CHEMICAL AND NUCLEAR EMERGENCIES: INTERCHANGING LESSONS LEARNED FROM PLANNING AND ACCIDENT EXPERIENCE

Vernon Adler
The U. S. Federal Emergency Management Agency
Washington, DC

John H. Sorensen
Oak Ridge National Laboratory*
Oak Ridge, TN

George O. Rogers
Oak Ridge National Laboratory
Oak Ridge, TN

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ABSTRACT

Because the goal of emergency preparedness for both chemical and nuclear hazards is to reduce human exposure to hazardous materials, this paper examines the interchange of lessons learned from emergency planning and accident experience in both industries. While the concerns are slightly different, sufficient similarity is found for each to draw implications from the others experience. Principally the chemical industry can learn from the dominant planning experience associated with nuclear power plants, while the nuclear industry can chiefly learn from the chemical industry's accident experience.

INTRODUCTION

The general goals of emergency preparedness for chemical and nuclear accidents are identical: to reduce human exposure to hazardous materials. For a release of radiation, the concern is mainly in reducing doses that may contribute to latent cancers. For chemicals the interest is in reducing both exposure to peak concentration and total dose to prevent acute lethality and chronic health effects. Despite the different reasons for reducing or preventing exposure, two key similarities exist. In both cases the inhalation pathway is of primary concern with secondary concern with deposition and ingestion pathways. Second, the major means of population protection are the same and include evacuation, sheltering, and respiratory protection.

Given these similarities, there is a compelling wisdom in the sharing of knowledge derived from planning and accident experience associated with chemical and radiological hazards. The transfer need not and should not be one way. The experience of the radiological programs in the U.S. can also provide valuable input into chemical programs as well. The major thesis of this paper advances the notion that the sharing of knowledge will improve planning for the two hazards beyond what can be achieved by merely drawing upon experience independent of one another.

The next section of the paper examines the U.S. experience with chemical accidents during the 1980's. The developments with emergency planning for chemical hazards in terms of national policy and community implementation of that policy are then reviewed. The next section illustrates how planning and accident experiences can be shared to improve preparedness for both chemical and nuclear incidents. Finally, some promising directions for future knowledge transfer are addressed.

THE U.S. EXPERIENCE WITH CHEMICAL ACCIDENTS

In the decade of the 1980's, there has been, at a minimum, almost 800 evacuations in the U.S. due to the release or threat of a release of hazardous materials. Figure 1 shows the incidence of evacuations broken down by whether they occurred during transportation or at a fixed site, and a residual category which includes unidentified causes and causes that do not fall into the transportation and fixed site distinction. On average, 90 evacuations occur each year. The number increased markedly in 1985. This reflects, we suspect, the influence of the Bhopal accident on reporting as well as decision making. Evacuations were likely to receive greater publicity after that event. In addition, there is reason to suspect that public officials have been more willing to recommend or order an evacuation in order to err on the side of caution.

During the period from 1980 through 1984 non-occupational exposure to chemicals, which led to reported injury, occurred in one out of every four incidents [1]. On average 28 people were injured due to exposure in those evacuations in which exposures occurred. During that same period only one suspected non-occupational fatality occurred. The experience world-wide and during other time periods in the U.S. shows a different picture of fatalities. The most serious accident in U.S. history was caused by a ship explosion (ammonium nitrate) in Texas City in 1947, which killed 552 people. Most recently a natural gas explosion in the USSR killed a reported 650 people. Estimates of the fatalities at Bhopal range between 2500 and 10,000 [2,3] with an additional 200,000 injuries [4].

Given this record two points germane to the thesis of this paper are clear. First, the U.S. has had much more experience with chemical accidents than with nuclear. The Three Mile Island accident (TMI) remains the only nuclear accident that has led to off-site response. Chernobyl did not disrupt the lives of residents of the U.S. as it did in Europe. In the U.S. readiness for a nuclear accident comes through exercises. These exercises, however, cannot fully duplicate the lessons learned from real emergency situations. The nuclear industry can therefore learn from the real world of chemical incidents. The second clear lesson is that the likelihood of injury or death is far greater in chemical accidents. Even at Chernobyl, no acute fatalities occurred in the general public.

STATUS OF EMERGENCY PLANNING FOR CHEMICAL ACCIDENTS

The Bhopal accident at the Union Carbide Plant in India on December 3, 1984 was caused by a release of methyl isocyanate (MIC). This initiated concern in the U.S. that catastrophic chemical accidents could also occur in U.S. facilities. This was partially confirmed when, on August 11, 1985 a release of chemicals during the production of aldicarb from Union Carbide's Institute, West Virginia facility sent 130 people to the hospital [5]. Later investigations revealed many violations of safety procedures and poor management practices. In 1986 Congress passed the Superfund Amendments and Reauthorization Act (SARA). Title III of that Act titled Emergency Planning and Community Right to Know defines the requirements for emergency planning for chemical accidents. Among the key features of Title III are:

- communities with chemicals facilities that store listed chemicals (extremely hazardous substance list) in amounts exceeding certain threshold values (which vary by toxicity levels) must form a Local Emergency Planning Committee (LEPC),
- the LEPC must prepare a comprehensive emergency plan,
- this plan must be reviewed at least yearly or when changes occur in the community or covered facilities,
- the LEPC must evaluate its need for resources necessary to develop, implement, and exercise the plan,
- plans must be submitted to the state for review, and
- a set of planning elements are specified in the law.

In 1988 a survey was conducted to ascertain the status of Title III implementation in U.S. communities [6,7]. The survey was replicated with a random sample of 400 communities in the Federal Emergency Management Agency's (FEMA) data base on community emergency plans that indicated that they had at least one fixed-site hazardous material facility in the community. Responses were received from slightly over 50% of the communities. This data provides us with the means of assessing the status of planning and preparedness for chemical hazards. Survey results regarding various practices is shown in Figure 2.

Almost all communities surveyed (98%) had a community emergency plan. Slightly over three-quarters of the communities addressed chemical hazards in their plan. Only 55% had annexes specific to individual facilities. Communities are slower in their development of emergency operating procedures. Only 28% had developed a procedure to make a protective action decision while slightly more had a procedure to make a decision to issue a public warning. About half of the communities had attempted to provide some form of public education on chemical emergency response.

In contrast all communities potentially affected by a release at a nuclear power plant are required to have plans that address the nuclear hazards associated with the specific plant in order to obtain an operating licence. Furthermore, these communities, often with the help of the nuclear industry, have installed emergency warning systems that are required to alert people within specified emergency planning zones concerning the potential hazards and notify them regarding appropriate protective actions within specified time limits.

The implications of these example findings are clear—chemical emergency planning lags far behind radiological planning in a number of ways including exercises, plans, procedures, and response capabilities. Communities surrounding chemical facilities are simply more poorly prepared to deal with emergencies. One way that communities can learn from the nuclear industry is in the vast and more rigorous planning experiences generated by the radiological emergency preparedness (REP) program.

Despite the fact that chemical accidents that lead to public protection occur far more frequently than nuclear accidents, that more people have been killed worldwide and in the U.S. by chemical accidents than nuclear, and far more people are exposed to chemical releases than nuclear releases, the requirements for emergency planning for chemical accidents are far less stringent than for nuclear power plants. This is underscored by recent events which illustrate problems in response to chemical emergencies. The prime example is that of the Valdez oil spill in Alaska which overwhelmed planning and response capabilities [8].

INSTITUTE, WEST VIRGINIA AND NANTICOKE, PENNSYLVANIA: CONTRASTING EXPERIENCES

The benefits of the REP program for chemical emergency planning are illustrated by the differences in the Institute accident in 1985 and a recent accident at Nanticoke, Pennsylvania. The Institute, West Virginia accident occurred when a release of unknown chemicals occurred while producing aldicarb which is manufactured from aldicarb oxime, methylene chloride and MIC [9]. Later analysis identified some 26 chemicals that were released. The accident occurred at 9:25 a.m on Sunday morning. The cloud, described as being yellowish in color drifted over the communities of Institute, Dunbar, and West Dunbar with a total population of about 11,500 people. Immediately after the release, warning sirens were sounded and radio and television announcements were made. The public was told not to evacuate. In fact no evacuation routes had been established nor did a community emergency plan exist [10]. A total of 130 people were treated for injuries.

Following the accident a random sample of 406 households in the three communities were surveyed [11] as well as the 130 victims. Of those in both samples, only 5% reported being warned by the sirens. Of those injured, 45% learned of the release by smelling the fumes, three times the rate for the random sample.

The Nanticoke accident took place on March 24, 1987. A few minutes before 12:30 a.m., an electrical fire at a metal processing plant generated a toxic cloud of unknown materials or toxicity [12]. The fire department was notified by 12:30 a.m. Twenty minutes later CHEMTREC was contacted. They advised the city to assume the worst case accident given the chemicals stored at the plant. Preplanning had identified this to be a fire involving sulfuric acid. At 1:45 a.m., the Mayor was contacted and asked to make a decision. At 2:21 a.m., the decision was made by the Mayor to begin the evacuation of western Nanticoke. Almost immediately sirens for the nearby nuclear plant were sounded and the county activated the Emergency Broadcast System (EBS) to order a precautionary evacuation. Volunteers went door-to-door to supplement the sirens and EBS. Mobile public address systems on fire trucks were also used. The evacuation was expanded to include other areas at 2:50 a.m. and the entire town at 3:10 a.m. The total evacuation of 16,000 people was completed in about two and one-half hours. No injuries to the population occurred. At 5:00 a.m. the fire was extinguished although the evacuation remained in effect until the afternoon as a precaution.

In the Nanticoke accident, a hazardous material evacuation plan had been developed to guide response. It was based on the same approach that had been used to develop a plan for a nearby nuclear facility that served as the model for an all hazards planning approach in the community [13]. While some minor problems occurred, post accident assessments generally agreed that the response was successful and evacuation went very well, mainly due to the prior planning using the REP framework [14,15]. While most residents heard the sirens, there was initial ambiguity over the meaning of the sirens. Tests by the nuclear power plant indicate that 77% of the population in the EPZ reported hearing a test of the sirens. This is in sharp contrast to the 5% who were warned by sirens at Institute. Overall, the incident indicates the impact that the REP program has had on emergency preparedness. When the Taft Louisiana evacuation occurred in the EPZ of the Waterford Power Plant, the REP plan had not been integrated with hazardous material planning [16], even though the planning process helped in achieving an effective evacuation [17].

LEARNING FROM CHEMICAL ACCIDENTS: EVACUATION EXPERIENCES

A study was conducted in 1987 at Pennsylvania State University to measure the risk of injuries and fatalities during emergency evacuations [18]. Data were collected from surveys sent to local emergency managers concerning 310 evacuations in the U.S. The purpose of the study was to estimate the risks of injury and fatality in an evacuation. While many of the central conclusions of the study are questionable, the data collected can be used to address other interesting emergency planning issues. Figure 3 shows data on the estimated size of the evacuation as measured by number of evacuees and the estimated clearance times as measured by the time it took to complete the evacuation to a safe location. This enables us to determine if it takes longer to move a greater number of people. The results, which are based on all chemical accidents with warning times of less than 10 hours, indicate that there is no significant relationship between the two variables. The prevailing logic among emergency planners is that it takes more time to move a greater number of people; this is not true.

Two factors seem to intervene. First, the time it takes to evacuate is partly determined by the urgency of the situation. If there is the need to move quickly people respond accordingly. If the situation is not immediately threatening, people take more time. Second, as population increases, the infrastructure to move a greater number of people also increases. To test this latter proposition, the size of the evacuation is compared with the evacuation rate as measured by the number evacuating per hour. A strong and significant relationship is found. As the number evacuating increases, the rate also increases. This supports the notion that infrastructures help move larger populations in similar time frames as smaller populations.

These results have significant implication for evacuation planning contentions being raised at Atomic Safety licensing Board (ASLB) hearings in the U.S. Interveners contend that populated areas cannot be evacuated in a safe and timely manner. This is not supported by these and other anecdotal data derived from experience with chemical emergencies.

LEARNING FROM CHEMICAL ACCIDENTS: WARNING EXPERIENCES

On Saturday, April 11, 1987 at 12:29 p.m., a westbound Conrail freight train derailed in Pittsburgh, Pennsylvania. In the process of derailing, the westbound train sideswiped an eastbound train causing it to derail. Four tank cars containing hazardous materials on the eastbound train were derailed. Sparks resulting from the accident ignited a fire, however, none of the hazardous materials ignited. Pittsburgh emergency personnel initiated an evacuation upon arrival at the scene, about 20 minutes after the accident. Some local residents in immediately adjacent areas had already begun to evacuate. Up to 22,000 people were evacuated as the initial evacuation area was expanded to accommodate changing weather conditions. The fire was extinguished by 3:30 p.m., however, the primary concern centered around a derailed tank car containing phosphorus oxychloride. This tank car developed a crack in the dome permitting between 30 and 100 gallons of lading to escape. By 5:50 p.m., the affected areas had been declared safe and the initial evacuation order was rescinded. A close inspection of the damaged tank car shortly after midnight detected continued degradation of the tank car. At 1:30 a.m. a second evacuation order affecting between 14,000 and 16,000 residents within a half mile of the scene was issued. This second evacuation order was not rescinded until 4:30 p.m. on Sunday, April 12, 1987. Approximately 25 people were treated for eye and throat irritation at area hospitals, and three people were hospitalized during the course of the accident.

On Wednesday, May 6, 1987 at 4:10 a.m., 21 of 27 "empty" tank cars carrying product residues. including propane, chlorine, caustic soda, carbon disulfide, methyl chloride, chloroform. and isobutane derailed in Confluence, Pennsylvania. Because tank cars carrying residue can haul up to 3% of the load, emergency officials had no way to determine the exact amount of products remaining in the cars. Emergency management officials initiated a precautionary evacuation of the 986 residents. A three-minute non-stop siren blast was sounded, which primarily alerted the volunteer firemen as residents could not be expect to be aware of the siren-blast's specific meaning.

At approximately 4:30 a.m., a door-to-door and portable loudspeaker alert and notification of the emergency began using volunteer firemen and untrained volunteers, and within 45 minutes the evacuation was complete. Assistance from area-wide emergency personnel sealed two leaking propane tankers by 9:48 a.m., but the chance of explosion and/or fire during wreckage cleanup prevented return until 6:10 p.m..

Data collected by mail and telephone surveys regarding the timing of warning receipt following the train derailments in Pittsburgh, Pennsylvania and Confluence, Pennsylvania are summarized in Figure 4 as the cumulative proportion warned by time of receipt in terms of minutes into the event [19]. This is the only known data that has been collected on the timing of warning receipt following a technological accident. The measurement difficulties are clearly evidenced by the proportion of respondents that reported receiving warning prior to its occurrence. This seems to occur at least partially because of the way people think about and recall time. For example, the noontime Pittsburgh event actually occurred at 12:25 p.m., but many of those reporting warning receipt prior to that time said they were warned at noon. This illustrates that many people would recall the time in terms of what they were doing (e.g., eating lunch) and report it as noon (i.e., 12:00 p.m.).

Both warning situations are characterized as primarily consisting of route-alerting and door-to-door warning systems. Each is characterized by an S-shaped curve, with the Confluence warning reportedly approaching 90% warned in about two hours, and the Pittsburgh event reportedly approaching 80% warned in about three hours. However, because of methodological uncertainties, it is only possible to identify people that positively report having received some kind of warning it is not possible to identify those not receiving warning. While the warning situation in both Confluence and Pittsburgh are characterized by rapid dissemination in the first hour and half of the event, only 12.5% report being warned in the first 15 minutes in Pittsburgh while 36.8% reported being warned in the same period in Confluence. In Confluence, nearly 70% report receiving warning in the first hour, while only 23% report having received warning in the same period in Pittsburgh. Neither event is characterized by complete (100%) warning, and both indicate that very rapid onset emergencies can result in people be engulfed in danger prior to receiving warning.

The implications of the findings are clear: ad hoc emergency response will not reduce exposure in events with short lead times. Without good planning and advanced warning technologies, protective actions cannot be quickly implemented. This reinforces the need for the REP warning requirements (15-minute 100% notification within 5 miles) given the possibility of radiological accidents with little or no forewarning.

AREAS FOR FURTHER INTERCHANGE

This paper briefly explored the interchange of information that can benefit both the radiological and chemical emergency planning programs in the U.S. We are clearly seeing some positive benefits from shared experiences and knowledge. This is also manifesting itself in other ways at FEMA.

For example, FEMA is developing a program to improve preparedness for accidents at chemical weapons storage facilities in the continental U.S. In developing that program, many of the lessons learned from the REP program are being incorporated. For example, the program planning checklist and program standards are being modelled after NUREG 0654/FEMA REP 1 [20].

FEMA is also preparing a technical guidance on public alert and notification systems for chemical emergencies. Much of the background in the report on alert and notification technology is based on experience with developing FEMA REP 10 [21]. In addition, valuable data derived from FEMA's efforts to certify the alert/notification criteria in NUREG 0654/FEMA REP 1 is being incorporated. The REP program has pushed warning system technology into the modern age and such benefits can be shared in integrated planning.

Other areas which create opportunities for the REP program to build on chemical experiences are being pursued. For example, FEMA has just initiated a study that will investigate public response to shelter advisement in a chemical emergency. One fairly large planning uncertainty is whether the public will comply with an order to "button-up." In addition, FEMA has funded a study of evacuation experiences of institutional populations in chemical emergencies [22]. Furthermore, studies of human response to siren-based warning systems in chemical accidents may help validate results of FEMA surveys on public notification following siren tests.

As improved emergency preparedness systems are developed and implemented, it also should not be forgotten that the nuclear industry can learn from the response of the chemical industry in the U.S. to the Bhopal accident. First, the industry, through the Chemical Manufacturers Association, initiated a program of enhanced chemical preparedness [23]. The CAER program relies on industry initiative in working with local governments. The program seems to have been implemented seriously by major chemical manufacturers, although not by more marginal firms. Second major firms initiated steps to reduce the potential source terms by reducing chemical inventories or by changing production methods. At one point, both the chemical and nuclear industries believed bigger was better. The economies of scale, however, failed to fully capture the costs of catastrophic accidents. This was recently reflected in the oil spill from the massive Valdez tanker. In the long run such economies must be recalculated in order to achieve publicly accepted technologies.

This poses a subtle irony; due to regulatory response to accidents the status of emergency planning is most secure for nuclear plants. Due to recent efforts such as CAER and source term reduction, larger chemical facilities are much safer than a decade ago. Small marginal facilities still pose significant risks to public safety. Although, I would rather live by a nuclear power plant than on the border of a major chemical plant; I would most clearly rather live near that major chemical plant than next to Joe's furniture stripping factory.

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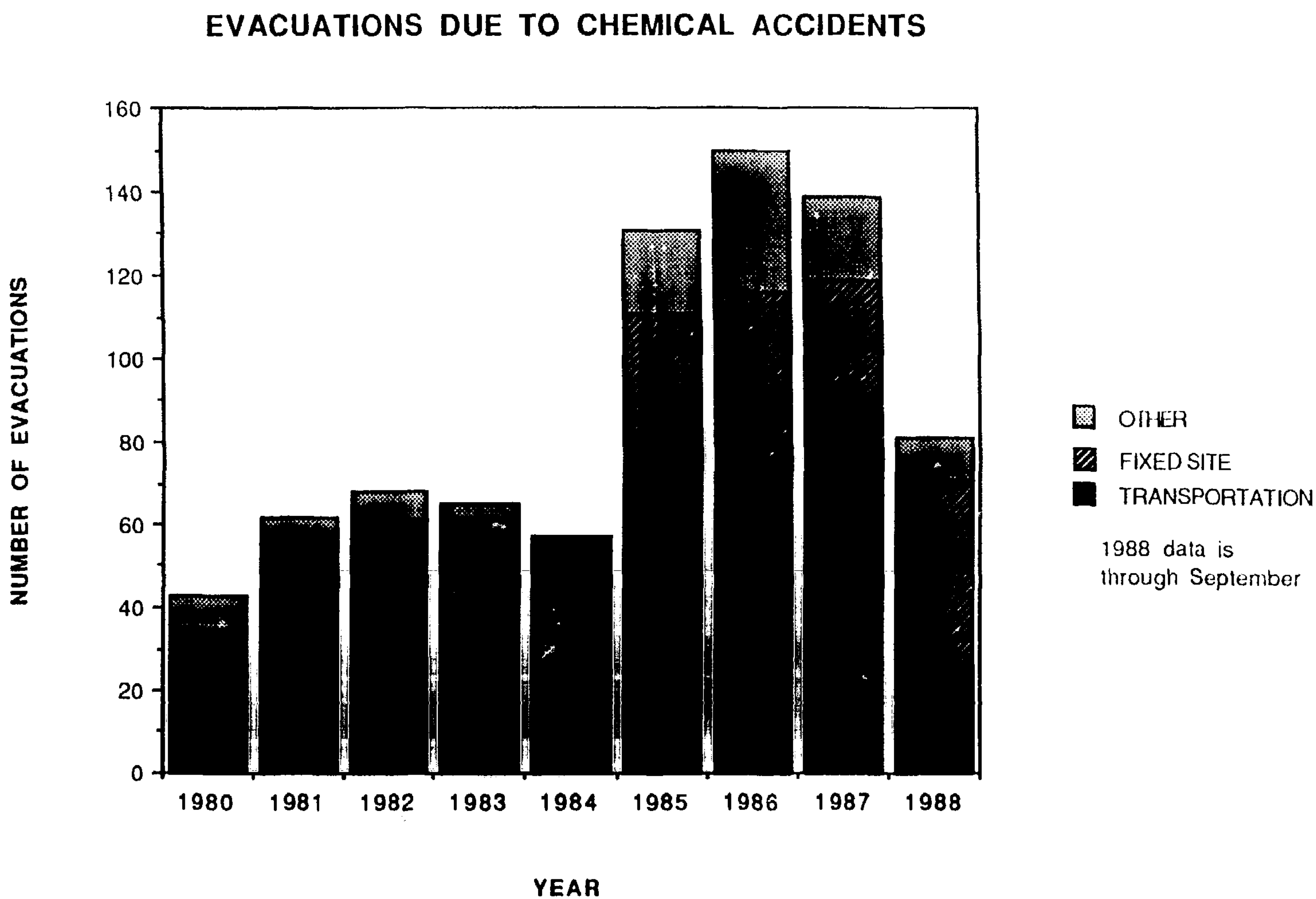
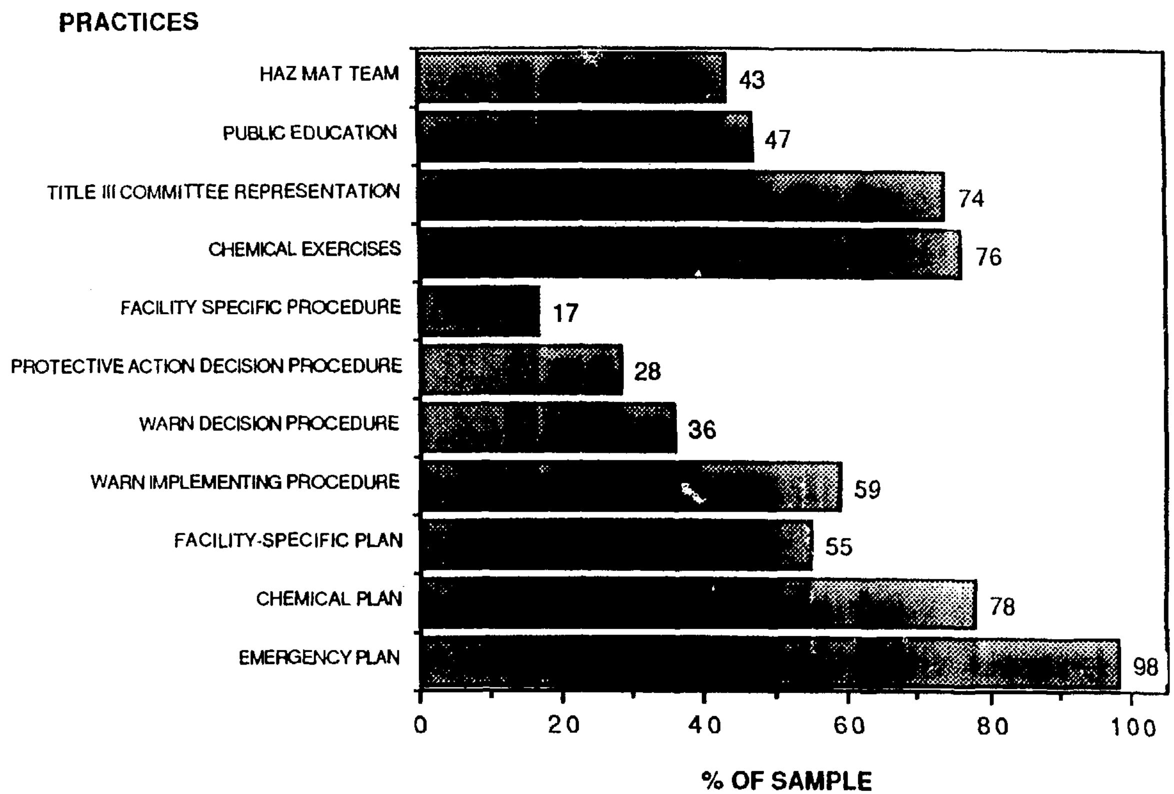
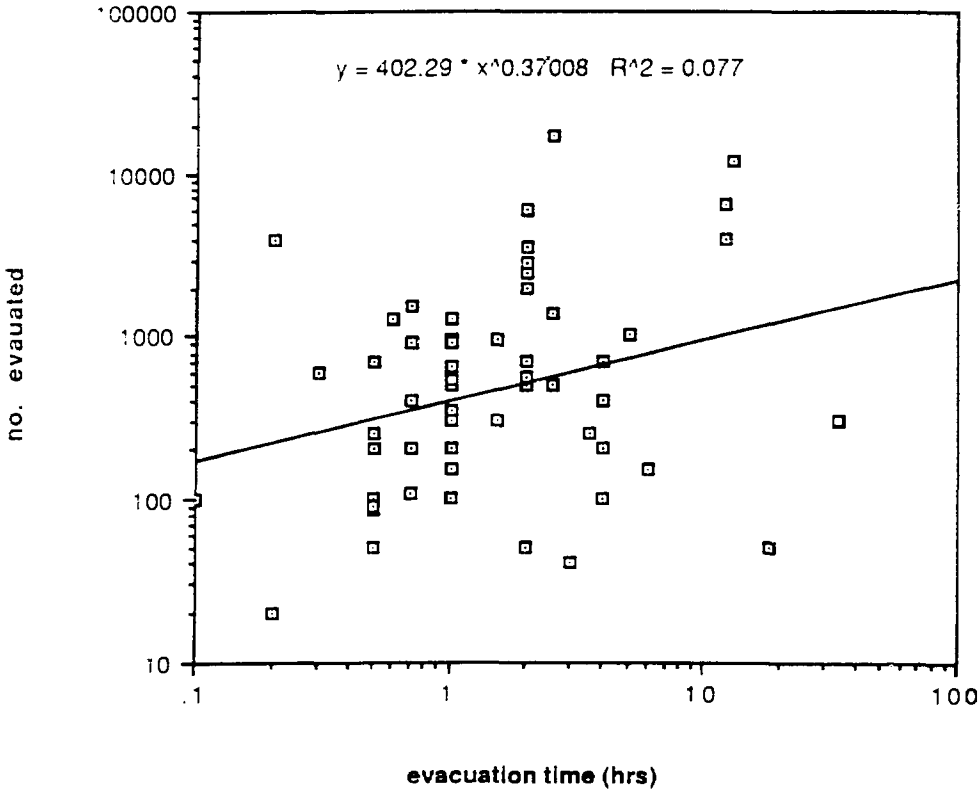

EVACUATIONS DUE TO CHEMICAL ACCIDENTS
NUMBER OF EVACUATIONS
0
20
40
60
80
100
120
140
160
1980
1981
1982
1983
1984
1985
1986
1987
1988
YEAR
OTHER
FIXED SITE
TRANSPORTATION
1988 data is through September

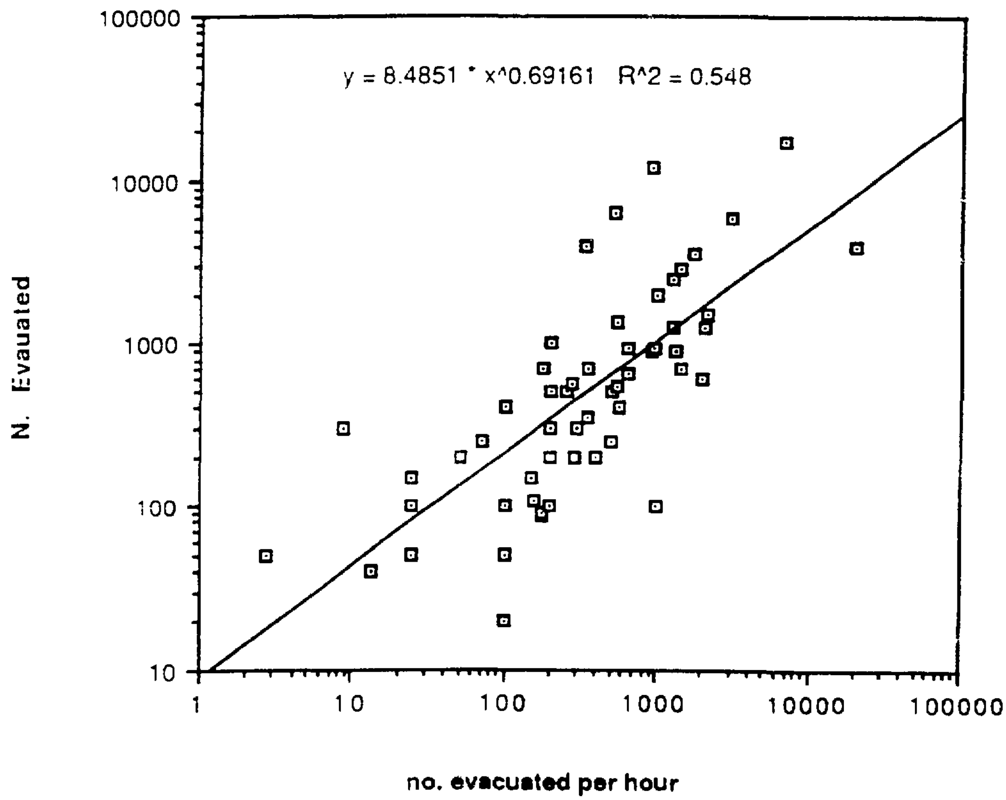
ADOPTION OF PLANNING PRACTICES

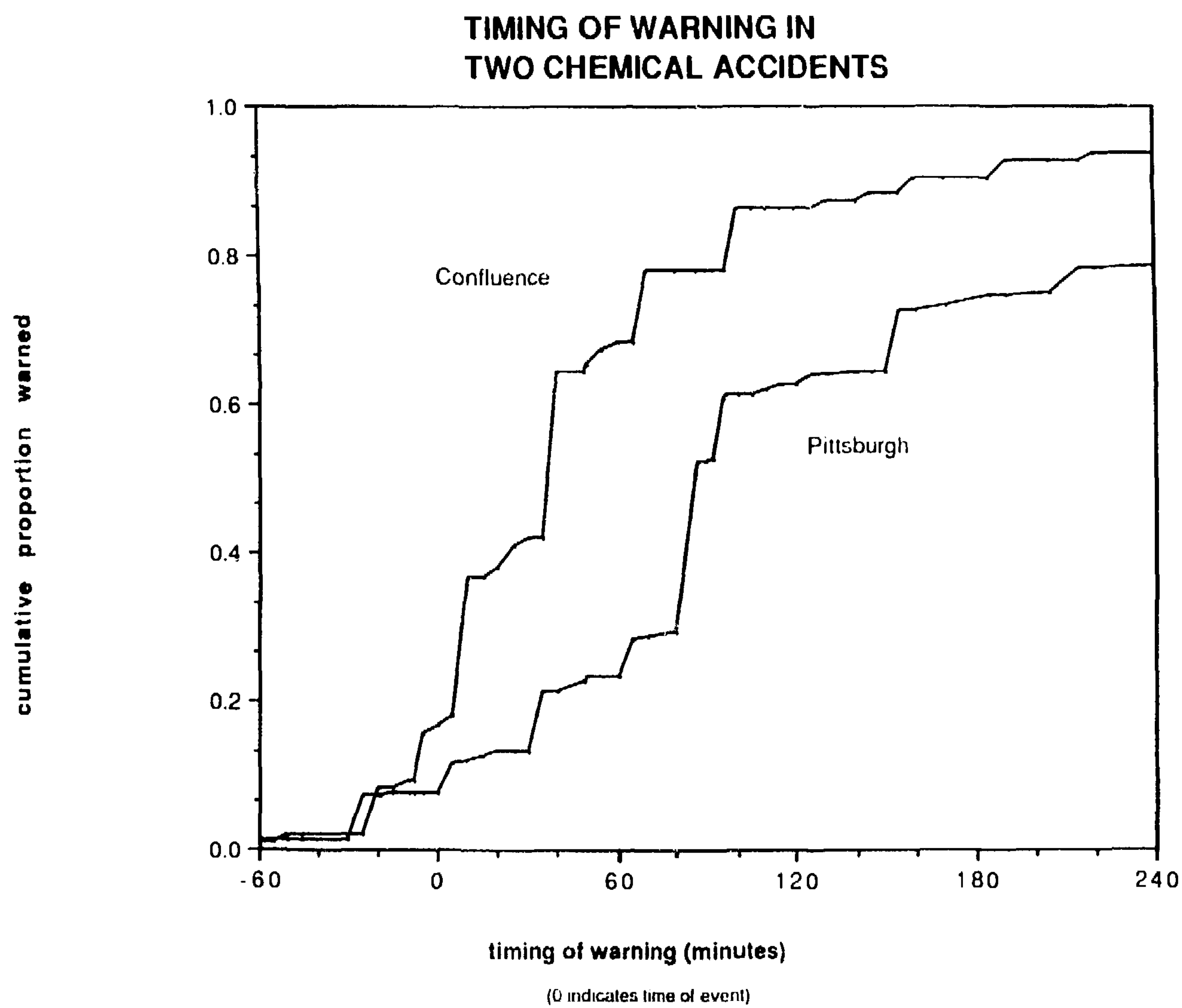


EVACUATION TIME BY SIZE FOR CHEMICAL SPILLS AND FIRES



EVACUATION RATE BY SIZE FOR CHEMICAL SPILLS AND FIRES




TIMING OF WARNING IN
TWO CHEMICAL ACCIDENTS
1.0
0.8
0.6
0.4
0.2
0.0
cumulative proportion warned
Confluence
Pittsburgh
-60
0
60
120
180
240
timing of warning (minutes)
(0 indicates time of event)