

# CHEMICAL RELEASES CAUSED BY NATURAL HAZARD EVENTS AND DISASTERS

INFORMATION FOR  
PUBLIC HEALTH  
AUTHORITIES



World Health  
Organization



# **CHEMICAL RELEASES CAUSED BY NATURAL HAZARD EVENTS AND DISASTERS**

INFORMATION FOR PUBLIC  
HEALTH AUTHORITIES



**World Health  
Organization**

Chemical releases caused by natural hazard events and disasters – information for public health authorities

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Cover photograph from Wenchuan earthquake in China courtesy of E Krausmann.

## 1. INTRODUCTION

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Disasters resulting from natural hazards such as earthquakes, hurricanes, tsunamis and floods, are increasing in intensity, frequency and impact, in part due to climate change (1, 2). They can cause severe environmental and infrastructural disruption and significant economic losses. Disasters can directly affect human health through injuries, death and disease outbreaks, and longer-term impacts may include noncommunicable diseases, psychiatric morbidity and disabilities. The capacity of the health sector to respond to these effects is frequently impaired by damage to health facilities and disruption to health services (3).

A natural hazard can trigger a chemical release. When the release is the result of a technological accident it is called a 'Natech' (natural-hazard-triggered technological) event. Natech events can exacerbate the impact of a natural disaster on the environment and on human health because of the release of hazardous materials, fires and explosions (4–6).

The causes and consequences of Natech events are relatively recent areas of study by risk managers. It has been observed that, while there may be prevention and preparedness measures and response and recovery plans to deal with the risks from either technological or natural hazards, these are rarely integrated (4). Moreover, there is a lack of methods and tools for Natech risk analysis and mapping (4). In areas prone to natural hazards it is, therefore, important to develop plans that incorporate the possibility of dealing with natural and secondary technological disasters at the same time.

## 2. PURPOSE, SCOPE AND STRUCTURE OF THIS DOCUMENT

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This document aims to provide brief information to planners in the health sector and to public health authorities who wish to learn more about chemical releases resulting from natural hazard events. While the main theme of the document is Natech events, information is also provided about other sources of chemical release subsequent to a natural hazard event. The particular challenges with

Natech events are described. The document then gives an overview of the role and activities of the health sector at all stages of the risk-management cycle. Hazard-specific annexes (Annexes A–C) provide information on the mechanisms of chemical release resulting from earthquakes, floods and cyclones and the subsequent health impacts, as well as brief information on response activities. The annexes are intended to be standalone documents; hence there is some repetition of information. The two final annexes list other resources relevant to this topic and provide information on hazard pictograms.

A natural hazard can also cause the release of radioactive material, e.g. following damage to a nuclear power plant caused by an earthquake or flood. While these types of release are outside the scope of this document, similar principles of prevention, preparedness and response apply.

## 3. POLICY FRAMEWORK

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In an effort to reduce the social, economic, environmental and health losses caused by disasters, governments adopted the *Hyogo framework for action 2005–2015* (7), which described the work that was required from different sectors and actors to reduce disaster losses. This was succeeded by the *Sendai framework for disaster risk reduction 2015–2030* (1), which has shifted the focus from managing disasters to managing risks. The Sendai framework has a wide scope, encompassing the risk of all types and scales of disaster, whether large or small, frequent or infrequent and natural or man-made. The framework specifically highlights the need for an integrated, all-hazard, multisectoral approach to disaster risk management and, in doing so, directly addresses the challenges presented by Natech events.

The Sendai framework has a strong focus on health; it emphasizes the need for resilient health systems and the integration of disaster risk management into health-care provision at all levels. This need is also reflected in a recent World Health Assembly Resolution, which urged Member States to strengthen all-hazards health emergency and disaster risk-management programmes and to integrate these into national or subnational health plans. Furthermore, Member States were urged

to facilitate access by relevant agencies to information on types and quantities of hazardous materials stored, used or transported, in order to support effective health emergency and disaster risk management (8). The International Health Regulations (2005) provide further direction to countries on the need for capacities to detect, assess and respond to public health events caused by all types of hazard (9).

## 4. WHAT IS A NATECH EVENT?

As mentioned above, a Natech event is a technological accident triggered by a natural hazard. These can include floods, earthquakes, lightning, cyclones and extreme temperatures (10, 11). A technological accident can include damage to, and release of chemicals from, fixed chemical installations, oil and gas pipelines, storage sites, transportation links, waste sites and mines. **Table 1** provides some illustrative examples. The frequency of such events is not well known, but an analysis of a number of chemical accident databases found that 2–5% of incidents resulting in the release of hazardous substances were triggered by natural hazard events, and these figures were considered to be underestimates due to the underreporting of low-consequence accidents (17, 18). It is likely that the risk and impact of Natech events is increasing, due to a combination of increasing industrialization and urbanization coupled with a predicted increase in hydro-meteorological hazards caused by climate change (13, 18). A database listing Natech events can be found at <http://enatech.jrc.ec.europa.eu/Home>.

### 4.1 CHALLENGES FOR THE MANAGEMENT OF NATECH EVENTS

If industrial or chemical-storage sites are located in hazard-prone areas, the probability of Natech events increases. Natech events are potentially more dangerous than chemical incidents during normal plant operation for a number of reasons. First, natural hazard events may cover a large geographical area and may, therefore, affect multiple chemical sites at the same time. Even on a single site, there are likely to be multiple and

simultaneous damage or failure events and chemical releases; moreover, safety mechanisms intended to prevent a chemical release or mitigate its consequences may be damaged during the event (4). Second, the ability of local authorities and services to respond to the chemical release will often be severely curtailed because of the other impacts of the natural event, e.g. blocked, damaged or flooded roads and overwhelming demand for rescue. The chemical release itself may prevent or hinder rescue operations because of the additional risks posed to emergency-response personnel.

The Kocaeli earthquake in Turkey (See **Annex A, Box A1**) illustrates the ways in which a natural hazard can cause a chemical release and how the Natech event can affect emergency response to the natural disaster. This earthquake triggered the release of highly toxic acrylonitrile, but also reduced response capacity by shutting down communication networks and causing roads to be inaccessible (19, 20). The lessons learnt from this and other Natech events highlight the need to regulate and plan for such events in order to minimize the risk of chemical releases, and emphasize the importance of intersectoral coordination and good communication.

### 4.2 SOURCES OF CHEMICAL RELEASE

Chemical releases may be caused directly or indirectly by a natural hazard. These releases may be small, e.g. household chemicals washed out of their storage place into floodwaters, or large, e.g. thousands of litres of a toxic chemical spilling from a ruptured storage tank. Large-scale releases are particularly likely from pipelines and at fixed chemical installations, where storage vessels and connecting pipes and flanges can be damaged by earthquakes and floods (18, 21). Lightning strikes, which often accompany cyclones, can ignite flammable materials in storage tanks causing fires, which may then spread (18). Damage to the power supply may cause process upsets or affect temperature and pressure monitors and control valves, potentially resulting in runaway chemical reactions and blow-down<sup>a</sup>. Damage to railways and roads can result

<sup>a</sup> A blow-down is the process by which a safety relief system is activated to depressurize process equipment, sending vapours and liquids to the flare to be burned.

**TABLE 1. EXAMPLES OF NATECH EVENTS**

	<b>COUNTRY, DATE</b>	<b>CHEMICAL FACILITY AFFECTED</b>	<b>CONSEQUENCES</b>
EARTHQUAKE	<b>Japan, 2011</b> (4, 12)	<b>Oil refinery</b>	The Great East Japan earthquake and resulting tsunami damaged a large number of chemical installations. A refinery was inundated causing structural damage. Fires started in storage tanks containing sulfur, asphalt and gasoline. After ignition of the sulfur and the formation of a toxic gas cloud, an evacuation order for a 2-km radius around the facility was issued. Fires and explosions at another refinery triggered further fires at neighbouring chemical facilities.
	<b>Turkey, 1999</b> (4)	<b>Industrial facilities, oil refinery tank farm</b>	There were substantial chemical releases from eight industrial facilities, including the release of crude oil, phosphoric acid and acrylonitrile. There were three separate, simultaneous fires at a tank farm. Response was hampered by the loss of electrical power, communication systems and on-site emergency water at affected facilities.
FLOODING	<b>Central Europe, 2002</b> (13)	<b>Chemical factories</b>	A prolonged period of heavy rain caused generalized flooding. A chemical factory close to the River Elbe in the Czech Republic was inundated causing chemical release including 80 tonnes of chlorine. After the flood, significant concentrations of mercury and dioxins were found in water and sediments, and surrounding farmland was considered unfit for agricultural use for a number of years. The same rains caused a dam on the River Mulde in Germany to burst. A chemical complex was flooded and a military operation was needed to prevent chemicals from being washed into the river.
	<b>Romania, 2000</b> (5, 14)	<b>Gold mine settling pond</b>	The combination of sudden snowmelt and heavy rain increased the water level in the settling pond, breaching the pond's dam. A large volume of wastewater containing cyanide and toxic metals was released into a river system that crossed borders into Hungary and Serbia. Initial cyanide concentrations in the rivers exceeded permissible limits so drinking-water abstraction had to be stopped. A large number of fish were killed.
	<b>USA, 1994</b> (4)	<b>Oil and gas pipelines</b>	Heavy rains caused the San Jacinto river to flood, rupturing eight pipelines and undermining 29 others. This resulted in the release of 36 000 barrels of crude oil and nearly 200 million m <sup>3</sup> of natural gas. The releases ignited, causing 545 injuries primarily due to smoke and vapour inhalation.
CYCLONE	<b>USA, 2005</b> (4, 15)	<b>Refineries and petrochemical facilities, vehicles, fuel stores, waste sites</b>	During hurricane Katrina, the combination of high winds and storm surge caused oil spills from refineries, the release of diesel fuel from abandoned vehicles, tanks and waste sites, and the remobilization of soil contaminants. Arsenic and benzo(a)pyrene were found in high concentrations in sediment around residential areas.
	<b>Honduras, 1998</b> (16)	<b>Waste sites</b>	Heavy rains associated with hurricane Mitch caused flooding of a number of waste sites. Agricultural chemicals were released into the environment.
EXTREME COLD WEATHER	<b>France, 2002</b> (11)	<b>Chemical plant</b>	Freezing temperatures caused cyclohexane to solidify in a pipe, resulting in blockages. As there was inadequate temperature control of the pipe and varying temperatures within, liquid cyclohexane trapped between the blockages expanded and ruptured part of the pipe causing a leak. The source of the leak was not identified until 30 hours later by which time 1200 tonnes of cyclohexane had escaped.
EXTREME HOT WEATHER	<b>USA, 2005</b> (11)	<b>Gas repacking site</b>	High ambient temperature and strong sunlight during a heatwave heated propylene gas cylinders, increasing the internal pressure and causing the relief device on a cylinder valve to open and vent propylene. This ignited and started a fire that swept through the storage area, causing other cylinders to explode and shoot through the air hitting surrounding homes and cars. A contributory factor was that the pressure relief device was set too low for the prevailing circumstances.

in derailment and/or overturning of tankers containing chemicals (22). Floods can cause direct contamination of drinking-water sources, either through the release of stored chemicals or by remobilizing chemicals that were already in the environment (23). Damage to health-care facilities and laboratories may also result in the release of chemicals such as reagents and disinfectants. Very low temperatures or prolonged periods of intense cold can cause pipes to freeze and then burst as the melting chemical contents expand. Heavy ice can cause structural damage to equipment and break pipes (11). High temperatures create conditions that increase the risk of ignition of substances stored outside. High temperatures also cause chemicals within closed storage vessels (e.g. cylinders and railcars) to expand, triggering the opening of pressure relief valves and venting of the chemical (11).

**Figure 1** gives an overview of potential sources of chemical release due to natural hazard impacts that may have serious health and other consequences. More information on the mechanisms of chemical release can be found in the annexes.

Carbon monoxide is a common example of an indirect chemical release. It is produced by the incomplete combustion of carbon-based fuels and is found in high concentrations in the exhaust of portable generators as well as in fumes from smouldering charcoal (25). It is typically associated with power outages and the need for alternative energy supplies. Outbreaks of carbon monoxide poisoning have been reported from the use of portable emergency power generators and water pumps inside the home or placed near ventilation inlets, and from burning charcoal indoors for heating and cooking (25, 26).

Another potential source of indirect chemical release is the increased use of pesticides to control vector-borne and zoonotic diseases. Environmental deterioration after a natural disaster can result in an increase in vector breeding sites and rodent populations, with a consequent increased risk of disease outbreaks (27). Public health authorities may decide to manage this risk through the extensive use of insecticides and rodenticides and this, in turn, may lead to an increased risk of exposure to these chemicals by the workers applying them and by local communities unless adequate precautions are taken.

During the clean-up and recovery phase there may also be chemical releases. Cutting and moving damaged asbestos-cement roofing and pipes may release asbestos fibres. The uncontrolled burning of post-disaster waste can result in the generation of toxic and irritant smoke.

## 5. THE ROLE OF THE HEALTH SECTOR IN RISK MANAGEMENT FOR CHEMICAL INCIDENTS TRIGGERED BY NATURAL HAZARD EVENTS

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The health sector is on the front line when it comes to dealing with the health impacts of an incident and it should play a role at all stages of the disaster risk-management cycle, i.e. prevention, preparedness, response and recovery (3). It may play an influencing, complementary or leadership role in these various stages (28). The health sector can raise the awareness of decision-makers and populations about chemical hazards during natural disasters and advocate for the protection of human health and vulnerable groups.

Each country or community has its own economic, social, health and cultural context and, therefore, each event will have unique characteristics to some extent. The role of the health sector will depend on national legislation, traditions and existing capacities. Understanding the role of the health sector is important so that effective capacities, including health emergency-response plans, are developed for managing the risks of chemical releases.

### 5.1 THE ROLE OF THE HEALTH SECTOR IN PREVENTION

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Preventive measures for Natech events are largely the responsibility of sectors other than health. These measures include the use of legislation and regulations, for example requiring relevant agencies and industries to develop plans for Natech events, and land-use and spatial planning controls to ensure that chemical installations, landfills and waste lagoons are not built on flood plains or in other areas at risk of natural hazards (12, 29, 30). The introduction and enforcement of adequate building codes can ensure that buildings

**FIGURE 1. EXAMPLES OF VULNERABLE SITES FOR CHEMICAL RELEASE CAUSED BY NATURAL HAZARDS AND EXAMPLES OF THE TYPES OF CHEMICALS THAT MIGHT BE RELEASED (24)**

### Fuel storage sites, tank farms

- kerosene
- petroleum
- propane
- butane



### Waste storage sites

- oil
- solvents
- polychlorinated biphenyls



### Gas and oil pipelines

- natural gas (methane)
- crude oil



### Tailing dams

- toxic sludge
- mine tailings containing cyanide and arsenic



### Petroleum or petrochemical industries

- ammonia
- benzene
- crude oil
- hydrogen sulfide



### Acid mine drainage (abandoned mines)

- aluminium
- arsenic
- cadmium
- lead
- manganese



### Chemical factories

- alkalis
- acrolein
- methanol
- organic peroxides



### Transport: railways, roads, rivers, sea

bulk chemicals e.g.:

- ammonia
- chlorine
- petroleum
- methanol



### Food processing plants

- ammonia



### Hospitals, laboratories, pharmacies

- reagents
- disinfectants
- medicines
- gases
- radiological material



### Pesticide storage depots

- carbamates
- organophosphates
- organochlorines



### Metallurgical industries

- toxic metals
- cyanide
- sulfuric acid
- ammonia



are resistant to earthquakes, floods or high winds. The structural design and operation of industrial facilities should include systems and measures to reduce the risk of damage to chemical process or storage equipment, and the protection of safety barriers<sup>b</sup> from the impact of natural hazards (30, 31). In areas at risk of flooding, there is a wide range of flood-control measures that can be employed, including the use of dykes and dredging or modifying watercourses (23). It is important that local communities understand the need for, and are engaged with, such preventive policies and measures to support their effective implementation.

The development of early-warning systems, including communication mechanisms, for natural hazards is an example of secondary prevention. Such systems may provide an opportunity for preventive measures to be put in place before the hazard event occurs, e.g. shutting down a chemical plant or moving hazardous substances to a safer location (31). These systems also provide an opportunity to convey health-protection messages to communities at risk (23). However, while early warning is feasible for weather-related events, it is unlikely to be available for earthquakes, emphasizing the importance of building in earthquake resistance to industrial installations and homes, as well as carrying out earthquake drills.

In the domain of prevention, the main role of the health sector is one of advocacy. By compiling information about the health impacts of previous events, and by carrying out vulnerability assessment and developing exposure scenarios, the health sector can make the case for the implementation of regulatory and policy measures, and of adequate planning directed at the prevention and mitigation of Natech events.

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<sup>b</sup> A safety barrier is a physical or non-physical means put in place to prevent, control, or mitigate an accident e.g. a pressure-relief valve.

## 5.2 THE ROLE OF THE HEALTH SECTOR IN PREPAREDNESS

Preparedness encompasses the knowledge and capacities developed by governments, industry, emergency responders, communities and individuals to anticipate, respond to, and recover from the impacts of a disaster such as a Natech event (32). Preparedness planning involves multiple agencies, including the health sector. This section summarizes the various steps involved in chemical incident preparedness and the ways in which the health sector can provide input. More details are provided in the WHO *Manual for the public health management of chemical incidents* (28).

### 1. Gathering relevant information

A key requirement for response is to have rapid access to relevant information. Therefore, an important preparedness activity is to compile and regularly update this information, including on:

- locations of hazardous sites where chemicals are stored and used, particularly sites in areas vulnerable to natural hazards;
- chemicals: their properties and toxicity, quantities, and management of exposure;
- health-care resources;
- emergency contacts, including poisons centres.

Health authorities at local, regional and national level should maintain databases of health-care capabilities and resources. This will facilitate contingency planning in case resources in one area become overwhelmed and will also highlight where there are gaps that need addressing. Tools to assist in the assessment of hospital capacities to deal with emergencies have been developed by WHO (33, 34). The identification of vulnerable or high-risk populations, their location relative to hazardous sites, and the specific needs of such groups should a Natech event occur, are also important for planning.

There are some tools for hazard identification and mapping, and it is important that the various authorities involved in hazard mapping share information ahead of, and during, an emergency. An example of a hazard-mapping tool is the *Flash environmental assessment tool* (FEAT). This is used by United Nations Disaster Assessment and Coordination (UNDAC) teams and emergency responders to identify existing or potential acute human health and environmental impacts caused by damage to infrastructure and industrial facilities (24). Tools to assist risk analysis and mapping for Natech events are being developed, for example RAPID-N (see **Annex D Sources of additional information**) (31).

## 2. Preparation of a Natech event response plan

The health sector should be involved in the development of response plans at local, regional and national level. These plans should integrate chemical incident response with emergency plans for natural hazards.

The health components include ensuring that:

- mechanisms are in place for assistance, e.g. laboratories, antidotes, decontamination equipment to be provided to local responders if needed;
- procedures are in place for mass casualty decontamination (35) and management;
- local plans consider the need to protect vulnerable populations;
- health-care workers and emergency responders are given adequate protection from exposure to chemicals.

Finally, contingency plans are needed for health-care facilities to enable them to cope with a surge in demand for services, including specialized measures for chemical exposure, and to deal with the possibility that the facility itself may be damaged during the natural hazard event. Authorities can reduce the risk of hospitals and health-care facilities being rendered inoperative during a disaster by following guidance developed by WHO in the *Comprehensive safe hospitals framework* (36). This guidance is supported by an assessment tool that gives national health decision-makers a snapshot of the status of safety and preparedness of their hospitals to remain operational in emergencies and disasters (37).

## 3. Community impact assessment

This is a qualitative or quantitative risk assessment, i.e. the assessment of the likelihood of adverse effects resulting from a possible future Natech event. It comprises five steps:

- scenario setting
- identification of exposure pathways
- population vulnerability assessment (e.g. Tables 10 and 11 in reference 23)
- health-impact assessment
- evaluation.

The health sector should be involved in all of these steps. Data collected from previous events can contribute to the risk assessment. Such data are particularly helpful for health-impact assessment, including the possibility of long-term health effects.

## 4. Incident management

External (off-site) emergency-response plans should be based on an all-hazard incident management system (IMS) that provides coordination mechanisms, including emergency operations centres, a clear command structure and communications strategy with all sectors that will be involved in response. The health sector should develop its own IMS incorporating relevant health disciplines (27, 28). The health sector should understand its role within the multisectoral IMS and health emergency plans, and operational arrangements should be interoperable with other sectors.

## 5. Communication

Timely and effective communication between agencies and adequate risk and crisis communication with the public are important components of response. In the preparedness phase, therefore, protocols and procedures for different kinds of communication should be developed and tested. Planning measures can include communications training, the development of communication checklists and templates, designation of

spokespersons and development of standard messages for possible scenarios (28). Some examples of pre-prepared messages include:

- what to do in case of a flood/earthquake/cyclone
- prevention of carbon monoxide poisoning
- precautions during clean-up, including handling asbestos cement.

## 6. Building human capacities

An important component of preparedness is the adequate training of personnel involved in event response. In the case of the health sector this includes training health professionals and first-responders. A core training programme should be developed for local response teams to ensure that staff from all organizations involved in a response have a basic understanding of each other's needs and roles. Training should be reinforced by regular exercises, again coordinated between agencies, so that these agencies become used to working together (27, 28).

## 5.3 THE ROLE OF THE HEALTH SECTOR IN RESPONSE

In the response phase the health sector has a number of roles. Public health services are responsible for health-risk assessment and communication for incidents, and they help to coordinate the overall health response (28, 38). They are also involved in assessing the possible long-term health impacts of an incident. Acute medical services are responsible for the triage and management of injured and ill people. All parts of the health sector will be interacting with other sectors to collect information on the chemicals involved and the affected populations (28). Information gathered during response activities, including on the effectiveness of prevention, preparedness and response measures, the management of mass casualties, and the health impacts of chemicals, can be used to inform future planning and, if necessary, to advocate for measures to prevent the recurrence of incidents and reduce the consequences.

The key steps in mounting a response are: risk assessment; containment and prevention of exposure; medical assessment and management; and risk and crisis communication (28). The amount of engagement by the health sector will vary at each stage.

### 1. Risk assessment

The purpose of the risk assessment is to determine the likely impacts of the chemical release on human health. It involves identification of the hazards concerned, and assessment of vulnerabilities, exposures and capacities for response. This is an iterative process and an assessment should be revised as new information becomes available. It includes the following steps.

i. Obtain information on potentially affected hazardous sites in order to assess the risks to health and determine the appropriate risk-management measures.

ii. Identify the chemicals involved in the accident: check if an inventory is available, e.g. in the site emergency plan; if not use the *Flash environmental assessment tool* (24) (see also **Annex D Sources of additional information**). Look for labels with hazard information (see **Annex E Examples of hazard warnings**).

iii. Collect and consider any clinical information available from exposed individuals, as this may help to identify some chemicals or chemical groups.

iv. If feasible, organize the collection and analysis of environmental samples (air, soil, water, crops) in order to identify and quantify contamination by chemicals. Mobile laboratories can provide results quickly, but even if the results are delayed they will provide information about pathways of exposure during the event that can assist in the assessment of possible longer-term health impacts as well as inform recovery plans.

### 2. Prevention of exposure

This involves the following activities.

i. Ensure that appropriate containment measures are applied. The primary responsibility for containment will normally be with the civil defence or fire services. However, prioritizing this activity may, in part, depend

on likely health impacts. Helpful information may be available in site emergency plans. Brief information on dealing with small chemical spills can be found in safety data sheets, the *International chemical safety cards* and the *Emergency response guidebook* (see **Annex D Sources of additional information**).

**ii.** Ensure that access to contaminated sites is restricted through barriers and warnings. Only those equipped with adequate personal protective equipment (PPE) should enter contaminated areas.

**iii.** In the case of airborne toxicants, decide whether it is feasible for people to shelter in place to protect themselves or whether evacuation is necessary.

**iv.** Ensure that people involved in clean-up and rescue operations are adequately equipped with personal protective equipment and are informed about the possibility of encountering chemical spills.

**v.** Decontaminate chemically-exposed individuals by removing clothing and washing or showering them in order to prevent continuing exposure and secondary contamination of the emergency responders, health personnel, health-care facilities and equipment (e.g. ambulances, stretchers and beds).

**vi.** Public health agencies at various levels (local, state/federal and national) should provide comprehensive information to the general public regarding precautionary measures (see 'Risk and crisis communication' below).

### 3. Medical assessment and management

This involves the following activities.

**i.** Ensure that chemically-exposed individuals are decontaminated before they enter the health-care facility.

**ii.** Health personnel and emergency responders should follow procedures for wearing PPE when managing chemically-contaminated victims.

**iii.** Conduct triage and patient assessment. Chemical injuries or poisoning may be combined with traumatic injuries and this may complicate management.

**iv.** Obtain advice on the management of chemical exposure from a poisons centre if available.

**v.** Provide specific medical treatment (e.g. antidotal treatment) as required.

**vi.** Consider the need to collect biological samples from chemically-exposed individuals (including first-responders) in order to identify and, if possible, quantify exposure. While this information will not necessarily guide management, it can assist in the assessment of possible longer-term effects.

**vii.** Register all exposed individuals and ensure adequate documentation and record-keeping in case there is a need for long-term follow-up.

**viii.** Ensure after the first response that measures are taken in the recovery stage to prevent indirect chemical effects and long-term exposures, and provide mental health and psychosocial support for affected communities (see below).

### 4. Risk and crisis communication

It is important to keep the public, responders and decision-makers informed about chemical and other hazards arising from the event, and about protective measures (39). Ideally, around hazardous installations there should already have been some risk communication to surrounding communities informing them about potential scenarios for chemical release, the meaning of warning signals (e.g. klaxons) and the action to take if warnings are issued, e.g. using the APELL process (see **Annex D Sources of additional information**). As carbon monoxide poisoning is regularly reported after natural hazard events that cause power outages, it is important to inform the public about prevention (25).

Crisis communication takes place during the incident itself and involves informing the public about (28):

- the Natech event(s)
- who is in charge
- what is being done

- the nature and hazards of the chemicals involved
- what individuals should do to protect themselves and their families
- when to seek medical attention
- how to get further information.

The available range of communication channels should be used, including mass and social media. Information and messages should be updated to address evolving public concerns.

## 5.4 THE ROLE OF THE HEALTH SECTOR IN RECOVERY

Recovery refers to the process of rebuilding and rehabilitating the population following an emergency (40). In the context of a Natech event there are two main dimensions: dealing with the longer-term health consequences of the event, and dealing with environmental contamination by chemicals in order to protect health and livelihoods.

### 1. Dealing with health impacts

This involves the provision of medical care, the provision of information about possible long-term health effects of exposure, registration of exposed persons, and follow-up and surveillance for adverse health impacts (28).

Medical care involves the management of the immediate physical consequences of chemical exposure, which may be accompanied by traumatic injury. It also involves anticipating and managing the mental health and psychosocial impacts of the event. Mental health and psychosocial problems are common among victims of natural disasters, arising from a range of stressors (41–43). Victims may have lost family members, friends, their property, they may have confronted death and severe injuries, and suffer from social disruption. In the case of Natech events, the fear of chemical contamination may be an additional stressor. The displacement of people whose houses have been destroyed by the disaster or are contaminated by chemicals has an important

psychological impact. People may have to live in temporary housing for many months. The impact on children must also be considered and managed.

Recovery from physical and psychological injuries from any disaster, including a Natech event, can take years. Therefore the health sector should support the victims by providing further medical care, including mental health and psychosocial support and follow-up. Health programmes should take into account the specific needs of different age and gender groups.

Provision of information regarding possible long-term health problems is important as it helps victims to recover. It is helpful to establish an information 'point of contact', who can provide appropriate and up-to-date advice (28).

The health sector should also undertake an appropriate evaluation of the Natech event, as well as an assessment of public health response, in order to identify lessons learnt, to avoid its recurrence and to improve the overall response (28, 39).

### 2. Environmental contamination

A Natech event may result in extensive environmental contamination and in the generation of contaminated waste such as debris, home furnishings and personal belongings. Typically, clean-up operations start as soon as the natural disaster event has stopped or abated. These are often initiated by the local community seeking to restore some order to their damaged environment and to protect their livelihoods, e.g. by clearing oil spills from shellfish breeding grounds. In many disaster-prone areas, asbestos cement is widely used as a building material and when damaged it can release harmful asbestos fibres. There may be a high risk of chemical exposure in this early clean-up phase and the rapid provision of advice on health protection is therefore important.

Longer-term decisions on clean-up and restoration will be informed by the results of environmental sampling and detailed environmental risk assessments. The health sector's role here is to assist with risk assessment and the identification and prioritization of the areas to be remediated, i.e. those that carry the highest risk of human exposure and health impacts. The health sector should also advise on safety measures for the people employed in remediation and clean-up.

### 3. Restoration of services

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After a Natech event, soil, animals, plants and water bodies can be contaminated by chemicals, affecting food and drinking-water production and supply. Restoration of these services involves a risk assessment and consideration of possible recovery options. Risk assessment follows the standard procedure of hazard identification (what chemicals are involved), hazard characterization (toxicity and guideline or reference values), exposure assessment (how could people become exposed and to what extent) and risk characterization (how does the estimated exposure compare to the guideline/reference value) (44).

Recovery options could involve taking no action if the risk to health is judged insignificant, treating food or water to remove contamination, diverting it to other uses, or disposing of contaminated food as waste (40).

Depending on the level of contamination it may be necessary to prohibit the use of areas for growing crops or for animal foraging for a period of time.

In the case of water, it may be necessary to test the water supply itself, as well as extraction sources, in case chemicals seeping through the ground have penetrated into supply pipes (40).

It is of course important to communicate risk assessment results and advisories relating to food and drinking water to the community, including food and water suppliers.

chemical release associated with natural hazards is well understood by all sectors involved in planning, preparedness and response, including the health sector. While industries are an important source of chemical release it should not be forgotten that the health sector itself uses large amounts of chemicals, e.g. laboratory reagents and public health pesticides, and this should be factored into its own prevention, preparedness and response activities.

## 6. CONCLUSIONS

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Chemical releases following natural hazard events are probably more common than the available data suggest. The combination of growing industrialization and urbanization together with the impacts of climate change mean that Natech events are likely to become an increasing problem.

Chemical releases complicate the response to natural hazards and potentially increase the disease burden associated with these hazards. It is important therefore that the nature of Natech events and other forms of

## REFERENCES

1. Sendai framework for disaster risk reduction 2015–2030. Geneva: United Nations Office for Disaster Risk Reduction; 2015 ([http://www.preventionweb.net/files/43291\\_sendaiframeworkfordrren.pdf](http://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf), accessed 7 July 2017).
2. Leaning J, Guha-Sapir D. Natural disasters, armed conflict, and public health. *New England Journal of Medicine*. 2013;369:1836–42. doi: 10.1056/NEJMr1109877 (<http://www.nejm.org/doi/pdf/10.1056/NEJMr1109877>, accessed 7 July 2017).
3. Emergency risk management for health: overview. Geneva: World Health Organization; 2011 ([http://www.who.int/hac/techguidance/preparedness/risk\\_management\\_overview\\_17may2013.pdf?ua=1](http://www.who.int/hac/techguidance/preparedness/risk_management_overview_17may2013.pdf?ua=1), accessed 7 July 2017).
4. Krausmann E, Cruz AM, Salzano E. Natech risk assessment and management: reducing the risk of natural-hazard impact on hazardous installations. Amsterdam: Elsevier; 2017.
5. Cruz AM, Steinberg LJ, Vetere Arellano AL, Nordvik J-P, Pisano F. State of the art in Natech risk management. Ispra: European Commission Joint Research Centre; 2004 (EC JRC, UN ISDR EUR 21292 EN; [http://www.unisdr.org/files/2631\\_FinalNatechStateofthe20Artcorrected.pdf](http://www.unisdr.org/files/2631_FinalNatechStateofthe20Artcorrected.pdf), accessed 7 July 2017).
6. Young S, Balluz L, Malilay J. Natural and technologic hazardous material releases during and after natural disasters: a review. *Science of the Total Environment*. 2004;322(1–3):3–20 ([http://dx.doi.org/10.1016/S0048-9697\(03\)00446-7](http://dx.doi.org/10.1016/S0048-9697(03)00446-7), accessed 7 July 2017).
7. Hyogo framework for action 2005–2015: Building the resilience of nations and communities to disasters. Geneva: United Nations Office for Disaster Risk Reduction; 2007 (<http://www.unisdr.org/we/coordinate/hfa>, accessed 7 July 2017).
8. Resolution WHA64.10. Strengthening national health emergency and disaster management capacities and the resilience of health systems. In: Sixty-fourth World Health Assembly, Geneva, 16–24 May 2011. Resolutions and decisions, annexes. Geneva: World Health Organization; 2011:10 (WHA64/2011/REC/1; [http://apps.who.int/gb/ebwha/pdf\\_files/WHA64-REC1/A64\\_REC1-en.pdf](http://apps.who.int/gb/ebwha/pdf_files/WHA64-REC1/A64_REC1-en.pdf), accessed 7 July 2017).
9. International Health Regulations (2005) and chemical events. Geneva: World Health Organization; 2015 (<http://apps.who.int/iris/bitstream/10665/249532/1/9789241509589-eng.pdf?ua=1&ua=1>, accessed 7 July 2017).
10. Report of the workshop on Natech risk management (23–25 May 2012, Dresden, Germany). Joint meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology. Series on Chemical Accidents No. 25. Paris: Organisation for Economic Co-operation and Development; 2012 (ENV/JM/MONO(2013)4; [http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono\(2013\)4&doclanguage=en](http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2013)4&doclanguage=en), accessed 7 July 2017).
11. Major Accident Hazards Bureau. Lessons learned. Bulletin No. 6: Natech accidents. Ispra: European Commission Joint Research Centre; 2014 (<https://minerva.jrc.ec.europa.eu/en/content/minerva/f30d9006-41d0-46d1-bf43-e033d2f5a9cd/publications>, accessed 26 September 2017).
12. Krausmann E, Cruz AM. Impact of the 11 March 2011, Great East Japan earthquake and tsunami on the chemical industry. *Natural Hazards*. 2013;67:811–28. doi: 10.1007/s11069-013-0607-0.
13. OECD Studies in risk management: Italy – Industrial hazards triggered by floods. Paris: Organisation for Economic Co-operation and Development; 2006 (<https://www.oecd.org/italy/36099995.pdf>, accessed 7 July 2017).

14. The cyanide spill at Baia Mare, Romania: before, during and after. Geneva: United Nations Environment Programme/Office for the Coordination of Humanitarian Affairs; 2002 (<http://archive.rec.org/REC/Publications/CyanideSpill/ENG/Cyanide.pdf>, accessed 7 July 2017).
15. Solomon GM, Rotkin-Ellman M. Contaminants in New Orleans sediment. New York: Natural Resources Defense Council; 2006 (<https://www.nrdc.org/sites/default/files/sedimentepa.pdf>, accessed 7 July 2017).
16. Balluz L, Moll D, Diaz Martinez MG, Merida Colindres JE, Malilay J. Environmental pesticide exposure in Honduras following hurricane Mitch. Bulletin of the World Health Organization. 2001;79:288–95 ([http://www.who.int/bulletin/archives/79\(4\)288.pdf](http://www.who.int/bulletin/archives/79(4)288.pdf), accessed 7 July 2017).
17. Campedel M. Analysis of major industrial accidents triggered by natural events reported in the principal available chemical accident databases. Ispra: European Commission Joint Research Centre; 2008 (Report EUR 23391 EN-2008; [http://publications.jrc.ec.europa.eu/repository/bitstream/JRC42281/reqno\\_jrc42281\\_def%20mik%2008%5b2%5d.pdf](http://publications.jrc.ec.europa.eu/repository/bitstream/JRC42281/reqno_jrc42281_def%20mik%2008%5b2%5d.pdf), accessed 7 July 2017).
18. Krausmann E, Renni E, Campedel M, Cozzani V. Industrial accidents triggered by earthquakes, floods and lightning: lessons learned from a database analysis. Natural Hazards. 2011;59:285–300. doi: 10.1007/s11069-011-9754-3.
19. Steinberg LJ, Cruz AM, Vardar-Sukan F, Ersoz Y. Risk management practices at industrial facilities during the Turkey earthquake of August 17, 1999: case study report, 2001. In: Proceedings of the First Annual IIASA-DPRI Meeting “Integrated disaster risk management: reducing socio-economic vulnerability”, IIASA, Luxembourg, Austria, 1–4 August, 2000 (<http://webarchive.iiasa.ac.at/Research/RMS/dpri2001/Papers/Cruz0602.pdf>, accessed 7 July 2017).
20. Girgin S. The Natech events during the 17 August 1999 Kocaeli earthquake: aftermath and lessons learned. Natural Hazards and Earth System Sciences. 2011;11:1129–40. doi: 10.5194/nhess-11-1129-2011 (<http://www.nat-hazards-earth-syst-sci.net/11/1129/2011/nhess-11-1129-2011.pdf>, accessed 7 July 2017).
21. Girgin S, Krausmann E. Lessons learned from oil pipeline Natech accidents and recommendations for Natech scenario development. Final Report. Ispra: European Commission Joint Research Centre; 2015 (EUR 26913 EN; <http://publications.jrc.ec.europa.eu/repository/bitstream/JRC92700/homepipelinefinalleur26913en.pdf>, accessed 7 July 2017).
22. Lindell MK, Perry RW. Hazardous materials releases in the Northridge earthquake: implications for seismic risk assessment. Risk Analysis. 1997;17:147–56. doi: 10.1111/j.1539-6924.1997.tb00854.x.
23. Menne B, Murray V. Floods in the WHO European Region: health effects and their prevention. Copenhagen: WHO Regional Office for Europe; 2013 ([http://www.euro.who.int/\\_\\_data/assets/pdf\\_file/0020/189020/e96853.pdf](http://www.euro.who.int/__data/assets/pdf_file/0020/189020/e96853.pdf), accessed 7 July 2017).
24. Flash environmental assessment tool (FEAT 2.0): pocket guide. Geneva: United Nations Environment Programme/Office for the Coordination of Humanitarian Affairs Joint Unit; 2017 (<http://www.eecentre.org/?p=1596>, accessed 7 July 2017).
25. Iqbal S, Clower JH, Hernandez SA, Damon SA, Yip FY. A review of disaster-related carbon monoxide poisoning: surveillance, epidemiology, and opportunities for prevention. American Journal of Public Health. 2012;102(10):1957–63. doi: 10.2105/AJPH.2012.300674 (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3490658/pdf/AJPH.2012.300674.pdf>, accessed 7 July 2017).

26. Waite T, Murray V, Baker D. Carbon monoxide poisoning and flooding: changes in risk before, during and after flooding require appropriate public health interventions. *PLoS Currents Disasters*. 2014 July 3, Edition 1. doi: 0.1371/currents.dis.2b2eb9e15f9b982784938803584487f1 (<http://currents.plos.org/disasters/article/carbon-monoxide-poisoning-and-flooding-changes-in-risk-before-during-and-after-flooding-require-appropriate-public-health-interventions/>, accessed 20 September 2017).
27. Environmental health in emergencies and disasters: a practical guide. Geneva: World Health Organization; 2002 (<http://apps.who.int/iris/handle/10665/42561>, accessed 7 July 2017).
28. Manual for the public health management of chemical incidents. Geneva: World Health Organization; 2009 ([http://www.who.int/iris/bitstream/10665/44127/1/9789241598149\\_eng.pdf](http://www.who.int/iris/bitstream/10665/44127/1/9789241598149_eng.pdf), accessed 7 July 2017).
29. Krausmann E, Cozzani V, Salzano E, Renni E. Industrial accidents triggered by natural hazards: an emerging risk issue. *Natural Hazards and Earth System Sciences*. 2011;11:921–29 (<http://www.nat-hazards-earth-syst-sci.net/11/921/2011/nhess-11-921-2011.pdf>, accessed 7 July 2017).
30. Addendum number 2 to the OECD guiding principles for chemical accident prevention, preparedness and response (2nd edition). To address natural hazards triggering technological accidents (Natechs). Series on Chemical Accidents No. 27. Paris: Organisation for Economic Co-operation and Development; 2015 (ENV/JM/MONO(2015)1; [http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono\(2015\)1&doclanguage=en](http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2015)1&doclanguage=en), accessed 7 July 2017).
31. Krausmann E, Cruz AM, Fendler R, Salzano E. Technological risk: Natech. In: Poljanšek K, Marin Ferrer M, De Groeve T, Clark I, editors. *Science for disaster risk management 2017: knowing better and losing less*. Luxembourg: Publications Office of the European Union; 2017. pp. 367–77 (EUR 28034 EN; <https://ec.europa.eu/jrc/en/publication/science-disaster-risk-management-2017-knowing-better-and-losing-less>, accessed 29 September 2017).
32. Terminology on disaster risk reduction [website]. Geneva: United Nations Office for Disaster Risk Reduction (UNISDR); 2009 (<https://www.unisdr.org/we/inform/terminology#letter-p> accessed 7 July 2017).
33. Hospital emergency response checklist: an all-hazards tool for hospital administrators and emergency managers. Copenhagen: WHO Regional Office for Europe; 2011 (<http://www.euro.who.int/en/health-topics/emergencies/disasterpreparedness-and-response/publications/2011/hospital-emergency-response-checklist>, accessed 7 July 2017).
34. Health Resources Availability Monitoring System (HeRAMS). In: *Humanitarian health action* [website]. Geneva: World Health Organization; 2017 (<http://www.who.int/hac/herams/en/> accessed 7 July 2017).
35. Patient decontamination in a mass chemical exposure incident: national planning guidance for communities. Washington DC: US Department of Homeland Security/US Department of Health and Human Services; 2014 ([https://www.dhs.gov/sites/default/files/publications/Patient%20Decon%20National%20Planning%20Guidance\\_Final\\_December%202014.pdf](https://www.dhs.gov/sites/default/files/publications/Patient%20Decon%20National%20Planning%20Guidance_Final_December%202014.pdf), accessed 7 July 2017).
36. Comprehensive safe hospitals framework. Geneva: World Health Organization; 2015 ([http://www.who.int/hac/techguidance/comprehensive\\_safe\\_hospital\\_framework.pdf?ua=1](http://www.who.int/hac/techguidance/comprehensive_safe_hospital_framework.pdf?ua=1), accessed 7 July 2017).
37. Hospital safety index: guide for evaluators, 2nd edition. Geneva: World Health Organization; 2015 ([http://www.who.int/hac/techguidance/hospital\\_safety\\_index\\_evaluators.pdf?ua=1](http://www.who.int/hac/techguidance/hospital_safety_index_evaluators.pdf?ua=1), accessed 7 July 2017).

38. Euripidou E, Murray V. Public health impacts of floods and chemical contamination. *Journal of Public Health*. 2004;26(4):376–83 (<http://jpubhealth.oxfordjournals.org/content/26/4/376.full.pdf>, accessed 7 July 2017).
39. Bridgman, Stephen A. Lessons learnt from a factory fire with asbestos-containing fallout. *Journal of Public Health*. 1999;21(2):158–65 (<http://jpubhealth.oxfordjournals.org/content/21/2/158.full.pdf>, accessed 7 July 2017).
40. UK recovery handbook for chemical incidents. London: Health Protection Agency; 2012 ([https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/201024/UKRHCI\\_publication\\_31st\\_May\\_2012\\_web2.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201024/UKRHCI_publication_31st_May_2012_web2.pdf), accessed 7 July 2017).
41. Mental health and psychosocial support in humanitarian emergencies: what should humanitarian health actors know? Geneva: Inter-Agency Standing Committee; 2010 ([http://www.who.int/mental\\_health/emergencies/what\\_humanitarian\\_health\\_actors\\_should\\_know.pdf](http://www.who.int/mental_health/emergencies/what_humanitarian_health_actors_should_know.pdf), accessed 7 July 2017).
42. Stanke C, Murray V, Amlôt R, Nurse J, Williams R. The effects of flooding on mental health: outcomes and recommendations from a review of the literature. *PLoS Currents Disasters*. 2012 May 30; Edition 1. doi: 10.1371/4f9f1fa9c3cae (<http://currents.plos.org/disasters/article/the-effects-of-flooding-on-mental-health-outcomes-and-recommendations-from-a-review-of-the-literature/>, accessed 29 September 2017).
43. Lock S, Rubin GJ, Murray V, Rogers MB, Amlôt R, Williams R. Secondary stressors and extreme events and disasters: a systematic review of primary research from 2010 to 2011. *PLoS Currents Disasters*. 2012 Oct 29; Edition 1. doi: 10.1371/currents.dis.a9b76fed1b2dd5c5bfcfc13c87a2f24f (<http://currents.plos.org/disasters/article/dis-12-0013-secondary-stressors-and-extreme-events-and-disasters-a-systematic-review-of-primary-research-from-2010-2011/>, accessed 29 September 2017).
44. WHO Human health risk assessment toolkit: chemical hazards. Geneva: World Health Organization; 2010 (<http://www.who.int/ipcs/publications/methods/harmonization/toolkit.pdf?ua=1>, accessed 7 July 2017).

## ANNEX A

### CHEMICAL RELEASES ASSOCIATED WITH EARTHQUAKES

#### What is an earthquake?

An earthquake is a sudden release of energy in the earth's crust caused by movement between tectonic plates along a fault line. It is characterized by violent shaking of the ground produced by deep seismic waves, which spread out from the initial point of rupture (1).

Earthquakes can result in ground shaking, soil liquefaction, landslides, fissures, avalanches and tsunamis. The extent of destruction and harm caused by an earthquake depends on its magnitude, intensity and duration, the local geology, the time of day that it occurs, building and industrial plant design and materials, and the risk-management measures put in place (2–4).

#### Classification of earthquakes

A number of scales have been defined to measure the intensity and magnitude of earthquakes (1, 4, 5), but the most commonly used are:

- The Mercalli scale (MM): this ranks earthquakes according to their destructiveness using a scale from I to XII in Roman numerals, with XII being the most severe. The scale is based on visual and other non-instrumental observations of the earthquake's effects.
- The Richter scale ( $M_L$ ): this indicates the amplitude of ground movement as measured by a seismograph. The scale is logarithmic to base 10, thus a magnitude 5 earthquake is 10 times more powerful than one of magnitude 4. A magnitude 4 earthquake is perceptible but mild, whereas a magnitude 8 earthquake is potentially devastating.
- The moment magnitude scale ( $M_w$ ): this is also based on seismographic measurement and is the magnitude assessed in terms of the release of energy across the area of rupture on the fault. It provides the most reliable estimate for very large earthquakes. The scale

has been defined so that it is close to the Richter ( $M_L$ ) scale up to a magnitude of 6.

#### Risk factors for chemical release

Sites where chemicals are produced, used or stored are vulnerable to earthquake-related damage and chemical release (2, 6, 7). Analysis of past events suggests that non-pressurized chemical-storage tanks, piping and old gas and oil pipelines are particularly vulnerable to rupture following an earthquake (2, 8). Factors that increase the risks to the population of a chemical release during an earthquake include the following (6, 9):

- inadequate planning and building regulations;
- location of industrial facilities in seismic areas;
- structures that are not seismically resistant;
- inadequate safety measures or emergency planning;
- high population density around industrial sites;
- inadequate warning systems;
- lack of public awareness about earthquake risks.

Other consequences of an earthquake may increase the Natech risk by reducing response capacity in the following ways (9, 10).

- Damage to on-site emergency equipment will hamper response, as will damage to essential infrastructure, such as the power supply, water supply and telecommunications.
- The off-site emergency-response personnel and other resources may not be available as they may be occupied in dealing with the consequences of the earthquake.
- The release of hazardous materials may hamper search and rescue operations.

In areas vulnerable to earthquakes, industrial site emergency-response plans must include earthquake

scenarios, so that workers and managers will be prepared for the specific conditions that exacerbate an emergency situation during and following an earthquake.

## Mechanisms of chemical release

Failure of containment leading to chemical release typically arises from structural damage caused by the horizontal and vertical shaking forces of the earthquake, by falling debris, and by soil liquefaction resulting in building collapse (2, 6, 10). There may be multiple and simultaneous chemical releases at a single site or over extended industrial areas. **Box A1** provides an illustrative case study.

At industrial sites, mechanisms of chemical release include: rupture of pipelines and connection flanges; buckling and rupture of storage vessels; liquid sloshing (which compromises the structural integrity of tanks that are full or nearly full) leading to tank-shell damage and collapse; and damage to the power supply, which can cause process upsets and affect safety measures such as temperature and pressure monitors and control valves (2). Liquid sloshing in floating-roof tanks can cause the metallic roof to bounce against the side-wall creating sparks and igniting flammable tank contents (2, 7). Damage to storage vessels at petroleum installations can release huge quantities of petroleum products into the environment, including into waterways (6).

In the case of warehouses and other storage sites, smaller vessels such as drums, barrels and sacks containing chemicals can be damaged by tipping and by falling structures. This may result in the mixing of chemicals with the generation of toxic reaction products or a fire or explosion hazard (6, 8).

Fires are a relatively common occurrence following earthquakes, for example caused by ignition of fuel storage tank contents and rupture of gas mains (2, 6). Fires at fuel storage depots may burn for several days releasing toxic combustion products into the air for a prolonged period (7). Fires in buildings can release large amounts of dust and fibres from asbestos and fibreglass insulation (6, 12).

Damage to railways and roads can result in derailment, tipping and collisions of tankers transporting chemicals with subsequent rupture and chemical release (8).

Clean-up operations can result in the release of asbestos fibres from asbestos cement. This material is commonly used in many countries for roofing and pipes. Clearing fallen or damaged structures may involve sawing, breaking up and moving asbestos cement, which releases harmful fibres into the air (13). The uncontrolled burning of post-disaster waste can result in the generation of toxic and irritant smoke.

## Potential impacts on human health

Chemicals released following an earthquake can cause dermal, respiratory and systemic toxic effects following direct exposure of victims and rescuers. Toxic effects and injuries may also result from environmental contamination, and fires and explosions. The general public, rescuers and those involved in clean-up operations may be exposed to a range of hazards, which can be divided into those related to chemicals and those unrelated (6, 14). Examples are given below.

### Chemical-related

- Burns from exposure to spilled corrosive chemicals.
- Respiratory tract injury from inhalation of irritant gases, combustion products, heavy dust and fibres (e.g. from damaged asbestos and fibreglass insulation) (6).
- Poisoning from exposure to spilled toxic chemicals and the consumption of contaminated food or water.
- Carbon monoxide poisoning resulting from the incorrect use of petrol/diesel generators, or the use of barbeques, braziers or buckets of coal or charcoal for heating and cooking, when electricity supplies are lost (3, 15).
- Injuries and poisoning in workers involved in rescue and clean-up (after the Loma Prieta earthquake in California, USA, nearly 20% of work-related injuries were caused by exposure to hazardous materials (6)).

## Non chemical-related

- Burns from fires.
- Electrocution from fallen power lines.
- Injuries and deaths as a result of falls, building collapse, falling masonry, etc. (3). Injuries may also occur during the rescue and clean-up phases, e.g. when cutting and moving fallen debris.
- Consequences of evacuation, e.g. increased risk of infectious diseases at the evacuation sites, exacerbation of pre-existing health problems during patient transfer, saturation of health-care facilities reducing ability to provide adequate treatment, potential problems with water supply and sanitation, etc. (16).
- Psychosocial effects, including post-traumatic stress disorder (14).

## Response and recovery considerations

Sections 5.3 and 5.4 (main document) describe in more detail the role of the health sector in the response and recovery phases. Summarized information is provided here.

### Risk assessment

- Obtain information on potentially affected hazardous sites in order to assess the risks to health and determine the appropriate risk-management measures.
- Identify the chemicals involved in the accident: check if an inventory is available, e.g. in the site emergency plan; if not, use the *Flash environmental assessment tool* (17) (see also **Annex D Sources of additional information**). Look for labels with hazard information (see **Annex E Examples of hazard warnings**).
- Collect and consider any clinical information available from exposed individuals, as this may help to identify some chemicals or chemical groups.
- If feasible, organize the collection and analysis of environmental samples (air, soil, water, crops) in order

to identify and quantify contamination by chemicals. This information may be particularly helpful in the recovery phase.

### Prevention of exposure

i. Based on the risk assessments, provide advice as required to the civil defence, fire or other designated service on the need for:

- containment measures
- restrictions on access to contaminated sites
- the need for personal protective equipment (PPE)
- shelter-in-place or evacuation advisories for affected communities.

ii. Ensure that people involved in clean-up and rescue operations are adequately equipped with PPE and are aware of the possibility of chemical spills.

iii. Organize facilities for decontaminating chemically-exposed individuals.

iv. Provide comprehensive information to the general public regarding precautionary measures (see 'Risk and crisis communication' below).

### Medical assessment and management

i. Ensure that chemically-exposed individuals are decontaminated before they enter the health-care facility.

ii. Ensure that health personnel follow procedures for wearing PPE when managing chemically-contaminated victims.

iii. Conduct triage and patient assessment. Note that chemical injuries or poisoning may be combined with traumatic injuries.

iv. Obtain advice on the management of chemical exposure from a poisons centre, if available.

v. Provide specific medical treatment (e.g. antidotal treatment) as required.

vi. Consider the need to collect biological samples from chemically-exposed individuals (including first-responders) in order to identify and, if possible, quantify exposure.

vii. Register all exposed individuals and ensure adequate documentation and record-keeping in case there is a need for long-term follow-up.

viii. Ensure that, after the first response, measures are taken in the recovery stage to prevent indirect chemical effects and long-term exposures. Provide mental health and psychosocial support for affected communities.

### Risk and crisis communication

Provide information, updated as necessary, to the public, first-responders and decision-makers about chemical and other hazards arising from the event. Ensure that the public is informed about:

- the Natech event(s)

- who is in charge
- what is being done
- the nature and hazards of the chemicals involved
- what individuals should do to protect themselves and their families
- when to seek medical attention
- how to get further information.

Some specific health-protection topics include:

- prevention of carbon monoxide poisoning
- precautions during clean-up, e.g. use of personal protective equipment, safe use of cutting equipment, handling of asbestos cement, etc.

## BOX A1. KOCAELI EARTHQUAKE, TURKEY, AUGUST 1999

On 17 August 1999 in Kocaeli, Turkey, a powerful earthquake (magnitude of  $M_w$  7.4) occurred. This area is heavily industrialized and densely populated, and the consequences of the earthquake were severe. Over 15 million people were affected, with over 17 500 fatalities and 44 000 injuries. Damage to property amounted to around US\$ 16 billion (7, 11). The earthquake caused numerous Natech events including an acrylonitrile spill at the AKSA acrylic fibre plant in Ciftlikkoy, one of the largest acrylic fibre production facilities in the world. Acrylonitrile was released into containment dykes and into the air. Damage to the dykes resulted in seepage of the chemical into the soil, contaminating an aquifer. In addition, the dykes overflowed allowing acrylonitrile to flow into the sea through a drainage channel. As elsewhere in the affected area, the electricity supply failed. Moreover, all of the water pipes on the site were damaged by the earthquake. Damage to the roads

meant that local emergency-response and rescue efforts were paralysed (7, 11).

The crisis centre in Yalova was not informed until about five hours after the leak was discovered. Since telecommunications were not operational, the security forces had to inform the public personally. Nearby fire brigades provided foam and pumps but could not directly assist in response because of a lack of personal protective equipment. Supplies had to be brought in by air and sea because the roads were inaccessible. The efforts to stop the leakage and further spread of the acrylonitrile took 40 hours (7).

As a consequence of the acrylonitrile spill, animals and vegetation within a 200 m radius around the tanks died. Birds and domestic animals were also reported to have died in the settlements close to the facility. Dead fish were reported in Izmit Bay. Some members of the emergency-response teams showed signs of

toxicity, as did members of the public living in the vicinity. Reported health effects included hoarseness, vertigo, nausea, respiratory problems, skin irritation, headache, and eye and nasal irritation (7). Members of the public were exposed as they tried to rescue neighbours and friends from collapsed buildings. Local hospitals and clinics were overcrowded with seriously injured people. They were not able to provide adequate treatment to chemically-exposed people, in part because the lack of telecommunications meant that experts at the AKSA facility could not be contacted about the toxicity of acrylonitrile and the management of exposure.

The produce of the farms located close to the plant was collected and subsequently destroyed. The environmental pollution required 5 years of continuous treatment for reclamation. The long-term health impacts are not known; however, concerns have been expressed about a possible increase in cancers (7).

This earthquake resulted in other Natech events. There were several fires, including one at a naphtha tank farm that took four days to extinguish. At a fertilizer plant close to the tank, workers deliberately opened the valves of ammonia storage tanks to prevent a possible explosion due to pressure build-up, releasing a large amount of ammonia into the air (7).

## REFERENCES

1. Gates AE, Ritchie D. Encyclopedia of earthquakes and volcanoes, 3rd edition. New York: Facts On File Inc; 2007.
2. Krausmann E, Renni E, Campedel M, Cozzani V. Industrial accidents triggered by earthquakes, floods and lightning: lessons learned from a database analysis. *Natural Hazards*. 2011;59:285–300. doi: 10.1007/s11069-011-9754-3.
3. Doocy S, Daniels A, Packer C, Dick A, Kirsch TD. The human impact of earthquakes: a historical review of events 1980–2009 and systematic literature review. *PLoS Currents Disasters*. 2013 Apr 16; Edition 1. doi: 10.1371/currents.dis.67bd14fe457f1db0b5433a8ee20fb833 (<http://currents.plos.org/disasters/article/the-human-impact-of-earthquakes-from-1980-2009-a-historical-review-of-events-1980-2009-and-systematic-literature-review/>, accessed 7 July 2017).
4. Measurement of an earthquake through its magnitude. In: Seismology Research Centre [website]. Victoria: Seismology Research Centre; 2017 (<http://www.src.com.au/earthquake-size/>, accessed 7 July 2017).
5. The Modified Mercalli Intensity Scale. In: Earthquakes Hazard Program, US Geological Survey [website]. Reston (VA): US Geological Survey; 2017 (<http://earthquake.usgs.gov/learn/topics/mercalli.php>, accessed 7 July 2017).
6. Young S, Balluz L, Malilay J. Natural and technologic hazardous material releases during and after natural disasters: a review. *Science of the Total Environment*. 2004;322(1–3):3–20 ([http://dx.doi.org/10.1016/S0048-9697\(03\)00446-7](http://dx.doi.org/10.1016/S0048-9697(03)00446-7), accessed 7 July 2017).
7. Girgin S. The Natech events during the 17 August 1999 Kocaeli earthquake: aftermath and lessons learned. *Natural Hazards and Earth System Sciences*. 2011;11:1129–40. doi:10.5194/nhess-11-1129-2011 (<http://www.nat-hazards-earth-syst-sci.net/11/1129/2011/nhess-11-1129-2011.pdf>, accessed 7 July 2017).
8. Lindell MK, Perry RW. Hazardous materials releases in the Northridge earthquake: implications for seismic risk assessment. *Risk Analysis*. 1997;17:147–56. doi: 10.1111/j.1539-6924.1997.tb00854.x.
9. Cruz AM, Steinberg LJ, Vetere Arellano AL, Nordvik J-P, Pisano F. State of the art in Natech risk management. Ispra: European Commission Joint Research Centre; 2004 (EC JRC, UN ISDR EUR 21292 EN; [http://www.unisdr.org/files/2631\\_FinalNatechStateofthe20Artcorrected.pdf](http://www.unisdr.org/files/2631_FinalNatechStateofthe20Artcorrected.pdf), accessed 7 July 2017).
10. Krausmann E, Cruz AM, Salzano E. Natech risk assessment and management: reducing the risk of natural-hazard impact on hazardous installations. Amsterdam: Elsevier; 2017.
11. Steinberg LJ, Cruz AM, Vardar-Sukan F, Ersoz Y. Risk management practices at industrial facilities during the Turkey earthquake of August 17, 1999: case study report, 2001. In: Proceedings of the First Annual IIASA-DPRI Meeting “Integrated disaster risk management: reducing socio-economic vulnerability”, IIASA, Luxembourg, Austria, 1–4 August, 2000 (<http://webarchive.iiasa.ac.at/Research/RMS/dpri2001/Papers/Cruz0602.pdf>, accessed 7 July 2017).
12. Bridgman, Stephen A. Lessons learnt from a factory fire with asbestos-containing fallout. *Journal of Public Health*. 1999;21(2):158–65 (<http://jpubhealth.oxfordjournals.org/content/21/2/158.full.pdf>, accessed 7 July 2017).
13. A brief guide to asbestos in emergencies: safer handling & breaking the cycle. Geneva: Shelter Centre and ProAct Network; 2009 (<http://www.humanitarianlibrary.org/resource/brief-guide-asbestos-emergencies-safer-handling-breaking-cycle-0>, accessed 7 July 2017).

- 
14. Shrubsole D. Natural disasters and public health issues: a review of the literature with a focus on the recovery period. Institute for Catastrophic Loss Reduction (ICLR) Research Paper Series No. 4. Toronto: ICLR; 1999 ([http://www.iclr.org/images/Natural\\_Disasters\\_and\\_Public\\_Health\\_Issues.pdf](http://www.iclr.org/images/Natural_Disasters_and_Public_Health_Issues.pdf), accessed 7 July 2017).
  15. Iqbal S, Clower JH, Hernandez SA, Damon SA, Yip FY. A review of disaster-related carbon monoxide poisoning: surveillance, epidemiology, and opportunities for prevention. *American Journal of Public Health*. 2012;102(10):1957–63. doi: 10.2105/AJPH.2012.300674 (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3490658/pdf/AJPH.2012.300674.pdf>, accessed 7 July 2017).
  16. Hasegawa A, Ohira T, Maeda M, Yasumura S, Tanigawa K. Emergency responses and health consequences after the Fukushima accident: evacuation and relocation. *Clinical Oncology*. 2016;28:237–44 (<http://www.sciencedirect.com/science/article/pii/S0936655516000054>, accessed 7 July 2017).
  17. Flash environmental assessment tool (FEAT 2.0): pocket guide. Geneva: United Nations Environment Programme/Office for the Coordination of Humanitarian Affairs Joint Unit; 2017 (<http://www.eecentre.org/?p=1596>, accessed 7 July 2017).

## ANNEX B CHEMICAL RELEASES ASSOCIATED WITH FLOODS

### What is a flood?

Floods are the most common natural hazard event and are the leading cause of deaths from disasters worldwide (1). The frequency of major flooding events is increasing as a consequence of climate change, urbanization and other factors (2, 3). A flood is a temporary situation where normally dry land is covered with water, e.g. as a result of the following (1, 2).

- Gradually rising inland water, such as rivers, lakes and groundwater, due to heavy rainfall or snowmelt.
- The accumulation of water on the surface due to prolonged rainfall resulting in water-logging and the rise of the groundwater table above the surface.
- The breaching of a dam or levee.
- Sudden flooding with short duration as a result of heavy rainfall in a storm or a release from a dam. This is known as a flash flood, and is particularly destructive on a sloping terrain where the water flows very rapidly.
- Coastal flooding caused by a tropical cyclone, storm surge or tsunami.

Some areas are particularly prone to flooding, for example low-lying coastal plains and along rivers. River floods are often seasonal. The severity of the hazard presented by a flood is influenced by the water height, the flow velocity and rate of rise, the duration of the flood and the season (4).

### Risk factors for chemical release

An analysis of past events suggests that storage tanks and pipework are particularly vulnerable to damage by floods (5). In addition, there are a number of factors that increase the vulnerability of an area to chemical release and damage to health during floods, including (1, 3):

- inadequate planning and building regulations;
- location of industrial facilities in flood-prone areas;
- structures that are not flood resilient;
- land with little capacity for absorbing rain, e.g. because of erosion, deforestation or impermeable coverings such as concrete;
- inadequate warning systems;
- inadequate safety measures or emergency planning;
- high population density around industrial sites;
- lack of public awareness about flood risks.

A flood may increase risks by reducing response capacity in the following ways (6, 7).

- Damage to on-site emergency equipment will hamper response, as will damage to essential infrastructure, such as the power supply, water supply and telecommunications.
- Off-site emergency-response personnel and other resources may not be available as they may be occupied in dealing with the consequences of the flood.
- The release of hazardous materials may hamper search and rescue operations.

Industrial site emergency-response plans should include flood scenarios, so that workers and managers will be prepared for the specific conditions that exacerbate an emergency situation during and following a flood.

### Mechanisms of chemical release

Rising floodwaters can displace and overturn chemical-storage tanks and rupture pipework and pipelines. Drums of chemicals can be lifted and carried in the floodwater. They can get damaged by collisions and release their contents. The released chemicals can mix and react with the water, potentially generating toxic reaction products or a fire or explosion hazard (5). When flammable hydrocarbons are released into floodwaters,

ignition can result in pool fires. These are buoyant flames above a horizontal pool of vaporizing hydrocarbon fuel and can carry a fire to new sources of flammable material or into residential areas (8). They are a particular risk at storage depots or refineries for petroleum products (see **Box B1**).

Damage to the power supply can cause process upsets and affect safety measures such as temperature and pressure monitors and control valves, potentially resulting in runaway chemical reactions and blow-down. Flooding of internal plant drainage systems may release waste oil or other chemical waste if not segregated from surface water drainage systems. Abandoned mines, such as coal mines, may flood, releasing acidic water containing sulfuric acid from the oxidation of sulfides upon exposure of the water to air (11). Tailings dams containing mining waste may burst under the pressure of water, releasing highly toxic waste and mud (4).

The inundation of an area with water can cause chemical release in other ways (2, 11). In rural areas, runoff from flooded areas can carry with it eroded soil containing fertilizers, herbicides and insecticides. Runoff from motorways, roads and bridges may contain heavy metals, petroleum hydrocarbons and polycyclic aromatic hydrocarbons. Runoff from inundated waste sites may contain a variety of toxic chemicals, depending on what was stored on the site (12).

Chemicals in floodwaters may contaminate drinking-water sources and, as floodwaters recede, may be deposited on farmland and in buildings such as homes and schools. Contaminated farmland may remain unfit for agricultural use for many years (3).

**Box B2** describes the contamination of soil by runoff from motorways in addition to toxic releases from a chemical factory during the 2002 floods in the Czech Republic.

## Potential impacts on human health

Chemicals released following a flood can cause dermal, respiratory and systemic toxic effects following direct exposure of victims and rescuers. Toxic effects and injuries may also result from environmental contamination, fires and explosions. The general public, rescuers and those involved in clean-up operations may be exposed to a range of hazards, which can be divided into those related to chemicals and those unrelated (12, 16). Examples are given below.

### Chemical-related

- Burns from fires and exposure to corrosive chemicals (formation of toxic and/or flammable vapours upon reaction of the released chemicals with the floodwaters).

## BOX B1. MOHAMMEDIA REFINERY, MOROCCO, NOVEMBER 2002

In November 2002, heavy rainfall hit the western and central part of Morocco causing significant flooding. Numerous deaths and missing people were reported. The region of Mohammedia, on the west coast of Morocco between Casablanca and Rabat, suffered the most; the industrial zones, as well as the airport, were heavily affected by flooding. At the oil refinery in Mohammedia, waste oil in the drainage system was lifted by the flood which reached a height of 1 m at the refinery. The waste oil was distributed all over the refinery with the floodwaters. This floating oil ignited

in contact with hot parts of refinery equipment, causing pool fires and explosions. The thermo-electric power plant, part of the refinery complex, was destroyed. Two people died in the explosion and four people were injured. As a result, the refinery closed for several months after the accident for repair and cleaning. After the flood, the country was short of fuel, because this refinery was the major processor of crude oil with an annual production of 8 million tonnes (5, 9, 10).

- Respiratory tract injury from inhalation of irritant gases, including combustion products.
- Poisoning from exposure to spilled toxic chemicals and the consumption of contaminated food or water. Depending on the speed, volume and flow of floodwaters, however, the risk of chemical exposure may be reduced by dilution in the water.
- Carbon monoxide poisoning resulting from the incorrect use of fuel-burning generators for electricity, barbeques, braziers or buckets of coal or charcoal for heating and cooking, or petrol-driven pumps and dehumidifiers to dry out flooded rooms (1, 2, 17).
- Injuries and poisoning in workers involved in rescue and clean-up, including excessive exposure to pesticides used for vector and rodent control.

### Non chemical-related

- Drowning.
- Hypothermia from immersion in water at less than 24 °C.

- Venomous bites and stings from displaced animals (1).
- Injuries and deaths as a result of floating debris. Injuries may also occur during the rescue and clean-up phases, e.g. when cutting and moving fallen debris.
- Consequences of evacuation, e.g. increased risk of infectious diseases at the evacuation sites, exacerbation of pre-existing health problems during patient transfer, saturation of health-care facilities reducing ability to provide adequate treatment, potential problems with water supply and sanitation, etc. (18).
- Psychosocial effects, including post-traumatic stress disorder (16, 19).

Chemical-related health problems were reported after flooding in Sandhurst (UK) in 2000 (see **Box B3**).

### Response and recovery considerations

Sections 5.3 and 5.4 (main document) describe in more detail the role of the health sector in the response and recovery phases. Summarized information is provided here.

## BOX B2. CZECH REPUBLIC, AUGUST 2002

In August 2002 a storm with persistent heavy rains hit central Europe, rapidly followed by a second storm severely affecting the Czech Republic. After a week of heavy rains, with approximately three times the average rainfall for August, the Elbe and a number of other rivers flooded. Hundreds of towns and villages were completely inundated, 220 000 people were evacuated and 19 deaths were reported (13, 14). In total, 3.2 million people were affected by the floods and the financial damages were estimated at 2–3 billion euros. Data collected by the Environmental Inspectorate showed that there were at least 20 accidents associated with the release of hazardous substances (14). The most serious was contamination from a chemicals factory in Neratovice, located north

of Prague along the Elbe river. In addition to oil and other chemicals produced by the plant, 80 tonnes of chlorine were released into the air and into the floodwaters. Comparisons of river water and sediment samples before and after the flood found significantly increased mercury and dioxin concentrations in water and sediments, especially around Neratovice. The investigations also found that floodwaters had washed toxic micropollutants from streets and roads (15).

A survey carried out in one district found that 46% of people felt a deterioration in their health during the flood and 39% in the six weeks after the flood. This feeling of impaired health persisted at 1 year after the flood in 73% of the population (14).

## Risk assessment

- i. Obtain information on potentially affected hazardous sites, including waste dumps, in order to assess the risks to health and determine the appropriate risk-management measures.
- ii. Identify the chemicals involved in the accident: check if an inventory is available, e.g. in the site emergency plan; if not use the *Flash environmental assessment tool* (21) (see also **Annex D** *Sources of additional information*). Look for labels with hazard information (see **Annex E** *Examples of hazard warnings*).
- iii. Collect and consider any clinical information available from exposed individuals, as this may help to identify some chemicals or chemical groups.
- iv. If feasible, organize the collection and analysis of environmental samples (air, soil, water, crops) in order to identify and quantify contamination by chemicals.
- v. Assess the possibility of contamination of drinking-water sources and foods.

### BOX B3. SANDHURST, GLOUCESTERSHIRE, UNITED KINGDOM, NOVEMBER 2000

On 30 October 2000 a fire, possibly triggered by lightning or wind, occurred at a waste management and recycling firm in Sandhurst, Gloucestershire, United Kingdom. Because of small explosions and the intensity of the fire, the fire service could not approach the site for several hours. Moreover, the accident occurred during a storm with strong winds and heavy rains, hampering access to the site by the fire service. People living close to the site were evacuated until the fire was extinguished later in the evening. The fire consumed tonnes of hazardous chemicals such as cyanide, pesticides, solvents and asbestos contained in drums.

Following continuing heavy rain the River Severn flooded, inundating the waste management site to a depth of 2.4 m of water. Chemicals were reported to have been released from the site in the floodwaters. People were once more evacuated because of concerns about their houses being chemically contaminated. The flood made the site inaccessible for several days, impeding the rapid removal of toxic

materials. Serious flooding continued to threaten the site until the end of November and the area flooded again in December. The clean-up of all materials could not start before the water receded.

Due to a large number of reported illnesses during the days following the fire and the flood, local health authorities undertook health surveys to assess the impact of the incident on the community. Health effects reported by local residents included sore throat, stinging eyes and difficulty in breathing, but these symptoms resolved a few weeks after the incident and no patient was admitted to hospital. Health authorities declared there was no evidence of long-term effects on public health or risks of food contamination. The major concern among residents was that their homes had been contaminated by chemicals, therefore local authorities collected samples of air, floodwater and mud and analysed them for different chemicals. Traces of chemicals were observed but no significant contamination was found (11, 20).

## Prevention of exposure

- i. Based on the risk assessments, provide advice as required to the civil defence, fire or other designated service on the need for:
  - containment measures
  - restrictions on access to contaminated sites
  - the need for personal protective equipment (PPE)
  - shelter-in-place or evacuation advisories for affected communities.
- ii. Ensure that people involved in clean-up and rescue operations are adequately equipped with PPE and are aware of the possibility of chemical spills.
- iii. Organize facilities for decontaminating chemically-exposed individuals.
- iv. Provide comprehensive information to the general public regarding precautionary measures (see 'Risk and crisis communication' below).

## Medical assessment and management

- i. Ensure that chemically-exposed individuals are decontaminated before they enter the health-care facility.
- ii. Ensure that health personnel follow procedures for wearing PPE when managing chemically-contaminated victims.
- iii. Conduct triage and patient assessment. Note that chemical injuries or poisoning may be combined with traumatic injuries.
- iv. Obtain advice on the management of chemical exposure from a poisons centre, if available.
- v. Provide specific medical treatment (e.g. antidotal treatment) as required.
- vi. Consider the need to collect biological samples from chemically-exposed individuals (including first-

responders) in order to identify and, if possible, quantify exposure.

- vii. Register all exposed individuals and ensure adequate documentation and record-keeping in case there is a need for long-term follow-up.
- viii. Ensure that after the first response, measures are taken in the recovery stage to prevent indirect chemical effects and long-term exposures. Provide mental health and psychosocial support for affected communities.

## Risk and crisis communication

Provide information, updated as necessary, to the public, first-responders and decision-makers about chemical and other hazards arising from the event. Ensure that the public is informed about:

- the Natech event(s)
- who is in charge
- what is being done
- the nature and hazards of the chemicals involved
- what individuals should do to protect themselves and their families
- when to seek medical attention
- how to get further information.

Some specific health-protection topics include:

- food and water advisories, in case of contamination
- prevention of carbon monoxide poisoning
- precautions during clean-up, e.g. use of personal protective equipment, safe use of cutting equipment, handling of asbestos cement, etc.
- potential hazards in flood-damaged homes.

## REFERENCES

1. Doocy S, Daniels A, Murray S, Kirsch TD. The human impact of floods: a historical review of events 1980–2009 and systematic literature review. *PLoS Currents Disasters*. 2013 April 16; Edition 1. doi: 10.1371/currents.dis.f4deb457904936b07c09daa98ee8171a (<http://currents.plos.org/disasters/article/the-human-impact-of-floods-a-historical-review-of-events-1980-2009-and-systematic-literature-review/>, accessed 7 July 2017).
2. Menne B, Murray V. Floods in the WHO European Region, health effects and their prevention. Copenhagen: World Health Organization; 2013 ([http://www.euro.who.int/\\_\\_data/assets/pdf\\_file/0020/189020/e96853.pdf](http://www.euro.who.int/__data/assets/pdf_file/0020/189020/e96853.pdf), accessed 7 July 2017).
3. OECD Studies in risk management: Italy – Industrial hazards triggered by floods. Paris: Organisation for Economic Co-operation and Development; 2006 (<https://www.oecd.org/italy/36099995.pdf>, accessed 7 July 2017).
4. Krausmann E, Mushtaq F. A qualitative Natech damage scale for the impact of floods on selected industrial facilities. *Natural Hazards*. 2008;46:179–97. doi: 10.1007/s11069-007-9203-5.
5. Cozzani V, Campedel M, Renni E, Krausmann E. Industrial accidents triggered by flood events: analysis of past accidents. *Journal of Hazardous Materials*. 2010;175:501–9.
6. Krausmann E, Cruz AM, Salzano E. Natech risk assessment and management: reducing the risk of natural-hazard impact on hazardous installations. Amsterdam: Elsevier; 2017.
7. Cruz AM, Steinberg LJ, Vetere Arellano AL, Nordvik J-P, Pisano F. State of the art in Natech risk management. Ispra: European Commission Joint Research Centre; 2004 (EC JRC, UN ISDR EUR 21292 EN; [http://www.unisdr.org/files/2631\\_FinalNatechStateofthe20Artcorrected.pdf](http://www.unisdr.org/files/2631_FinalNatechStateofthe20Artcorrected.pdf), accessed 7 July 2017).
8. Hamins A, Kashiwagi T, Burch RR. Characteristics of pool fire burning. ASTM special technical publication 1284. 1996. pp 15–41 (<http://fire.nist.gov/bfrlpubs/fire96/PDF/f96068.pdf>, accessed 7 July 2017).
9. Vallee A, Affeltranger B, Duval C. Flooding of industrial facilities. Vulnerability reduction in practice. In: Suter G, De Rademaeker E. 13th International Symposium on Loss Prevention and Safety Promotion in the Process Industry, June 2010, Bruges, Belgium. Antwerpen: Technologisch Instituut; 2010. pp 389–96. (<https://hal.archives-ouvertes.fr/ineris-00973563/document>, accessed 7 July 2017).
10. Morocco – floods. OCHA Situation Report No. 1. 28 November 2002. In: Reliefweb [website]. Geneva: United Nations Office for the Coordination of Humanitarian Affairs; 2002 (<http://reliefweb.int/report/morocco/morocco-floods-ocha-situation-report-no-1>, accessed 7 July 2017).
11. Euripidou E, Murray V. Public health impacts of floods and chemical contamination. *Journal of Public Health*. 2004;26(4):376–83 (<http://jpubhealth.oxfordjournals.org/content/26/4/376.full.pdf>, accessed 7 July 2017).
12. Young S, Balluz L, Malilay J. Natural and technologic hazardous material releases during and after natural disasters: a review. *Science of the Total Environment*. 2004;322(1–3):3–20 ([http://dx.doi.org/10.1016/S0048-9697\(03\)00446-7](http://dx.doi.org/10.1016/S0048-9697(03)00446-7), accessed 7 July 2017).
13. Sercl P, Stehlik J. The August 2002 flood in the Czech Republic. Abstract No 12404, EGS-AGU-EUG Joint Assembly, Nice, France; 6–11 April 2003 (<http://adsabs.harvard.edu/abs/2003EAEJA....12404S>, accessed 7 July 2017).

14. August 2002 catastrophic flood in the Czech Republic. Prague: Ministry of Environment of the Czech Republic; 2004 ([http://www.mzp.cz/web/edice.nsf/E80DF4F3457EE6ABC12570B6004D6EF4/\\$file/flood\\_2002.pdf](http://www.mzp.cz/web/edice.nsf/E80DF4F3457EE6ABC12570B6004D6EF4/$file/flood_2002.pdf), accessed 7 July 2017).
15. Chour V. August 2002 flood events in the Czech Republic – Some evidence on the extent of pollution diffused during the flood. Diffuse Pollution Conference, Dublin; 2003 ([http://www.ucd.ie/dipcon/docs/theme09/theme09\\_02.PDF](http://www.ucd.ie/dipcon/docs/theme09/theme09_02.PDF), accessed 7 July 2017).
16. Shrubsole D. Natural disasters and public health issues: a review of the literature with a focus on the recovery period. Institute for Catastrophic Loss Reduction (ICLR) Research Paper Series No. 4. Toronto: ICLR; 1999 ([http://www.iclr.org/images/Natural\\_Disasters\\_and\\_Public\\_Health\\_Issues.pdf](http://www.iclr.org/images/Natural_Disasters_and_Public_Health_Issues.pdf), accessed 7 July 2017).
17. Waite T, Murray V, Baker D. Carbon monoxide poisoning and flooding: changes in risk before, during and after flooding require appropriate public health interventions. PLoS Currents Disasters. 2014 July 3; Edition 1. doi: 0.1371/currents.dis.2b2eb9e15f9b982784938803584487f1 (<http://currents.plos.org/disasters/article/carbon-monoxide-poisoning-and-flooding-changes-in-risk-before-during-and-after-flooding-require-appropriate-public-health-interventions/>, accessed 20 September 2017).
18. Hasegawa A, Ohira T, Maeda M, Yasumura S, Tanigawa K. Emergency responses and health consequences after the Fukushima accident: evacuation and relocation. Clinical Oncology. 2016;28:237–44 (<http://www.sciencedirect.com/science/article/pii/S0936655516000054>, accessed 7 July 2017).
19. Stanke C, Murray V, Amlôt R, Nurse J, Williams R. The effects of flooding on mental health: outcomes and recommendations from a review of the literature. PLoS Currents Disasters. 2012 May 30; Edition 1. doi: 10.1371/4f9f1fa9c3cae (<http://currents.plos.org/disasters/article/the-effects-of-flooding-on-mental-health-outcomes-and-recommendations-from-a-review-of-the-literature/>, accessed 29 September 2017).
20. Report for the Deputy Prime Minister the Right Hon John Prescott MP into the major fire on 30 October 2000 at Cleansing Service Group Ltd, Sandhurst. London: Health and Safety Executive; 2001 (<http://www.hse.gov.uk/chemicals/sandhurst.pdf>, accessed 7 July 2017).
21. Flash environmental assessment tool (FEAT 2.0): pocket guide. Geneva: United Nations Environment Programme/Office for the Coordination of Humanitarian Affairs Joint Unit; 2017 (<http://www.eecentre.org/?p=1596>, accessed 7 July 2017).

## ANNEX C

### CHEMICAL RELEASES ASSOCIATED WITH CYCLONES

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#### What is a cyclone?

Cyclone, hurricane and typhoon are regionally specific names for a low-pressure weather system over tropical or subtropical waters characterized by thunderstorms, torrential rain and high wind speeds (1, 2). Cyclone intensity is predicted to increase as a consequence of climate change (3).

Cyclones are further classified according to wind speed and location (1, 2):

- tropical depression – sustained wind speed of 63 km/h or less;
- tropical storm – maximum sustained wind speed ranging from 63 to 117 km/h;
- hurricane, typhoon, severe tropical cyclone, severe cyclonic storm or tropical cyclone (nomenclature depending on the ocean basin) – an intense tropical weather system with sustained winds of at least 119 km/h.

Hurricanes can be categorized according to their sustained wind speed using the Saffir-Simpson Hurricane Wind Scale, which runs from 1–5. A category 1 hurricane has wind speeds of 119–153 km/h and will cause some damage. A category 5 hurricane has wind speeds greater than 252 km/h and will cause catastrophic damage (4).

The typical seasons for this weather phenomenon are as follows (2):

- typhoons in the western North Pacific region: May to November;
- hurricanes in the Americas and the Caribbean: June to November, peaking in August and September;

- cyclones in the South Pacific and Australia: November to April;
- tropical cyclones in the Bay of Bengal and Arabian Sea: April to June and September to November;
- tropical cyclones on the east coast of Africa: November to April.

Cyclones can be hundreds of kilometres wide and can bring destructive high winds, storm surges, inland flooding, lightning and, occasionally, tornadoes (2). A storm surge is the abnormal rise of water generated by strong winds. Storm surges and battering waves can cause extensive damage along the affected coastline. In addition, a storm surge can travel several kilometres inland along rivers and estuaries (5).

#### Risk factors for chemical release

Analysis of past events suggests that petroleum refineries and other hazardous installations are susceptible to high winds, tornadoes, flooding and lightning leading to hazardous chemical releases (6, 7). Cyclones can also cause major infrastructure damage that will hamper response.

Factors that increase the risk of a chemical release and harm to health during or after a cyclone include the following (8, 9):

- inadequate planning and building regulations;
- location of industrial and chemical-storage facilities in coastal zones;
- structures that are vulnerable to storm damage and lightning strikes;
- inadequate safety measures or emergency planning;
- inadequate warning systems;
- high population density around industrial sites;
- lack of public awareness about cyclone and flood risks.

A cyclone may increase risks by reducing response capacity in the following ways (7, 10).

- Response activities are impossible until the storms have died down sufficiently to allow safe movement.
- Damage to on-site emergency equipment will hamper response, as will damage to essential infrastructure such as the power supply, water supply and telecommunications.
- The off-site emergency-response personnel and other resources may not be available, as they may be occupied in dealing with the consequences of the cyclone.
- The release of hazardous materials may hamper search and rescue operations.

## Mechanisms of chemical release

Cyclones can result in a chemical release in a variety of ways (11, 12). High winds and tornadoes can directly damage buildings and structures at chemical installations by tipping over storage tanks and dislocating piping and connections between storage and processing units. Such high-force winds may also launch objects such as tree branches and rooftops into the air and into storage vessels and pipework (6). Gaseous toxic chemicals released from punctured or ruptured storage tanks can be blown over populated areas or can dissolve in rainwater to produce toxic or corrosive rain (6).

High winds and powerful waves can damage freight ships and oil tankers either directly or indirectly through collision with rocks. This can release chemicals into the sea that may then be washed onto shore. In the case of hydrocarbons that float on water, these may be blown onto shore in the form of fine spray. As an example, during Typhoon Haiyan in 2013, which severely affected the Philippines, a power barge broke loose from its moorings, hit the shore and ruptured, releasing about 800 000 litres of bunker fuel oil into the sea. Most of the oil was washed ashore and contaminated many kilometres of coastline (13; see **Box C1**).

Floods caused by heavy rain and hurricane winds can displace and overturn chemical-storage tanks and rupture pipelines. Drums of chemicals can be lifted and carried in the floodwater. They can be damaged by collisions and release their contents. The released chemicals can mix and react with the water, potentially generating toxic reaction products or a fire or explosion hazard (14). When flammable hydrocarbons are released into the floodwaters, ignition can result in pool fires. These are buoyant flames above a horizontal pool of vaporizing hydrocarbon fuel and can carry a fire to new sources of flammable materials or into residential areas (15). They are a particular risk at storage depots or refineries for petroleum products.

Flooding of internal plant drainage systems may release waste oil or other chemical waste if not segregated from surface water drainage systems. Runoff from inundated areas can carry chemicals with it such as eroded soil containing fertilizers, herbicides and pesticides (in a rural catchment area), or heavy metals, petroleum hydrocarbons and polycyclic aromatic hydrocarbons (runoff from roads, motorways and bridges) (16, 17).

Lightning can directly strike structures and storage tanks that contain flammable materials, causing fires or explosions (6, 18). Oil and gas facilities are particularly vulnerable. Lightning strikes can also disrupt electrical circuitry and safety control systems, leading to chemical release (18).

General damage to the power supply can cause process upsets and affect safety measures such as temperature and pressure monitors and control valves, potentially resulting in runaway chemical reactions and blow-down.

## Potential impacts on human health

Cyclones, when they come onto land, can lead to heavy rain, strong winds and large waves. The general public, rescuers and those involved in clean-up operations may be exposed to a range of hazards, which can be divided into those related to chemicals and those unrelated (9, 19). Examples are given below.

## Chemical-related

- Burns from fires and exposure to corrosive chemicals (formation of toxic and/or flammable vapours upon reaction of the released chemicals with the floodwaters).
- Respiratory tract injury from inhalation of irritant gases, including combustion products, and fibres (e.g. from damaged asbestos and fibreglass insulation).
- Poisoning from exposure to spilled toxic chemicals and the consumption of contaminated food or water. Depending on the speed, volume and flow of floodwaters, the risk of chemical exposure may be reduced by dilution in the water.
- Carbon monoxide poisoning resulting from the incorrect use of fuel-burning generators for electricity, barbeques, braziers or buckets of coal or charcoal for heating and cooking, or petrol-driven pumps and dehumidifiers to dry out flooded rooms (16, 20, 21).
- Injuries and poisoning in workers involved in rescue and clean-up, including excessive exposure to pesticides used for vector and rodent control.

## Non chemical-related

- Drowning.
- Electrocution, lightning strikes.
- Hypothermia from immersion in water at less than 24 °C.
- Venomous bites and stings from displaced animals (21).
- Injuries and deaths as a result of flying, falling and floating debris. Injuries may also occur during the rescue and clean-up phases, e.g. when cutting and moving fallen debris.

- Consequences of evacuation, e.g. increased risk of infectious diseases at the evacuation sites, exacerbation of pre-existing health problems during patient transfer, saturation of health-care facilities with consequent inability to provide adequate treatment, potential problems with water supply and sanitation, etc. (22).
- Diarrhoeal, vector- and rodent-borne diseases.
- Psychosocial effects, including post-traumatic stress disorder (16, 19).

## Response and recovery considerations

Sections 5.3 and 5.4 (main document) describe in more detail the role of the health sector in the response and recovery phases. Summarized information is provided here.

### Risk assessment

- i. Obtain information on potentially affected hazardous sites, including waste dumps, in order to assess the risks to health and determine the appropriate risk-management measures.
- ii. Identify the chemicals involved in the accident: check if an inventory is available, e.g. in the site emergency plan; if not, use the *Flash environmental assessment tool* (23) (see also **Annex D Sources of additional information**). Look for labels with hazard information (see **Annex E Examples of hazard warnings**).
- iii. Collect and consider any clinical information available from exposed individuals as this may help to identify some chemicals or chemical groups.
- iv. If feasible, organize the collection and analysis of environmental samples (air, soil, water, crops) in order to identify and quantify contamination by chemicals.
- v. Assess the possibility of contamination of drinking-water sources and foods.

## Prevention of exposure

- i. Based on the risk assessments, provide advice as required to the civil defence, fire or other designated service on the need for:
  - containment measures
  - restrictions on access to contaminated sites
  - the need for personal protective equipment (PPE)
  - shelter-in-place or evacuation advisories for affected communities.
- ii. Ensure that people involved in clean-up and rescue operations are adequately equipped with PPE and are aware of the possibility of chemical spills.
- iii. Organize facilities for decontaminating chemically-exposed individuals.
- iv. Provide comprehensive information to the general public regarding precautionary measures (see 'Risk and crisis communication' below).

## Medical assessment and management

- i. Ensure that chemically-exposed individuals are decontaminated before they enter the health-care facility.
- ii. Ensure that health personnel follow procedures for wearing PPE when managing chemically-contaminated victims.
- iii. Conduct triage and patient assessment. Note that chemical injuries or poisoning may be combined with traumatic injuries.
- iv. Obtain advice on the management of chemical exposure from a poisons centre, if available.
- v. Provide specific medical treatment (e.g. antidotal treatment) as required.

- vi. Consider the need to collect biological samples from chemically-exposed individuals (including first-responders) in order to identify and, if possible, quantify exposure.
- vii. Register all exposed individuals and ensure adequate documentation and record-keeping in case there is a need for long-term follow-up.
- viii. Ensure that, after the first response, measures are taken in the recovery stage to prevent indirect chemical effects and long-term exposures. Provide mental health and psychosocial support for affected communities.

## Risk and crisis communication

Provide information, updated as necessary, to the public, first-responders and decision-makers about chemical and other hazards arising from the event. Ensure that the public is informed about:

- the Natech event(s)
- who is in charge
- what is being done
- the nature and hazards of the chemicals involved
- what individuals should do to protect themselves and their families
- when to seek medical attention
- how to get further information.

Some specific health-protection topics include:

- food and water advisories, in case of contamination
- prevention of carbon monoxide poisoning
- precautions during clean-up, e.g. use of personal protective equipment, safe use of cutting equipment, handling of asbestos cement, etc.
- potential hazards in flood-damaged homes.

## BOX C1. TYPHOON HAIYAN, ESTANCIA, PHILIPPINES, NOVEMBER 2013

On 8 November 2013 Typhoon Haiyan hit the Philippines with winds blowing up to 275 km/h. National authorities reported 14.1 million affected people, 4.1 million people displaced and 6155 deaths. About 1.1 million homes were damaged and half of them completely destroyed. The region of Visayas was most affected. Significant damage was reported throughout the area affecting cities, villages and important infrastructure, such as Tacloban airport. A power barge anchored south of Estancia, in the province of Iloilo, broke loose, hit the shoreline and was ruptured. There was a release of over 800 000 litres of bunker C heavy fuel along 10 km of coastline south of Estancia. For health and safety reasons hundreds of families living in this area were evacuated. Authorities were concerned about toxic compounds evaporating from the oil, as well as the risk of accidental fires and injuries.

The typhoon left main roads severely damaged and remote areas were not accessible for logistic support. People started manually cleaning up the oil-contaminated debris, as well as the oil itself. As they did not have adequate protective equipment, people had skin exposure to the oil. Containment

booms were installed to trap the floating oil spill. However the use of mechanical clean-up equipment was delayed because of the inaccessibility of the site. As a consequence, local people, who mainly depended on fishing and tourism, were not allowed to return to their homes until mid-December. This had an important impact on their recovery, as they were dependent on humanitarian aid. Moreover, until the end of December, heavily damaged houses and schools were not accessible.

Spilled oil polluted many kilometres of coast, affecting vegetation and wildlife. Tree trunks, roots and dead branches covered with oil were observed in mangroves up to 3 km inland. Oil-contaminated debris remained on the coastline and the sand was polluted up to a depth of 10–20 cm. Many fishing boats damaged by the typhoon and contaminated with oil were observed near Estancia. Some of the contaminated areas were left to be naturally cleaned up by tide action. As there was no industrial waste-treatment facility in the region that could handle the oily debris, it had to be shipped to another island, introducing additional costs and the need for control measures (13).

## REFERENCES

1. What is a hurricane, typhoon or tropical cyclone? In: Frequently asked questions [website]. Miami: National Oceanic & Atmospheric Administration; 2017 (<http://www.aoml.noaa.gov/hrd/tcfaq/A1.html>, accessed 7 July 2017).
2. FAQs – Tropical cyclones. In: World Meteorological Organization [website]. Geneva: World Meteorological Organization; 2017 (<http://public.wmo.int/en/About-us/FAQs/faqs-tropical-cyclones>, accessed 7 July 2017).
3. Protecting health from climate change: vulnerability and adaptation assessment. Geneva: World Health Organization; 2013 (<http://www.who.int/globalchange/publications/vulnerability-adaptation/en/>, accessed 9 January 2018).
4. Saffir-Simpson Hurricane Wind Scale. In: National Hurricane Centre, National Oceanic & Atmospheric Administration [website]. Miami: National Oceanic & Atmospheric Administration; 2016 (<http://www.nhc.noaa.gov/aboutsshws.php>, accessed 30 December 2016).
5. Hurricane preparedness: hazards. In: National Weather Service, National Oceanic & Atmospheric Administration [website]. Miami: National Oceanic & Atmospheric Administration; 2017 (<http://www.nhc.noaa.gov/prepare/hazards.php>, accessed 7 July 2017).
6. Cruz A, Steinberg L, Luna R. Identifying hurricane-induced hazardous material release scenarios in a petroleum refinery. *Natural Hazards Review*. 2001;2(4):203–10.
7. Krausmann E, Cruz AM, Salzano E. Natech risk assessment and management: reducing the risk of natural-hazard impact on hazardous installations. Amsterdam: Elsevier; 2017.
8. Cruz AM, Steinberg LJ, Vetere Arellano AL, Nordvik J-P, Pisano F. State of the art in Natech risk management. Ispra: European Commission Joint Research Centre; 2004 (EC JRC, UN ISDR EUR 21292 EN; [http://www.unisdr.org/files/2631\\_FinalNatechStateofthe20Artcorrected.pdf](http://www.unisdr.org/files/2631_FinalNatechStateofthe20Artcorrected.pdf), accessed 7 July 2017).
9. Young S, Balluz L, Malilay J. Natural and technologic hazardous material releases during and after natural disasters: a review. *Science of the Total Environment*. 2004;322(1–3):3–20 ([http://dx.doi.org/10.1016/S0048-9697\(03\)00446-7](http://dx.doi.org/10.1016/S0048-9697(03)00446-7), accessed 7 July 2017).
10. Krausmann E, Renni E, Campedel M, Cozzani V. Industrial accidents triggered by earthquakes, floods and lightning: lessons learned from a database analysis. *Natural Hazards*. 2011;59:285–300. doi: 10.1007/s11069-011-9754-3.
11. Cruz AM, Krausmann E. Vulnerability of the oil and gas sector to climate change and extreme weather events. *Climatic Change*. 2013;121:41–53.
12. Godoy, LA. Performance of storage tanks in oil facilities damaged by hurricanes Katrina and Rita. *Journal of Performance of Constructed Facilities*. 2007; 21(6):441–9.
13. Oil spill in Estancia Iloilo Province, Western Visayas, Philippines, resulting from Typhoon Haiyan (Yolanda). Geneva: United Nations Environment Programme/Office for the Coordination of Humanitarian Affairs Joint Unit; 2013 (<http://reliefweb.int/sites/reliefweb.int/files/resources/Estancia%20Oil%20Spill%20Initial%20Assessment%20Report%20FINAL%282%29.pdf>, accessed 7 July 2017).
14. Cozzani V, Campedel M, Renni E and Krausmann E. Industrial accidents triggered by flood events: analysis of past accidents. *Journal of Hazardous Materials*. 2010;175:501–9.
15. Hamins A, Kashiwagi T, Burch RR. Characteristics of pool fire burning. ASTM special technical publication 1284. 1996. pp. 15–41. (<http://fire.nist.gov/bfrlpubs/fire96/PDF/f96068.pdf>, accessed 7 July 2017).

16. Menne B, Murray V. Floods in the WHO European Region: health effects and their prevention. Copenhagen: World Health Organization; 2013 ([http://www.euro.who.int/\\_\\_data/assets/pdf\\_file/0020/189020/e96853.pdf](http://www.euro.who.int/__data/assets/pdf_file/0020/189020/e96853.pdf), accessed 7 July 2017).
17. Euripidou E, Murray V. Public health impacts of floods and chemical contamination. *Journal of Public Health*. 2004;26(4):376–383 (<http://jpubhealth.oxfordjournals.org/content/26/4/376.full.pdf>, accessed 7 July 2017).
18. Renni E, Krausmann E, Cozzani V. Industrial accidents triggered by lightning. *Journal of Hazardous Materials*. 2010;184:42–48.
19. Stanke C, Murray V, Amlôt R, Nurse J, Williams R. The effects of flooding on mental health: outcomes and recommendations from a review of the literature. *PLoS Currents Disasters*. 2012 May 30; Edition 1. doi: 10.1371/4f9f1fa9c3cae (<http://currents.plos.org/disasters/article/the-effects-of-flooding-on-mental-health-outcomes-and-recommendations-from-a-review-of-the-literature/>, accessed 29 September 2017).
20. Waite T, Murray V, Baker D. Carbon monoxide poisoning and flooding: changes in risk before, during and after flooding require appropriate public health interventions. *PLoS Currents Disasters*. 2014 July 3; Edition 1. doi: 10.1371/currents.dis.2b2eb9e15f9b982784938803584487f1 (<http://currents.plos.org/disasters/article/carbon-monoxide-poisoning-and-flooding-changes-in-risk-before-during-and-after-flooding-require-appropriate-public-health-interventions/>, accessed 20 September 2017).
21. Doocy S, Daniels A, Murray S, Kirsch TD. The human impact of floods: a historical review of events 1980–2009 and systematic literature review. *PLoS Currents Disasters*. 2013 April 16; Edition 1. doi: 10.1371/currents.dis.f4deb457904936b07c09daa98ee8171a (<http://currents.plos.org/disasters/article/the-human-impact-of-floods-a-historical-review-of-events-1980-2009-and-systematic-literature-review/>, accessed 30 December 2016).
22. Hasegawa A, Ohira T, Maeda M, Yasumura S, Tanigawa K. Emergency responses and health consequences after the Fukushima accident: evacuation and relocation. *Clinical Oncology*. 2016;28:237–44 (<http://www.sciencedirect.com/science/article/pii/S0936655516000054>, accessed 7 July 2017).
23. Flash environmental assessment tool (FEAT 2.0): pocket guide. Geneva: United Nations Environment Programme/Office for the Coordination of Humanitarian Affairs Joint Unit; 2017 (<http://www.eecentre.org/?p=1596>, accessed 7 July 2017).

## ANNEX D

### SOURCES OF ADDITIONAL INFORMATION

#### Natech

- **RAPID-N: Rapid Natech Risk Assessment and Mapping Tool [website]. Ispra: European Commission Joint Research Centre; 2017**

RAPID-N is a web-based scientific software application for the rapid assessment and mapping of industrial accident risks due to natural disasters (Natech). By using the natural hazard scenario as input, it estimates the extent and probability of damage to industrial process equipment and models consequences of probable Natech events (e.g. fire, explosion, chemical release) that may be triggered by the natural hazard damage. RAPID-N aims to facilitate Natech risk assessment/mapping and enhance information sharing on Natech events by providing a collaborative environment. Available at: <http://rapidn.jrc.ec.europa.eu/>

- **Addendum No. 2 to the OECD guiding principles for chemical accident prevention, preparedness and response (2nd ed.) to address natural hazards triggering technological accidents (Natechs) ENV/JM/MONO(2015)1. Series on Chemical Accidents No. 27. Paris: Organisation for Economic Co-operation and Development; 2015**

The addendum addresses the risk management of natural hazard-triggered technological accidents (Natech). The addendum consists of a number of amendments to the guiding principles and the addition of a new chapter to provide more detailed guidance on Natech prevention, preparedness and response. Available at: [http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono\(2015\)1&doclanguage=en](http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2015)1&doclanguage=en)

#### Chemical incidents in general

- **Disaster risk management for health fact sheets. Geneva: World Health Organization; 2017**  
Information sheets for health workers engaged in

disaster risk management and for multisectoral partners to consider how to integrate health into their disaster risk-management strategies.

Available at: <http://www.who.int/hac/techguidance/preparedness/factsheets/en/>

The following link refers to a sheet on chemical safety: [http://www.who.int/hac/events/drm\\_fact\\_sheet\\_chemical\\_safety.pdf](http://www.who.int/hac/events/drm_fact_sheet_chemical_safety.pdf)

- **Manual for the public health management of chemical incidents. Geneva: World Health Organization; 2009**

This manual, targeted at public health and environmental professionals, describes various phases of the emergency cycle – prevention, planning and preparedness, detection and alert, response and recovery – and the roles and responsibilities of public health within these various phases. Available at: [http://www.who.int/environmental\\_health\\_emergencies/publications/Manual\\_Chemical\\_Incidents/en/](http://www.who.int/environmental_health_emergencies/publications/Manual_Chemical_Incidents/en/)

- **Environmental health in emergencies and disasters: a practical guide. Geneva: World Health Organization; 2002**

This guide provides managers and field staff with a framework for thinking about and planning for disasters and emergencies – including an overview of the technical aspects of environmental health management and measures to reduce the impact of disasters on environmental health infrastructure. Chapter 3.5.2 contains a general model for disaster-preparedness planning with 12 steps. Available at: <http://apps.who.int/iris/handle/10665/42561>

- **Awareness and preparedness for emergencies at local level (APELL) – handbook. Paris: UN Environment; 2015**

This handbook is designed to assist decision-makers and technical personnel in preparing emergency-response plans and improving community awareness. The handbook provides the basic concepts for initiating and managing the APELL process, and is organized in 10 conceptual elements within five phases of activity. Available at: <http://apell.eecentre.org/ResourceDetailInfo.aspx?ReadDetails/id=105>

- **Flash environmental assessment tool (FEAT 2.0): pocket guide. Geneva: United Nations Environment Programme/ Office for the Coordination of Humanitarian Affairs Joint Unit; 2017**

This tool helps to identify existing or potential acute environmental impacts that pose risks for humans, human life-support functions and ecosystems, following sudden-onset natural disasters. FEAT focuses primarily on immediate and acute impacts arising from released hazardous chemicals. It consists of a printed decision framework and look-up tables. Available at: <http://www.eecentre.org/ToolGuidanceDetails.aspx/id/32/lan/en-US>

- **International chemical safety cards (ICSC). Geneva: World Health Organization International Labour Organization; 2017**

The ICSC are data sheets that provide essential safety and health information on chemicals and as such promote the safe use of chemicals in the workplace. The ICSC are developed by WHO and the International Labour Organization. Currently more than 1700 cards are available. Available at: <http://www.ilo.org/dyn/icsc/showcard.home>

- **Emergency response guidebook. Washington (DC): US Department of Transportation/ Transport Canada; 2016**

This guidebook is provided free-of-charge. It is intended for use by first-responders during the initial phase of a transportation incident involving hazardous materials. It is applicable to hazardous materials transported by road, rail, air, waterways and by pipeline. The guidebook is issued every four years and is available in English and Spanish (*Guía de Respuesta en Caso de Emergencia*). It assists responders to quickly identify the hazards of the material(s) involved in the incident, and advises on the appropriate measures to protect themselves and the general public during the initial response phase. Available at: <https://www.tc.gc.ca/eng/canutec/guide-menu-227.htm>

- **UN Recommendations on the transport of dangerous goods – model regulations nineteenth revised edition. Geneva: United Nations Economic and Social Council; 2015.**

This guidance (also known as the UN Orange

Book), has been developed by the United Nations Economic and Social Council to harmonize dangerous goods transport regulations. Most dangerous goods regulations, such as the International Maritime Dangerous Goods (IMDG) code, IATA and other national regulations, are developed based on the Recommendations. The model regulations cover principles of classification and definition of hazard classes, listing of the principal dangerous goods, general packing requirements, testing procedures, marking, labelling or placarding, and transport documents. Available at:

[http://www.unece.org/trans/danger/publi/unrec/rev13/13nature\\_e.html](http://www.unece.org/trans/danger/publi/unrec/rev13/13nature_e.html)

- **Globally harmonized system of classification and labelling of chemicals (GHS), Rev 7. Geneva: United Nations Economic and Social Council; 2017.**

The GHS addresses classification of chemicals by types of hazard and proposes harmonized hazard communication elements, including labels and safety data sheets. It aims to ensure that information on physical hazards and toxicity from chemicals is available to enhance the protection of human health and the environment during the handling, transport and use of these chemicals. The GHS also provides a basis for harmonization of rules and regulations on chemicals at national, regional and worldwide level; an important factor for trade facilitation. Available at: [http://www.unece.org/trans/danger/publi/ghs/ghs\\_welcome\\_e.html](http://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html)

- **UK recovery handbook for chemical incidents. London: Health Protection Agency; 2012.**

This handbook provides guidance to aid the decision-making process for developing and implementing a recovery strategy in the aftermath of a chemical incident. It focuses on environmental decontamination and provides guidance and checklists for dealing with contaminated food production systems, inhabited areas and water environments. Available at: [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/201024/UKRHCI\\_publication\\_31st\\_May\\_2012\\_web2.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201024/UKRHCI_publication_31st_May_2012_web2.pdf)

## Emergencies in general

- **Comprehensive safe hospitals framework. Geneva: World Health Organization; 2015**

The Safe Hospital framework presents a structured approach for actions to strengthen the safety and preparedness of hospitals and health facilities for all types of hazards. It was developed for use by governments, health authorities, financial institutions and disaster management organizations. The framework describes medium- to long-term goals and achievable outcomes, and proposes four main components of safe hospital programmes. It also describes an implementation mechanism with guiding principles that support key actions in a country setting. Available at: [http://www.who.int/hac/techguidance/comprehensive\\_safe\\_hospital\\_framework.pdf?ua=1](http://www.who.int/hac/techguidance/comprehensive_safe_hospital_framework.pdf?ua=1)

- **Hospital emergency response checklist: an all-hazards tool for hospital administrators and emergency managers. Geneva: World Health Organization; 2011**

This checklist is intended to assist hospital administrators and emergency managers in responding effectively to the most likely disaster scenarios encompassing all hazards. This tool comprises current hospital-based emergency management principles and best practices and integrates priority action required for rapid, effective response to a critical event. The tool is structured according to nine key components, each with a list of priority actions. References to selected supplemental tools, guidelines and other applicable resources are provided. The principles and recommendations included in this tool may be used by hospitals at any level of emergency preparedness. Available at: <http://www.euro.who.int/en/health-topics/emergencies/disaster-preparedness-and-response/publications/2011/hospital-emergency-response-checklist>

- **Health resources availability monitoring system (HeRAMS). In: Humanitarian health action [website] Geneva: World Health Organization; 2017**

HeRAMS is a rapid online system for monitoring health facilities, services and resources availability

in emergencies. It monitors the availability of services and resources at the 'point of delivery', therefore it is applicable to almost all types of health-care delivery methods employed in emergencies. Available at:

<http://www.who.int/hac/herams/en/>

- **Effective media communication during public health emergencies. A WHO handbook. Geneva: World Health Organization; 2005**

This handbook describes a seven-step process to assist public health officials and others to communicate effectively through the media during emergencies. Available at: [http://www.who.int/csr/resources/publications/WHO\\_CDS\\_2005\\_31/en/](http://www.who.int/csr/resources/publications/WHO_CDS_2005_31/en/)

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## ANNEX E

### EXAMPLES OF HAZARD WARNINGS FOUND ON LABELS OF CHEMICAL CONTAINERS

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These pictograms are from the *UN Recommendations on the transport of dangerous goods, model regulations* and the *Globally harmonized system of classification and labelling of chemicals* (GHS<sub>c</sub>).

They are usually supplemented with warning statements that specify the hazard. There may also be information on precautionary measures and first aid.

Note that a single GHS pictogram (white background, red outline) may indicate a number of related hazards.

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<sup>c</sup> [http://www.unece.org/fileadmin/DAM/trans/danger/publi/ghs/ghs\\_rev05/English/05e\\_annex1.pdf](http://www.unece.org/fileadmin/DAM/trans/danger/publi/ghs/ghs_rev05/English/05e_annex1.pdf)

SYMBOL	HAZARD CATEGORY
    	Explosive (e.g. unstable explosive, projection hazard)
    	Flammable material (e.g. gas, aerosol, vapour, solid)
 	Risk of spontaneous combustion if exposed to air; self-heating
  	Emits flammable gas in contact with water
 	Oxidisers (may cause or intensify fire)
  	Organic peroxide: heating may cause fire or explosion
  	Gas under pressure (e.g. pressurized container, may burst if heated; refrigerated gas – may cause cryogenic burns)
 	Toxic substance
 	Corrosive
	Health hazard e.g. effect on specific organs, cancer hazard, reproductive hazard, allergy
	General warning





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