up. - *For the communications networks*, it has been found that the major operators in France did not pay sufficient attention to ensuring that their (fixed or mobile) networks were secure. There was pressure on the telephone system as people tried to	- *Electricité De France* launched a study addressing the lessons learnt and intends to propose ways of improving these deficiencies. - Areas which need underground lines in order to make them less vulnerable were identified. - Development of a more relevant priority user management policy is

[2] There are two types of entries regarding the input into risk management: in green colour are those inputs that have already been carried out in the area affected and in violet colour are those inputs that should be implemented (as of January 2002).

			Note: 1) Each department in France has an electricity emergency plan (only for major establishments) designed to provide mobile power units to establishments requiring permanent power supply. 2) This event also occurred at the same time as the preparations for the "millennium bug" was set in place. Thus, emergency operators were on alert and were more ready for disaster to strike.	report electricity faults or enquire about reconnection plans, causing temporary overload at some exchange. - Stocks of emergency material and equipment (generators and tarpaulins in particular) were quickly exhausted. The storm also affected 40 other departments, making it impossible to get reinforcements from outside. This proved all the more unfortunate as two days later the southern half of the country was hit by another storm. Extra tarpaulins were obtained by requisitioning all tarpaulins in the department; in particular from farming co-operatives, followed by the establishment of six distribution points in the department operated by the fire brigade. As regards electricity generators, the search for replacement facilities was very limited, as virtually all private generators had already been rented out to factories or administrations expecting possible power cuts caused by the millennium bug.	envisaged. - Medium-sized establishments (e.g. in health sector) should also be obliged to have generators. (Only major establishments, have their own generator, making them independent from a power cut.) - Ensure that other communication mechanisms are available to prevent overloading of communication systems during a disaster.
26 December 1999, Baden-Württenberg, Germany	Storm	Electricity supply	Approximately 5,000 failures in the electricity grid (540,000 people)	There were problems regarding the information dissemination within the power supply company: slow information channels; delay in the management of information; partial insufficiency of the quality and quantity of data provided.	An internal definition for a "serious grid fault or incident" was created, which enables the grid control personnel to decide quickly if the fault or incident has to be reported immediately.
26-31 December 1998, Northern Ireland, UK (Clements in	Storm	Electricity systems, telecommunication systems, water supplies	There was disruption to power supply due to physical damage to cables and poles for a	- It is necessary to have additional generators available, water tankers and distributors of fuel and resources for drawing on alternative suppliers and	- The electricity provider has invested heavily in making the call handling system much more robust.

Colombo and Vetere Arellano, 2001)			very large proportion of the country, along with disruption to water supply, due to loss of electricity and failure of back up Generators.	additional assistance with manning levels. - The electricity provider was completely overwhelmed by the sheer volume of calls from members of the public wishing to report problems with their power supplies, leading to overloading, placing a significant strain on the system. - Organizations did not have a mechanism for passing on information other than by public lines, which were already jammed. - Many of the problems encountered were the result of knock on effects of the loss of power supplies.	- Inter-agency phone numbers have been developed so that organizations may communicate with each other directly rather than using the same numbers.
3-4 December 1999, Denmark (Ryborg and Johansen in Colombo and Vetere Arellano, 2001)	Storm	Electricity systems	About 400 000 homes were without electricity for a shorter or longer period of time because of the hurricane.	- No plans took the specific case of a hurricane into account, as meteorological phenomena such as these are extremely rare in Denmark. - It essential to make power systems less vulnerable to disasters. - The capacity of the 112 emergency terminals was not sufficient during the event.	- Widespread revisions of emergency plans locally, regionally and centrally in Denmark. The National Commissioner of Police added a chapter on natural disasters to their general emergency plan, which also includes large scale, multi-facetted and geographically widespread emergencies. - An analysis of the power supply sector was conducted to understand how to reduce its vulnerability. - The capacity to provide emergency information, including the expansion of the 112 terminals was carried out.

25-26 March 1998, Attica and Peloponnese, Greece (Kakagliagou and Holevas in Colombo and Vetere Arellano, 2001)	Storm	Electricity systems, water supply, road and rail network, telecommunications network	Electricity supply problems were reported in several parts of Greece: Athens, Attica, Distomo (Voiotia), Aspropyrgos and Eubea. Damages to roads were reported in Northern Athens (Gerakas, Stavros, Glyka Nera). In southern regions of Athens, the asphalt subsided. The airports in Attica were closed because of the gale winds.	- Problems in water supply were evident in several regions following the problems in electricity supply. Same problems occurred in the main sewage plant in Psitalia.	- Periodic maintenance of infrastructure networks such as water supply, electricity and telecommunications should be carried out in a systematic way.
February 1999, Northern Swiss Alps (Ammann in Colombo, 2000; Ammann in Hervas, 2003)	Avalanche	Road and rail infrastructures; power and communication lines	More than 1,000 avalanches occurred during three periods of the month. Some regional and international high voltage lines were damaged, including road and railway infrastructures. The direct damages amounted to 440 million Swiss Francs (approx. 190 MEuro)	- There is a need to establish a network of avalanche experts. - Early warning and information systems are needed.	- A standardised method for hazard mapping for all alpine hazards has been developed. It will then lead to the development of risk maps. As of early 2003, 90% of avalanche hazard maps were available.
26 October 1995, Flateyri (West Fjords), Iceland (Kjartansson and Magnusson in Colombo, 2000)	Avalanche	Electricity supply	There were damages to the electrical supply system.	The preventive measures were inadequate. Warning was issued in time but the danger was vastly underestimated.	Structural and non-structural measures have been identified and applied (e.g. deflecting walls were built) in Flateyri to protect critical infrastructure.
13 September	Earthquake	Electricity supply,	The transportation	- Risk assessment and land use	- Risk assessment of

1986, Kalamata, Greece (K. Ioannides and V. Dikeoulakos in Theofili and Vetere Arellano, 2001)		transport system, electric power lines, communication lines	facilities (airport, national road network, railway and seaport) were only slightly affected, resulting in a quick response to emergency demands. The temporary failure of the telecommunication network was mainly due to overload caused by drastic increase of phone calls from panic-stricken citizens, making emergency response and aid actions difficult to carry out.	planning should also be incorporated as part of the prevention measures. - The long-term (more than a few days) evacuation of a city is a complex initiative with two parallel facilities, social support and service networks functioning in interaction. Thus, the prompt repair of lifelines and the fast establishment of the subsidiary one for the city's evacuation camps are needed. - Provision of communication lines to the population affected is needed.	critical infrastructure (Electricity supply, transport system, communication lines, etc.) and the potential impact of their destruction should be incorporated in risk assessment and land use planning. Possible contingency mechanisms should be developed. - Ensure that evacuation plans have contingency plans also. - Ensure that other communication mechanisms are available to prevent overloading of communication systems during a disaster.
7 September 1999, Mt. Parnitha – Athens, Greece (Dandoulaki in Theofili and Vetere Arellano, 2001)	Earthquake	Hospitals	Serious damage and interruption of function was reported in several hospitals. No major damage to bridges, road, rail or pipeline network was reported.	The complexity of metropolitan areas should be taken into consideration in emergency planning. The administrative structure and the continuity in space of functions (e.g. health services), networks, flows, etc., must be addressed, regardless of the official limits of responsibility and administrative boarders between municipalities, prefectures and regions.	The complexity of urban areas should be taken into account in risk management, along with the relatively higher potential risk of the occurrence of domino effects and simultaneous technological hazards.
5 November 2000, South and East Ireland (John Barry and Caroline Lyons in Colombo and Vetere Arellano, 2002)	Flood	Electricity supply, road and rail networks	Electricity supplies were affected by high winds and flooding. Approximately 5,000 customers were without supply at midday on Monday, 6 November. Transport was also	- Need to identify vulnerable areas and associated sources of flooding, and consider what procedures might be adopted to mitigate the effects of flooding. - Local authorities should put in place regular maintenance to drains, gullies, water cuts, and culverts, keeping them	-

			disrupted, with floods affecting road and rail infrastructure. Bus services were disrupted or delayed where roads were closed or diversions in operation.	clear and facilitating removal of rainwater from roads and other public areas, including their clearance at the onset of severe rainfall.	
2000, Western, Central and Southwestern Romania (Septimius Mara in Colombo and Vetere Arellano, 2002)	Flood	Road network, bridges, sewage networks	1,381.5 km of roads were disrupted.	- There was a lack of maintenance of a very small sewage network, which was not able to cope with the flood. - The transport capacity of the bridges or footbridges were exceeded because of the underestimated design and also because of the clogging of the flowing section with wood, debris and waste deposited in the riverbed area or removed from the slopes.	-
November 2000, Stoze and Predelica, Slovenia (Ales Horvat in Hervas, 2003)	Landslide	Bridges, road network, electricity supply and communication network	2 bridges on the state road to Italy (Bovec-Predel Pass-Tarvisio) were destroyed, along with the road to Predel; Mangart Col road was cut off over a 1km stretch; two hydropower plants were damaged along with electricity and communication lines.	- Hazard zoning is the best prevention measure. - Hazard assessments should be continually updated, especially erosion hazard.	- Changes in land use plans were made. - A law has been put in place addressing hydro-meteorological hazards (floods, landslides), including zoning.
October 1997, San Miguel Island Azores, Portugal (Antonio Cunha in Hervas, 2003)	Landslide	Bridges, communication, transport and energy systems	Several bridges were partially or totally destroyed; communications, transport and energy supply systems were disrupted. Material loss totaled 21 million Euro	- Strategies of risk reduction should be developed in direct collaboration with scientific and civil protection structures. - The elaboration of hazard maps is crucial, as it enables authorities to implement eventual prevention measures.	

Damage to utility services commonly present at industrial facilities, such as boilers, cooling water towers, process air, and refrigeration units, can result in uncontrolled changes to process or storage vessel conditions, leading to unexpected hazmat releases, or requiring the emergency release of a hazmat to avoid a greater catastrophe.

The analysis of natural disaster vulnerability of lifeline systems in a region is important in order to identify and address the potential problems that can arise including the ability to provide prompt emergency response and to avoid potential for secondary hazards such as hazmat releases.

1.2.4 Emergency Preparedness and Response Planning for Natech Events

Lindell and Perry (1996) note that the level of disaster preparedness of a region is linked to the level and completeness of vulnerability assessments. In other words, the authors observe emergency planning processes can only address the threats that have been identified. Therefore, communities, industrial facilities and local response agencies must take into account the series of problems that can arise during a joint natech disaster in order to be better prepared. Growing populations and industrialization increase the probability of a natural disaster, technological disaster, or natech disaster as well as increasing the level of potential damage posed by these disasters (Cruz, 2003).

In general, emergency management entails a comprehensive approach in combining the four elements that constitute a successful emergency management program (Sylves and Waugh, 1990; Jackson County, 1998):

(1) *Mitigation*: those activities, which eliminate or reduce the probability of disaster. These include conducting a risk analysis, including hazard identification, vulnerability analysis, impact assessment, cost-benefit analysis, and the resulting prioritisation and recommendations.

(2) *Preparedness*: those activities which governments, organizations, and individuals develop to prevent loss of lives and minimize damage. These activities include development of multi-hazard plans, plan validation through exercising, and regular reviews and plan updates.

(3) *Response*: activities carried out to save lives and property, and provide emergency assistance. The response phase includes resource management, coordination, and mutual aid among different entities/agencies.

(4) *Recovery*: short- and long-term activities, which return all systems to normal or improved standards.

In the case of a natech event, the elements for emergency response to a natural disaster such as an earthquake or a flood event must be melded with those for response to a chemical emergency. This aspect of emergency management and planning has received limited attention, and little guidance is available to create natech emergency response plans. However, review of the available literature (Lindell 1994, Lindell and Perry 1996, Lindell and Perry 2001, Cruz et al. 2001, and Steinberg and Cruz 2004) in emergency response planning indicates that emergency response during a natech disaster will depend on how well a large number of factors have been prepared to deal with the emergency at hand, and how their interaction during the event is integrated so that a coordinated response can be made. These factors include:

Hazardous materials	Previous identification and detection of sites that handle hazardous materials; chemical type and toxicity, release type and quantity, and, knowledge of appropriate first aid and clean up procedures and evacuation measures by both individuals (residents affected) and emergency workers (from local fire departments and industry), and their level of preparedness.
Human resources	Number of emergency workers available; skills and competencies level.
Communications	Warning systems and activation procedures; communication means such as telephones, radios, pagers, and alarm systems.
Transportation	Availability of resources such as vehicles and drivers, identification of transportation and evacuation routes, etc.
Fire services	Detection and suppression of fires and/or hazardous material releases, mobilization of personnel, equipment and supplies to support debris clearance, evacuation, and search and rescue operations.
Mitigation strategies	Adequacy of onsite and offsite mitigation measures in place.
Health and Medical	Adequate treatment and transportation of injured/exposed persons and general health concerns with respect to the hazmat release.
Population at risk	Number of people at risk; population density;
Natural disaster	Intensity of event and concurrent damage to roads, infrastructure, communication lines, power generation plants, water supply, and so on.

The unique aspects of response planning for natural disasters in conjunction with technological disasters may be ignored by many emergency planners. One of the objectives of this report is to disseminate knowledge regarding the potential for joint disasters to decision-makers, civil defence authorities, industrial risk managers, and disaster management officials, so that they may be made aware of the need to develop conjoint disaster management plans.

1.2.5 Urbanization and Natech Disasters

Natural hazards such as earthquakes or floods may go unnoticed when they affect unpopulated or sparsely populated areas. Natural hazards become disasters when they affect communities and their livelihood. In a similar way, technological accidents can have serious consequences when they affect densely populated areas, as occurred on November

19, 1984 in Mexico city. A gas truck exploded in a liquefied gas storage depot in the suburbs of the city killing over 450 people, injuring more than 4000, and affecting homes in a 20 block area (Hewitt 1997).

Disasters result from the interaction of the physical environment, including hazardous events, social and demographic characteristics of communities, and the constructed environment (Mileti 1999, Hewitt 1997). Urbanized areas have higher concentrations of people and human-made structures including industrial facilities. Furthermore, today's urbanized areas, particularly mega-cities such as Los Angeles or Istanbul, are larger, more complex and interdependent than ever before (Davidson et al. 1998), therefore increasing the risk of natural disasters and secondary effects such as technological disasters.

For example, rapid urbanization in the high seismic region of Kocaeli created the natech disaster scenario in Turkey. Urbanization in Turkey was accompanied by social and economic changes increasing the risk from natural and technological hazards. However, little was done to prevent or prepare for an earthquake disaster. Turkey's population went from mostly rural (76 %) in 1923, to more than sixty five percent urban in 1998 (Sevkal 2001). Rapid urbanization changed the landscape of cities in Turkey. Industrial facilities were built along the corridor between Istanbul and Ankara, Turkey's capital. Attracted by job opportunities, large urban settlements around these industrial facility clusters soon developed. Furthermore, government officials were caught unprepared to provide housing to the newly arrived migrants. These took matters into their hands by illegally appropriating lands and building their homes in the absence of any land use planning or public housing measures, and without following adequate building regulations (Sevkal 2001). The extensive damage to residential buildings (more than 215,000) and the hazmat release disasters during the Kocaeli earthquake (U.S. Geological Survey 2000) resulted among other problems as a consequence of poor decisions, lack of clear housing and land use policies, and lack of oversight of building regulations. The earthquake effects on residential and commercial buildings was compounded by damage to industrial facilities and the consequent multiple hazmat releases that followed. The proximity of industrial facilities to urban areas resulted in large numbers of people affected by the hazmat problems.

Recent research confirms that losses caused by natural and technological disasters are higher in urbanized areas. Mileti (1999) measured hazard losses by state, and assessed the relative hazardousness of different parts of the United States by ranking states according to frequency of events, deaths, injuries, and damage over the period 1975-1994. Mileti found that extensive urbanization and high population density in California and Florida, coupled with their high risk potential, clearly explained why these two states ranked highest.

Davidson et al. (1998) based on data reported by the United Nations indicate that by the year 2005, 50% of the worlds population will be gathered in urban areas, and by 2025, more than 60% will be in urban areas. By taking measures to reduce the risk of disasters in urban areas, Davidson et al. observe, most of the world's population is being considered.

Furthermore, many of the areas with higher population growth (both in the developed and developing world) are also areas subject to high natural disaster risk. For example, job opportunities, mild weather, and natural beauty attract thousands of people every year to cities such as Los Angeles and Miami. Both cities are high risk for earthquakes and hurricanes. With more and more people concentrated in areas of high natural disaster risk, it is prudent to improve our understanding of the interactions between natural and technological disasters, and to propose ways of minimizing the risk to people, property and the environment.

CHAPTER 2. NATECH RISK MANAGEMENT AT THE EUROPEAN COMMUNITY LEVEL

At the European Community level there are several legal acts that directly or indirectly address natech risk through rules governing industrial establishments housing hazardous materials, landfill sites and waste treatment plants. Regulations that govern lifeline systems operations such as electrical power plants, gas and oil pipelines, and water resources and trans-boundary issues may also indirectly address natech risk reduction. However, there is no specific legislation or any type of guidelines that encompasses the entire natech disaster risk assessment and management at the EU level.

2.1 Seveso II Directive

Requirements governing prevention of chemical accidents in the European Community appear in the Seveso II Directive (98/82/EC). The aim of the Seveso II Directive is to:

> *"Prevent major accidents which involve dangerous substances, and to limit their consequences for man and the environment with a view to ensuring high levels of protection throughout the Community in a consistent and effective manner."*

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.

The requirements of these regulations are usually met by an industrial facility through the creation and implementation of the safety report. Typically, the safety report includes three components: identification of hazards, implementation of adequate safety measures to prevent chemical accidents, and establishing emergency response plans. The hazard assessment includes a process safety analysis; process safety information; evaluation of mitigation measures; external events analysis; and consequence analysis. The emergency response program incorporates measures taken to protect human health and the environment in response to an accidental release. The emergency response plan requirements also include notifying the public and local agencies; and reviewing and testing of the plans.

Although the Seveso II Directive does not have any specific requirements for natech risk management, it is addressed indirectly. First, the Seveso II Directive calls for the analysis of external events in "The identification and accidental risk analysis and prevention methods" section (Section IV of Annex II). The analysis of "external events" which may lead to a chemical accident implies the consideration of the potential threat of natural hazards in the hazard analysis, and carrying out preventive measures to reduce the likelihood of an accident and to establish preparedness measures in case an accident occurs. However, the Directive does not specify methodologies or actions that can be taken to achieve these requirements, therefore the levels of preparedness vary among countries.

Second, Article 8 of the Directive calls for the analysis of potential domino effects. In the requirements of Article 8, the competent authority must study the likelihood of domino effects of a major accident given the location, the proximity of several establishments to one another, and their inventories of dangerous substances in order to reduce the consequences if an accident does occur.

And third, Article 12 of the Directive requires that prevention of chemical accidents and mitigation of their potential consequences be taken into account through the establishment of land use policies. Through land use policies competent authorities can assure that appropriate distances are kept between establishments, residential areas and areas of particular “natural sensitivity”.

Both Articles 8 and 12 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 (Cruz and Steinberg 2004, Cruz et al. 2001, Lindell and Perry 1997). 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 (Khan and Abbasi 1996), and the consequences will undoubtedly increase with the proximity of residential areas.

The European Commission has published a set of Guidelines (see Papadakis and Amendola 1997, Mitchison and Porter 1998, and Christou and Porter 1999) to help member states fulfill the requirements of the Seveso II Directive. The guidelines specifically recommend analyzing the potential effects of natural hazards (e.g. floods, earthquakes, extreme temperature changes, winds) and other external hazards in the hazard analysis. The guidelines however 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 may be overlooked.

2.2 Analysis of other EU Legislation

Table 3 presents a summary of other EC Directives indicating how they address natechs. For example the Water Framework Directive explicitly calls for the adoption of measures to prevent or reduce the likelihood of or to reduce the impact of accidental pollution incidents, for example as a result of floods. Some measures include the use of systems to detect or give warning of such events and the adoption of all appropriate measures to reduce the risk of accidental pollution to aquatic ecosystems. The Council Directive on the landfill of waste requires that these be located taking into consideration requirements relating to the risk of flooding, land subsidence, landslides or avalanches on the site.

Table 3. Summary of secondary legislation at EC level indicating how they address natech-related issues

Type of secondary legislation	**Name of secondary legislation that addresses natech-related issues to some degree**	**Natech risk management-phase addressed**	**Assisting Quote (if link to natural hazard is not obvious in the name of the legislation)**
Directives	DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive – WFD)	Prevention/ preparedness	" …any measures required to prevent significant losses of pollutants from technical installations, and to prevent and/or to reduce the impact of accidental pollution incidents for example as a result of floods, including through systems to detect or give warning of such events including, in the case of accidents which could not reasonably have been foreseen, all appropriate measures to reduce the risk to aquatic ecosystems." (p.15)
	COUNCIL DIRECTIVE 1999/31/EC of 26 April 1999 on the landfill of waste Official Journal L 182 , 16/07/1999 P. 0001 - 0019	Prevention	"The location of a landfill must take into consideration requirements relating to… the risk of flooding subsidence, landslides or avalanches on the site …" (p.22)
	COUNCIL DIRECTIVE 92/57/EEC of 24 June 1992 on the implementation of minimum safety and health requirements at temporary or mobile construction sites (eighth individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC)	Prevention	""Suitable precautions must be taken in an excavation, well, underground, working or tunnel… to prevent hazards entailed in the fall of a person, materials or objects, or flooding" (p.25)
	COUNCIL DIRECTIVE 82/883/EEC of 3 December 1982 on procedures for the surveillance and monitoring of environments concerned by waste from the titanium dioxide industry, Official Journal L 378 , 31/12/1982 P. 0001 - 0014	Response	"Member States may derogate from this Directive in the event of flooding or natural disaster or on account of exceptional weather conditions." (p.5)
Other	EUROPEAN COMMISSION BACKGROUND DOCUMENT (Dec 2003) Undergrounding Electricity Lines in Europe		See following pages: 3, 4, 10, 16, 23, 35

CHAPTER 3. NATECH RISK MANAGEMENT IN SELECTED COUNTRIES

Recognizing the dearth of information available on natech incidence, prevention, and response in Europe, the JRC/EC, in cooperation with the UN/ISDR held a workshop in October of 2003 to explore the state of the art regarding natechs. The workshop brought together the contributions of thirteen representatives from EU, Accession, and Candidate countries from the respective Civil Protection Authorities, along with representatives from the research community in Japan and the United States. The contribution to the workshop included four keynote speaker papers, six country papers addressing natech related issues, four case studies of natech events, and a day and a half of parallel working sessions, where the country representatives worked together in groups to address a series of questions concerning natech disaster impacts, vulnerability, and risk reduction. The following sections in the chapter summarize the workshop and country papers.

3.1 Summary and main conclusions of Workshop Working Sessions

The workshop included a day and a half of parallel working sessions and discussion. During the parallel sessions, the country representatives were divided into two groups, and each group worked together to address a series of questions concerning natech disaster impacts, vulnerability, and risk reduction. The individual workgroups then convened in a plenary session at the end of each day to present the workgroup results and allow for discussion. End result of the workshop was a set of proposed key actions plans for natech risk reduction.

There was general agreement that "emergency planning" for natechs at all levels of government was a key element of any action plan to reduce natech risk. Based on the input from both groups, this activity is interpreted as including risk analysis (including prevention), risk assessment, and response planning. The importance of public participation was highly rated as well as the need to consider the local population's perception of the level of the natech risk they are willing to accept. Also, residents in the community should be educated and prepared to act in a safe manner in case of a natech. It was noted that educational materials might have to be written or presented differently depending on the targeted vulnerability group. In addition, decision-makers need to be educated and made aware of natech risk, and should be participants in natech emergency planning.

Industry should do risk management specifically directed towards natech risk reduction. Modifying the SEVESO Directive and other legislation to include natural-hazard triggers is one strategy to achieve this. Additional risk management actions which could make plants less vulnerable to natechs were also discussed including: the use of redundant safety systems, natural hazard-resistant designs, the provision of guidelines to inform industry about natech planning, and requiring the strategic placement of hazardous substances inside a plant.

Furthermore, there was general agreement that land use planning is an important technique for separating residents and technological facilities, and that risk mapping, possibly tied to a centralized information center, would facilitate natech risk reduction.

The following section presents summaries of individual country papers on natech risk management.

3.2 Summary of Country Reports on Natech Risk Management

3.2.1 Bulgaria

The primary concern regarding the triggering mechanism for natechs in Bulgaria is earthquakes, since the entire country is subject to earthquakes of intensity VII or higher. Other possible natech triggering mechanisms in Bulgaria include:

1) Floods, especially along the Danube,
2) Landslides. 350 landslide sites have been identified in highly populated areas
3) Strong winds
4) Heavy snowfalls and ice storms

Bulgaria has carried out a number of natech risk assessments for individual facilities. These include:

The nuclear electric power plant at the town of Kozlodui: The risk assessment is done for the whole site and in particular for each of the production blocks. The site follows strict regulations for observation and risk assessment. Technological safety and protection systems against natural disasters are under permanent control by internal authorities (e.g., "State agency for control on the electric power consumption", "Committee for using nuclear power for peacefully purposes", "State agency for civil protection") and other international organizations which are concerned with nuclear plant safety.

Hydro technical facilities:

- Dams – 215 dams;
- Embankments along the Danube River – 295 km – 10% of all embankments;
- Setting basins for cinder and slag deposits – 72 basins.

Industrial establishments: Plants and enterprises with technological installations and equipments operating with dangerous chemicals and other products.

Electrical Power Transmission:

High voltage power transmission lines (e.g., 750 voltage – 85 km, 400 voltage – 1852 km).

A description of how these risk assessments have been done follows.

Vulnerability

In general, the natech risk assessments begin with an investigation of the vulnerability of the site to natechs. In addition to information available on the national level, this portion of the study also includes an analysis of:

- Micro seismic characteristics of the region,
- Hydrological aspects,
- Geological aspects,
- General seismic stability of the buildings, facilities and technological equipment, taking into account additional factors resulting from the production processes including:
  - wear of the different kinds of elements;
  - corrosion;
  - construction changes of the structures;
  - substitution of construction elements;
  - prohibitive or sustained overload;
  - considerable damage to structures, and type and level of the effects on building stability, or on the stability of equipments.

Next, the potential harm that might result from a natech is evaluated. In order to determine the recurrence interval that is to be used in this assessment, a determination of the importance of the site to the national economy and the size of the population which would be endangered by a natech is first made. The following recurrence intervals are typically used:

- When this site is of "special importance" the assessment is done based on a 5000 year- recurrence interval.
- When the site is "very important" this period is1000 years.
- When the site is "important" this period is 475 years.

Finally, scenarios of a natech release, including triggering event, initial release, possible domino effects, and impacts on the community, are created.

Mitigation

There are no specific national regulations which require mitigating against natech disasters. However, there are building codes which require earthquake-resistant design. These date back to 1957, with updates making seismic codes more rigorous in 1964, 1977, and 1987. Thus, a major concern is that older buildings may be unprotected or inadequately protected from earthquake forces. With respect to natechs, this implies that structures housing hazmats may also be inadequate and could potentially fail to contain hazmats during an earthquake, thereby triggering a catastrophic hazmat release.

3.2.2 France

Natural and technological disaster prevention and preparedness have generally been dealt with separately in France. France has a series of regulatory requirements that govern natural disaster risk prevention and prevention of technological disasters. However, there is no specific management system for natech disasters.

Following a series of hazardous material releases and other damage to industrial establishments caused by flooding in Southern France in 2002, the government of France recognized the potential for natechs. In 2003, a new law, N°2003-699 of 30/07/2003, was passed that in part addresses natechs. The law establishes rules regarding compensation for natech damage, and requires that prevention plans have to be carried out for technological risks as well as for the natural risks.

Vulnerability

The territory of France is subject to several types of natural hazards such as floods, landslides, earthquakes, avalanches, storms, forest fires, in addition to volcano eruptions and cyclones in overseas departments and territories which could potentially lead to natech disasters. Furthermore, France is home to a large number of establishments that use hazardous materials or produce toxic waste including industrial facilities, establishments for intensive breeding and waste treatment, and nuclear power plants and mines. Because of the juxtaposition of these facilities with areas subject to natural hazards, natural disaster-triggered technological disasters are a real threat.

Mitigation

France does not have a specific management system for natech disasters. However, regulations exist that both address prevention of natural disasters and prevention and preparedness for technological accidents.

Natural disaster risk prevention in France is governed by the Natural Risk Prevention Plan (RPP) law of 02/02/1995 (Article L.562-1 of the Environment Code), which constitutes one of the essential regulatory instruments of the State for this purpose. The RPP seeks to identify the hazards, assess the potential risks, carry out monitoring and warning programs, develop prevention and mitigation policies and regulations including the establishment of lawful zoning maps, develop disaster preparedness and emergency response plans, establish short and long term recovery programs, and promote public participation, education and awareness. The RPP has mechanisms in place that promote feedback from previous disaster experience in order to be better prepared during future natural hazard events. This was the case of the floods in 2002 which resulted in the enactment of the new law (N°2003-699 of 30/07/2003) that in part addresses natech risk reduction.

The regulations for industrial establishments that manage hazardous materials call for an analysis of external events (such as earthquake hazards) in their hazard analysis. Thus natechs are implicitly addressed. Industrial facilities and intensive breeding and waste treatment facilities are regulated by the Classified Installations for the Protection of the Environment (ICPE) legislation. This regulation seeks to identify and analyze the risks, whether their root causes are internal or external (natural hazard, for instance), to assess the consequences of the major accidents identified, to reduce the level of risk by implementing appropriate prevention and mitigation measures, to supply information to enable internal and external emergency plans to be drawn up in order to take the necessary measures in the event of a major accident, to inform the staff and the potentially affected population, and to provide sufficient information to the authorities to enable decisions to be made in terms of siting of new activities or developments around existing establishments (land-use planning). The decree N°77-1133 of September 21, 1977, and the circular of May 10, 2000 specifically indicate that external hazards, such as natural hazards, must be addressed in the safety report. However, the regulation does not propose specific actions to be taken and only lightning risk and seismic risk are governed the ICPE legislation.

Natech Examples

Two recent flood events, one in Northern France in December of 1999 and one in the Southern part of the country in 2002, caused severe damage to industrial establishments and triggered hazardous materials releases. Flooding affected several hydrocarbon storage facilities resulting in damage to electrical equipment such as pumps and motors, damage to safety systems such as gas detectors and other monitoring systems and emergency water systems, and leakage of hazardous materials such as hydrocarbons, hydrogen chloride, and sulphuric acid. In one facility power shortages threatened the cooling system of the cryogenic ammonia storage tank.

From these incidents, it was recognized that there is need to consider flood scenarios in the RPP reports, and that development of flood risk prevention plans including implementation of prevention and mitigation measures to reduce losses are needed. Examples include construction of protection levees or flood resistant walls, placing reactive chemicals at higher elevation or having plans to move them to a safe dry location, and anchoring of storage tanks so that they do not float off their foundations.

3.2.3 Germany

Germany does not have a specific natech disaster management program. However, it has an integrated system of prevention and warning systems so that the harmful effects of a natural disaster or technological disaster can be reduced considerably. Germany recognizes the need to identify and assess the risks to which it is subject to, to learn from past experience, and to develop appropriate prevention and mitigation measures to reduce their impacts. However, there are no specific natech risk reduction regulatory requirements or programs in place.

Vulnerability

Germany is subject to several natural hazard including floods, mudslides and avalanches, storms and forest fires. The presence of hazardous installations such as nuclear power plants and industrial facilities makes the country vulnerable to hazardous materials accidents caused by natural disasters. In Germany a mechanism is available whereby every disaster event is evaluated and the knowledge and experiences gained are incorporated into special measures and/or special disaster management plans. For example, following the floods of August 2002, the federal government in Germany is evaluating flood hazard in Saxony and Saxony-Anhalt in order to improve prevention measures and emergency plans and minimize flood losses during the next inundation event.

Mitigation

Although no specific natech risk management program exists, the country has several regulatory requirements and programs that govern natural disaster risk prevention and chemical accident prevention and preparedness.

Preparation of natural disaster emergency response plans are required under the Bavarian Disaster Control Law (BayKSG). Because storms represent a major threat, storm warning systems are now required by law. Under the Proclamation of Decree No. ID4-3041-ç/71 (AllMBl P. 362), passed by the Bavarian State Department of the Interior in 19 April 1991, warning of the population during an imminent storm became mandatory. These laws have promoted a series of programs including the development of hazard risk maps that include identifying the location of nuclear power plants and other hazardous installations, the creation of a publicly accessible hazard information system, the establishment of warning systems, and land use planning and hazard zoning.

In general chemical accident prevention is regulated by the Seveso II Directive, and the UNECE industry accident convention which regulates dangerous activities that can result in cross-border consequences. Analysis of potential incidents resulting from installations near the borders with the Czech Republic, Austria and Switzerland have been examined and mapped, and response plans have been developed in coordination with these neighboring countries. Based on the Seveso II Directive and the UNECE industry accident convention the operators of an industrial establishment must inform the public of any potential risk and the appropriate safety and emergency response actions that should be taken in the case of an accidental release. In addition, special disaster management plans have been developed to address recognized hazards related to critical transportation routes, nuclear power plants, pipelines, airports, railroads, train yards and water supply lines, among others.

Following the August floods which not only affected Germany, but also Austria and the Czech Republic, the German Federal Ministry of the Interior for Civil Defense (ZfZ) is carrying out a study entitled "Risks in Germany" to assess the risk of unusual dangers (such as natechs) or hazardous situations with national relevance in order to promote civilian safety precautions.

3.2.4 Italy

The Department of Civil Protection recently undertook a nationwide study to determine the adequacy of existing civil protection plans in case of flooding on the Arno River. The study pointed to Empoli, in the region of Tuscany, as a location particularly vulnerable to hazmat releases due to Arno River flooding. As a result of the study, the Department of Civil Protection has released a prototypical plan for preventing and mitigating a hazmat released caused by flooding, and focusing on the industrial district of Terrafino in Empoli. The plan has been widely disseminated to industrial facilities in Terrafino and has met with approval by local industrial associations. A number of individual factory efforts to implement the plan are underway, including one factory which has built an exterior steel structure for the purpose of raising hazmats off the ground where they had previously been piled up outside the factory. Elements of the Department of Civil Protection's prototype plan for Terrafino are described below.

Vulnerability

It was determined that the following accident scenarios could be triggered during a flood event:

– dispersion and transport through air (toxic cloud), water and soil of toxic/harmful substances dangerous for humans and the environment; even minimal quantities of these substances is of concern

– violent reactions because of contact between water and chemical compounds that generate toxic gases;

– fires and explosions.

The plan illustrates the consequences of the damaging effects triggered by these scenarios in the Figure 1 below:

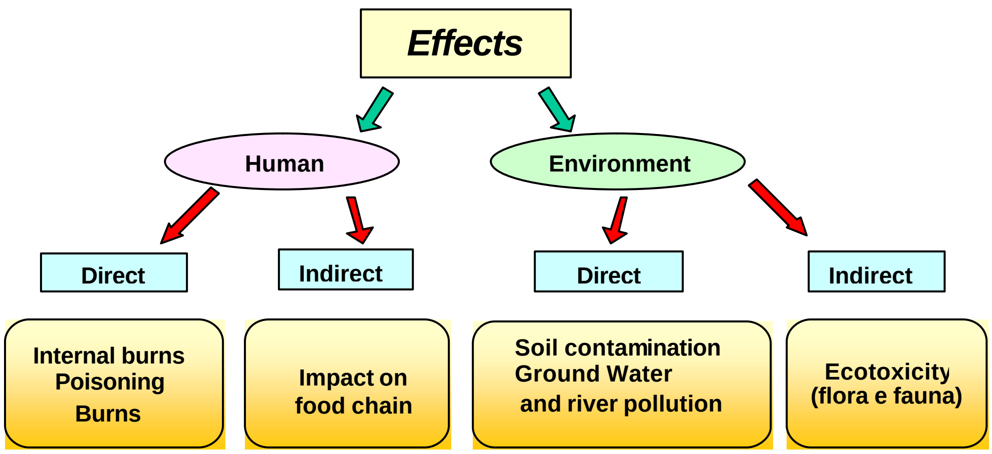


Figure 1 - Consequences of damaging effects triggered by accident scenarios.

Mitigation

In order to avoid accidents the plan suggests that a series of precautions be adopted in the presence of a flood emergency:

– Preventive measures involving fixed interventions such as:

  - o strategic placement of substances inside the plant in order to avoid chemical incompatibility;

- boosting the resistance of structures by appropriate choices of materials and design solutions;
- placement of pressurized and cryogenic storage systems above the maximum height reachable by water;
- creation of a drainage system;
- construction of trapezoid-section walls to protect the points most at risk.

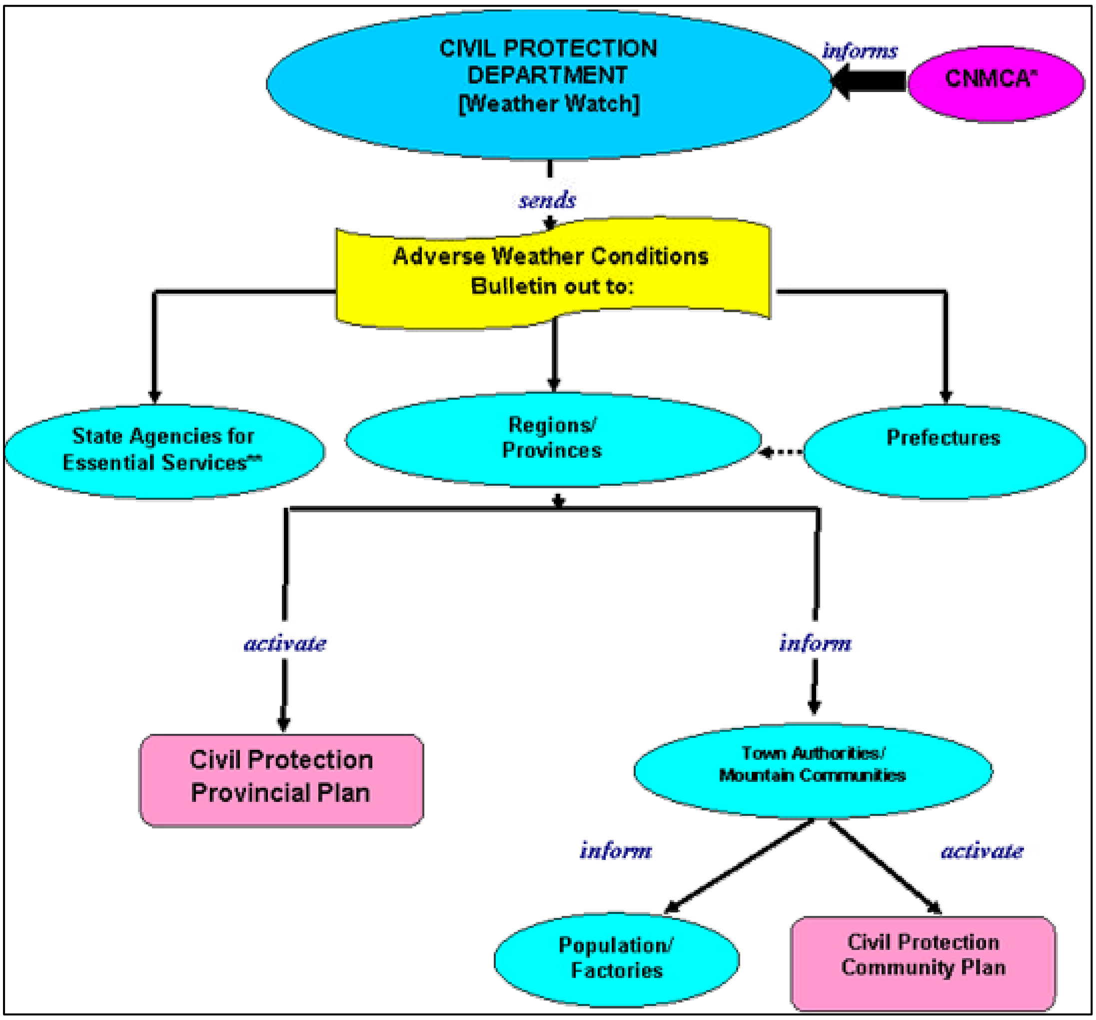
– Protective measures leading to temporary interventions in the case of imminent danger:
  - interruption of the production process;
  - anchorage of structures most exposed or least resistant with steel cables or the like;
  - verification of storage tanks seals;
  - securing of all dangerous materials and substance storage systems located in risk areas.

The timing of these temporary interventions is closely linked with the timeframe within which local authorities are able to disseminate flood alerts. At present, adverse weather advisories are disseminated according to the system illustrated in Figure 2. The system is currently being revised, however, to include the introduction of regional centres that receive, assess and disseminate advisories in real time.

After the factory is alerted by the civil authorities to the possibility of a major flood ("inform population/factories" in figure 2), it is expected that the factory will carry out the following set of emergency procedures, which do not require an interruption of the production process:

– Wearing of protective clothing necessary when transporting substances;
– Preparation of means for transporting the substances to safe storage and loading start-up;
– Wrapping of substances in watertight packing and precise labelling of contents;
– Giving transport priority to the most dangerous substances (those that react violently to water and air exposure);
– Raising of all containers above the maximum height reachable by water;
– Hermetic sealing of silos and underground storage tanks.
– anchorage of vulnerable structures

Table 4 describes the distribution of factories falling within the "Seveso II" category according to North, Centre and South and Islands of Italy.



** National Airforce Meteorology and Climatology Centre*
***Polstrada, Autostrade SpA, ANAS, Telecom, FFSS, Servizio Nazionale Dighe, ENEL*

Figure 2 – Scheme Flow-chart for the communication of adverse weather conditions bulletin.

Table 4 - Distribution of factories falling within the "Seveso II" category according to North, Centre, South and Islands.

	Art 8	Art 6	Total	%
NORTH	220	333	553	49.7
CENTRE	120	182	302	27.1
SOUTH and ISLANDS	116	142	258	23.2
Total	456	657	1.113	100

If the flood appears imminent, the factory will proceed to "pre-alert" stage in which an intensification of emergency procedures is undertaken:

– Interruption of utility systems (water, steam, compressed gases);
– Interruption of the flow of fuel to electrical plants;
– Interception of substances flowing inside pipes;
– Shutting down of electrical and heating systems;
– Interruption of the operative production phase;
– Removal of all materials and equipment on the production floor so as to reduce the risk of impact;
– Evacuation of personnel not essential to emergency operations.

Finally, in the "alert" stage, special teams of experts in the reduction and mitigation of the consequences of hazmat releases into the environment are sent to the factory.

3.2.5 Portugal

There is no specific system for natech risk management in Portugal. Although Portugal has been subject to several natural hazards, such as floods, strong winds or forest fires, the country has thus far not experienced a major natech event, although a near-miss natech incident provides valuable lessons. The Civil Protection Authority recognizes that several major gas pipelines and industrial facilities are vulnerable to natural hazards and could potentially lead to a natech disaster.

Vulnerability

Portugal is subject to several natural hazards which could trigger natech disasters. These include:

– Earthquakes or landslides which could trigger industrial accidents, pipeline collapse or dam breaks;
– Forest fires that can trigger fires in chemical plants or at storage terminals located near forestland;
– Floods which could cause leakage of dangerous substances from chemical plants or damage pipelines through soil erosion and possible collapse.

Earthquakes: Recognizing the threat posed by seismic activity in the metropolitan area of Lisbon and surrounding municipalities, the Ministry of Internal Affairs through the National Service for Fire and Civil Protection (SNBPC) started a project in 1997 to assess seismic vulnerability of this region. The main goal of the project was the development of an emergency contingency plan. Portugal is subject to moderate seismic activity characterised by long return periods associated to great magnitude events. The metropolitan area of Lisbon and the Algarve region, in the south, are the most vulnerable to natechs due to seismic risk, location of industrial establishments and gas and fuel pipelines, and also because it is one of the most densely populated regions in the country.

The final product of the seismic assessment project is a GIS-based simulator of seismic scenarios, containing all the available information on geophysical, geological, housing, important structures, lifelines of all kinds, population, etc., for the given region. Damage and loss estimation can be computed for large geographical areas or divisions. Although the program does not estimate damage and losses due to natechs, the Civil Protection authorities recognize that damage can be seriously increased if fires, tsunami, rupture of dams, rupture of pipelines and other natech events occur and impact the population.

Flooding: Portugal has identified that floods can trigger non-hazmat related natechs such as natural hazard-induced dam failures. Floods can occur in the territory of the country and they can affect riverine areas and dams, with resulting transboundary effects. In Portugal, water management during flood time is performed in close partnership between the Civil Protection authority, the National Water Institute and the Portuguese Meteorological Institute. Permanent contact is also maintained with dam management organizations and Spanish authorities to ensure the adjusted management of water flows in trans-boundary rivers.

Civil Protection has access to real-time data from more than 60 meteorological stations spread all over the country. Additionally, Civil Protection has access to a Surveillance and Alert System (sustained by the Water Institute) in order to ensure permanent analysis on the water resources. This system allows Civil Protection to follow the evolution of the hydrological situation in the Portuguese main hydro-graphic basins, in a real time basis.

Landslides: The potential for natech disasters caused by landslide has been studied, and it has been determined that at a gas and liquid fuel terminal located near Lisbon is particularly vulnerable to this type of natech. The location of this terminal in areas with high slope represents a potential threat, so some measures have been implemented to prevent landslide risk which could lead to a hazardous materials release.

Pipelines and industrial facilities: In Portugal hazardous materials releases could potentially occur from gas and fuel pipeline systems that traverse the country, and from more than 112 industrial establishments covered by the Seveso II Directive. There are two major pipelines in operation: a natural gas pipeline and a fuel pipeline. The gas pipeline starts near the border, with natural gas coming from Magreb, injected in the pipeline in the spanish territory. Natural gas is distributed in several lines through Portugal, crossing 13 districts and several municipalities. The fuel pipeline transports fuel, gasoline and LPG from a refinary located in Sines (south of Portugal) to a storage plant located in Aveiras de Cima, in the metropolitan area of Lisbon.

Mitigation

Portugal has implemented a series of prevention and mitigation measures to protect its citizens from natural hazards and potential technological disasters. For example, in the area with high slope and landslide risk, vegetation was planted to affix land and retaining walls were constructed. In other areas, a land drainage system for rainfall was constructed to avoid soil erosion. To prevent landslide and seismic damages at the gas and liquid fuel terminal, LPG storage tanks have been retrofitted with the support of 18 m foundation piles.

Seismic activity is also monitored at an LPG underground storage tank in Sines with 3 seismographs.

Industrial establishments are subject to the Seveso II Directive chemical accident prevention requirements. Although natech events are not contemplated in ordinary hazard analysis, some natech prevention and mitigation strategies are implemented due to other legislative restrictions. For example, legislation concerning seismic activity is analysed when a new plant is built (Regulation of Security for Structures - RSA, 1983) and seismic design standards are applied according to the seismic risk class - A to D (Figure 3) where the plant is located.

Natech Examples

During two flood events in December 2000 and January 2001 a major natech disaster was developing threatening nearby populations. Heavy and prolonged precipitation lead to flooding along the Mondego River basin. Despite emergency management efforts to prevent a flood disaster, a natech event started to develop: large flow eroded buffer-soil located over and under a gas pipeline, leading to its exposure. The exposed pipeline posed the threat of a gas release if ruptured, threatening a main Portuguese motorway, and the city of Coimbra and neighbouring villages.

In the 60's, a complex system of dams, channels and dykes were constructed to protect the region from inundation. The false sensation of security caused by the dykes, led population to build new houses and construct new roads in ancient flood plains, increasing risk to the population.

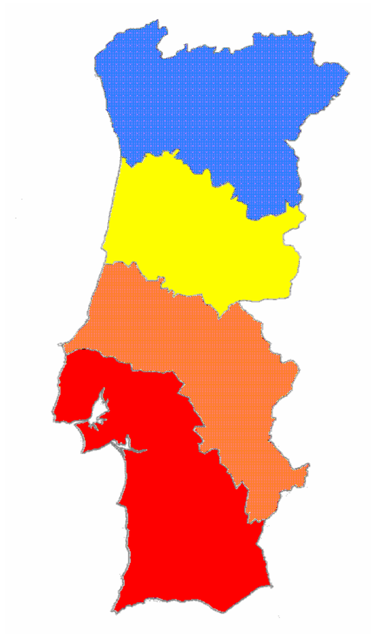


Figure 3 – Seismic zoning of Portuguese Continental territory (RSA, 1983).

The floods along the Mondego River basin increased tensions on the dyke systems. Initially the dykes were able to contain the river inside the banks. However, on the evening of 26 January 2001, after two days of rain, the dykes started to collapse. During 5 days, dyke-breaks caused floods in several towns and agricultural areas, threatening one of the main gas pipelines, and leading to evacuation or isolation of more than one hundred people. In cooperation between Civil Protection organizations, the Water Institute and the gas pipeline owner, emergency operations were carried out to avoid a natech disaster. Mitigation measures were immediately put in place such as the implementation of a concrete footing to prevent the pipeline from floating away. Taking in account potential gas release scenarios, specific actions to protect the public were considered such as the evacuation of nearby residents and road-traffic suppression. The emergency situation abated, however, so that these measures did not need to be taken.

The following lessons were noted by the Civil Protection in Portugal:

- The important to focus on the role of the Emergency Management Authority as the main coordinating organization for Civil Protection Operations.
- The need to focus on the role of Civil Protection as an interface between scientific knowledge and operational issues.
- The need to prepare natech risk scenarios and updated geographical information.
- The need to update emergency plans to consider the potential for natural disaster-triggered accidents.
- The need to improve articulation between organizations specialized in providing meteorological data (winds) and those doing gas dispersion modeling.
- The need to improve articulation between Civil Protection authorities at the local, district and national levels.
- Adoption of natech mitigation measures, such as recovery of dykes and pipeline stabilization (implantation of concrete footing to prevent floating) are very important.

3.2.6 Sweden

Sweden applies an all-hazards approach to risk management and emergency response, and has no specific natech risk management program. Swedish risk management programmes are managed at a local level and the municipalities have a responsibility for many aspects of public safety, which includes natech incidents. Fortunately, Sweden has had very few problems with natechs.

The Swedish government believes that natech management should be integrated into normal risk management work through existing mitigation policies. Land-use planning and environmental and safety permit granting for establishments are two important strategies for preventing and mitigating natech incidents. Risk mapping is an excellent tool for risk management as well helping in the process of land-use planning and to increase awareness and preparedness for natech incidents.

Vulnerability

Natechs can be triggered in Sweden by floods, landslides and snowstorms. Other natural hazards of less importance include storms and fires. Every year the country suffers from flood events, therefore the adoption of prevention and mitigation measures for flood control are promoted. For example, the government introduced a grant from which municipalities can apply for subsidies to cover the work of preventive measures against landslides and floods in built-up areas. Every year sees some snowstorms that paralyze large areas of Sweden. They often cause traffic accidents, power cuts, and other disruptions. The railways sometimes experience problems from avalanches.

There are technological establishments that are situated in areas subject to natural hazards, so there is potential for natech incidents in Sweden. Because natural disasters in general are rare and Sweden is a large country with very few built- up areas, natechs are a minor problem. However, there could be future problems because of an increase in major natural hazard incidents due to climate change.

Mitigation

Sweden has chosen the all-hazard approach and has no specific natech risk management programme. There are no guidelines or legislation specific for managing the risk of technological disasters triggered by natural hazards. However, there are a lot of legislation and guidelines and practical work in progress aimed at reducing risks posed by technological installations and to prevent natural disasters. Some of these measures include land use planning, risk mapping (e.g., of flood prone areas and general mapping of soil stability conditions), environmental and safety examinations, and industrial safety requirements such as the Seveso II Directive.

Municipalities in Sweden are responsible for carrying out risk inventories within their own borders, for taking preventive measures and establishing emergency plans. This applies to all kinds of emergencies including natural disasters and technological disasters. For example, the municipalities have the overall responsibility for land- use planning. This means that they have the responsibility for knowing about the natural conditions (e.g. areas with poor ground-stability, dams and calculated flood areas) in the municipality and responsibility for the location of new buildings. The construction of vulnerable buildings and technical installations should be avoided in areas that suffer from natural hazards. However, a large proportion of buildings have been constructed before careful consideration was given to the natural risks in the area.

There are no specific natech preparedness programs. However, plans to respond to floods, fires, chemical emergencies, and rail and road traffic accidents exist. Sweden provides training in emergency prevention and mitigation. The course also covers society's vulnerability and the consequences of disruptions to important technical supplies.

A new law states that all municipalities have to be prepared for crises and emergencies. The municipalities are obligated to carry out risk and vulnerability analyses at a local level. The risk and vulnerability analyses should include natechs.

Natech Events

The few natech related incidents that have occurred are primarily as a result of floods and have mainly affected transportation. It is common for roads and railways to become impassable as a result of heavy cloudbursts and floods. In some cases natural hazards have led to secondary accidents, incidents or disruptions to technical installations. Sometimes there will be disturbances to the electricity supply, phone systems, water supply systems, sewage treatment works, warning, alarming and security systems, and radio and television services.

3.2.7 The United States

In the United States natural and technological disasters have generally been dealt with as separate events. United States policy to protect property, workers, the public, and the environment from the effects of hazmat releases has not, for the most part, been linked to triggers by natural hazards. Thus, the vulnerability of industrial facilities and communities to hazmat releases is unnecessarily high, and response efforts are likely to be inadequate should a major release(s) occur consequent with a natural disaster. There are however a number of ways in which industrial facilities and neighboring communities are safeguarded from natechs. These measures all help to reduce the risk and/or impacts of natechs to some extent, but do not eliminate them.

Vulnerability

The United States has an extensive territory and is subject to all kinds of natural hazards including earthquakes and tsunamis, hurricanes, tornados, storms and snowstorms, flooding, landslides and mudslides, avalanches, forest fires, and volcanic eruptions. Some of the most densely populated regions of the country are also those that are subject to the highest natural hazard risk such as the states of California (subject to earthquake risk) and Florida (subject to hurricane risk). The US is also subject to technological hazards resulting from industrial activities, nuclear power plants, super-fund sites, and dams and levees, among others.

Mitigation

In the United States, there are a number of ways in which industrial facilities and neighboring communities are safeguarded from natechs. These measures all help to reduce the risk and/or impacts of natechs to some extent, but in many cases the risk remains. Prevention and mitigation measures presently in place can be categorized into:

- Design criteria
- Chemical process safeguards
- Combined natural hazard and chemical process safeguards
- Community Land Use
- Disaster Mitigation and Response Planning

Design criteria: The use of seismic building codes such as the Uniform Building Code, which requires that structural design include provisions for seismic resistance of the 475 year earthquake, or the more stringent International Building Code, which requires seismic design for the 2475 year earthquake. For wind loadings, most communities refer to the ASCE guidance (ASCE 7-98) which requires designs for the 50 year wind speed with an importance factor for structures containing hazmats which results in the equivalent of a 500 year wind speed for these structures. With respect to flooding, building in the 100 year flood plain is generally prohibited by communities, unless buildings are raised so that they are above the 100 year flood contour.

Chemical process safeguards: The United States Occupational Health and Safety Administration (OSHA) requires safety management and planning for chemical processing plants every five years. The primary objective of these plans is to protect the health and safety of the plant workers from accidental releases of hazardous chemicals. There are also two sets of requirements which apply to facilities that handle hazardous Chemicals. These requirements are administered by the United States Environmental Protection Agency. Unlike OSHA requirements, these are meant to guard communities located near industrial facilities from chemical hazards. Under the Risk Management Plan (RMP) provisions of the Clean Air Act, industrial facilities must prepare a safety management plan to minimize the risk of hazardous material releases affecting nearby ("fence-line") communities. These requirements however, do not require the consideration of natural hazard triggers in the prevention of chemical accidents or preparedness plans in case one does occur.

Combined natural hazard and chemical process safeguards: The California Accidental Release Program (CalARP) is similar to the RMP program of the Clean Air Act. It also requires off-site worst case analyses of potential chemical releases as well as planning for hazardous materials releases, but it also explicitly requires consideration of earthquake-caused hazmat releases. Special seismic guidelines provide specific recommendations on seismic design at chemical facilities.

Community land use planning: Communities have local land use jurisdiction and can restrict industrial facilities to industrial parks or require other types of separations between industrial facilities and residential areas. In this way, communities may be protected by long distances which the chemicals must travel before contacting the public.

Disaster mitigation and response planning: Each state has a State Emergency Management Agency which is linked to the national Federal Emergency Management Agency (FEMA) and supports county and local governments in the areas of civil defense, disaster mitigation and preparedness, planning, and response to and recovery from man-made or natural disasters. FEMA is now part of the Department of Homeland Security. The Disaster Mitigation Act of 2000 requires community mitigation planning across all hazards in order for communities to receive government aid. According to the this Act "Mitigation Planning is a collaborative process whereby hazards affecting the community are identified, vulnerability to hazards assessed, and consensus reached on how to minimize or eliminate the effects of these hazards." In implementing this Act, communities have taken it to include technological hazards, and many have acknowledged the possibility of natural hazard-triggered technological disasters.

Lessons Learnt

Natechs have been documented in the United States, indicating an increasing trend in this type of emergency. Some recent examples of natechs in the United States include:

- *Hurricane Georges, 1998*: Floating roof sinks, releases oil from storage tank in oil refinery. Also, tank with hazardous gasoline additives floats off its foundations.
- *Hurricane Floyd, 1999*: sets drums of hazardous chemicals afloat in Raritan River, New Jersey.
- *Northridge Earthquake, 1994*: 134 incidents of hazmat releases (including gas leaks) recorded; estimates state that 19% of industrial facilities probably experienced hazmat releases (Lindell and Perry 1997).
- *Loma Prieta Earthquake, 1989*: Numerous instances of hazardous chemicals from laboratories, hospitals, etc. found to have spilled.
- *Lightening strike to Louisiana refinery, 2001*: sets tank on fire and causes community evacuation.

These events, and foregoing analysis indicates that a large earthquake, powerful hurricane, or properly sited tornado could trigger a catastrophic release of hazardous materials in the United States. Because we have generally not prepared for natechs, such a release would likely be extremely difficult to respond to effectively. The response problem might be quickly exacerbated by simultaneous releases from the common triggering natural disaster, and emergency response to the natural disaster might be quickly overwhelmed. In addition, because local planners and the public have not been adequately prepared for natechs, the public and community will not be able to respond appropriately and mitigation measures designed for "normal" operating conditions, such as those evaluated under OSHA requirements, would likely fail. Thus, the gaps discussed above would both permit a natech to occur as well as help incapacitate response efforts.

3.3 Case Studies

In addition to the "state of the art" pieces, three case studies describing actual natech accidents were provided by workshop participants. Summaries of the case studies are given below.

3.3.1 The Italian Blackout of September 28, 2003

The Incident

This blackout was caused by a spruce-fur tree which fell under the force of high winds in Brunnen, Switzerland. The tree fell onto an electrode, cutting electrical power on a line supplying Italy with 1320 MW. Within twenty minutes, the Italian electrical grid automatically detached from the European network, thereby losing 6300 MW of power – more than 25% of its total consumption requirement. As a result, there was a power outage throughout almost all of Italy at 3:20 a.m. It was not restored to northern Italy for several hours; in central and southern Italy the situation remained critical until late afternoon. The emergency was finally declared over throughout Italy on the morning of September 29.

We include this case study in this report as an accident that represents what can happen under a broader definition of a natech – one in which a naturally-caused event triggers, not a hazmat release, but the malfunction of a technological system. It is important to note that the Italian Blackout was not a unique event, although the area affected by the outage was unusually large. Other European countries have reported similar weather-related power outages, most notably France in December 1999.

Effects of the Blackout

Some of the most notable effects of the blackout were:

Transportation and Communications

Railways: Service on 110 trains is disrupted, inconveniencing 30,000 passengers and leaving them stranded in complete darkness.

Metropolitan Transit: The greatest level of inconvenience was experienced in Rome where a special event is being held for the first time, known as the "Notte Bianca" (the city stays open all night) is underway. Metro trains are packed with passengers taking advantage of the all-night events, and they are forced to abandon the trains and reach the nearest station on foot.

Airports and Ferries: No major disruptions are noted.

Mobile Phone Service: Many areas of the country lost their signal reception.

Hospitals

Operating rooms lost power, but emergency generators were used to maintain sufficient power for critical operations. The generators were also used to maintain power to life-support equipment.

Calls for help

59,000 calls for emergency aid were received, including 3600 to fire departments. Ultimately, 8750 teams of state police and gendarmes, 4000 railway police, 1360 motorway patrols, and tens of thousands of volunteers were deployed to respond to the emergency.

3.3.2 The Tokachi-oki Earthquake, Japan, September 26, 2003

The Earthquake

On September 26, 2003 at 4:50 am, an earthquake with magnitude 8.0 struck the northern island of Japan, Hokkaido. The epicenter of the quake is shown in the figure below (figure A3.a). The earthquake caused a tsunami with a maximum height of 4.0 m According to the Japanese Minstry of Education, Culture, Sports, Science, and Technology, this earthquake had a 60% chance of occurring within 30 years.

As a result of the earthquake, two deaths and 844 casualities were reported. 60 homes were destroyed and almost 1400 were damaged. Total direct economic losses are estimated to be $187 million.

The Hazmat Release

The major hazmat release due to this earthquake occurred at the oil refinery at Tomakomai City, located on the coast 200 km from the earthquake's epicentre. The only damage reported at the refinery occurred at the oil storage facilities, where 45 of the 105 tanks were damaged by the earthquake. Two fires were reported. The first fire was apparently caused by sloshing of the fuel in the tank, which caused vertical rotation of the floating roof, permitting the oil to be exposed to the atmosphere and providing a ready opportunity for ignition of the oil. The second fire was caused when a chemical extinguisher covering the tank broke off due to earthquake shaking. A second fire also occurred in the tank farm, but its cause has not been determined. Fire fighting efforts were quickly underway, but were hampered by insufficient quantities of fire-fighting foam. The United States and other countries provided back-up supplies of foam.

As a result of the fires, the area was engulfed in an unpleasant-smelling plume of vapours, and soot and fire extinguisher foam were carried through the air to neighbouring residential areas. Economic losses due to the fire were heavy and the entire Tokakomai port was closed for a number of days.

3.3.3 The Kocaeli, Turkey Earthquake of August 17, 1999

The Earthquake

The magnitude 7.4 earthquake in Kocaeli, Turkey in August 17, 1999 resulted in over 17,000 deaths and more than 40,000 people injured. Thousands of residential and business units were damaged, and more than 350 industrial facilities in Kocaeli reported damage to their plants. In addition, the earthquake triggered large fires, toxic air releases of dangerous substances and oil spills at several industrial facilities. Kocaeli is one of the most densely populated regions of Turkey, and accounts for 30% of industrial production in Turkey.

Data for this study were obtained through a series of interviews and visits at nineteen industrial facilities in the affected region subject to Modified Mercalli Intensity of X. Interviews of government officials in charge of industrial risk management and emergency response were also carried out.

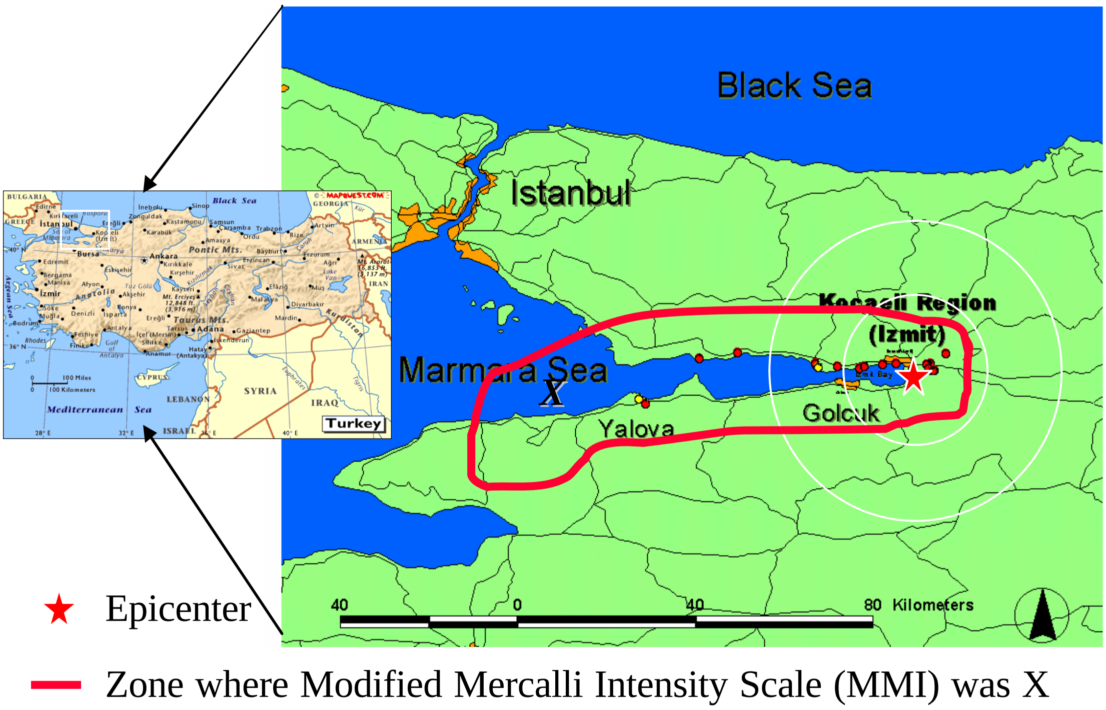


Figure 4 - Map depicting the epicenter of the Kocaeli earthquake of August 17, 1999 and the location of industrial facilities visited for the study.

Earthquake Effects

Eighteen of nineteen industrial facilities reported damage to their plants. Hazmat releases were reported at 14 (of 19) facilities, eight of these industrial facilities reported substantial hazmat releases with offsite consequences. A total of twenty one hazmat incidents were documented. Examples of hazmat releases include the release of 50,000 kg of crude oil into Izmit Bay, the release of 1.2 million kg of cryogenic oxygen, the spill of 100,000 kg of phosphoric acid, and three simultaneous independent fires at an oil refinery (Steinberg and Cruz 2004).

Problems with lifeline systems and onsite utilities were also reported. A total loss of electrical power and communications capabilities were reported in all facilities. All facilities reported problems with water supply, while five suffered loss of onsite emergency water. Furthermore, insufficient personnel to respond to hazmat releases was reported at all the plants that suffered hazmat problems.

Emergency Response to the Hazmat Problems during the Earthquake

Emergency response to the earthquake-triggered hazardous materials problems were imbued with many problems. Although safety and emergency response measures for accidental chemical releases existed, they were not designed to operate in the aftermath of a large earthquake or to withstand EQ forces. Industry emergency response plans for chemical accidents did not address hazmat releases during earthquakes, therefore considerations on how to respond to the earthquake triggered fires and hazmat spills in the absence of water, electrical power, and communications had not been properly analyzed. Furthermore, there were very little workers and emergency response personnel available. Panic behavior in the form of "flight away from danger" was blamed for emergency response deficiencies by almost all people interviewed at the industrial facilities visited.

Cascading Events Triggered by the Earthquake

The Kocaeli earthquakes caused secondary disasters, such as multiple hazardous material (hazmat) releases and fires described above, through a series of direct and indirect cascading events. The cascading events included various mechanisms and failure paths, in some cases involving the intersection of highly improbable and independent events. Cascading failures helped exacerbate the difficulties in responding to the joint natech events.

The following example illustrates the cascading events that were triggered by the earthquake in the naphtha tank farm at an oil refinery in Kocaeli:

- Vibration of the floating metal roofs against the tank shells creates sparks that ignite four naphtha tanks;
- Simultaneously, the earthquake damaged a flange connection on one of the burning naphtha tanks;
- Naphtha leaks through the damaged flange;
- The Naphtha leakage from the damaged flange ignites;
- The ignited naphtha flows downstream through a drainage canal;
- The fire spreads through the drainage canal to two additional tanks;
- Damages to power lines and main water pipelines delay fire fighting efforts;
- The large fires pose a threat to nearby storage tanks containing liquefied petroleum gas (LPG) and ethylene;
- The threat of explosion of LPG tanks threatens anhydrous ammonia storage tanks in nearby fertilizer plant. Due to the threat, an evacuation of 5 km area is ordered only 12 hours after the quake, and 200 tons of ammonia are intentionally released;
- Search and rescue is abandoned in evacuated areas.

The earthquake triggered cascading events that led to hazmat releases and that affected the capacity to respond to the hazmat releases. Furthermore, the hazmat releases triggered other hazmat problems, threatened other industrial facilities in the region, and had a negative effect on search and rescue of earthquake victims.

Similar events were experienced by an acrylic fiber plant in Yalova during the earthquake. The earthquake triggered the exposure and spill of 6.5 million kg of highly volatile acrylonitrile from three (out of 8) storage tanks.

3.3.4 Natech example from the Baia Mare Cyanide Spill in Romania

The Release

On the night of January 30/31, 2000, heavy precipitation and a sudden, unusual increase in ambient temperature resulted in the melting of a 43 cm thick snow strata covering a settling pond filled with cyanide-containing wastewater. The resulting increase in the pond level caused a breach of about 25 m in the pond's dam, allowing 100,000 m3 of wastewater to escape into the Lapus River, ultimately flowing into the the Somes River and crossing the border into Hungary and then Serbia.

The path of the spill can be seen on Figure 5. The maximum observed concentration was measured on the Szamos River at Csenger, where a concentration high of 32.6 mg/l was recorded. Concentrations decreased downstream. At Tiszasziget on the Tisza River in Hungary, the maximum observed concentration was 1.43 mg/l. Under Romanian law, the maximum permissible amount of cyanide in surface waters is 0.01 mg/l.

Figure 5 - Location and the evolution of the cyanide pollution Natech event

Emergency Response

Using the Principal International Alert Centre for Accidental Pollution on the Danube River (PIAC), all the downstream countries (Hungary, Yugoslavia, Bulgaria and Ukraine) were informed of the cyanide release, as well as the Secretariat of the International Commission for the Danube River Protection from Vienna. The PIAC is the Romania component of the multi-country Trans-National Monitoring Network which was created under the Bucharest Declaration to improve water quality management of the Danube river. It is part of the Accident Emergency and Prevention Warning System (AEPWS) which consists of all Danube catchment areas in each of the riparian countries. During this event, PIAC dispatched 128 warning messages, beginning on January 31, 2000, to the PIAC in Budapest, Hungary, and ending on March 02, 2000 with a final message to the Danube Secretariat in Vienna indicating that the cyanide pollution was totally diluted. In addition, local authorities of the affected water courses were warned to temporarily cease use of the river water for domestic needs and animal-drinking needs, and to prohibit the consumption of fish taken from the contaminated waters. Figure 6 below shows the information flow that proceeded from the accident.

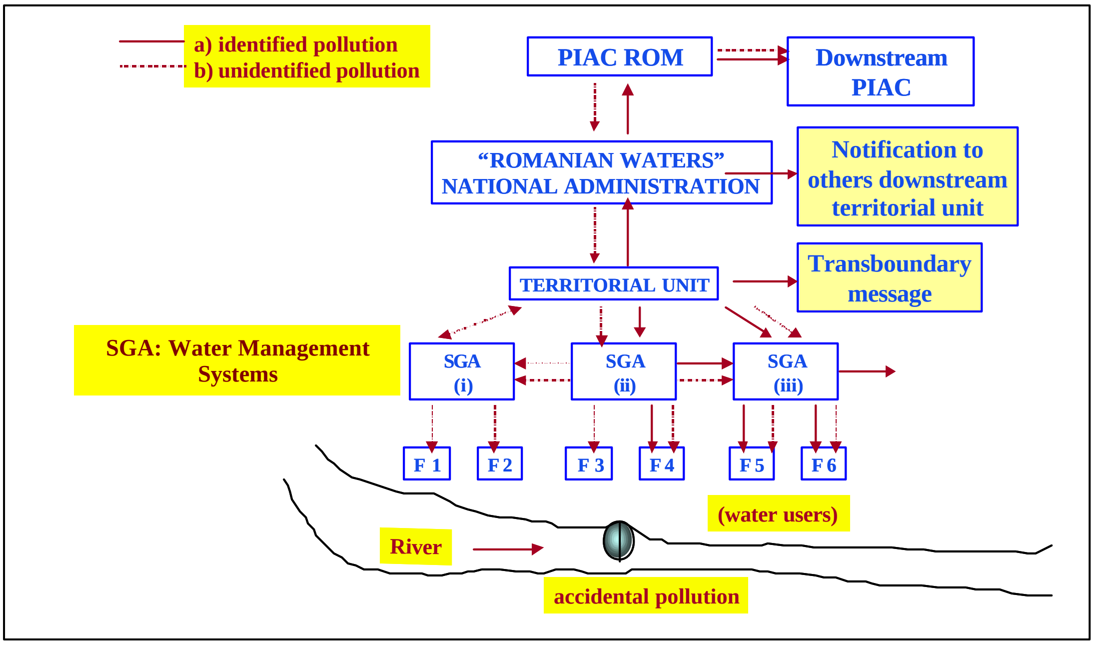


Figure 6 - Primary information flow in case of a local accidental pollution (with transboundary effect) at the level of a hydrographical basin.

In addition to the notification steps taken, the following actions occurred quickly:

- all activities at the metals-extracting plant which operating the settling pond were halted;
- the dam breach was closed;
- water which continued to be discharged from the settling pond was neutralized with sodium hypochlorine;
- a series of water samples were taken in order to determine the cyanide concentration in the affected waters and to monitor of the level of pollution.

Long-Term Response

In the aftermath of the spill, the Romanian Ministry of Agriculture, Forests, Waters and Environment has taken a number of actions to reduce the risk of environmental pollution from breached dams. These include the development of methodologies for establishing dam importance categories, and assessing dam, reservoir, and industrial wastewater holding ponds safety. Also, a national law requiring greater regulation of dam operation was passed, including dams and dykes on industrial settling ponds, and a national program of dam inspection was instituted. Water quality monitoring system will be modernized by adding automatic stations for the continuous surveillance of water quality constituents, and additional pollution source controls on Tisa and Soma river catchments were instituted. Finally, a new water supply for the population affected by the cyanide spill was developed.

At the international level, a number of responses have occurred:

- A coordinated plan of response in case of an accidental chemical spill was elaborated for the rivers of the Upper Tisa basin, together with Hungary and Ukraine.
- An updated list of hot spots in the Danube watershed has been prepared. Hotspots have been identified in 3 sectors: municipal, agriculture and industry, and are divided into high and medium priority.
- The International Task Force for Assessing the Baia Mare accident was created and tasked with:
- Analyzing the conditions which led to accidental pollution;
- Assessing the damages on the Lapus, Somes, Tisza and Danube aquatic ecosystems; and
- Establishing the necessary actions to be carried out in order to avoid further accidental pollution, including publishing an "Inventory of High Risk Sites" in the mining, extractive and ore processing industries in the Tisa River basin.

CHAPTER 4. ANALYSIS AND CONCLUSIONS

This report presents an overview of the state of the art of natech risk management in Europe, and the United States. The literature available on natech disasters and natech risk management is scarce. The majority of the studies refer to risk management practices in the United States, and are mainly concerned with earthquake triggered hazardous materials releases. Clearly, more detailed studies of natech planning and mitigation at the national, regional and local levels are needed. In Europe, there is some evidence of natech risk management practice that can be detected from the countries selected for study in Chapter 3 and from the various legal acts that address natech-related aspects in Table 3. However, there is presently no organized and systematic manner in which natechs are dealt with in Europe. The OECD International Futures Project is currently carrying out various risk management practice pilot studies in several European countries. This may lead the way to highlighting the needs of each European country's reality in identifying how to improve risk management and how to mainstream it as part of each institution's governance strategy.

All of the countries have disaster management systems in place for natural disasters and technological disasters. Most of the countries use an integrated emergency response management system which allows them to address the multi-hazards to which their countries are subject to. Nevertheless, 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. A summary of actions that directly or indirectly address natech risk at the EC level and at the individual country level is presented in Table 5.

All of the countries have specific regulations in place for chemical accident prevention and to protect its citizens from the impacts of natural hazards. As was discussed in the introduction, 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, 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. All of the countries have systems in place for reporting and 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.

Finally, 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 such as Italy, France, Portugal and the State of California in the United States.

Table 5. Summary of actions that directly or indirectly address natech risk at the EC level, and in individual countries.

Country	**Action**					
	Laws related to chemical accident prevention: Seveso II Directive	Laws related to natural hazards	Systematic reporting and recording of natechs	Natech risk mapping	Specific natech risk management programs/laws	Awareness/ concern about natech risk
European Community level	Through Articles 6 and 8 addresses prevention, preparedness and response. Requires analysis of external hazards such as seismic risk or floods Little guidance available on specific actions to be taken. Only governs sites housing certain regulated chemicals, others with non-Seveso II chemicals may not be protected	Natechs addressed indirectly through: - Seismic design codes - Floodplain management - Land use requirements	No Reporting of certain major chemical accidents, no specific process for natechs Database of Seveso II establishments kept for EU countries, needs to incorporate incoming countries Database not specific for natechs, querying not always possible	No	No	Yes, growing concern among research community following floods in August 2002
Italy	Seveso II Directive, same as above	Same as above	No Reporting of certain major chemical accidents, no specific process for natechs	Superimposing of flood risk areas with areas of high industrial facility density	No However, the Italian Civil Protection is carrying out a case study of a flood warning system to prevent natechs in northern Italy	Yes

Bulgaria	Seveso II requirements are being put in place	Major hazard involves earthquakes Natechs addressed indirectly through seismic design codes and other construction standards, and land use requirements. However, construction standards have varied to incorporate new seismic hazards in the territory. Older facilities may not be designed to current codes	No Seveso II requirements Country maintains database and map of major hazardous installations.	No	No However, natech risk assessment has been done for certain major hazardous installations	Yes
France	Seveso II Directive, same as above	Natechs addressed indirectly through seismic construction codes, land use planning, flood plain management, among others. Only seismic and lightning risk specifically considered for regulated facilities	No Seveso II requirements Country maintains database and map of major hazardous installations.	No	No New law (N°2003-699 of 30/07/2003) that in part addresses natech risk reduction.	Yes, particularly after natech events during floods in 1999 and 2002.
Germany	Seveso II Directive, same as above	Natechs addressed indirectly through seismic construction codes, land use planning, flood plain management, among others.	No Seveso II requirements	No	No However, after recent floods gov't implements project to assess the risk of unusual dangers (such as natechs)	Yes, particularly after floods in August 2002.
Portugal	Seveso II Directive, same as above	Natechs addressed indirectly through seismic construction codes, land use planning, flood plain management, construction of preventive infrastructure, among others.	No Seveso II requirements Country maintains database and map of major hazardous installations.	No	No However, natech risk reduction measures have been taken to protect gas and oil pipelines and fuel terminals from flood, earthquake and landslide hazards.	Yes, particularly after floods along Mondego River in 2001

United States	Federal risk management and emergency response requirements under OSHA and RMP to protect workers and the public from accidental chemical accidents Does not require analysis of external hazards such as seismic risk or floods. Only governs sites housing certain regulated chemicals, others with non-regulated chemicals may not be protected	Natechs may be addressed indirectly through seismic design codes, land use planning, flood plain management, construction of preventive infrastructure, among others.	No States and federal government maintain databases of chemical accidents. Changes in formats and reporting criteria make it difficult to identify natechs and trends on natech incidence.	No An initiative to determine the incidence of natechs and construct natech probabilistic hazard maps is underway at Tulane University under the direction of Dr. Laura Steinberg	Not at Federal level However, the State of California requires analyses external hazards such as seismic risk in the hazard analysis when planning for chemical accidents. It also explicitly requires consideration of earthquake-caused hazmat releases. Special seismic guidelines provide specific recommendations on seismic design at chemical facilities.	Yes Particularly after the Lomaprieta and Northridge earthquakes in California and recently following the Kocaeli earthquake
Japan	Not provided	Natechs may be addressed indirectly through strict seismic design codes, land use planning, flood plain management, construction of preventive infrastructure, among others.	No	No	No	Yes Particularly after the recent earthquake triggered fires in Hokaido
Sweden	Seveso II Directive, same as above	Natechs are addressed indirectly through construction design codes, risk mapping, land use planning, flood plain management, construction of preventive infrastructure, among others.	No	No	No However, new law states that all municipalities must perform risk and vulnerability analysis including natechs	Yes

Although there is some attention given to natech preparedness, mitigation, and response in most countries, there are still major gaps in these areas. These gaps were best summarized by Steinberg (in VETERE ARELLANO ET AL. 2004) as follows:

1. Lack of first hand data. There is a need for centralized reporting of natechs. Currently data is closely held by local governments and industry, and what is reported to is difficult for the public to access. In addition, there is little sharing of information regarding natech occurrences and risk reduction measures between counties.
2. Probabilities of natechs occurring have not been calculated – this would complement similar data on other hazards. An assessment of the probability of natech occurrence, as a function of location and type of natural hazard, would stimulate and facilitate better natech planning.
3. Vulnerability assessments to technological hazards have been left to industry to perform – it is difficult to verify the information provided and to determine if sufficient safeguards have been implemented. Furthermore, industry vulnerability assessments do not include natural hazard triggers and therefore preparedness, mitigation, and response plans do not consider special natech-related problems and obstacles.
4. Older facilities do not meet current design standards. In some areas design standards for seismic loadings have steadily gotten more stringent in the last 40 years or so, but many facilities housing hazardous materials were built many years ago, and therefore do not meet current standards. In many cases, these facilities are not required to upgrade current standards.
5. Community mitigation and response plans do not incorporate simultaneous and multiple disasters. Similar to the planning and risk management by industry (#3 above), local communities are generally planning only for either a natural or technological disaster, but not for a natech.

Design standards can be exceeded. Infrastructure built to protect citizens from natural hazards sometimes give a false sense of security leading to urbanization and industrialization of areas of high natural disaster risk as occurred in the Mondego River basin in Portugal. Even current design standards, more stringent than in years past, can still be exceeded if a natural disaster is severe enough. Society must explicitly be asked to consider and decide upon the level of risk (and subsequent losses)with which it is comfortable.

The case studies presented confirmed that natural disaster forces can act as a common force capable of initiating multiple and simultaneous independent events that combined can result in devastating consequences. The case study presented by Cruz (see VETERE ARELLANO ET AL. 2004) clearly illustrates the main problems that can arise with respect to natech risk management and emergency response. These include:

- The natural hazard design considerations are generally not applied to safety and mitigation measures.

- Safety and mitigation measures at industrial facilities are generally designed based on the availability of lifelines. That is they are designed to prevent and respond to chemical accidents during normal day-to-day plant operation.
- Emergency response (ER) plans for hazmat releases generally consider one hazmat incident at a time. Single or multiple events from one or more sources are not considered; therefore emergency response may be inadequate.
- The proximity of the industrial facilities to urban areas can affect not only nearby residential areas, but also neighboring communities.
- The natech disasters pose additional health and psychological problems to an already devastated population.
- Local emergency management officials may be unprepared to respond to multiple hazmat releases and chemical accidents. The hazmat problems will use up much needed resources to respond to natural hazard victims.

The case study of the Kocaeli earthquake showed that the consequences of natechs can be higher in large metropolitan areas because there are more people and infrastructure at risk. In this context, analysis of vulnerability to natechs in large urban areas is essential for natech risk reduction.

The study findings show that the analysis of external hazards such as earthquakes must be carried out and incorporated in plant designs. However, this may not be sufficient, unless industrial risk management and emergency response measures are also designed to operate in the absence of water or electrical power, which often occurs during natural disasters.

Those in charge of community disaster prevention and preparedness must be made aware of the potential dangers associated with natech hazards so that they may be prepared to respond to these types of events. Identifying potential release scenarios will help in emergency preparedness planning for multiple and simultaneous events.

Finally, addressing natechs will require that people typically working in industrial and technological risk management work together with those involved in natural disaster risk reduction.

5. Recommendations for Future Research

This report suggests that more detailed studies are needed at the national and local levels that assess risk management and emergency response practices by government agencies, industrial facilities, and communities to natural disaster-induced technological disasters and other systemic risks. These studies would also serve to identify innovative natech risk reduction strategies, such as those implemented by the Italian civil protection authorities, and allow for knowledge transfer to other regions in Europe and in the developing world.

Systematic data on natech incidents is needed. Most countries already collect data on chemical accidents, therefore collection of data on natechs would require only a small effort. Having data on the incidence of natechs in a region would be helpful in developing natech hazard maps.

It is not clear what a natech disaster, as compared to a natural disaster, means in terms of economic, human, and environmental costs. The collection of data on social-economic losses due to natechs is crucial, both to clearly identify the magnitude of the problem, and to permit cost-benefit studies to determine if prevention and mitigation of natechs really pays.

Natural disasters have the potential to trigger simultaneous technological failures from single or multiple sources. Designing preparedness plans for multiple and simultaneous accidents would prove valuable not only for addressing natechs, but other type of disasters involving multiple accidents such as acts of terrorism.

Urbanization has been found to be an important factor in the increase of natural disasters and economic losses from disasters in regions subject to natural hazards. Analysis of economic development policies and industrialization to determine how they affect vulnerability to natech disasters and other systemic risks would help guide future development programs in the developing world. In addition, case studies could be developed to promote sustainable risk reduction practices and coping mechanisms in regions of high natech risk.

Finally, the current research shows that preparedness for natech disasters is low. However, it is difficult to establish actual levels of preparedness for natechs or any other type of disaster. The development of comparative indicators of preparedness for natechs and other hazards would help decision-makers design appropriate policy options to protect those regions that need it the most.

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