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# EVACUATIONS DUE TO OFF-SITE RELEASES FROM CHEMICAL ACCIDENTS: EXPERIENCE FROM 1980 TO 1984*

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## Summary

This paper describes research to document the frequency and cause of evacuations associated with chemical accidents from 1980 through 1984. A data base describing each accident was constructed from wire service accounts of the accidents. Using this data, a profile of evacuations is developed. During the time period studied nearly 300 evacuations took place. The average size of an evacuation was 1000 people and the largest involved 30,000 evacuees. The most frequent cause of evacuations were industrial accidents followed by train derailments. For every 1000 people who evacuated, eight were injured by exposure to chemicals. Injury occurred in 25 percent of the evacuations. No injuries from the act of evacuating per se were found. Over the five-year period the yearly total of evacuations fluctuated mildly, however, the number due to industrial accidents rose steadily.

## Purpose and approach

The accident at the Union Carbide chemical plant in Bhopal, India, in December 1984, has generated increased concern over emergency preparedness in the chemical industry in the United States. Following this accident, considerable effort was expended to determine if such an event could occur in this country and what could be done to prevent one or manage an event should one occur. The general results of these investigations suggested that while an event of the magnitude of Bhopal is highly unlikely, accidents that would threaten public safety could occur. While the prevailing sentiment of the investigations was that the industry was not fully prepared to handle emergencies, they generally had the capabilities to develop adequate prevention and response systems. Such capabilities were tested in August, 1985, in Institute, West Virginia, when a leak occurred at a Union

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Carbide chemical plant. As a result of inadequate detection and warning, and despite emergency upgrades following the Bhopal accident, 133 people received injuries from inhalation of vapors from the release. Due to the inadequacy of response in this case and continued international experiences with large scale evacuations such as the recent nuclear power accident in the U.S.S.R., it is likely that further questions regarding the general emergency capabilities for handling chemical accidents will be raised.

Much has been written recently on chemical emergencies. This has included case studies of incidents [1—5], emergency response guidance [6—11], and technical guidebooks [12,13]. Little has been done, however, to document the frequency of chemical accidents, other than those involving transportation, that have necessitated a protective response by the public.

In this context the research reported in this paper sought to establish a historical record of chemical accidents that have led to public evacuations. Incidents that involve evacuation are a subset of the total accidents with off-site releases that define the total risk of chemical accidents. This record includes the type of accidents that have caused evacuations, the frequency of evacuations, the cause of the accident, the location, the types of chemicals involved, and the number of injuries from exposure to the released chemicals. A recent EPA draft report, as yet unavailable, documents experiences with a broader range of incidents. In constructing this data the incidents have been limited to one that have had "off-site" impacts. Thus, industrial accidents are not included unless they impacted persons off the industrial site. In addition, accidents were not limited to the fixed-site industrial events like Bhopal, but include transportation and storage events as well.

The data was collected over a five-year period from 1980 through 1984. The primary source was national, regional, and state wire service coverage of accidents. Using an automated search of "NEXUS", a data base of newspaper and periodical publications, all stories on chemical evacuations were identified. These were collected and arranged chronologically. A coding sheet was prepared for each event and, using the newspaper stories plus other reports, data on each incident was entered on the coding sheets. This provided a fairly comprehensive listing of all major evacuations due to chemical incidents, although it may under-report minor events (less than 10 evacuees).

## Incident frequency and cause

Based on the accounts reviewed, almost 300 events occurred over the five-year period that led to a public evacuation. The yearly number ranged from 43 in 1980 to 68 in 1982 with a mean of 59 per year (Table 1). Of these the most frequent cause of an evacuation is a release at an industrial site. This category of events includes explosions, fires, spills, or accidents at warehouses and plants where chemicals are used in the manufacturing of

TABLE 1

Chemical accident evacuations by cause and year

| Cause of evacuation | 1980 | 1981 | 1982 | 1983 | 1984 | Totals |
|---|---|---|---|---|---|---|
| Train derailment | 14 | 8 | 13 | 12 | 8 | 55 |
| Train car spill/fire | 3 | 6 | 5 | 4 | 5 | 23 |
| Truck accident | 9 | 9 | 6 | 6 | 5 | 35 |
| Truck spill/fire | 1 | 11 | 4 | 9 | 7 | 32 |
| Chemical plant release | 5 | 10 | 15 | 8 | 5 | 43 |
| Industrial plant release | 3 | 10 | 18 | 23 | 24 | 78 |
| Pipeline | 2 | 1 | 1 | 0 | 0 | 4 |
| Ship incident | 2 | 1 | 0 | 0 | 1 | 4 |
| Waste site accident | 0 | 1 | 2 | 3 | 1 | 7 |
| Other | 4 | 5 | 4 | 0 | 1 | 14 |
| *Totals* | 43 | 62 | 68 | 65 | 57 | 295 |

various products. These industries range from small businesses such as a furniture stripping plant to large plants that make plastic products. The second most frequent cause of evacuations are train derailments where chemicals are released by tank leaks, fires or explosions. In some incidents chemicals are not released but the threat of a release prompts emergency actions. The third major cause of evacuations are releases from plants that produce chemicals. These mainly occur due to equipment failures, explosions from mixing of different chemicals, human errors, and fires.

The fourths most frequent cause of evacuations are tanker truck accidents which result in leaks or fires. This category is followed by truck leaks or fires not related to traffic accidents. The sixth major category are rail car spills where no derailment occurs. Often the spills are located in rail yards where cars are being temporarily parked or being transferred to another line. Less frequent are pipeline leaks and explosions, ship or barge accidents and waste site accidents. This latter category involves fires or spills at a waste disposal site but does not include the discovery of acute episodes of release from a chronic waste problem site (such as Love Canal or Times Beach) that require relocation. In addition, other accidents were identified that did not fit into the above classes. These included a helicopter crash, a plane crash, a sewer gas episode, an oil well explosion, a swimming pool chlorine accident, a major pesticide spill in a retail store, a mine fire, two missile silo accidents, and two electrical transformer leaks.

Data collected in this manner for transportation related accidents can be compared to data collected by the U.S. Department of Transportation (DOT), Office of Hazardous Materials Transportation concerning evacuations associated with rail and highway incidents. Using data from the Hazardous Materials Information System [14], a frequency count of evacuations by state was prepared. This data is summarized in Table 2 along with the comparable data from this study. For the years 1980 through 1983, the frequency

TABLE 2

A comparison of collected data with DOT reported data on evacuation frequencies

| Year | Rail incidents | | Highway incidents | |
|---|---|---|---|---|
| | Collected | DOT[a] | Collected | DOT[a] |
| 1980 | 27 | 14 | 10 | 5 |
| 1981 | 14 | 6 | 20 | 6 |
| 1982 | 18 | 11 | 10 | 8 |
| 1983 | 16 | 4 | 16 | 6 |
| 1984 | 13 | 17 | 12 | 16 |

[a]Source: U.S. Department of Transportation, Hazardous Materials Information System.

of evacuation reported to DOT are less than recorded by this research. This is true for both rail and highway incidents in approximately equal proportion. In 1984 the trend was reversed with greater frequencies being recorded by DOT.

Several reasons for the discrepancies could exist. First, it is possible that not all incidents that involved an evacuation are reported to DOT. Second, this research may use a different definition of what constitutes a transportation incident that DOT uses. Third, a different population threshold may be used by DOT in coding an evacuation into the data base than was employed in this research. Fourth, the incident may be reported but not the evacuation that resulted from it.

Under the Transportation Safety Act of 1974 (PL 93-633) carriers are required to submit a detailed hazardous materials incident report to DOT within 15 days of an accidental release of hazardous materials in transportation. A review of the reporting form indicates that there is no specific provision for reporting the occurrence of an evacuation or the details of the evacuation. In addition, carriers are required to give immediate notice by phone to DOT of more extreme accidents in which fatilities, injuries, extensive damages, radioactive releases, etiological agent releases or continuing dangers to life occur. Such reports would contain information on evacuation, but not in a systematic way.

Furthermore, although the regulations require the reports to be filed, DOT has no real means of enforcing the reporting. Thus it is up to the carriers and local responders to help gain compliance. Thus a variety of factors, including nonresponse to the incident reporting requirements and lack of a specific reporting requirement on evacuation experience, explain the discrepancies observed here.

## Evacuation size

The evacuations identified ranged in size from two households to about 30,000 people. The 30,000 people evacuated from the Embarcadero area

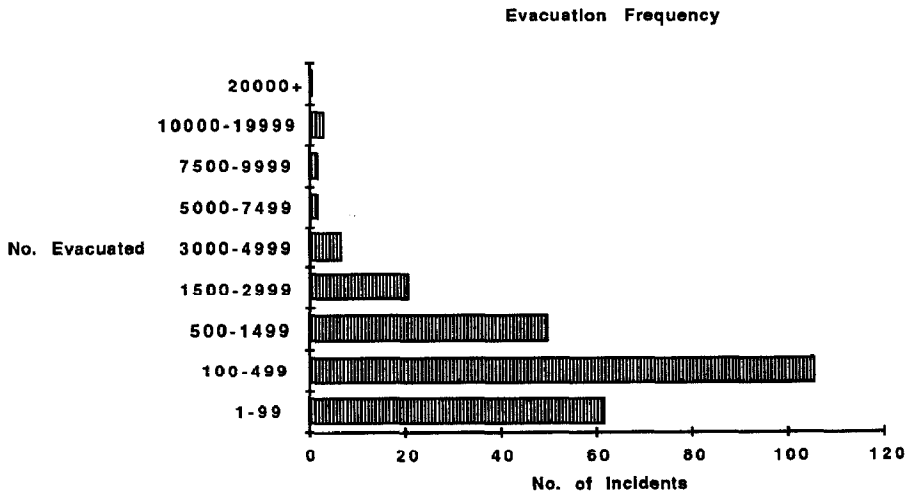


Fig. 1. Evacuation size distribution.

of downtown San Francisco following a pipeline break which released PCB's. The Mississauga evacuation in Canada due to a train derailment, not included in this data because of its Canadian location, is the largest evacuation due to a chemical accident and involved an estimated 225,000 people [4,5]. Figure 1 depicts the frequency of evacuations in the U.S. by the number of people who evacuated for the 254 events for which estimates have been made. Some caution should be exercised in interpreting this data as newspaper accounts may not accurately estimate the size of the evacuation. As might be expected, the frequency of evacuations declines as the number of evacuees increases. In total, about 250,000 people evacuated over the five-year period for an average of 50,000 per year. The average size of an evacuation is 1,000 persons. Most evacuations ($n$ = 168) involved less than 500 people, while only a few ($n$ = 8) involved over 5,000 people.

## Locations of the evacuations

The evacuations are distributed over 43 of the 50 states in the country (Table 3). The greatest number occurred in states such as California, Texas, Pennsylvania, Louisiana, New York, North Carolina, and Ohio which are heavily industrialized in manufacturing and petrochemicals and have large volumes of chemicals being transported within the state. These states also tend to have large populations. The next grouping of states, with around 10 evacuations each, contains either high volume transport states (Illinois, Indiana) or primarily industrialized states (New Jersey). Those states with a low incident of evacuation are neither high volume transport or industrialized states and tend to experience isolated events in all categories of accidents. The states without evacuations tend to be either small or isolated, have little industry, and have small populations.

TABLE 3

Number of evacuations by state from 1980 through 1984

| | | | |
|---|---|---|---|
| Alabama | 8 | Montana | 0 |
| Alaska | 0 | Nebraska | 2 |
| Arizona | 8 | Nevada | 0 |
| Arkansas | 5 | New Hampshire | 2 |
| California | 28 | New Jersey | 10 |
| Colorado | 3 | New Mexico | 3 |
| Connecticut | 3 | New York | 13 |
| Delaware | 1 | North Carolina | 13 |
| Florida | 6 | North Dakota | 0 |
| Georgia | 5 | Ohio | 16 |
| Hawaii | 0 | Oklahoma | 2 |
| Idaho | 4 | Oregon | 0 |
| Illinois | 10 | Pennsylvania | 15 |
| Indiana | 11 | Rhode Island | 0 |
| Iowa | 6 | South Carolina | 1 |
| Kansas | 4 | South Dakota | 0 |
| Kentucky | 11 | Tennessee | 3 |
| Louisiana | 21 | Texas | 15 |
| Maine | 1 | Utah | 2 |
| Maryland | 3 | Vermont | 0 |
| Massachusetts | 9 | Virginia | 5 |
| Michigan | 11 | Washington | 2 |
| Minnesota | 3 | West Virginia | 9 |
| Mississippi | 3 | Wisconsin | 2 |
| Missouri | 9 | Wyoming | 1 |

To a major extent the distribution of evacuation sizes reflects the locations in which the accidents occur. Most tend to take place away from densely populated suburban or downtown locales. Most industrialized areas housing manufacturers who use chemicals and chemical producers are zoned away from populated locations. Truck accidents and train derailments frequently take place in rural areas with low population densities. Occasionally an accident occurs in a city or is of such a magnitude that it puts a urban area at risk and consequently large numbers of people are moved.

## Evacuation injuries

In the 300 incidents reviewed, no evidence of injuries or fatalities from the act of evacuation per se were found. This is consistent with other investigations of evacuation [15]. Injuries did occur, however, from exposure to chemicals either prior to or while evacuating. Table 4 summarizes the number of injuries by accident type and year. These do not include occupational injuries (e.g., to truck drivers, to plant workers injured by fires or explosions, or to emergency workers) but do include injuries to workers who were evacuated due to a release.

TABLE 4

Non-occupational exposure injuries not prevented by evacuation by accident cause and year

| Cause of evacuation | 1980 | 1981 | 1982 | 1983 | 1984 | Total injuries | Total incidents | Total with injuries | Percent with injuries | Average injuries per accident | Average injuries per evacuation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Trail derailment | 10 | 12 | 5 | 1 | 0 | 28 | 55 | 7 | 13 | 4 | 0.5 |
| Train car spill/fire | 46 | 0 | 2 | 2 | 13 | 63 | 23 | 5 | 22 | 12.6 | 2.7 |
| Truck accident | 0 | 0 | 55 | 3 | 0 | 58 | 35 | 4 | 11 | 14.5 | 1.7 |
| Truck spill/fire | 105 | 109 | 10 | 52 | 26 | 302 | 32 | 12 | 38 | 25.2 | 9.4 |
| Chemical plant release | 31 | 39 | 51 | 12 | 13 | 146 | 43 | 12 | 28 | 12.2 | 3.4 |
| Industrial plant release | 49 | 65 | 224 | 195 | 139 | 672 | 78 | 25 | 32 | 26.9 | 8.6 |
| Pipeline | 1 | 33 | 0 | 0 | 0 | 34 | 5 | 3 | 60 | 11.3 | 6.8 |
| Ship incident | 3 | 0 | 0 | 0 | 0 | 3 | 4 | 1 | 25 | 3 | 0.8 |
| Waste site accident | 0 | 0 | 0 | 700 | 0 | 700 | 7 | 1 | 14 | 700 | 100 |
| Other | 0 | 41 | 4 | 0 | 0 | 45 | 14 | 3 | 21 | 15 | 3.2 |
| Total injuries | 245 | 299 | 351 | 965 | 191 | 2051 | | | | | |
| Total incidents | 43 | 62 | 68 | 65 | 57 | 296 | 296 | | | | |
| Total with injuries | 14 | 15 | 19 | 13 | 12 | 73 | | 73 | | | |
| Percent with injuries | 33 | 24 | 28 | 20 | 21 | 25 | | | 25 | | |
| Average per accident | 17.5 | 20 | 18.5 | 74 | 15.9 | 28.1 | | | | 28.1 | |
| Average per evacuation | 5.7 | 4.8 | 5.2 | 14.8 | 3.4 | 6.9 | | | | | 6.9 |

In total, 2051 injuries and one death are reported to have occurred because of exposure to the chemical releases. Of these, one event, an alleged illegal dumping of hazardous wastes in New Jersey, accounted for 700 reported cases of respiratory and skin problems. The remaining injuries, mostly of a similar nature, are distributed among 72 events. When injuries occurred, a mean of 28.1 people were affected. Injuries occurred in about one of every four evacuations. Overall, eight were injured for every 1000 people who left.

Three indices can be used to compare different categories of events. First, the percentage of events in which exposure occurred and injury resulted is computed. Second, the average number of injuries per event in which injuries occurred is given. Third, the average injuries per total number of evacuations is computed. All three indices varied with accident type. Due to the single large event, waste disposal accidents account for the highest average injuries per event although only one of seven events produced injuries. Industrial plant releases and truck spills produced high injury rates as well. Pipeline accidents were the most likely to produce injuries, but they were not a common occurrence. Frequent injuries were also noted for truck spills and industrial plant releases. More moderate injury rates and frequencies were observed for chemical plant incidents and train spills. Train derailments and truck accidents produced very low frequencies of injuries and low average injury rates. It is difficult to determine if these differences in injury rates and frequencies are significant given the short time frame and uncertainties in the data, and if significant, why these differences exist. Several hypotheses can be formed. First, injuries may be more prevalent in transportation leaks and spills as opposed to derailments and accidents because an accident gives a clear alerting signal while the spill may go undetected. Second, injuries may be lower in chemical plant emergencies than in industrial plant emergencies because of greater attention given to safety and emergency preparation in the former [16]. Data limit drawing grounded hypotheses concerning the other categories, but several more speculative hypotheses can be offered. First, chemical disposal incidents may present the greatest potential for injuries if an evacuation is needed due to the lack of planning and citizen awareness. Second, pipeline accidents result in a higher portion of events with injuries because they happen quickly and will either not impact people or confront them with an immediate threat. Third, ship incidents have a low frequency of events producing injuries but historical events such as the 1947 Texas City, Texas, ship collision and the 1973 Louisville, Kentucky, chlorine barge grounding suggest the potential for large injuries in single events.

## Trends in evacuations 1980—1984

While a five-year period does not provide as long a data record as would be desirable to observe trends, patterns of evacuations during this period

differ among categories of events. Figure 2 provides graphs of the seven major categories of events. Train derailment evacuations fluctuated over the five-year period with a downward trend in the last two years. Train

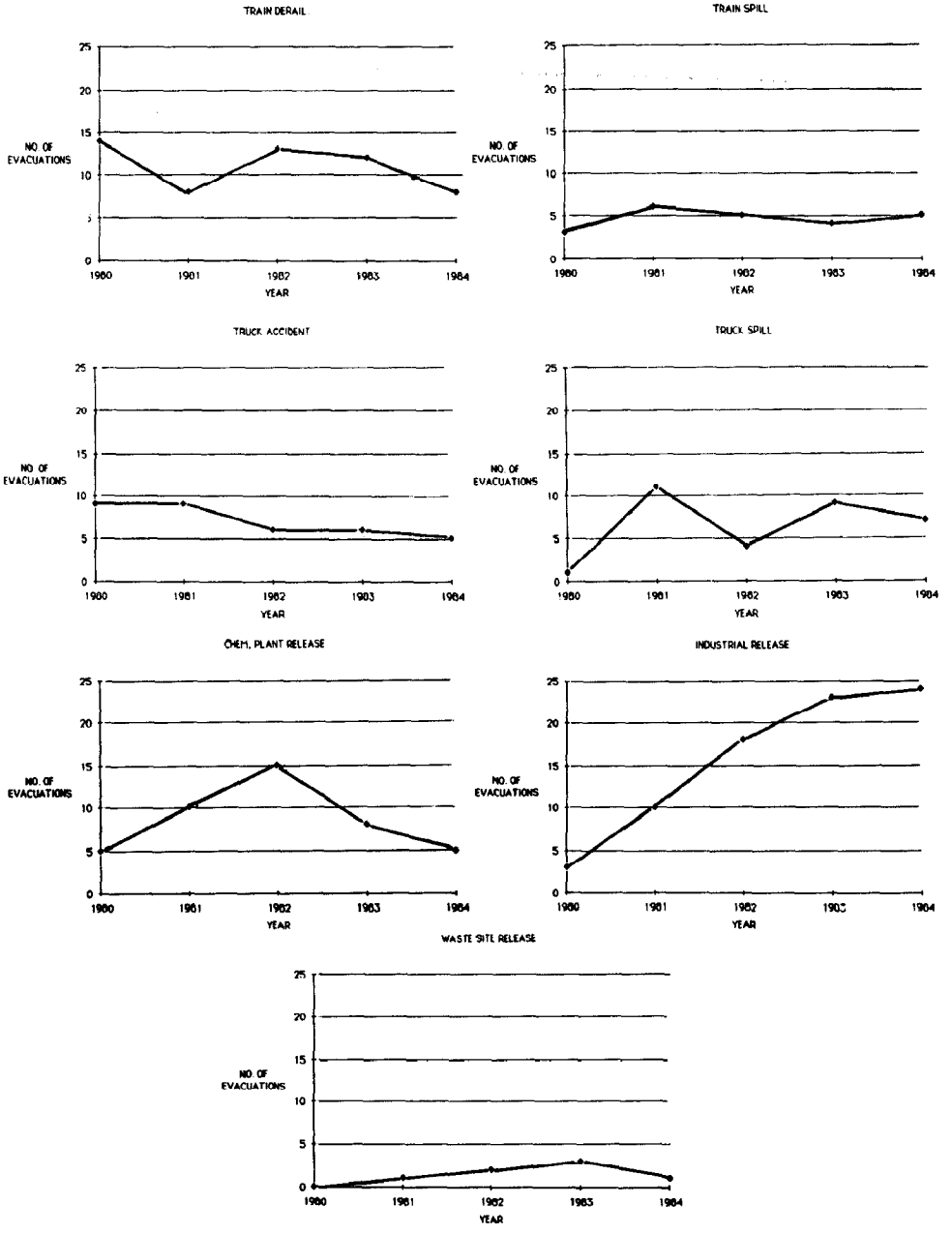


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Fig. 2. Yearly evacuation frequencies by accident type.

spill evacuations also fluctuated with no pronounced swings. Truck accident evacuations have slowly declined during this time period. Truck spill evacuations have fluctuated widely.

Chemical plant evacuations showed a peak in 1982 and have declined since then. Industrial release evacuations, on the other hand, show a gradual rise over this time period. Waste site evacuations show a rise with that trend reversing in 1984.

These trends suggest that the total number of evacuations will probably not increase or decrease drastically from year to year but, on the average, may gradually rise. Transportation-related evacuations will likely continue to fluctuate in a somewhat random pattern. Waste site events will also probably fluctuate. Industrial-related evacuations may continue to rise. Evacuations at chemical plants may continue to fluctuate but will probably not increase greatly.

## Implications and directions

This analysis has provided a descriptive account of most evacuations due to accidents involving chemicals from 1980 through 1984. Such evacuations are not rare events; they occur on the average of once every six days somewhere in the country. Some states and even some cities have accidents with much greater frequency than others and hence may have developed greater emergency response capabilities. For example, the Houston, Texas, ship channel and Kanawha Valley, West Virginia, have emergency groups responsible for responding to chemical incidents. Overall evacuations have been successful in preventing fatalities. In the approximate 300 cases reviewed, only one public fatality allegedly occurred and the link to the release was not at all certain. The lack of public fatalities in chemical accidents does not necessarily mean that further attention to the problem is not warranted. Better evacuation procedures and earlier warning would help to reduce exposure injuries from the accidents. Given the frequency of events, further efforts at improving warning and response capabilities at the state and local level are justifiable and might reduce the incidence of accidents with short-term injuries and possible long-term health effects. The evacuation planning effort for nuclear power plants provides useful information on a possible planning method for the chemical industry as does Tierney [17].

Several further research questions are raised by this work. First, it would be desirable to expand the data base to a 10- or a 15-year time frame in order to develop a better picture of long-term trends in evacuation. Second, it would be desirable to validate the data base by field checks of the information. Third, it would be interesting to compare individual accounts in this data base with those in the DOT data base to ascertain why differences exist. Fourth, it would be useful to further analyze the size of the source terms (amount of chemical released) and the size of the area evacuated

and to compare the areas actually evacuated with recommended evacuation distances to gain a better understanding of how emergency officials who responded to the incidents define the risks of various accidents. Fifth, it would be valuable to extract data on the causal or initiating events that led to the accidents in order to gain a better understanding of how to prevent further evacuations from occurring.

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