Population Evacuations in Industrial Accidents: A Review of the Literature about Four Major Events

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MIC = methyl isocyanate
TMI = Three Mile Island

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Abstract
This article reviews the literature describing four chemical and nuclear accidents and the lessons learned from each regarding the evacuation of civilian populations. Evacuation may save lives however, if poorly orchestrated, it may cause serious problems. For example, an inaccurate assessment of danger may lead to the evacuation of the same population twice, as the area requiring evacuation becomes larger than originally expected. Evacuation programs should focus on the vulnerable components of the populations, such as the elderly, children, and the disabled, and also should include plans for the care of pets and other animals. Training programs for civilians living near industrial centers and other high-risk areas should be considered. Finally, pre-event planning and preparation can improve the evacuation process and prevent panic behavior, and thus result in fewer casualties.

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Introduction

Worldwide economic development involves the construction of power plants, industrial zones, and nuclear reactors, all of which increase the risks for industrial accidents involving chemical and/or radiation exposure. The information collected from the numerous accidents that have occurred during the last century allows the formulation of some principles regarding the management of such events.[1]

There are thousands of types of dangerous industrial materials; radioactive substances are one such group. While the professional literature tends to regard their threat as comparable to other dangerous materials, the civilian population fears them more.[1,2]

Industrial zones that produce and store dangerous materials sometimes are located near, or even within, populated areas. Technical accidents, personal mistakes, or a terror attack can precipitate disasters with thousands of victims.[1,2]

This review describes one mechanism for reducing casualties from industrial accidents—population evacuation. Eventually, the civilian population almost always leaves the danger zone. In some cases, the process is initiated by the authorities while in other instances, people flee on their own initiative. This article is a review of the evacuation of civilian populations in four industrial accidents (Table 1).

Train Accident in Mississauga

The first of the four accidents reviewed occurred in November 1979 in Mississauga, Canada, a city with a population of 200,000. It started with a train accident that led to a fire in a tanker car containing 90 tons of liquid chlorine, which turned into a toxic gas upon vaporization into the atmosphere.[2,3]

The derailment, explosion, and fire occurred on a Saturday at 23:55 h, while most of the citizens were asleep. Police and fire teams were on the scene within minutes. A strong suspicion that the car with the toxic chlorine was in

Incident	Three Mile Island	Mississauga	Bhopal I	Bhopal II	Chernobyl
Date	29 March 1979	10 November 1979	02–03 December 1984	16–17 December 1984	26 April 1986
Nature of disaster	Nuclear power plant accident and threat of release of radioactive water to the atmosphere.	Chlorine leakage caused by railroad accident.	Explosion at Union carbide plant and release of MIC.	Deactivation of the chemicals that remained at the plant.	Explosion of nuclear reactor radioactive material release to atmosphere.
Number evacuated	144,000–150,000	220,000	70,000–500,000	100,000–300,000	445,000–500,000
Evacuation process	Self-evacuation of many despite the authorities recommendation that only pregnant women and small children should distance themselves at least 8 km from reactor.	Gradual self-evacuation. Authorities asked the population to evacuate. Most people used private cars.	Fleeing, self-evacuation without any announcement from the authorities.	Self-evacuation despite the authorities' announcement that there is no threat	Governmental evacuation despite local resistance. All persons evacuated by governmental transport.
Authorities informed of accident	Immediately due to announcement from the nuclear plant	Immediately due to the nature of the accident—Fire and explosion	Several hours after the release of the MIC	Knew about the reactivation several days beforehand	Immediately due to the nature of the accident—Explosion of the nuclear reactor
The authorities decide to evacuate	Part evacuation—Only pregnant women and little children in close proximity to the nuclear plant	Total evacuation	No decision was taken regarding the evacuation	No evacuation—Fleeing of the population due to fear	Total evacuation in large radius and partial evacuation in an even larger radius
Time from the accident until to the decision about the evacuation	The authorities weren't sure that evacuation is necessary. People started leaving on their own	Two hours	Wasn't any decision about the evacuation people fled from the city	Authorities thought that evacuation wasn't necessary	Twenty hours—Very slow decision making
Speed of evacuation process	Slow evacuation—because of different announcements about the danger from the officials	Very fast—Several hours and gradual evacuation	Very fast—several hours	Slow evacuation— As people knew when the plant will restarted and started to evacuate several days before	Very fast—Several hours and gradual evacuation
Self or governmental evacuation	Self-evacuation	Self-evacuation	Self-evacuation	Self- and government evacuation	Governmental evacuation
The transport	Different types of the transport	Mostly private cars	Several types of transport—Walking, cars, buses, trains etc.	Different types of the transport	Government buses
Destination of the evacuees	People leaved to other cities.	Most of the persons evacuated to hotels and friends. Little part only evacuated to governmental center	People fled to another cities and to the refugees camps that organized around Bhopal	People fled to another cities and to the refugees camps that organized around Bhopal	Most children evacuated to summer camps. Adults to another region and dislocated in private houses of aborigines
Forced evacuation	Authorities don't support the evacuation	People that didn't want to evacuate stay at home	People just fled from the city	The official information was that there is no danger. Still, authorities helped move evacuees e.g. special trains	Population of Pripiat forced to evacuate despite resistance (people didn't see the danger and the reason for evacuation).
Double evacuation	No	Yes, evacuation area widened	No	No	No Data
Evacuation forces	No	Police	No	No	Army of USSR

Table 1—Comparison of four industrial accidents population evacuation

the burning section was raised after two hours and was confirmed two hours later. Meanwhile, the first city evacuation order was issued two hours after the accident.[2,3] According to police records, 213,000 people were evacuated. Evacuation proceeded in stages: 50% of the households were evacuated within 30 minutes, and 80% of the households left the city within 60 minutes, despite the late hour.[4] Speedy evacuation was facilitated by the following factors: (1) the event was highly visible and audible; (2) most families were together on Saturday night, minimizing the need to search for a missing family member, and thus, delaying departure; (3) most residents anticipated that their absence from home would be short—much shorter than it eventually became; (4) most residents of Mississauga owned cars that were in running order, could afford hotels, and in some instances, owned a second home; (5) most residents had friends and relatives with whom they could stay; (6) the network of roads in and around Mississauga was excellent; and (7) the evacuees did not fear that their homes were likely to be looted.[5]

Information was delivered by radio and television, as well as through public address announcement by police cars.[5] Most evacuees (88%) used their private cars to evacuate, 9% rode in the cars of friends or neighbors, and 2% used taxis or public transportation. If the evacuation had been declared for the entire city at once, 76,000 vehicles would have been on the roads within the first hour, but gradual evacuation prevented the occurrence of traffic jams.[4]

Most evacuees went to private homes; only 14,000 (less than 7% of the 213,000 evacuated persons) came to officially declared evacuation centers. More than one-third of evacuees at official centers stayed <24 hours, and then moved to hotels or private homes. Only 8,700 persons (<4.5%) stayed >24 hours. The evacuees tended to be low-income families, members of large families, elderly, single persons, people with pets, and non-English speakers.[4]

In many industrial accidents, including this case, "double evacuation" occurs, where some of the citizens (29% in this instance) initially are evacuated to an area just outside the declared danger zone, only to be evacuated again as the declared danger zone is expanded.[4]

In Mississauga, a relatively high proportion of evacuees (19%) tried to re-enter the evacuation zone before it was officially reopened. The most common reasons for early re-entry identified through interviews were to look after pets or to retrieve some clothes (28% each). Most citizens who succeeded in returning early were in their house for a very short time, but some remained at home for the remainder of the evacuation period. Burton *et al* estimate that between 1,000 and 4,000 people were traveling in and out of the evacuation zone each day after Monday, despite police orders.[4]

In spite of the danger and official calls to evacuate, some people (at least 1,200 families) chose to stay in their homes. The factors that contributed to their decision included: (1) their belief that there was no real danger to them; (2) the belief that should the situation change, they would be prepared to leave on short notice; (3) the need to stay to look after a large number of plants and/or animals; (4) the fact that they were not approached directly by the police; and (5) the fact that they had no friends/relatives to stay with.[4]

Approximately 60% of the evacuation zone population evacuated their entire household, while 40% evacuated only some family members. When the population outside the evacuation zone was asked why they evacuated, the residents said that they either were: (1) worried about danger (34%); (2) believed they were told to go (14%); (3) were close to the evacuation zone (11%); (4) saw others leaving (9%); or (5) were concerned about pregnancy/children (8%).[4]

Accidental Release of Dangerous Gas in Bhopal, India

The second accident reviewed occurred on 03 December 1984 in Bhopal, the second largest city of the state of Madhya Pradesh, India. It occurred at a pesticide plant located in the city and owned by the Union Carbide (now Dow Chemicals) Corporation. The population of Bhopal in 1984 was approximately one million.[6]

At 01:00 h, a large cloud of methyl isocyanate (MIC) was released from the Union Carbide plant located in the city. A combination of strong winds and cold temperatures, prevented the gas from dissipating into the atmosphere and moved the toxic cloud into a populated zone.[7]

Nearly 20% of the Bhopal population lived in 156 slum encampments, many of which were located alongside hazardous facilities. Throughout the city, water only was available for a few hours each day, there was no sewage treatment system, and cuts and reductions in available electrical power were a continuing problem. Bhopal's antiquated and highly unreliable telephone system included only 10,000 lines serving more than one million people. The medical system consisted of 1,800 hospital beds and 300 doctors. When the accident occurred, this poor infrastructure limited the city's ability to mitigate the damage.[8,9]

Neither plant management nor government authorities had prepared plans for a major disaster involving Bhopal. The Union Carbide officials did not sound a general alarm until some hours after the accident. It was reported that some key personnel in charge of public safety had departed hastily with their families, rather than report to their stations.[2]

As soon as people in the affected districts, most of whom were sleeping, detected the noxious fumes, they began to flee, if they were physically capable of doing so, without waiting for official announcements or directives.[7] Residents were unaware that the simple act of covering their faces with wet cloths and lying indoors on the floor would provide effective protection against the gas.[10] In the beginning, most evacuees simply walked away from the city. Later, people used trains, cars, buses, or planes to evacuate. Some evacuees went to Serohe, a small town 35 km from Bhopal and were directed to the town hospital. Hundreds of evacuees arrived in Ujjain and Indore, 165 km from Bhopal.[2]

Later the morning of 03 December, the scene was horrendous. According to Prasad *et al*, 11 leaked gases were trapped under a nocturnal temperature inversion, in a shallow bubble that blanketed the city within five miles of the plant. Estimates regarding the number of dead vary from a low of 1,400 to a high of 10,000, but hasty mass burials and cremations prevented accurate data collection.[12] An additional 1,500 died in subsequent months from injuries relat-

ed to the exposure. Approximately 200,000 people received medical attention: 60,000 of these individuals displayed serious symptoms from exposure to MIC, while as many as 17,000 persons may have been permanently disabled.[2] According to various estimates, the number of evacuees ranged from 85,000–500,000. The toll also included the death of least 7,000 animals, which as well, along with as environmental damage, mostly went unassessed.[11]

The failures that led to the disaster were: (1) the indifference or ignorance of the hazards by top plant and company management; (2) the failure of India's state and federal government to identify the hazard; (3) the location of the plant in a densely populated area; (4) an unprepared community; and (5) inadequate infrastructure and housing.[10] The Bhopal crisis was a landmark event, as in terms of immediate fatalities, it was the most severe industrial event to date.[10,13]

People began to return to their home several days after the event. The return stopped as soon as it was announced that the plant would be reactivated for several days in order to neutralize the chemicals still present. All attempts to explain that it would be done in a controlled manner did not help. The announcement of the decision to restart the plant caused instant terror, precipitating a second exodus, possibly as large as the first one, and marked by similar panic.[2,8,9,14]

According to press reports, regular and special trains were packed and overflowing with approximately 18,000 persons leaving daily—a single bus depot sold 60,000 tickets. According to estimates of this second, undirected evacuation, 200,000–300,000 citizens left. People started to return several days after the event.[2]

In the political elections held six weeks after the event, citizen participation was only 40%, in contrast to an average of 65% in other areas. Some citizens probably had not yet returned to the city,[7] while others still were hospitalized or otherwise incapacitated by the accident.[2]

Accident at the Nuclear Power Plant—Three Mile Island, USA

The third industrial and the first nuclear accident reviewed occurred at Three Mile Island (TMI) on 28 March 1979. In the early hours of the morning, due to human error, the temperature of the power plant's nuclear reactor began to rise. Thousands of liters of boiling radioactive water were released from the reactor and entered the buildings. In the first few days nobody knew exactly what had happened or how much radioactive substance had been released into the atmosphere.[15,16]

Prior to this accident, the Nuclear Regulatory Center had only required nuclear plant operators to develop emergency plans for the facility and the surrounding low-population zone.[17]

The accident was communicated via the media several hours after its occurrence. Between 28 March and 04 April, approximately 144,000 people living within a 25 km radius of the power plant left their homes, despite lack of such directives from the authorities.[18] Some individuals left a few hours after the event; others on 30 March, when authorities announced that radioactive gas was present in the atmosphere, and citizens were requested to stay at home with closed windows. Area schools also were closed. According to estimates, approximately 50% of the people living within an 8 km radius from the reactor left their homes, and one-third of those living between 15 km and 25 km from the reactor followed suit.[17] According to estimates, most evacuees moved to a great distance (120–150 km) from the reactor.[17,19]

A study by Mitchell and Barnes in 1979 found that 33% of persons living within a 35 km radius of the plant were prepared to leave, but did not do so.[20]

Looking at the differences between evacuees and those who elected to stay, the former included a large percentage of women, pregnancies, families with small children, white-collar workers, as well as young and wealthy people.

The Explosion of the Nuclear Power Plant in Chernobyl, Ukraine

The fourth industrial and second nuclear event reviewed occurred in Chernobyl, Ukraine on 26 April 1986, in a nuclear power plant that had been operating since 1977. There were two towns near the plant: Pripyat (population 35,000) and Chernobyl (population 15,000). Ukraine's capital city of Kiev (population 2,200,000) was 110 km from the nuclear plant.[21]

The tragic event was the result of an experiment being conducted in Reactor No. 4 (there were four nuclear reactors in the Chernobyl power plant).[22] This reactor previously had been plagued by problems. Errors were committed during the experiment on the night of 25 April. Shortly after midnight, there was a powerful steam explosion, followed a few seconds later by a hydrogen explosion. Eighty million curies of iodine^{131} and 6 million curies of caesium^{137} were released, compared to 15 curies of iodine^{131} in the TMI accident.[23]

Although only two people were killed in the explosion, the total death toll was higher due to the ensuing radiation effects. Estimates of the number of injured vary from a few thousand to approximately one million.[24]

According to some sources, the accident destroyed the Chernobyl-4 reactor and killed 30 people, including 28 from radiation exposure.[22] An additional 209 persons involved with the clean-up were treated for acute radiation poisoning; 134 of them had confirmed radiation sickness; all recovered initially, but 19 subsequently died from effects attributable to the event. No off-site individuals suffered from acute radiation illness. However, large areas of Belarus, Ukraine, Russia, and beyond were contaminated.[22]

Major General G.V. Bedrov, a Ukrainian Deputy Minister of the Interior, arrived in Pripyat at dawn on 26 April. Advance teams from Moscow, including physicians and top atomic physicists, also arrived on the morning of 26 April. The decision to evacuate Pripyat, Chernobyl, and other settlements within a 30 km radius was made that evening. The evacuation was organized quickly and efficiently, mainly using public buses and trucks brought from nearby Kiev. A convoy of 300 trucks and 1,216 buses left Kiev shortly after midnight, and, on 27 April at 02:00 h, entered the 10 km zone to begin the evacuation. Some

35,000 persons were transferred within either two hours and 45 minutes or four hours (conflicting accounts of evacuation times exist within sources).[25] Approximately 135,000 persons were evacuated between 27 April and 31 May.[26] The two-day delay in public acknowledgment of the accident and the 40 hours taken to organize the evacuation of Pripyat may suggest that Moscow remained ignorant of the Chernobyl events for some time after they occurred.

Ten thousand children were taken directly to summer camps in the Ukraine and other republics, and 25,000 adults were directed westwards to the Polevskoye region (whose population doubled when the evacuees arrived) to be housed initially with rural families. As evacuees believed that they would return home soon, many of them left with little or no luggage. When they understood that the evacuation period would be long, they asked to return to retrieve belongings, and were allowed to do so for brief, supervised visits. A special team of drivers was used to recover several hundred private cars.

The exclusion zone initially was limited to 10 km, but on 02 May, it was expanded to 30 km.[24] In addition to the exclusion zone, other areas were affected, even if only temporarily. On 08 May, the Health Minister of Ukraine announced that the wind had changed and was now blowing toward Kiev. Because of this, he directed children <10-years-old to be sent early to their summer camp. By mid-May some 250,000 children and many pregnant women and mothers had left Kiev; 60,000 children were sent away from the Gomel region.[24]

Difficulties with the evacuation included: (1) reluctance to move (residents of Pripyat sent a delegation to Major-General Bedrov, to protest the evacuation order); (2) many families were separated during the evacuation, (weeks after the accident, people still were searching for relatives); (3) some evacuees were inconvenienced by a shortage of basic necessities; (4) people were led to believe that they were being evacuated for a short time and didn't take their belongings with them; (5) there were cases of looting; and (6) the sale of untested, possibly radioactive articles.[2]

This industrial accident had a long-term effect. Most of the 400,000 men, women, and children relocated after the accident never returned home. Most of the evacuees were peasants, used to a traditional way of life that involved producing their own food and living in villages where their families had lived for generations. The skills of these peasants were not useful in an urban setting, leading to a high rate of unemployment among the evacuees.[27]

Discussion

Chemical and nuclear accidents may have catastrophic effects, causing loss of life, injuries, and long-lasting devastation for entire communities. In the four events reviewed (two chemical and two nuclear), the main factors associated with successful management were proper disaster preparedness of the authorities coupled with correct and timely decisions.

Preparation is essential for the successful management of almost any disaster, especially those caused by chemical or nuclear hazards. In Bhopal, the authorities had no contingency plans for the occurrence of a major disaster. Union Carbide officials did not sound a general alarm until hours after the accident. The citizens were not informed of the accident and received no instructions or evacuation orders. In fact, as soon as the population in the affected districts detected the noxious fumes, they began to evacuate in a disorganized manner for fear of their lives.

This review indicates that a larger percentage of the affected population tends to leave their homes following a radioactive accident compared to a chemical accident. Moreover, the evacuees flee to further distances. The fact that the threat cannot be smelled, seen, or felt, and that it is harmful without displaying any immediate symptoms is one possible explanation for the high level of fear of radioactive accidents. In the TMI accident, for example, thousands left their homes with no official request, distancing themselves >100 km from the site. The only official recommendation was that pregnant women and young children should distance themselves by at least 8 km from the reactor.[2]

Official decisions at the onset of the event are of tremendous importance. In Mississauga, authorities began evacuation almost immediately after the accident, and the process proceeded gradually with the evacuees being kept informed through several channels. Despite the large number of evacuees, no one was injured by the chemical accident.

In Chernobyl, evacuation was prompt; some 35,000 people were transferred within three to four hours. One major problem was that people were not informed that they were leaving their homes for a prolonged period and as a result, some returned to the evacuation zone for their clothes and other belongings.

As is evident in the incidents reviewed, a number of variables can affect behavior during evacuation. These include the social and economic status of the population, the age of the evacuees, the type of hazards (chemical or nuclear), and the actions taken by the authorities.

Experience shows that several days after an evacuation, people return to their homes even if they have not been told to do so. This happened in Bhopal, though after it was announced the plant would reactivate for several days, the return terminated.

Evacuation is the most effective strategy for reducing casualties in events due to chemical or nuclear hazards. However, if poorly planned or executed, evacuation can be hazardous. For example, the authorities should supervise the evacuation of people from a radioactive zone in order to prevent radioactively polluted evacuees from contaminating other people. The example of the chemical accident highlights the necessity of having a sufficient number of evacuation vehicles. In their absence, the decision to exit home may be a mistake. Contingency plans can reduce panic and the number of victims as well as improve civilian compliance with the directives issued by the authorities.

Another important prerequisite for effectively coping with disasters is an accurate assessment of the danger. The double evacuation of people is but one consequence of an erroneous initial assessment.

In evacuation programs, vulnerable populations (the elderly, children, the disabled, etc.) must be targeted specifically. Pets and other animals must be included in the evacuation plan.

Conclusions

This literature review suggests the following core principles for evacuation preparedness and management: (1) contingency planning for various scenarios; (2) early evaluation of the danger; (3) early announcement of the event and the possible need to evacuate the civil populations; (4) use of multiple alarm and notification systems—television, radio, police cars; (5) teams of evacuation forces; (6) correct evaluation of the required evacuation distance (to prevent multiple evacuations); (7) early, gradual evacuation process; and (8) training programs for the civilian population living near dangerous industrial centers.

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