

Industrial disasters and epidemiology

A review of recent experiences¹

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BERTAZZI P-A. Industrial disasters and epidemiology: a review of recent experiences. *Scand J Work Environ Health* 1989;15:85–100. Disasters of industrial origin are usually overt, but sometimes their source is silent and their occurrence diluted in time. Thus, the ascertainment of the health impact is not the sole epidemiologic task; epidemiology is often needed to identify the disaster source; in addition, a postdisaster scenario may represent an unfortunate, unplanned experimental setting from which scientific knowledge and public health achievements can be drawn. In the aftermath of a disaster, three sets of illness determinants ought to be considered: the relevant exposure; the stressful experience of the population; the response measures. Ecological, geographic, and personal indicators might be used to ascertain individuals' exposure. Relevant health outcomes (early and long-term) are either exposure-related or stress-related (mental and physical). A cohort approach should be sought to avoid major selection/information biases and facilitate later studies. Early planning is of paramount importance to identify study goals, problems, and resource requirements.

Key terms: Bhopal, Chernobyl, dioxins, environmental carcinogens, environmental health, industrial accidents, Seveso, toxic oil syndrome.

From time immemorial, man has experienced natural disasters. Disasters are also produced by man's activities however. In this century, the worst man-made disasters have been caused by war, transport, and industrial activities. I am concerned here with industrial disasters. At first, they mainly affected people engaged in specific occupations (miners, for example), but later, particularly after War World II with the rapid growth and expansion of the chemical industry and the use of nuclear power, these occurrences led to serious danger even to people outside work areas and to the general environment.

The first chemical disaster with industrial origins for which I found documentation goes back to the 1600s. It was described by Bernardino Ramazzini (1). I found this three-century old report instructive for various reasons. In the first place, it demonstrates that the toxic effects of industrial activity cannot only strike workers, but also the general population. And, in fact, the episode became known precisely because a private citizen sued the owner of a chemical laboratory "... on the ground that he poisoned the whole neighborhood whenever his workmen roasted vitriol in the furnace to make sublimate [p 51]." In addition, it shows that the possible effects of an industrial disaster are not

always obvious. To bring them to light, investigations are often necessary that are based on objective data, are longitudinally conducted, and that provide quantitative estimates in comparison with a reference population: "To prove the truth of his accusation he produced the sworn testimony of the doctor of Finale and also the parish register of deaths, from which it appeared that many more persons died annually in that quarter and in the immediate neighborhood of the laboratory than in other localities [p 51]." In the third place, it emphasizes the necessity of documenting not only the general impact on health, but also the specific impact in relation to the nature of the toxin and knowledge of its effects: "Moreover, the doctor gave evidence that the residents of that neighborhood usually died of wasting disease and diseases of the chest; this he ascribed to the fumes given off by the vitriol, which so tainted the air near by that it was rendered unhealthy and dangerous for the lungs ... [p 51]." It is also apparent from this episode that results of an epidemiologic investigation may lead to advice on how to prevent similar occurrences: "The citizen ... demanded that he should move his workshop outside the town or to some other place ... [p 51]." Another element of this historical example which is quite contemporary is that the epidemiologic data were not judged to be sufficiently credible by the decision makers, and the citizen lost the case: "Various cleverly worded documents were published by both sides, and this dispute which was literally 'about the shadow of smoke', as the saying is, was hotly argued. In the end the jury sustained the manufacturer, and vitriol was found not guilty [p 51]." Ramazzini concluded his report with a rather bitter remark, which can proba-

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bly be applied even now to many unresolved cases in our own countries: "Whether in this case the legal expert gave a correct verdict, I leave to the decision of those who are experts in natural science [p 51]."

Nature of the problem

From my review of the relevant literature I ended up identifying five main characteristics of today's industrial disasters. They do not necessarily provide a classification of general value, but they can help one appreciate the nature of the problem and the challenge epidemiologists have to face.

Overt disasters

Examples of environmental releases which left no ambiguity about their sources and their potential or actual harm are Seveso, Bhopal and Chernobyl.

Seveso has played the role of prototype for chemical industrial disasters for at least one decade (2—4). The accident took place on 10 July 1976 in the Seveso area, close to Milan, Italy, in a plant where trichlorophenol was produced, and it caused the contamination of several square kilometers of populated countryside by the powerfully toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). More than 700 people were evacuated, and restrictions were applied to another 30 000 inhabitants. The most clearly established health effect was chloracne, but the picture of health consequences possibly linked to this incident has not yet been completed (5).

Bhopal represents, probably, the worst chemical industrial disaster ever (6—9). On the night of 2 December 1984, a gas leak caused a deadly cloud to spread over the city of Bhopal, in central India, leaving thousands killed and hundred of thousands injured in the space of a few hours. The accident occurred because of a runaway reaction in one of the tanks in which methyl isocyanate (MIC) was stored. The concrete storage tank, containing some 42 t of this compound, which was used to manufacture pesticides, burst open and vented MIC and other breakdown chemicals into the air. Above and beyond the obvious catastrophic impact of the accident, questions still exist as to the possible long-term consequences on human health (10, 11).

The nuclear accident in Chernobyl, 80 km north of Kiev in the Soviet Union, occurred on 25 April 1986 during the testing of safety systems (12—14). The immediate cause was a power surge resulting in a rapid heating of the fuel, which in turn caused a massive steam explosion, followed in a few seconds by a second explosion. One quarter of the graphite in the core was ejected in the explosions, which ripped through the steel plate encasement and the roof of the reactor. The initial explosion took two lives, one from severe heat burns and one when the building collapsed. Rescuers and plant personnel suffered the most serious

consequences, with an official death toll of 31 on the first anniversary of the accident (15, 16).

Diluted disasters

This type of industry-linked disaster, ie, diluted disasters, may become apparent only because human targets happen to be on the release path or because, as time passes, some environmental evidence of a threat from noxious materials crops up.

One of the most impressive and instructive examples of the first type is "Minamata disease." In 1953 unusual neurological disorders began to strike people living in fishing villages along Minamata Bay, Japan. "Kibyo," the mystery illness, seemed the only suitable name to indicate that disease. After numerous investigations, poisoned fish emerged as the probable culprit, and in 1957 the disease was produced experimentally by feeding cats with fish caught in the bay. The following year, the suggestion was put forward that the clinical picture of Kibyo, which included polyneuritis, cerebellar ataxia, and cortical blindness, was similar to that due to poisoning by alkyl mercury compounds. A source of organic mercury had to be sought, and it was eventually found in a factory discharging its effluent into Minamata Bay. By July 1961, the disease had occurred in 88 persons, of whom 35 (40 %) had died (17).

A prototypal example of the second type of diluted disaster is Love Canal, an excavation site near Niagara Falls in the United States. The area had been used as a chemical and municipal disposal site over about a 30-year period until 1953. Homes were later built next to the landfill. In the late 1960s complaints of chemical odors in the home basements and chemical leaching in areas surrounding the site began to be increasingly reported. In the 1970s, residents began to fear that a serious threat to their health could surface, and this shared perception prompted environmental and health investigations to be carried out. To date, none of the published studies have conclusively supported a causal link between exposure to chemicals at the disposal site and adverse health effects among the residents (18—21). Yet, there is no doubt that serious social and psychological consequences have resulted among the population in the area, particularly those who were evacuated (22).

The disposal of waste chemicals is an issue of major and growing concern either because of the huge number of such sites or because of the persistency and insidious diffusion of the compounds involved (18, 23—25).

Mass poisonings

I thought it also appropriate to include in this review mass outbreaks of poisoning caused by toxic chemicals not directly released by industrial sites, but nonetheless related to the use of chemicals in the han-

dling and processing of food. (See reference 26 for a review.)

One of the most serious episodes of this type recently occurred in Spain (27—29). It was in May 1981 when an outbreak of a previously unknown syndrome began to appear in the working-class suburbs of Madrid. Over 20 000 persons were ultimately involved. By June 1982, 315 patients had died (around 16 deaths per 1 000 cases). Initially, the clinical features included interstitial pneumonitis, diverse skin rashes, lymphadenopathies, intense eosinophilia, and gastrointestinal symptoms. Nearly one-fourth of those who survived the acute phase required later hospitalization for neuromuscular alterations ranging from simple myalgia to mixed polyneuropathy, to progressive paralytic neuromuscular illness. Scheroderma-like changes of the skin were also observed in this late stage, along with pulmonary hypertension and Raynaud's phenomenon. This sort of combination of symptoms and illness progression, as well as the occurrence pattern of the syndrome, appeared unique. One month after the occurrence of the first cases the illness was found to be associated with the consumption of inexpensive denaturated rapeseed oil, sold in unlabeled plastic containers and usually acquired from itinerant salesmen. The warning issued by the Spanish government against the consumption of the suspected oil caused a dramatic fall in the number of hospitalizations from toxic pneumonitis (30, 31).

Polychlorinated biphenyls were involved in widely reported accidental mass food poisonings in Japan (32) and Taiwan (33).

Transnational disasters

One further characteristic feature of today's man-made disasters is transnationality; disasters do not necessarily respect national political boundaries. An obvious example is Chernobyl, whose contamination almost unified Europe, even though for a very unpleasant reason, from the Atlantic Ocean to the Ural Mountains (34). Another example comes from Switzerland (35, 36). On 1 November 1986, shortly after midnight, a fire developed in a warehouse operated by the multinational pharmaceutical company Sandoz in Schweizerhalle, 10 km southeast of Basel, and some 30 t of the chemicals stored in the warehouse were drained along with water from the fire extinguishers into the nearby river Rhine. Severe ecological damage occurred over a length of about 250 km. Apart from symptoms of irritation reported in the parts of the Basel area reached by gases and vapors produced by the fire, no cases of serious illness were reported. Yet the possible damage to health resulting, in the long run, from such ecological disasters needs to be appreciated. Schweizerhalle triggered such concern in at least four European countries (Switzerland, France, Germany, The Netherlands).

Transnationality does not only apply to consequences and harm caused by disasters, but also to their causes as well. Bhopal might serve as an example. In analyzing the causes of that disaster, some persons reached the conclusion that "The Bhopal disaster occurred because of specific acts and decisions which were taken in Danbury, Connecticut or elsewhere in the corporate superstructure of Union Carbide but not in Bhopal [p 17]" (8).

"Developing" disasters

The emerging pattern of industrialization, as well as the modernization of agriculture, in developing countries involves the application and use of imported or adopted technology and products within contexts which are quite different from those in which they were intended to be. The tightening of regulations in industrial countries prompts exportation of hazardous industries to world regions where less stringent measures for protection of the environment and public health exist. Industrial activities become concentrated in existing urban settlements and add significantly to the pressure caused by overcrowding and shortages of community services. Such activities are distributed between a small highly organized sector and a large unorganized sector; governmental controls in regard to labor and environmental safety in the latter sector are less stringent (37). An example comes from Pakistan, where among 7 500 field workers in a malaria control program in 1976 as many as 2 800 experienced some form of toxicity (38). It was also estimated that about 500 000 acute pesticide poisonings occur annually, resulting in about 9 000 deaths, and that only about 1 % of the deadly cases occur in industrialized countries which consume, instead, about 80 % of the total world agrochemical production (39).

Given such a scenario, the world might, at present, not only be witnessing industrial disasters in developing countries but also might be facing a season of "disasters in development" in those regions.

It has also been argued that developing societies might actually find themselves carrying a "double burden" instead of being cleared from the one of underdevelopment. It could be, in fact, that the consequences of improper industrialization are simply being summed with those of the countries' underdeveloped states (37).

Extent of the problem

Accidents with a possibly disastrous off-site impact are only partially covered by the scientific literature. Probably, a fully comprehensive list does not exist because, among other things, of the differences in the definition of such events by different authors and organizations — see, for example, reference 18. Data banks of chemical accidents have been or are being set up. Information is obtained from a variety of sources, in-

cluding the media, and concentrates mainly on the broad features of the happening and the immediate losses. Health consequences in the postemergency phase are not covered. Thus these data banks could be considered unsuitable for some purposes. Nonetheless, I thought it useful to explore the type of information retrievable from one of the most comprehensive banks, the Major Hazard Incident Data Service (MHIDAS). It contains over 3 000 records concerning chemical accidents which have occurred in the last 25 years with an off-site impact in some 95 countries (40). The countries with the most recorded incidents are the United States (N=924), the United Kingdom (N=438), Canada (N=84), Germany (N=83), France (N=62), and India (N=40). No doubt, such a ranking is heavily affected by the availability of information and the extent of reporting in different countries. Yet it is remarkable that India ranks sixth. This is certainly a good indicator of the problem of disasters in developing countries.

An ad hoc search was made for accidents involving pesticides, herbicides, and dioxin. One hundred records were obtained regarding 85 incidents, which had occurred in 13 countries (United States 45, Federal Republic of Germany 15, United Kingdom 11, Italy 3, France 3, and one each in Austria, Canada, India, Mozambique, The Netherlands, New Zealand, Switzerland and Sweden). The origin of the accidents had been as follows: process (43 %), storage and warehouse (33 %), transport (17 %), and waste (7 %). The total number of immediate fatalities was 17 (but for 41 accidents no information available), the number of persons injured was 1 880 (for 28 accidents no information available), and the number of evacuated higher than 51 000 (despite 52 accidents without information). One could note that such collections of accident data are far from exhaustive, yet they may constitute a useful tool with which to awake people to the extent of the problem even in the absence of catastrophic happenings such as Bhopal, which, alone, had a heavier toll than the aforementioned 85 incidents.

Role of epidemiology

In almost every report concerned with disasters that I had the opportunity to look at, the role of epidemiology was underlined, and the need for epidemiologic studies was stressed. But to what extent can epidemiology meet the many expectations people have of its capabilities? From the review of the actual role epidemiology has played in different types of disasters, three major achievable tasks seemed to emerge.

Health impact ascertainment

We are confronted typically with two situations, one in which the consequences to people's health are obvious and another in which such consequences can be

revealed only by means of formal, sometimes complex, and often long-lasting investigations.

In Bhopal, the adverse effects were immediate and led tens of thousands of people to seek medical care. Vision and lung impairment was evident either in its severity or in its frequency. Official figures put the numbers of dead at over 2 000 within the first week of the disaster (7), but the actual number will probably never be exactly known. According to a report in the *Journal of the Indian Medical Association*, "So great was the impact of the catastrophe that the whole town became a city of grave-diggers busy in disposing of the dead . . . [p 72]" (6). Indeed, not much epidemiology was required in order to ascertain such devastating consequences. Yet a descriptive analysis of the type and frequency of occurrence of health consequences was attempted, and renal, gastrointestinal, mental, and pregnancy disorders became apparent, in addition to those already mentioned (7). Also in Chernobyl the immediate health impact was self-evident but small in terms of fatalities (15, 41). In Seveso, the ascertainment of early adverse health effects of the TCDD exposure required some epidemiologic descriptive work. The mapping of chloracne and skin lesion cases according to residence and the estimate of the proportion of people affected at increasing distances from the plant, along the diffusion path of the toxic cloud, was an example (42).

In such instances, however, the real impact is far from being described exhaustively by such early data. In order to appreciate the full range of health consequences, long-term investigations and surveillance systems ought to be designed and implemented. In Chernobyl the population of the Kiev region is undergoing surveillance (43). A follow-up of Bhopal survivors with visual disability has been attempted (10, 44, 45). In Seveso, long-term investigations have been conducted, and some results are available (5, 46–50).

In addition to the completion of the health impact ascertainment, longitudinal studies might prove very useful for evaluating postdisaster measures. In Seveso, for instance, investigations have been performed on people employed in the reclamation work. They entered the contaminated area with protective clothing and underwent strict medical checks. It was possible to show that, among these workers, no adverse effects occurred, at least until the end of their operating in the area and the end of the examinations (51).

Source identification

Source identification is a task with which epidemiology can be of great help, especially in cases of diluted disasters and mass poisonings, and, more in general, when the hazard source may be "silent," but not necessarily "mute."

The "toxic oil syndrome" in Spain may well serve as an example (28). The key factor in identifying the origin of the food poisoning was the description of case

occurrence in relation to the most evident determinants, such as residence (working-class suburbs but not the middle-class center of Madrid being affected); social class (the highest incidence occurring among lower social strata); type of community affected (multiple hospital admissions and readmissions from families, but no contagion in hospitals, barracks, and schools); age (no cases reported among children under six months of age); etc. Following this descriptive analysis, case-referent studies proved to be very useful. The first and simplest one was performed in the Niño Jesus Hospital, Madrid. All of the 345 sick children admitted to the hospital for the syndrome, but only 6 % of the children admitted for other reasons, turned out to have consumed the suspected oil (52). In the province of Avile, case households were compared to size-matched reference households. The oil had been consumed in 100% of the former households versus less than 30% of the reference households (53). Numerous case reports and case-referent studies (54, 55) added support to the suggested association and led to a definite clarification of the disaster source, if not to the responsible chemical agent (56—58).

A second example, drawn from the nuclear setting, is not concerned with an actual disastrous occurrence, yet it clearly illustrates how epidemiology can be helpful in identifying silent hazard sources and elucidating relevant determinants of their potentially disastrous impact on the population's health. In a village in the United Kingdom, close to a nuclear fuel reprocessing site, suggestive evidence based on geographic analysis was accrued of an excess incidence of childhood leukemia. A follow-up study was instituted on two cohorts, one of children born elsewhere but attending school in the village and the other of children born to mothers resident in the village (59, 60). The excess cancer risk was confirmed for the cohort of children born in the village, but not for the school cohort. The results corroborated, thus, the early findings, but, at the same time, seemed to delimit the hypothesis of an association between the nuclear establishment and the cancer risk of the young population in the area to etiologic factors acting on a locality-specific basis before birth or early in life. Research is in progress to investigate further such a hypothesis.

Natural experiment exploitation

When I use the term "natural" here, I mean not planned, yet man-made. The most prominent examples are given by radiation studies on people exposed as a consequence of medical investigations or treatment and nuclear testing or bombing (61). In fact, all these events had been carefully planned, but they were not meant to be experimental work on the unwanted health effects of radiation on human health. A full account of the research programs following the A-bomb explosion over Hiroshima and Nagasaki was given by Beebe in 1979 (62). Much of what is known about the

effects of ionizing radiation on man comes from this continuing work. The study of A-bomb survivors contributed particularly to the knowledge of specific tumors caused by whole-body radiation, the dose-response aspects of radiation carcinogenesis, the role of environmental and host factors in the carcinogenic response, induction and latency period, etc (61—63). Thus, for instance, it was possible to establish that for leukemia the elevated risk occurs 10—15 years after exposure, while for other cancers the risk may be small in the same period, but it subsequently remains elevated for many decades (61). The A-bomb survivor studies are still contributing to scientific knowledge in several ways. Revised dose estimates are being derived which will provide better grounds on which to base estimates of the risk pertaining to radiation exposure, and the continuing follow-up is enhancing our present scarce knowledge of radiation effects 30 or more years after exposure (64). It has been shown, for example, that a roughly linear dose-response relation also exists between radiation exposure and breast cancer risk and that modifying factors might play a central role in determining the extent of the risk (65). The continuously refined methodology, as well as the results of these studies, recently proved to be very useful after the Chernobyl accident when appropriate investigations for the study of long-term effects in radiation-exposed populations had to be designed (66).

Chemical disasters have provided the same sort of scientific opportunity. Thus Bhopal offered for the first time the chance of studying the human toxicology of MIC and of planning long-term investigations of chronic responses and sequelae (67, 68).

Study design and conduct issues

Disasters differ in their nature and scenarios, and, accordingly, the epidemiologic investigations aimed at assessing and examining their associated health problems vary as well. Yet epidemiologists happen to be confronted with common problems in the design and conduct of these investigations. From the reviewed material, the major problems seem to concern evaluating the exposure, identifying the exposed population, and ascertaining the delayed effect.

Determinants of illness occurrence

Three major sets of determinants ought to be considered in industrial disasters, ie, the exposure (chemical or radiological), the shock of the event, and the measures taken in response to the disaster.

Exposure. Assessing the type of exposure is by no means a trivial step, even in the case of overt disasters. For example, the nature of the chemical compounds involved in the Bhopal disaster has been a subject of argument. The main chemical was no doubt MIC, but

the role of unanticipated derivatives, apart from cyanide, has not been fully clarified (45, 69). In particular, the suggested presence of methylamine and N,N-dimethylurea (DMU) might have contributed to the systematic effects observed either in the medical survey or in the autopsies performed on gas victims and dead cattle (70). Sometimes the nature of toxic contaminants can be theoretically predicted, as in the case of accidents involving trichlorophenol plants. Thus, in Seveso it was the stage at which the reaction was interrupted that determined the presence of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) as the major contaminant of the toxic release (71), while the discovery of unexpected TCDD isomers (1,3,6,8 TCDD and 1,3,7,9,TCDD) pointed towards the existence of additional contamination sources other than the trichlorophenol plant (3). The nature of the exposure obviously has much bearing on the design of the study, particularly in assessments of the route and extent of exposure (depending upon the environmental fate of the substance), and the expected health effects (depending on its toxic properties). The TCDD released in the Seveso area was a poorly water-soluble compound with a strong tendency to be absorbed in soil and water sediment, and with a significant potential for bioaccumulation. Hence the resulting environmental contamination tended to be stable and long lasting, implying a possible long-term human exposure (72). The cloud of radionuclides released from the Chernobyl reactor contained many different fission products and actinides (73). Of the several pathways of exposure possibly occurring after a nuclear accident, the most important ones for the populations in Europe turned out to be exposure from radionuclides deposited on ground and other surfaces (external) and the ingestion of contaminated food and water (internal). As regards health significance, the principal radionuclides were iodine-131 (half-life 8 d), cesium-134 (half-life 2.1 years) and cesium-137 (half-life 30 years). Contrary to the iodine-131 dose, the radiocesium dose is still being delivered either because of its longer half-life or because of its accumulation in food products. The expected health effects vary as well in relation to the type of exposure (43). Thus doses of radioiodine are received largely by the thyroid gland.

Radiocesium is, however, distributed in a fairly uniform manner throughout the body, and its associated effects are likely to be comparable to those from external radiation. Doses of radiostrontium mainly affect the bones, and those of actinides the lungs, bones, bone marrow, and liver.

The characteristics of the release context might be as important as the nature of the released materials in determining exposure, and they might well override the absolute magnitude of the release in relevance. Bhopal investigations, for example, shed light on several off-plant determinants of the disaster. Some of them were obvious, as the siting of an urban aggregate of several hundred thousand people in the immediate surroundings of the plant. Other determinants were housing structure, height from the ground, the narrowness and poor illumination of the streets, the lack of communication and transportation, the lack of knowledge and warning of the incumbent hazard, etc (74). Of course, the information gained was not much relief for the affected people; yet it has value in terms of either preparedness in analogous situations or prevention of the most disastrous consequences of such happenings. The time of year played a major role in determining the relative levels of the deposition of radionuclides from the Chernobyl plume. Thus, those European countries which experienced heavy rainfall (eg, Austria and some Nordic countries) recorded the highest deposition levels. Food-chain exposure in southern European countries was instead a major factor, since several crops were ready for harvesting and dairy cattle were grazing on new forage (34).

The habits and activities of exposed individuals are also influential (diet, food source and processing, time spent outdoors, etc).

In order to ascertain population exposure, different kinds of exposure indicators may be adopted (table 1). It was probably in Seveso that the longest experience in assessing human exposure to a chemical toxic release has been gained (3, 72, 75–77). Measurements of TCDD levels were repeatedly taken in the following ecological media/systems: (i) surface soil (provided evidence of decreasing levels with increasing distance from the point release source and suggested that the cloud had been moving in a definite direction, with gradual dispersion on the edges of the main pathway), (ii) deeper soil layers (suggested that the vertical gradients varied only slightly with time, over 90% of the detectable TCDD still in the upper 15 cm after several months), (iii) ground and surface water and sediment (confirmed the low solubility of TCDD and its high affinity for soil and sediment), (iv) airborne dust levels (varied according to the season and distance from the release source), (v) vegetation (leaves, grass, vegetables) (TCDD levels decreased rapidly with distance from the plant; both preexisting tissues and new growth were found to be contaminated; and the ability of plants to absorb and translocate TCDD was shown, with a progressive increase in TCDD level with

Table 1. Examples of indicators for the ascertainment of individual exposure after industrial disasters.

Ecological	Type of exposure indicators	
	Geographic	Human
Soil	Residence	Early signs/symptoms
Vegetation	— distance from the emission source	Biological samples
Animals	— calendar time	Personal habits and activities
Water	— length of stay	
Dust		

plant maturation), (vi) farm animals (TCDD was detected in the liver of different farm animals, and these animals also exhibited a mortality distribution fairly consistent with the soil contamination measurements), (vii) wildlife (bird deaths were observed shortly after the release; several wild mammals showed positive levels of TCDD in both skin and liver; other wildlife forms, instead, apparently disappeared from the most contaminated area), and (viii) cow's milk (higher levels were found in samples from the farms closest to the trichlorophenol plant).

Human bodies also showed early signs of contact with the chemical cloud. Irritative symptoms were reported by those who happened to be in its path, and dermal chemical lesions soon became apparent among those, particularly children, who had been outdoors at the time. In addition, specific signs (chloracne) of absorption of the major contaminant, TCDD, began to appear on the fourth day. It is easy to appreciate how relevant these early signs are for establishing individual exposure. Attempts were made to integrate the various pieces of information in order to obtain comprehensive estimates of exposure. Certain evaluations included data on animal deaths, in addition to TCDD in soil and skin changes, and raised questions about the accuracy of the established boundaries of the contamination areas (78, 79).

The analysis of human biological samples was the weakest part of the exposure evaluation, due to numerous practical reasons which will be dealt with later. It is, nonetheless, appropriate to stress the importance of collecting biological samples when the nature of the exposure indicates it might prove valuable. Such samples, once properly stored, may also be used for later analyses, either for ascertaining individual exposure with advanced techniques or for measuring new types of biological indicators, should they become available, particularly in the field of molecular biology (80—82).

Exposure via food (type, source, processing, etc) and other factors can be estimated by means of questionnaires and interviews or from descriptive information regarding cultural, social, and occupational characteristics of the population, or subgroups within it.

The affected territory can be subdivided into subareas exhibiting varying degrees of contamination, depending usually upon the distance from the release source. These subareas may correspond to existing units (household, street, village, town, etc) or be delimited ad hoc, as in the case of Seveso, where the contaminated area included portions of more than one town (3). In the case of persisting exposure, individuals may further be characterized by the length and calendar period of their stay in the area. Official residence and/or ad hoc interviews may be of value in this respect.

As regards radiological exposure after Chernobyl, the WHO Regional Office for Europe has issued a report entirely concerned with the estimation and

monitoring of exposure to radiation doses from cesium-134, cesium-137, and other nuclides with long half-lives (73).

Postdisaster stress. A second set of determinant factors is linked to the disastrous or catastrophic nature of the event, as experienced by the population. Increasing attention is being paid to psychosocial aspects of disasters (83—88). The term posttraumatic stress disorder (PTSD) was introduced into standard psychiatric nomenclature in 1980 on the basis of the great amount of work done on the consequences of stressful experiences of survivors of catastrophies, both man-made and other (89, 90).

Logue and his co-workers (91) proposed to incorporate the risk factors pertaining to the disaster-associated stress into the two categories of objective losses/experiences and perception/evaluation of the disasters. Both are present in any type of disaster, although with varying intensity. Industrial disasters often result in a high level of perceived risk, even though objective losses are few. And, in fact, several surveys have ranked chemicals and nuclear power among the highest of perceived hazards (92). Seveso might serve again as an example. In my opinion, the following five major components of the stressful experience of the disaster can be singled out:

1. Uncertainty. The nature of the contaminant was made known only on the tenth day, and what was made known was that TCDD was one of the most powerful toxic compounds whose effects on man had only been partially ascertained; yet, most probably, they were long-lasting and late-appearing. The fear of unknown health damage was matched with a strong feeling of lack of protection, notwithstanding the social and medical support received from the local, regional, and central governments.

2. Housing and job insecurity. Different factors contributed; the evacuation of some of the area inhabitants, the fear of contamination of homes and premises, and the drop in orders for local products were among them.

3. Social rejection. Despite the commitment of many official and voluntary groups, the people in Seveso suffered discrimination for some time as if they carried some mysterious and noxious contagion.

4. Media siege. For months and years representatives of the media came to this area from all over the world. In the public's perception what had happened or was going to happen should, then, become necessarily the worst case in the century. A possible negative side-effect of the otherwise precious role of the media in disasters has been already described (93).

5. Cultural pressure. People became the target of many, often conflicting public pressures and messages on how to behave, what to expect, etc. Hot issues were

raised, the hottest being legalization of abortion for exposed women.

This brief account underlines the fact that powerful stressors may also be acting during the recovery from the disaster situation, and not just at the time of the event. Such stressors can play a role as additional, individual risk determinants, but they can also influence the extent of exposure to the toxic release. Compliance with protective measures, for instance, highly depends upon the way risk is perceived by people.

Response measures. The third set of determinants of postdisaster health sequelae is comprised of response measures, for instance, evacuation. Displacing people from a polluted area has the obvious merit of preventing further exposure. Yet such a policy may add, as just discussed, further risk determinants to the experience of the population (94). In Seveso other response measures included the prohibition of harvesting, using local crops, and raising farm animals; daytime displacement of children younger than 12 years and pregnant women from certain areas where permanent evacuation was not deemed necessary; regulations regarding food and water consumption; etc. Similar countermeasures (sheltering, food restriction, etc) were also taken in the aftermath of Chernobyl; from the examination of tens of thousands of Soviet citizens with personal radiation dosimeters it was possible to show that the levels of cesium-134 and cesium-137 dropped to levels 10–20 times lower than expected from model calculations (73).

Social support is another response measure which has been shown to modify quite obviously the effect of disaster on individuals (91).

Consideration of these measures has relevance either for estimating the actual exposure of individuals or, at a later stage, for evaluating the effectiveness of the response strategy.

Health outcomes

The toxic properties of the agent(s) released are, thus, the principal, but by no means the unique, predictor of the adverse health effects to be investigated. Other accident-related determinants ought to be taken into consideration, as well as those characteristics of the exposed population that can influence the susceptibility state. A further relevant factor is feasibility, in terms of availability of scientific and/or technical and/or organizational resources and tools. Three categories of health outcome will be considered: exposure-related (early and long-term) outcomes, stress-related (mental and physical) outcomes, and outcomes of general scientific and public health interest.

Exposure-related outcomes. Health consequences may become apparent at various times after the event, de-

pending upon the toxicologic properties of the released agent, the nature and history of the disease process, and the persistency of the exposure in the environment, which, in turn, depends upon the nature of the agent, the disaster context, and the response strategy.

Early effects should be given great attention not only in the assessment of health impact, but also in the planning of further action (eg, allocation of resources for treatment and rehabilitation, and long-term surveillance of particular groups). One example is the Chernobyl experience, where a great deal of attention was devoted to the identification of people who had received massive radiation doses. On the basis of a set of biological indicators and symptom characteristics, they were grouped into four categories of increasing severity of acute radiation syndrome (ARS) which served as a guide for treatment and medical resources allocation, including decisions regarding bone marrow transplants (15, 41). Two other examples relate to the relevance of early health impairment in the study of long-term consequences. The follow-up of people who contracted chloracne in Seveso, for instance, was relevant not only to following their progress to complete recovery, but also to identifying possible delayed sequelae in subjects who exhibited such established markers of TCDD exposure (46). Quite instructive was the case of a 1,3-dichloropropene spill which caused rather severe symptoms in nine firemen. Two of them developed lymphoma almost simultaneously after several years (95).

Feasibility has a great deal of bearing on the study of health outcomes, especially delayed ones. The critical phase following any disaster almost inevitably carries a burden of “disproportion, hypercomplexity, and strongly destabilizing tendencies [p 13]” (96). Accounts of the difficulties pertaining to the planning and conducting of long-term studies in Seveso have been published (5, 48, 78). They include social, political, technical, cultural and motivational aspects. Several studies, as, for instance, those concerning spontaneous abortions, immune status, neurology, and cytogenetic damage, remained thus inconclusive or were interrupted; also much of the information accrued remained unexploited.

Results of other long-term studies are available. The study of all live births and stillbirths between 1977–1982 to residents in the contaminated area at the date of the accident failed to demonstrate any increased risk of birth defects (49). The repeated testing of liver function and lipid metabolism in children from the contaminated area between 1976 and 1982 showed slight elevations of the values of some tests, but the results later proved to be reversible (50). The follow-up of 193 chloracne cases, and of a reference group, up to 1985 demonstrated the complete recovery of all cases but one (46). Other studies, specifically the ones based on “hard” records, are continuing, and they are concerned with mortality and cancer morbidity. Mortality for the ten-year period following the incident

(1976–1986) is being analyzed, and indications of an increased risk of cardiovascular death and death from cancer of some specific sites are emerging. Such mortality results are only suggestive, but nonetheless important, in flagging the exact problem of delayed effects on which follow-up studies should continue. To illustrate this point, tables 2 and 3 show cancer causes (with the addition only of “blood diseases”) for which mortality noticeably departing from expectation was noted among the men and women in three zones (A, B, and R) having decreasing mean contamination levels.

Stress-related outcomes. Stress-related consequences are either mental or physical. Mental consequences do not entail only immediate signs, such as anxiety, anger, depression but may find expression months or years later, a point which is often overlooked (83, 85, 88, 97, 98). As regards physical consequences, data from the mortality study in progress in the Seveso area illustrate the point well. From table 4 it is apparent that, in the aftermath of the event, the population of the most contaminated area (zone A), which had suffered

the greatest psychosocial impact of the accident, exhibited a general pattern of cardiovascular mortality noticeably higher than that of a comparable population from an area with similar social, environmental, and cultural features. The small size of the population is, no doubt, a limiting factor in the interpretation of the results, yet the data strongly suggest an unusual cardiovascular mortality rate. Scientific grounds to support an association between cardiovascular death (particularly in the form of precipitation of preexisting ill health) and stress experience are quite sound (84).

Outcomes of general interest. In a postdisaster situation there is, at least theoretically, a unique opportunity to observe the full temporal range of exposure-associated effects. This observation, in principle, may allow the exploitation of a number of health-related phenomena for scientific purposes. In the WHO document concerned with epidemiologic activities related to the Chernobyl nuclear disaster (43), one can find several such proposals, as, for instance, the study of deoxyribonucleic acid repair efficiency, the use of glycophorin A assay, the evaluation of chromosome

Table 2. Preliminary results of the mortality study in the Seveso area, 1976–1986 — relative risk (RR) and 95 % confidence interval (95 % CI) for selected types of cancer causes among the male population of the three zones of the contaminated territory, the three having decreasing mean soil contamination levels (A, B, and R, respectively) (47).

Cause of death ^a	Zone A			Zone B			Zone R		
	Observed deaths	RR	95 % CI	Observed deaths	RR	95 % CI	Observed deaths	RR	95 % CI
All cancers (140–209)	3	0.49	0.2–1.5	45	1.10	0.8–1.5	255	0.87	0.8–1.0
Liver cancer (155)	—	—	—	3	1.88	0.5–7.7	8	0.50	0.2–1.0
Lung cancer (162)	2	1.03	0.3–4.1	17	1.33	0.8–2.2	73	0.80	0.6–1.0
Soft tissue sarcoma (171)	—	—	—	—	—	—	2	6.34	0.9–45.1
Melanoma (172)	—	—	—	1	15.43	1.6–148.4	2	4.36	0.7–26.1
Bladder cancer (188)	—	—	—	3	2.28	0.7–7.3	7	0.74	0.3–1.6
Brain cancer (191)	—	—	—	—	—	—	5	1.27	0.5–3.3
Leukemia (204–208)	—	—	—	2	1.72	0.4–7.0	4	0.49	0.2–1.4
Myeloid leukemia (205)	—	—	—	1	4.56	0.6–5.7	4	2.59	0.8–8.3
Blood disease (280–289)	—	—	—	—	—	—	5	4.04	1.3–12.3

^a Code of the International Classification of Diseases, ninth revision, in parentheses.

Table 3. Preliminary results of the mortality study in the Seveso area, 1976–1986 — relative risk (RR) and 95 % confidence interval (95 % CI) for selected types of cancer causes among the female population of the three zones of the contaminated territory, the three having decreasing mean soil contamination levels (A, B, and R, respectively) (47).

Cause of death ^a	Zone A			Zone B			Zone R		
	Observed deaths	RR	95 % CI	Observed deaths	RR	95 % CI	Observed deaths	RR	95 % CI
All cancers (140–209)	3	0.84	0.3–2.6	13	0.60	0.3–1.0	151	0.87	0.7–1.0
Liver cancer (155)	—	—	—	—	—	—	3	0.48	0.1–1.5
Cancer of the gallbladder and biliary tract (156)	1	13.94	1.9–103.0	2	4.50	1.1–19.0	4	1.10	0.4–3.2
Soft tissue sarcoma (171)	—	—	—	1	17.63	1.8–169.7	—	—	—
Breast cancer (174)	1	1.11	0.2–7.9	5	0.92	0.4–2.2	28	0.62	0.4–0.9
Brain cancer (191)	—	—	—	—	—	—	5	3.11	1.1–9.0
Hodgkin's disease (201)	—	—	—	1	6.81	0.8–56.7	3	3.09	0.8–12.4
Leukemia (204–208)	—	—	—	1	1.13	0.2–8.2	3	0.60	0.2–1.7

^a Code of the International Classification of Diseases, ninth revision, in parentheses.

Table 4. Mortality from cardiovascular causes by follow-up period among the population, aged 20–74 years, of the area (zone A) most severely affected by the Seveso incident in 1976 — preliminary results (47). (RR = relative risk, 95 % CI = 95 % confidence interval)

Cause of death ^a	1976–1981		1982–1986		1976–1986	
	RR	95 % CI	RR	95 % CI	RR	95 % CI
<i>Men</i>						
All circulatory diseases (390–459)	1.97	0.9–4.1	1.65	0.6–4.4	1.84	1.0–3.3
Ischemic heart diseases (410–414)	2.34	0.9–6.3	—	—	1.35	0.5–3.6
Acute myocardial infarction (410)	1.55	0.4–6.2	—	—	0.86	0.2–3.4
Chronic ischemic heart diseases (412, 414)	5.12	1.3–20.7	—	—	3.45	0.9–13.9
Cerebrovascular diseases (430–438)	2.41	0.6–9.7	5.12	1.6–16.0	3.51	1.5–8.5
<i>Women</i>						
All circulatory diseases (390–459)	1.12	0.3–4.5	3.18	1.2–8.5	1.96	0.9–4.4
Chronic rheumatic heart diseases (393–398)	20.57	2.7–156.2	34.90	8.0–151.5	28.97	8.9–94.8

^a Code of the International Classification of Diseases, ninth revision, in parentheses.

damage as a predictor of increased cancer risk, the examination of the role of immune status alterations, and so on. Recommendations and plans have also been made for studying leukemia risk in the first years after exposure, prenatal effects on the central nervous system, short- and long-term effects of iodine prophylaxis, etc.

Study population

After a chemical or radiological release has occurred, some of the affected persons are readily identifiable, either because they suffer immediate health damage or because they report signs, symptoms, or circumstances clearly indicative of exposure. The study population, however, ought to be comprised not only of the disaster victims, but also of all those who suffered disaster exposure, irrespective of the presence of immediate markers (biological or otherwise).

The identification of the exposed population rests, in general, on the delimitation of the spatial extent of the contamination. All people living within the geographic boundaries at the time of the accident should be considered potentially exposed, and thus relevant to the study. Major problems may arise, however. In Bhopal, for example, the status of the citizens' registration systems complicated any attempt of comprehensive identification and complete enumeration of the exposed (74). In Chernobyl, the evacuated area around the plant served, instead, as a geographic identifier of the persons to be included in the investigation program (115 000 people). However, subsequent environmental radiological contamination studies led to the inclusion of 200 000 additional persons (66). In Seveso, the best available means to meet the need to enumerate the population and follow each individual member of it turned out to be the town-based vital statistics registration, which has a rather strong internal and inter-locality consistency. It was then decided to include in the study every person residing in the contaminated portions of the affected towns, as of the date of the release or later, up to the end of 1986. This last cri-

terion stemmed from the available information regarding TCDD persistency in the territory (76, 99). Still, some of the exposed population could have remained excluded, as, for instance, those who had been living or working in the area for some time but who resided elsewhere.

In any disaster there are, however, groups of people who are identifiable as potentially exposed no matter where their residence is. They include workers in the plant in question, and those involved in emergency or postemergency activities, such as firemen, field researchers collecting contamination samples, reclamation workers, and so on. A complete roster of these individuals should be compiled, kept, updated, and used for health surveillance.

The population of a geographic area is subject to change. People move in and out. In a disaster-affected area, the persons leaving it are of paramount importance for the study, while those moving in are less and less relevant as time passes. Accordingly, in the design of studies on health consequences of major disasters (A-bomb, Seveso, Chernobyl), it has been an almost unanimous choice to select a cohort rather than to use a population registry approach (43, 47, 62). This approach can help avoid two major biases. One is the dilution of the exposure prevalence in the population within which investigations are conducted. The second is the selective migration of people from the disaster area; their moving, in fact, can be associated — as it is the case, by definition, when evacuation occurs — with their disaster experience. Hence the involvement of epidemiologists is extremely important in the immediate aftermath of man-made disasters, in order to set up, in cooperation with other researchers and experts, active mechanisms of population identification and enumeration.

The size of the population involved in industrial disasters is often large; nonetheless due consideration ought to be given to aspects of the study possibly influenced by small sample size. This point is illustrated by table 5 in which projected risks are given for three radiation-associated conditions among the population

of Europe on the basis of radiation dose estimates after the Chernobyl incident (73). Similar added risks might go unnoticed, notwithstanding the huge size of the population. Thus, one must remember that there might be disaster-associated effects that the planned investigations will not have the power to reveal. This result is quite different from concluding that such adverse effects have not occurred.

A second problem might stem from the limited size of subgroups of special interest. Consider again tables 2 and 3. Several relative risks had remarkably high values, but it is also apparent that the estimates had a rather wide variability. And, in fact, small sample size affects precision (100). Should the results then be considered scarcely significant? I would hardly share such a view. Rather, it seems to me that the results are relevant and of interest, at least, if nothing else, as sentinel findings and guiding evidence for further research and/or decision. The results in these tables further exemplify the previous point. For example, given an estimated annual spontaneous mortality from soft tissue sarcoma of approximately three among one million persons, one is not surprised not to find this disease among the 700 inhabitants of the most polluted area (zone A) after 10 years.

Validity issues

Following an incident, one has in theory the opportunity to assemble a cohort defined as to exposure to the hazard and follow its experience prospectively, an approach which in principle allows a fair control of sample composition, determinant definition, and outcome identification even in nonexperimental research. In practice, things change dramatically in postdisaster settings.

Information

Cohort composition. When the design of the mortality and cancer incidence investigations on the Seveso population was started in 1983, it became clear that the available database had many inconsistencies. The reasons were not difficult to determine and were all related to the hectic social climate of the emergency phase. The definition of the spatial extent of contamination had suffered from scientific uncertainty, the scarcity of technical resources, and political pressure. Data gathering and input also occurred under time

pressure, not enough attention being given to the control of their accuracy, completeness, and homogeneity. A decision was then made to rely on the only homogeneous and comprehensive person identification and enumeration source, ie, the official residence registrations at the vital statistics offices of the towns in question. The existing database was checked against such registrations: missing people were identified, others were excluded, some ten thousand records needed some type of correction. In this way subjects who were somehow involved in the incident were certainly excluded, but something more important for the purposes of the study was gained, ie, a homogeneous roster containing the basic information needed to follow the exposed people over a period of time. And, in fact, the tracing in the mortality study turned out to be successful for over 99 % of the study subjects (47).

In general, it is apparent from the reviewed disaster experiences how difficult it is to find a remedy for the inadequacy of vital statistics data in the postimpact phase and for the lack of database and information systems suitable for the enumeration and follow-up of the population of the affected area. If such resources do not exist on a routine basis, they should be established as part of the siting policy for potentially dangerous establishments. They can then serve the purpose of surveillance during "normal" operation conditions and also help to ascertain the health impact of disastrous events.

Exposure assessment. Other information problems are linked to exposure assessment, either because of the aforementioned points or because of the many pressures under which sampling and analysis are performed, often by different laboratories, a procedure which jeopardizes quality control (internal and external). In addition, analytical capability evolves, and it may become apparent only later that measurements taken in the early phase were not accurate. Figure 1 illustrates such a problem in Seveso. Years after the accident new studies were undertaken on the environmental behavior and persistence of TCDD in soil, under strictly controlled conditions and with the use of advanced equipment. The changes in the TCDD soil concentrations over time are represented by the line, which was closely predicted by the measurements taken four or more years after the accident. It may be inferred from this reevaluation that the mean values

Table 5. Upper estimate of additional radiation risk to 550 million people in Europe (excluding the Soviet Union but including Turkey) after Chernobyl. All of the values in the table are approximations (73).

Projected health effects	Estimated spontaneous incidence	Added cases	Percentage added to spontaneous incidence
Fatal cancers (50 years)	110 000 000	7 000	0.006
Severe genetic ill health (first generation)	28 000 000	700 ^a	0.003 ^a
Severe mental retardation	50 000	200	0.4

^a Added risk from first-year dose.

measured in the one and a half years following the accident were affected by underestimations of 25 to 35 % (99).

Outcome registration. Understandably, changes may occur in the attitude of health professionals and the performance of health services with respect to the diagnosis and recording of health outcomes in the disaster aftermath. Moreover, additional services and professionals become temporarily operative at the disaster scene. The way a common protocol for the diagnosis of radiation-associated syndrome was designed after Chernobyl has already been mentioned (15, 41). In the mortality study in Seveso an attempt was made to cope with this possible source of bias with comparisons of pre- and postaccident data. Typical results are shown in table 6. Overall, no obvious, systematic

changes in death registration became apparent. Examples of relevant information (among the women) are the relative risks for brain tumors, which turned out to be elevated even before the accident, and for leukemias, which showed indications of a possible postaccident change in terms of underregistration.

When a follow-up is planned, two options are available, ie, to set up an ad hoc registration system or to rely upon existing and validated systems. The former has the appealing feature of being specifically targeted to health consequences linked to disaster experience. However, from the experience reviewed it appears that only for limited subgroups and periods of time can such systems maintain consistent quality and comprehensive coverage of the people concerned. The second option provides a better guarantee of validity for the collected information, particularly in terms of homogeneity over time and coverage of the relevant subjects. Rarely, however, can one explore health outcomes different from the ones recorded on death certificates and by cancer registries with such systems.

Comparison

A reference population is needed when long-term effects or subtle effects appearing early after exposure are the objects of investigation. The lack of sound reference data was among the major problems encountered in the interpretation of results of certain investigations in Seveso (48, 78). The mortality study had more room to make allowance for such an issue. Mortality data, either national or regional, were available. They were discarded, though, in favor of the mortality of the population resident in the territory surrounding the contaminated area, with a view to assuring comparability of the contrasted populations in terms of the effects of other environmental, social, and cultural factors on their mortality. A potential drawback of this approach was possible misclassification in terms of exposure, had the contamination zones not been accurately delimited. Good comparability of information was instead a merit. The reference population, in fact, was followed as a cohort concurrently with the exposed population and thus assured close homogeneity

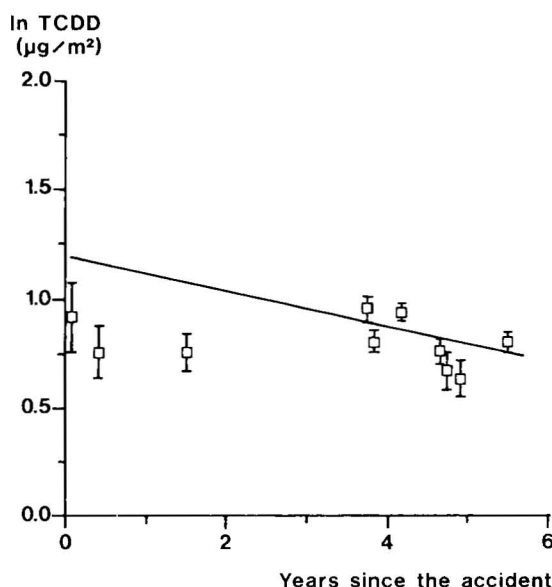


Figure 1. Persistency of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) in the soil after the Seveso accident (1976) — Mean values (squares) and standard errors (bars) of successive measurements from the most contaminated area (99).

Table 6. Pre- and postaccident relative risks for selected causes of death by calendar period among the population involved in the Seveso incident in 1976.

Cause of death ^a	Men			Women		
	1969—1975	1976—1981	1982—1986	1969—1975	1976—1981	1982—1986
All causes (001—999)	1.07	1.01	1.07	1.08	1.02	0.99
All cancers (140—209)	1.10	0.99	1.02	1.05	0.97	0.92
Liver, gallbladder and biliary tract (155—156)	1.18	1.28	1.05	0.46	0.76	0.84
Lung (162)	1.09	0.86	0.98	1.07	1.16	1.13
Breast (174)	—	—	—	1.08	1.08	1.04
Brain (191)	1.40	1.54	0.47	2.11	2.67	2.06
Leukemia (204—208)	0.85	1.20	0.77	1.83	0.62	0.57
All circulatory diseases (390—459)	1.07	1.03	1.14	1.06	1.01	1.09
Cirrhosis of the liver (571)	1.17	0.99	0.77	1.30	1.00	1.06

^a Code of the International Classification of Diseases, ninth revision, in parentheses.

ty of the data gathered and consideration of the baseline migration pattern.

Once categories of the relevant determinants can be properly established and measured, comparisons across them offer the best way to explore the association between the noted effects and the incident. Few examples of such investigations exist in the disaster literature, either because of the difficulties in accurately assessing the individuals' exposure or because of the size of the groups and the poor control of confounding. In Seveso attempts are being made to analyze mortality by comparing subgroups defined not only as to their place of residence in the contaminated area, but also as to the length and calendar year of their stay in the area. Such a categorization is based on a new attempt of modeling the environmental transfer of TCDD and the correct extent and level of contamination in the area (101).

Confounding

Two factors work together in hampering the satisfactory control of confounding, ie, the often very large size of the affected population and the availability or the feasibility of the collection of relevant data in an emergency situation. Apart from factors such as age and gender, information on characteristics such as diet, occupation, personal habits, health history, etc, is difficult to acquire under postdisaster crisis conditions, either because of the objectively disrupted social situations or the attitude of individual people (victims and researchers), depending on their disaster experience and perception. Interviews and questionnaires might prove to be of particularly poor validity in such a context.

Confounding seems to be satisfactorily controllable only when specific issues and particular groups are the object of study. This is the case in the surveillance of persons exhibiting a specific early effect or with cases of a particular disease appearing later in time. Hence, it is important to plan case-referent studies nested within an appropriately constructed cohort, especially when the causal nature of an association is being investigated. This, for example, is the type of study being designed in Seveso in order to examine the association between the noted excess risks and the TCDD release thoroughly.

Lessons learned

Despite the variety of industrial disasters and related studies, some strong points of common relevance emerged from this review. Most of these points had already been established when the most exhaustive and long-lasting postdisaster investigations of which I am aware were reviewed (62).

1. Different experts should be on the scene working in close coordination; they should usually cover the fields related to the environmental fate of the agent,

its toxic properties to humans and biota, analytical methods, clinical medicine and pathology, biostatistics, and epidemiology.

2. Based on preexisting and/or early available evidence, a comprehensive study plan should be developed as early as possible to identify goals, problems, and resource requirements.

3. Early phase activities affect the course of any subsequent action. Since long-term effects should be expected after virtually every type of industrial disaster, great care should be devoted to ensure the availability of requisite information for later studies (eg, proper identifiers of the exposed for follow-up).

4. Feasibility should be given high consideration to facilitate scientific and public health achievements and the clarity of communication.

5. Overall, for reasons of validity and cost-effectiveness, it is advisable to rely on "hard" information, whenever available, either in identifying and enumerating the study population (eg, residence) or in estimating exposure (eg, environmental and biological measurements) and choosing the end points (eg, mortality).

6. International cooperation ought to be urgently strengthened in three domains: scientific work, public health, and industrial siting and safety policy.

Of course, only the particular features of each disaster can dictate the most suitable approach. Nonetheless, this review seemed to suggest the following.

When the disaster origin is evident, the major task is the assessment of the health impact. Early case identification is relevant for the allocation of services, treatment and rehabilitation and for the planning of further investigations. Surveillance of delayed effects completes the health impact assessment (which is relevant for compensation purposes, too), allows the evaluation of the postemergency measures, and, along with the environmental investigations, may elicit the detection of the persistence of a health threat. A cohort approach is advisable, among other things, also in order to provide the most suitable base population for later studies; a surveillance of sentinel events (102) might be relevant either for the discovery of effects specifically related to the type of exposure or for evaluation purposes. The experience gained is relevant for preparedness in similar occurrences and should, therefore, be recorded and the record disseminated.

In case of a silent origin, the identification of the disaster source may benefit from descriptive, cohort, and, particularly, case-referent approaches. The major task is to identify determinants whose manipulation helps to stop the progression of the outbreak and/or prevent an even worse impact, as well as the occurrence of similar events in the future.

With any type of approach, general scientific and public health achievements can be sought. Examples

of the first type are the possibly unknown range of effects of exposure, the natural course of illness, induction and latency period, dose-response relationship, role of modifying factors (eg, personal characteristics and countermeasures). From the public health standpoint, the major acquisitions may concern the prevention of similar occurrences and the evaluation of the effectiveness of secondary measures (eg, screening and prevention).

Closing remarks

The extent of the phenomenon of man-made disasters is certainly impressive. I could be biased in drawing such a conclusion since, in the last few months, I have been reading shelves of papers related to this issue. But I do not think this is the case. If not every day, certainly every week the newspapers have been printing, especially recently, of this pending hazard. While I was pondering such an alarming scenario, I happened to become aware that, after the Chernobyl disaster, a Ukrainian magazine published coverage of the incident with the headings "I pala zvezda Chernobyla [And fell the star Wormwood]." It was a citation from the book of Revelation which in full reads: "The third angel blew his trumpet, and a great star fell from heaven, blazing like a torch, and it fell on a third of the rivers and on the fountains of water. The name of the star is Wormwood. A third of the waters became wormwood, and many men died of the water, because it was made bitter [Revelation, 8, 10—11]." I do not want to draw any conclusion, but I was struck by the fact that Chernobyl means Wormwood. According to the Bible, this angel is the third in a series of seven who have to blow their trumpets. Let us suppose then that we are almost half way. One might think that we do not have much time ahead. I would prefer to think that there is still much time available to cope with the world pollution and environment degradation problem. We, as people committed to scientific knowledge and public health, have certainly a major role to play in the pursuit of such an achievement.

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