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Future prevention and handling of environmental accidents

by Pier Alberto Bertazzi, MD[1]

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According to the 1995 World Disaster Report, accidents are second only to floods in frequency. Chemical accidents leading to a serious danger to the general public and to the environment rank 10th, just after epidemics and followed by landslides. Can the occurrence of these environmental accidents be reduced in the future and their consequences minimized? The answer is yes, provided that decisions are made and actions implemented now. Future management of environmental accidents requires that the same effort so far devoted to relief measures in the postimpact phase be devoted to advance planning in the preaccident period. International cooperation should be activated to predispose risk reduction measures, including a hazard-oriented approach to prevention, preparedness plans for possible incidents in major hazardous installations, and collaborative programs and resource sharing for response to accidents and the follow-up of their consequences. Clear and unequivocal communication with the public, with other professionals, decision makers, and the media play a key role in each step.

Key terms accident prevention, disaster preparedness, emergency response, environmental health, industrial accident.

In recent years, there has been increasing concern about the hazards of chemicals to human health and the environment. Sharpened by an increased societal sensibility to environment and health protection issues, this concern has arisen in response to many factors as, for example, the visible widespread dissemination of chemicals stemming from human activities (primarily, industrial processes), information on the poorly controlled discharge of wastes and dumping of toxic materials, and recent occurrences of environmental accidents (eg, Seveso, Bhopal, Chernobyl) that caused disrupting effects on the social life and health of entire communities on different continents (1, 2). Today, the potential for such accidents is increased by the transfer of dangerous productions from their original locations to less protected and more vulnerable sites (3—5), by the novel and sometimes tumultuous (and hence less controlled) development of industrialization in certain countries (6, 7), and by the migration of needy, yet unskilled and poorly trained populations to highly industrialized areas (8).

This paper addresses environmental and occupational health aspects of the future prevention and management of accidents caused by "industrial explosions, major fires and major toxic release, involving one or more hazardous substances, leading to a serious danger to the workers, to the public and to the environment" [p 2] (9). Other major types of accidents affecting the environment (eg, radiation accidents, transportation accidents, natural disasters) have been dealt with elsewhere (10—14). Similarly, the specific contribution of other related disciplines (eg, disaster medicine, epidemiology) has been presented in recent publications (15, 16).

Frequency and time trend

In the 1995 World Disaster Report covering the period 1969—1993, accidents are second only to floods in frequency. Chemical accidents with industrial origin and serious human and environmental consequences rank 10th just after epidemics and followed by landslides (17). The United Nations Awareness and Preparedness for Emergencies at Local Level (APELL) program (18) compiled a list of selected accidents updated to 1997. With the use of this information, the frequency pattern of environmental accidents in the last 2 decades was produced.

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The results by year, country, and accident origin are shown in tables 1 and 2. The absolute number is steadily increasing with time, even though the information for the latest period, although incomplete, seems to suggest a reduction. It is also apparent that the most common origin is during process plant operations, followed by transportation. Reporting rates are certainly dissimilar across periods and countries. Admittedly, the available picture shows that the Americas, taken together, lead for the number of disasters, followed by Asia; the frequency in Europe is fairly close to that of North America. A consistent picture can be obtained from the data base developed by the Centre for Research on the Epidemiology of Disasters (CRED) at the Department of Public Health, Catholic University of Leuven (Belgium), covering different types of disasters (both "natural" and "manmade") and their consequences (14).

International regulations

Fortunately, along with concern, public and governmental awareness has also increased in recent decades, prompting new legislation to be issued in many countries and by international bodies. They represent a stable and fertile soil in which to root projects for the future in the handling of major accidents. The following are some examples:

- The "EU Directive on Major Accident Hazards of Certain Industrial Activities" — the so called "Seveso directive" — issued in 1982 (9) following the Flixborough (19) and Seveso (20) disasters, later updated and modified (21, 22) after the Bhopal (23) and Basel (24) accidents. The directive is concerned with the prevention of major accidents which might result from certain industrial activities and with the limitation of their consequences for humans and the environment.
- The convention of the International Labour Organisation (ILO) concerning the prevention of major industrial accidents (ILO 80th session, 2 June 1993) clearly delineates the responsibilities of employers (risk identification and notification, safety and hazard control, in-site emergency plans and procedures), competent authorities (off-site emergency preparedness, inspection), duties and rights of workers and their representatives (information, compliance), and responsibility of exporting states (information) (25).

Table 1. Number of environmental accidents[a] by calendar period and (sub)continent.

Years	World areas						
	Asia	North America	Europe	Central & South America	Africa	Oceania	Total
1970—1974	8	8	5	2			23
1975—1979	5	18	10	8	1		42
1980—1984	10	17	6	8	2	1	44
1985—1989	20	25	22	5	1		73
1990—1994	49	21	25	9	6	2	112
1995—1997[b]	15	4	11	7	2		41
Total	107	93	79	39	12	3	333

[a] Included are accidents that caused 25 deaths or more, or 125 injured or more, or 10 000 evacuated or more, or 10 000 people or more deprived of water, or USD 10 million or more damage to 3rd parties. Excluded are accidents due to defective products, to voluntary destruction of airplanes or ships, to oil spills at sea from ships, and to mining accidents (14).
[b] Three-year category.

Table 2. Number of environmental accidents[a] by calendar period and origin.

Years	Explosion	Fire	Leakage	Transport	Release	Other	Total
1970—1974	11	3	2	5	1	1	23
1975—1979	18	2	6	6	1	9	42
1980—1984	15	8	9	7	1	4	44
1985—1989	22	13	13	8	6	11	73
1990—1994	42	25	13	10	13	9	112
1995—1997[b]	14	11	2	6	1	5	41
Total	122	62	45	42	23	39	333

[a] Included are accidents that caused 25 deaths or more, or 125 injured or more, or 10 000 evacuated or more, or 10 000 people or more deprived of water, or USD 10 million or more damage to 3rd parties. Excluded are accidents due to defective products, to voluntary destruction of airplanes or ships, to oil spills at sea from ships, and to mining accidents (14).
[b] Three-year category.

- The major accident provisions of the amendments of the United States Clean Air Act, promulgated in final form in 1996 and concerned with the prevention of and response to chemical accidents, requires, under section 112(r), that certain facilities develop risk management programs for chemical accident release prevention. The resulting regulation, which applies to an estimated 66 000 facilities that manufacture, process, use, store, or otherwise handle regulated substances at or above specified threshold quantities in the United States, was developed by the Chemical Emergency Preparedness and Prevention Office (CEPPO) of the United States Environmental Protection Agency. An evaluation of its implementation was recently attempted, and the role of communities in prevention and response, the importance of risk communication, and the role of 3rd parties in informing and protecting the public in the area of chemical hazards were considered especially relevant (26).
- The (APELL) program, launched in late 1988 in cooperation with industry and government, by the Industry and Environment Office of the United Nations Environment Programme (UNEP), had the aim of preventing technological accidents and reducing their impact (18). This aim is achieved by assisting decision makers and technical personnel to increase community awareness of hazardous installations and to prepare response plans in case sudden events at these installations should endanger life, property, and the environment.
- The *Guiding Principles for Chemical Accident Prevention, Preparedness and Response*, published in 1992 by the Organisation for Economic Cooperation and Development (OECD) as a result of international workshops attended by representatives of industry, labor, public authorities, and other involved parties, provides guidelines which cover issues from planning and constructing chemical installations to employee training, community awareness, and technology transfer (27).

Lessons from experience

The characteristics of recent environmental accidents of industrial origin and their consequences to the individual, to society, and to the environment have been examined and compared (1, 28—31). Some of the common features they share are extremely relevant for a future vision:

- *They represent a concrete possibility, linked to the inherent complexity of the process industry*, including fixed installations and transport and distribution. This was the basic principle, for example, of the 1982 European Union "Seveso directive" (9), aimed at ensuring the highest standard in risk reduction measures and industrial safety inside the plant (prevention) and, at the same time, at developing preparedness, training, and response capabilities, onsite and offsite, in case of emergency.
- *They often involve more than one single country.* This feature may concern the origin of the accident or its consequences. It has been noted, for example, that the Bhopal, India, disaster may have originated from decisions made at the parent company headquarters located in the United States (1). The Chernobyl, Ukraine, and Schweizerhalle, Switzerland, accidents had consequences that affected numerous countries. The radioactive emission from the Ukrainian nuclear reactor almost covered the entire northern hemisphere (10), and the contamination of the river Rhine by toxic chemicals involved at least 4 European countries (24). It appears thus that international cooperation is needed not only in the emergency response to such accidents but especially in the prevention and preparedness phases.
- *Their onset can be subtle*, and hazards may become apparent only when vulnerable human targets happen to be in their path or when environmental signs of a threat crop up. The former was the case with the methyl mercury disaster in Minamata, Japan (32), and the latter with the Love Canal accident, an estate built on a dumping site in the United States (33). The need is for a comprehensive inventory of hazard sources at the community level and efficient warning systems based on early events of process or containment failure.
- *Knowledge of the hazard represented by certain chemicals is often limited,* especially for compounds that are not actual basic raw materials, but rather are intermediates in certain reaction phases or conditions, as has been the case with 2,3,7,8-tetrachlorodibemzo-*para*-dioxin (TCDD) (20) and methyl isocyanate (MIC) (34). Safety-oriented research should be an essential element in preparedness to contrast, reduce, and cure the adverse effects on human health and environment of *all* potentially hazardous aspects of given production. Similarly, research is essential in the postaccident phase, which may represent an unfortunate (but extremely useful for future preparedness and prevention) "unplanned experiment" on the effects of certain dangerous and toxic substances.
- *Acute casualties are not a prerequisite for an accident.* The most serious health effects may become apparent after years, sometimes decades, and possibly affect future generations. This is the reason why even decades after the acute episode causing exposure, surveillance systems are still active, and new studies are being planned in environmental accident areas (35). Long-term follow-up of the affected population should always be part of any response plans.
- *The accident in itself, and not just the released*

substance(s), may represent an ill-health determinant, with outbreaks of psychological and stress reactions producing mental and physical consequences, even in the long run. Disastrous occurrences always carry a burden of fear, anxiety, and distress linked to loss, concern, and uncertainty about delayed health sequelae — especially for the most vulnerable subjects (eg, fertile women, children) — lack of social support after the disruption of the community fabric, and the like. Little attention has been given to this type of consequence after industrial accidents, which, instead, have been carefully evaluated in the case of natural disasters (36, 37); partial exceptions are Seveso, (38), Three Mile Island (39) and Love Canal (40).

- *The consequences to the environment*, and not only to humans, may also be *delayed and long lasting*. An essential part of the postaccident investigations program is the long-term monitoring of ecology systems to verify effective reclamation of the affected territory and identify the possible persistence of health threats (41).
- *Environmental accidents affect every country of the world, but it is the poorest countries where people most frequently lose their lives*, as is clearly visible from *World Disasters Report* statistics (14), because some of the most hazardous substances increasingly tend to be used, processed, or manufactured in these areas, because in these countries industrial safety rules and control, and environmental and health protection legislation are less stringent, and also because an environmental accident always represents a "disruption of the human ecology that exceeds the capacity of the community to function normally" [p 1] (42), and communities in the poorest countries often live in extremely vulnerable ecological contexts, as the Bhopal accident clearly demonstrated (43). The burden of thousands of lives was taken primarily from the crowd of workers and their families living in shanty houses next to the plant walls. In similar contexts, consequences to people are aggravated, and recovery and rehabilitation become much more difficult (5).

A hazard-oriented approach

The overall lesson is that, to prevent possible accidents in major hazardous industrial installations and reduce the risk to the environment and populations, the focus should be on the hazards. Accordingly, the same effort devoted to relief measures in the postimpact phase should be devoted to advance planning in the preaccident period. Environmental accidents can be forecast, prepared for, and controlled. According to this approach, the management of an environmental accident hazard should always include the following 4 phases:

- *prevention,* which ranges from risk reduction measures in the design of plants to legislation establishing high standards of industrial safety and means to enforce and evaluate these measures; at the community level, prevention is mainly a matter of hazard identification and vulnerability analysis;
- *preparedness* is meant to enable a community and its key services to function to reduce morbidity, mortality, and material losses, even in a situation of disruption and emergency, as in the accident aftermath;
- *emergency response,* on-site and off-site, not only involves rescue squads and disaster medical teams, but also professionals able to ascertain the type and extent of exposure and immediate and projected health and environmental effects and to prepare the ground for long-term activities;
- *follow-up* is essential for assessing late effects and evaluating response measure. This is also the recovery and reconstruction phase of the social and environmental contexts.

Occupational and environmental health professionals bring a particular and specific contribution to the multidisciplinary team in charge of these activities by providing timely and appropriate information on the nature of the agent(s) and likely health effects, the environmental contamination and routes of human exposure, the most susceptible sectors within the population, the health criteria for evacuating parts of a community, and the risks to personnel employed in emergency response.

Prevention

Prevention is essentially a matter of hazardous sources control. A hazard control system should be targeted with a 2-fold aim, reducing the probability of occurrence of accidental events and containing their severity and extension to mitigate their consequences.

ILO convention no 174 (25) provides a useful framework for these activities (figure 1). Hazard assessment at the community level requires the identification of sources of critical events capable of initiating serious incidental sequences (ie, possible accidents). The identification of "major hazard installations" by governmental authorities and employers and the regular review and updating of this inventory is the primary requirement. The definition implies, see, for example, directive 82/501/EEC (9) and a report by the UNEP (18), a list of hazardous chemicals, thresholds for the quantity of substance in store or in use, and the location of the plants in any particular region or country. Inside the industrial activity, action for operating and maintaining a safe facility is the responsibility of employers. Information about plant design and operation should be gathered and arranged systematically and should be accessible to all concerned parties. The duties of government and other competent authorities include licensing, inspection,

Government	Employers	Community	Workers
Land-use planning Licensing Inspection Legislation enforcement Hazard assessment	Design Inside plant safety Training Hazard assessment	Information Hazard assessment Vulnerability analysis	Information Training

Figure 1. Duties and responsibilities of different parties in accident prevention.

enforcement of legislation, and land-use planning. Workers can play their role to the extent they have access to relevant information and receive adequate training.

That prevention is lacking was made evident by the mode of occurrence of recent environmental accidents and by the identification of the determinants of their disastrous effects (10, 13, 23, 29), which were as follows:

- plant location, not separated from vulnerable human and environmental surroundings;
- incongruous design for operating conditions;
- inadequate safety rules and safety systems inside the plant;
- insufficient education and training of personnel.

These 4 elements, by contrast, represent the key components of any accident prevention system. As has been noted (44, 45), technological accidents can be ascribed to the combined effect of design defects, conflicts between safety and productivity goals, poor operating and maintenance procedures, and inadequate training. According to data from the European Union (9), 90% of major chemical accidents are attributable to operating failures resulting from organizational deficits, insufficient or inappropriate training, or incomplete knowledge of risk from human error. As to the role of human error, in complex high-risk technology, errors by "front line" operators often merely represent the triggering event manifesting latent failures linked to decisions made earlier in the organizational and managerial spheres (44).

Design and training thus become central in accident prevention. Their importance is further emphasized by the migration of technology, production, and even people, which is taking place at an increasing pace. The ILO 1993 convention (25) and the 1990 UN APPEL program (18) underline the duties of the exporting member state to the importing country: implementation of and compliance to similar regulations should become a priority in international relations. Similarly, education and training in newly industrialized countries and of newly employed people need special attention and effort if such problems as hazard perception in different cultures and even language comprehension are to be coped with (46).

Preparedness

Preparedness is aimed at mitigating the severity and containing the extension of the consequences of accidents. As with prevention, relatively little international effort has been devoted to accident preparedness when compared with the situation for relief measures in the past. Although investment in accident protection is costly, there is now a large body of scientific and technical knowledge available, which, if applied correctly, would make a substantial difference to the health and economic impact of accidents, and particularly technological accidents, in all countries (47).

For preparedness purposes, it is necessary that a structure exist at the national, regional, and local levels re-

Hazard identification

- Establishing and maintaining an inventory of potential risk sources
- Formulating realistic scenarios
- Securing availability of production and safety information and environmental and biological exposure data
- Identifying information on background levels of chemical contaminants
- Training and equipment for environmental and biological measurements
- Link with data base on relevant substances or agents, including poison information centers
- Link with external institutions and experts to supply additional equipment capability and expertise
- Link with data base and surveillance system on accidents

Population-at-risk identification

- Identifying sources of demographic information
- Specifying content and format of the information
- Exploring methods, equipment and personnel needed to gain access to the information
- Defining different situations requiring access to different sources
- Developing a population register of those pertaining (because of their residence, activities, etc) to the relevant area
- Link with external institutions and experts for health effects assessment and long-term studies

Figure 2. Core activities for accident preparedness, according to the World Health Organization (16).

sponsible for the planning for emergencies under existing legislation with industry and competent authorities. The aim of these plans is to set up a system for response, rehabilitation, and follow-up of the acknowledged, probable, and possible environmental and health effects following exposure. Having identified, in the prevention phase, the sources of possible accidents, the probability of their occurrence should be estimated in order to set priorities. Defining spatial-temporal extension of the adverse consequences is the following step, taking into account type or mode of occurrence and target vulnerability (eg, a certain impact zone with high probability of lethal consequences, a damage zone with serious harm to healthy population, an attention zone with possible harm to susceptible targets, etc). Guidelines for emergency response and protocols for medical treatment should be drafted. Collaborative training sessions should be run with all the parties involved. Arrangements should be made to obtain all necessary equipment, supplies, and personnel either in advance or at short notice in case of accident.

From our perspective, the core of a preparedness system is the capacity to identify the nature and extent of the hazard and the population at risk. Figure 2 lists the requirements for such an identification (16). Interagency and external cooperation, in particular with centers and experts already involved in incidents pertaining to the present scenario, have great relevance. Prepared access to demographic information is extremely helpful. It can greatly contribute to the enumeration of the at-risk population, in choosing study and reference groups, applying sampling schemes when indicated, targeting persons to be interviewed or examined, noting incident-related mobility of the population, and the like. A strong argument illustrating how preparedness is central in accident management comes from the 1997 statistics on disasters prepared by CRED (14). They noted that "Asia heads the league table for numbers of disasters reflecting a combination of natural hazards (floods and earthquakes), rapid industrial development and the simple issue of population numbers. The Americas suffered from a high number of disasters but, through improved disaster preparedness, was able to keep death tolls and injury numbers well down" [p 147].

Response

In the response phase, occupational and environmental health greatly contribute to the ascertainment of the accident consequences and their follow-up (28, 16), with the identification of the affected population, the characterization of their exposure, and the short- and long-term health assessment (table 3). These activities may be hampered after an environmental accident by several constraints, including time, resources, people's anxiety, anger and fear, political pressure, and the like. Preparedness is meant to make these activities possible even in the disrupted and hectic postaccident scenario.

The *population affected* by an environmental accident is composed of those exposed, not of those sick, and always includes the general population, resident or transient in the area, and, whenever appropriate, the personnel from the facility of the occurrence (eg, workers, drivers, etc), and the emergency response personnel. Two categories of people should be identified, those for whom health effects are present (or should be expected) and those (possibly) exposed and hence at risk. The former might need special care and will definitely need medical surveillance; the latter may need medical surveillance (delayed effects should be considered) and, in addition, they constitute the base for studies on long-term incident-related health effects. Enumerating this population and identifying its characteristics (size, special groups, location, and residence) become possible thanks to activity in the preparedness phase (figure 2).

Characterizing exposure in quantitative and qualitative terms in response to an accident becomes, in turn, possible provided that appropriate steps are taken in the prevention and preparedness phases. Exposure assessment activities include the following:

- source description (identity and properties of the agent(s) involved, release rate, and total quantity released, etc)
- dispersion modeling (physical state of the released material, speed and direction of the wind, etc)
- exposure modeling obtained, for example, by linking people's whereabouts and exposure-relevant behavior to the modeled concentrations.

Table 3. Essential activities to investigate health consequences in accident response, according to the World Health Organization (16).

Activity	Purposes served
Identifying the affected population	Estimate the actual resources, means and networks required to cope effectively with the immediate health consequences Design and implement appropriate surveillance systems and study projects to investigate the possible later health impact of the event
Characterizing exposure in qualitative and quantitative terms	Assess the risk possibly posed by the incident to exposed people Characterize people's (individuals or groups) exposure for long-term studies of the health impact Evaluate effectiveness of interventions to contain environmental contamination and reduce human exposure
Short- and long-term health assessment	Identify subjects needing action to treat present and prevent later adverse health effects Ascertain type and frequency of accident-related effects to quantify health impact Improve knowledge on toxic properties of involved substances Evaluate effectiveness of interventions to prevent or mitigate health impairment

The distribution of the chemical in the environment is determined through environmental monitoring and the use of ecological markers (flora and fauna, study of food chain).

Individual exposure is measured through direct or proxy indicators either qualitative or quantitative, taking into account toxicokinetic properties of the chemical(s) and different routes of exposure. Questionnaires and interviews may be useful to ascertain exposure opportunities and circumstances as, for example, activities or locations during the occurrence that may modify exposure (eg, staying indoors or outdoors, sheltering, etc). Quantitative, individual exposure markers in human body mediums (urine, blood, hair, fat, and the like) are the measurements of choice; however, organizational, financial, and technical constraints may render their collection and analysis problematic. Whenever indicated and possible, a bank of samples (environmental and human) could be maintained since the advancement of knowledge and technical capabilities may allow the use of these samples in the future. In Seveso, measurements of individual dioxin concentrations in small serum samples stored immediately after the accident were made possible by technological advancements some 10 years later (48).

Health assessment (short- and long-term) of the exposed population serves several purposes (table 3). In particular, the identification of *acute effects* guides the allocation of technical and social support services, treatment and rehabilitation, and the planning of further investigations. Surveillance of *chronic effects* is essential to gain a faithful and complete picture of the disaster-associated risks, and it allows the evaluation of post-emergency measures.

As already emphasized, postaccident health outcomes are almost inevitably associated with 2 types of determinants. One is related to the toxic, or otherwise noxious, properties of the substance(s) or agent(s) involved, and the other stems from the exposure to a disastrous occurrence as such, independent of the specific type of chemical or agent involved (49). The consequences of the traumatic experience may be mental or physical and also depend on the person's perception of the risk (50). The emotional cost of accidents has often been beyond reckoning (51—53).

Detailed discussions of the specific problems entailed by the design and conduct of ad hoc epidemiologic studies and by the screening for prevalent conditions in a postaccident scenario are available (16, 28, 30)

Communication as a key element

Finally, in making the accident management effective and successful, communication with the public, among professionals, and with the media is of paramount importance (16, 54—56). Communication should be maintained as long as incident-related activities persist, and it should be continuously evaluated and modified as needed. The message should be clear and agreed upon by all the experts involved; confused or controversial messages only cause additional stress among the affected population and frustration to the personnel.

Researchers should make the information available to the whole scientific community through peer-reviewed and readily accessible journals. The design and results of all activities should be made known to policy and decision makers and to regulators at the local, national, and international levels. This information may prove invaluable for those confronting similar events. In communication, media are essential, but they are not just means. Rather often they have their own message to deliver. Time should be spent with them, therefore, trying to explain the actual message coming from the programs implemented and the results obtained.

Concluding remarks

Environmental accidents represent an area of current and growing concern by the public, policy makers, and researchers in all nations.

In 1990 the United Nations launched the International Decade for Natural Disaster Reduction (IDNDR) program, which called for international cooperation in predisposing prevention (from design to alarm), and risk reduction (preparedness plans) measures (42). This approach appears inherently even more feasible for man-made environmental accidents than for natural disasters, and it represents, in my view, the key component of any possibly successful program to prevent (or minimize) the risk of such accidents in the future and to prevent (or minimize) the adverse health consequences associated with the accident.

In our society, industrial production and economy have global dimensions. By necessity it is at that same level that the prevention of industrial accidents and community preparedness to reduce and cure their effects become possible. International legislation and regulations do exist and are continuously updated and improved. What remains necessary, however, is to expand their implementation and compliance to them by interested subjects. Enforcement is indispensable, but its success greatly depends upon parallel cooperative action aimed at motivation, assistance, and control. Therefore, health professionals should not see their role as limited only to the postimpact emergency phase. They need to be involved in the development of preventive measures and in all phases of predisaster planning, within the framework of local, national, and international collaborative programs.

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