Sheltering in Place as a Public Protective Action

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Introduction

Sheltering in place as a public protective action has received large amounts of attention as a result of the submission of Risk Management Plans (RMP). Although sheltering in place has been used by emergency management officials for many years, very little data have been collected on how it has been used and its effectiveness. Both supporters and critics alike have expressed interest in such a collection of data about sheltering in place.

The National Institute for Chemical Studies (NICS) has had a long-standing interest in public protective actions during chemical emergencies**.** NICS is a nonprofit organization established in 1985 by a group of community leaders in Charleston, West Virginia following the Bhopal chemical accident. Its mission is to bring industry and the public together to seek ways to protect the health, safety, environment and economic vitality of communities where chemicals are manufactured, stored and transported.

NICS works to fulfill this mission through research and information-sharing on chemical risk; training and support for those with responsibilities for chemical risk management; promotion of industry-community dialogue; and facilitation and consulting services to groups and agencies seeking to resolve issues related to chemicals in the community.

Since 1985 NICS has served as an independent, objective third party in addressing chemical risk issues. The organization bases its work on the principles of information sharing and open dialogue, and in building partnerships with diverse stakeholders**.**

The following report provides a look at chemical accidents where sheltering in place was used as a public protective action.

Protective Actions for the Public during Hazardous Materials Emergencies

Many, if not most communities in the United States are vulnerable to the health and safety impacts of a hazardous materials emergency. These types of emergencies can result from accidents that occur at a wide variety of places including industrial facilities, government and educational institutions, commercial establishments, farms, and during transport. When these events occur, emergency response officials have two basic tools to protect the threatened public. One is to evacuate the public out of the area affected by the hazardous material release. The other is to request that the public "shelter in place, " that is, go indoors, close up the building and wait for the danger to pass.

Evacuation has long been used to move the public away from danger. Its goal in hazardous materials emergencies is to avoid or minimize exposure to dangerous chemicals. When evacuation can be completed before dangerous levels of hazardous materials move into the community, it is the public protective action of choice. This will avoid exposure to the hazardous material completely. It may also be preferable when the leak is large, unpredictable and difficult to control, or when there is a high risk of explosion or flash over. However, evacuations can take a very long time to complete, particularly in areas with high population density. And evacuating has inherent risks unrelated to the hazardous material. Managing an evacuation is a resource-intensive activity for local emergency management agencies.

Shelter in Place as a Public Protective Action

Shelter in place as a public protection tool has gained acceptance as a public protection tool. The goal of sheltering in place during hazardous materials accidents is to minimize the exposure of the threatened public to the dangerous chemical(s). Sheltering in place uses a structure and its indoor atmosphere to temporarily separate people from a hazardous outdoor atmosphere. The people will still be in the endangered area, but will be protected by the barrier created by the shelter and the short-term protection of its indoor atmosphere. Over time, small cracks in buildings will allow contaminated air to enter the indoor atmosphere. Some exposure will occur, but if properly undertaken, sheltering in place can

provide substantial protection from doses high enough to cause injury. The selection of sheltering in place to protect the public may be preferable when the leak is very fast, a migrating toxic vapor cloud could quickly overtake unprotected or evacuating citizens, the material released has a low health hazard, or evacuation would create problems that would outweigh its usefulness.

The amount of protection from sheltering in place varies mainly with the air tightness of the building and the length of time the building is exposed to a hazardous plume. Modern, energy efficient and weatherized homes provide the most effective air movement barrier. But even the most weather-tight home will allow contaminated air to enter slowly. Infiltration of contaminated air into a building can be further reduced by sealing windows, doors and vents with plastic sheeting and duct tape.

Many local emergency planning committees (LEPCs) have adopted shelter in place as an alternative to evacuation. Depending on the risks posed to the community and degree of public education provided, one of four levels of sheltering may be implemented. The Oak Ridge National Laboratory[1] has defined these levels as follows:

- **Normal Sheltering** - Closing all doors and windows and turning off all furnaces, air conditioners or other ventilation equipment.
- **Expedient Sheltering** - In addition normal sheltering, taking simple measures to reduce infiltration. These are placing plastic sheeting over windows and vents and taping over electrical outlets, around doors and other openings.
- **Enhanced Sheltering** - Making modifications to the structure to reduce infiltration. These modifications are steps that are often used in weatherizing homes such as caulking around windows, doors and other places where surfaces meet, using weather stripping and installing storm windows.
- **Pressurized Sheltering** - Using special gas-particulate filter-blower units to pressurize a sealed room, building or other enclosure with filtered air. The filter-blower produces a outward flow of air through leakage points which prevents contaminated air from entering the shelter. Pressurized shelters are expensive to implement and are not typically in use for the general public.

Normal and expedient sheltering are the most commonly used sheltering techniques in communities around the country. Both are easy and quick to implement if a chemical emergency occurs. And both will provide protection for occupants of the shelter under certain conditions.

Other factors that affect the amount of protection that can be provided by sheltering in place are weather conditions and behavior of the threatened population. Winds can increase infiltration rates, but also disperse hazardous plumes much more quickly. Large temperature differences between the outside and inside air also will increase infiltration rates.

More important than these factors, however, are the actions of those citizens at risk from a chemical release. To maximize the protective value of sheltering in place, threatened people must know how to shelter effectively and quickly. Public education in emergency preparedness must include information on how and why to shelter in place. In addition, communities must have ways to alert the public to a chemical threat. Emergency alert systems should be able to provide the public with information about the emergency, simple protective action instructions, and information on where to find additional information about protective actions. In many communities, emergency preparedness instructions, including how to shelter in place, can be found in local phone books. LEPCs in various areas also have implemented strong public education programs for emergency preparedness.

Scientific studies of Sheltering as a Protective Action

The reduction in dose from sheltering in place, compared to remaining outside, can be substantial. A number of studies, both modeled and field tested, have shown varying degrees of potential dose reduction under different conditions of sheltering in place. In most studies of sheltering effectiveness, focus is entirely on infiltration rates.

Some experts feel there is a lack of appreciation of the concept of dose by the general public, and that sometimes any exposure to a hazardous material is incorrectly equated with a harmful or fatal exposure. This misunderstanding may account for some of the suspicion of the effectiveness of sheltering in place by some people.

For our purposes, dose can be simply considered a measurement of how much (concentration) and for how long a person is exposed to a toxic material. If a person is exposed to a higher concentration for a longer period of time, the dose received will be higher. And the higher the dose

of toxic material received, the more likely a person will become sick or die as a result of the exposure. If the dose of an accidentally released toxic material can be held to a low level, unhealthy effects of exposure can be minimized or avoided.

Some early studies of sheltering effectiveness calculated that, for a typical dwelling and a plume lasting 10 minutes, the dose indoors would be about one-tenth of the outside dose. For other types of dwellings and releases, the indoor dose could be as little as one percent of that received outdoors.[2]

The figure above shows how sheltering in a closed up house helps reduce the amount or concentration of hazardous gas to which a person might be exposed. The graph is a simplified representation of the concentrations both indoors and outdoors after an accidental release has occurred. The numbers on the graph are calculated indoor and outdoor concentrations during a hypothetical toxic gas release of 10 minutes.[3]

In this modeled example, a person staying outside would have been exposed to 400 parts per million of the toxic gas for 10 minutes. On the other hand, a person who immediately closed up his house prior to the arrival of the cloud would have been exposed to no more than 60 parts per million during the same 10 minutes. If the hypothetical toxic gas causes harmful effects in a person exposed to 100 parts per million for 10 minutes, it is clear that sheltering in place would have been beneficial to a person using this technique.

Scientific studies conducted by the Army[4] at the Aberdeen Proving Grounds were focused on determining how much protection sheltering in place could provide for residences exposed to nerve agents and mustard gas. The research program was designed to measure the rate at which a tracer gas entered a variety of buildings, that is, to measure infiltration rates for various types of residential structures. The 36 tracer gas experiments showed, in the 12 buildings tested, that air exchange rates varied in the houses from 0.16 air exchanges per hour (ACH) to 0.86 ACH with mean air exchange rates of 0.295 upstairs and 0.313 downstairs.

In two mobile homes, the average air exchange rate was 0.471. The houses were of brick, stone, and frame construction and were built in the 1920s, 1930s and 1950s. All had replacement windows and some had storm windows. The two mobile homes tested had an average air

exchange rate of 0.471 air changes per hour. When expedient sheltering measures were taken in the "safe room", that is, when windows were covered with plastic and doors/vents taped in a pre-selected room in the house, the air exchange rates were significantly reduced. For bathrooms with a window, air exchange rates were, on average, 34.3% lower than in the house as a whole.

Air exchange rates were converted to protection factors from hazardous chemicals in the outdoor atmosphere. For the 12 houses that were tested and for the specific weather conditions that existed during the tests, protection factors for safe rooms using the best sealing methods ranged from 39 to 101 for a ten-minute exposure to hazardous atmospheres and from 7 to 17 for a one-hour exposure. This means that during a ten-minute exposure, an occupant in a safe room with good sealing could be expected to receive only 1/39 to 1/101 as much exposure to hazardous chemicals as someone outside.

A second study[5] involved the construction of a small cottage to simulate a typical frame house. The cottage was exposed to the nerve agent, sarin (GB), mustard (HD) vapor and to a chemical that simulated mustard gas. The infiltration rate of the cottage was measured. The experiments placed a steady concentration of the agent in the atmosphere around the cottage for one hour. Samplers and instruments were used to measure the concentration of vapors that entered the cottage.

Based on infiltration rates alone, certain concentrations of agent could be predicted. However, instrument readings showed far lower concentrations of test agent than would have been expected. Researchers have found that the surfaces, cracks and pores of buildings act as a filters. Test agents, as they entered the cottage through those cracks and pores condensed onto surfaces or were absorbed into the building materials.

In hour-long exposures to mustard gas, filtering by the cottage structure increased the protection factors by 15 to50. This means that for the conditions of the test, the protection provided by sheltering in place is up to 50 times greater than would be expected based on infiltration rates alone.

For hour-longs tests with sarin vapor, protection factors were two to three times higher than expected based on infiltration rates. Mustard gas is much less volatile than sarin, and it is expected that, in general, hazardous chemicals with lower volatility will be filtered more effectively

by building structures.

The experiments also showed that filtering by the structure is greater when air exchange rates are reduced. When expedient sheltering techniques are used, air flows into the “safe room” at a slower rate, and chemicals in the air have a longer period of time in contact with building surfaces. Tighter buildings, that is, buildings with low air exchange rates are more efficient filters.

The tests conducted by the Army also showed how important it is to ventilate and/or leave a structure after a contaminated cloud has passed. With tight buildings, any vapors that may have entered the structure during its exposure to hazardous vapors will leave the building very slowly. Chemicals that have sorbed onto building surfaces will also gradually desorb. If an occupant remains in the building without radically increasing the air exchange rate, exposure to the hazardous chemical will continue and dosage of that chemical will increase. By opening windows and turning on air moving equipment, the air exchange rate of the building will be substantially increased, and hazardous vapors will be removed at a greater rate.

Case Studies of Sheltering in Place During Chemical Emergencies

Chemical Plant Explosion[6]
West Helena, Arkansas
May 8, 1997

Basis of Study: Research study of a chemical plant explosion

Citation: Oak Ridge National Laboratory, 1999, " Description of Survey Data Regarding the Chemical Repackaging Plant Accident; West Helena, Arkansas", Oak Ridge, Tennessee

Protective Actions: Evacuation and shelter-in-place

Abstract: A mid-day explosion occurred at a pesticide packaging plant, which resulted in both evacuations and shelter-in-place actions within a three-mile downwind zone proximal to the incident site.

Several problems were noted in communications and in public confidence in instructions provided by response authorities as well as compliance with these instructions.

Several inaccuracies in media reports also led to the development of problems in both compliance and confidence with respect to evacuation instructions issued by responders to the general public.

Incident Description: The incident began at 10:00 AM on May 8, 1997 with the delivery of agricultural chemicals to the plant, which is located in West Helena, Arkansas. Employees noted that some of the 1500-pound bulk containers of azinphos-methyl had a strange odor that was described as "almost rancid".

At approximately 1:00 PM, a container began to emanate fumes causing a smoky haze to develop in the building. This caused the employees to evacuate the facility and call the fire department. The smoke was described as layered with two distinct colors. The lower layer was a smoky gray and the upper layer was a smoky yellow color.

At approximately 1:15 PM, firefighters from the West Helena, Arkansas Fire Department arrived. Twenty minutes later an explosion occurred causing a significant structural collapse and a rapid escalation of the incident.

The building was heavily damaged at this point and approximately 10,000 ponds of mixed chemicals were now involved in the incident. The fire department was not operationally equipped to respond to a HAZMAT incident, however, and attempts to control the fire were made initially with little success. Large volumes of "foul smelling" smoke were noted as moving downwind of the incident.

Local authorities decided to order an evacuation of the 2-mile downwind corridor and to recommend sheltering in place for the 3-mile downwind corridor. Tornado warning sirens were used for initial warning. The Phillips County Office of Emergency Services issued radio broadcasts to advise the residents of the protective action recommendations

The only major medical center in a 50-mile radius was forced to evacuate. It was closed for six days and required extensive decontamination to reopen.

This incident resulted in the deaths of three firefighters, the downwind evacuation of a 2-mile downwind corridor, as well as the sheltering-in-place for a 3-mile downwind corridor.

No civilian fatalities were reported and all injuries were reported as either minor or psychosomatic.

Media reports of the incident prompted the Governor of Arkansas to request a stockpile of atropine (an antidote to the primary chemical involved in the incident) to be brought to the scene from the U.S. Army's Arsenal in Pine Bluff, Arkansas.

The bulk of the fire was eventually extinguished the next day. However spot fires continued to erupt for a week or more during clean up operations. The public was unaware of these fires and any potential dangers that they posed.

Incident Timeline:

5/8/1997	10:00 am	Delivery of containers of azinophos-methyl
5/8/1997	12:50 pm	Discovery of a fire
5/8/1997	1:02 pm	First call to 911
5/8/1997	1:09 pm	Second call to 911
5/8/1997	1:15 pm	First Fire Department unit on scene
5/8/1997	1:34 pm	Sprinkler alarm activates

5/8/1997	1:39 pm	Approximate time of explosion
5/8/1997	1:40 pm	Medical center evacuation begins
5/8/1997	1:45 pm	General area evacuation ordered
5/8/1997	2:40 pm	Medical center is evacuated
5/8/1997	3:00 pm	Hazmat team arrives
5/8/1997	10:00 pm	Area reopened to public
5/14/1997	12:00 pm	Medical center reopens

Hazardous Materials Involved: The original chemical involved in this incident was azinophos-methyl which is a highly persistent organophosphate-based insecticide. The most notable effect of this chemical is disruption of the nervous system.It is especially toxic to children.

Additionally, as many as eight other chemicals were in the building. The total weight of the involved materials was estimated at 10,000 pounds. The building exploded. The primary route of exposure was inhalation of toxic by-products from the fire and ensuing smoke plume.

Population at Risk: Phillips County, Arkansas is an economically depressed county with a 1995 census of 27,386 people. A high ratio of residents live below the poverty level (43%) and a high percentage of residents are above the age of 65 (14.1%). The county is predominately populated by minorities with the majority of the population being black (54.6%). The housing is old and mostly wood frame construction with poor sealing qualities.

The Phillips County Regional Medical Center is a county-owned medical facility with a 155-bed capacity, including critical care and maternity wards. At the time of the incident, the facility had 4 or 5 serious patients including at least one ventilator-dependent patient, one active maternity patient and 17 rehabilitation patients.

Meteorological Conditions: Weather factors did not play a role in this incident, other than wind direction and speed.

Time Factors: The incident occurred mid-day. A large irritating smoke cloud rapidly migrated toward the populated areas in the down wind zone within 3-miles of the plant.

The evacuated area remained closed to the public until 10:00 PM the evening of the explosion.

A period of 6 days would be required to re-enter and ensure that a thorough decontamination of the medical center had been done.

Communications Capabilities: Initial evacuation alerting was accomplished using two tornado warning sirens with additional warnings issued by radio broadcast by the Phillips County Office of Emergency Services.

Deputies were also utilized for face-to-face notification for evacuation of the immediate area. Telephone problems were noted in respect to the Phillips County Medical Center, and ham radio operators were used for dispersion of information.

Interagency communications between the medical center and the fire department did not exist at the time of the incident. This caused problems in getting needed resources to the hospital for the evacuation to take place.

Some residents in the evacuation zones decided to not evacuate but rather sheltered in place while others in the shelter in place zone decided to evacuate.

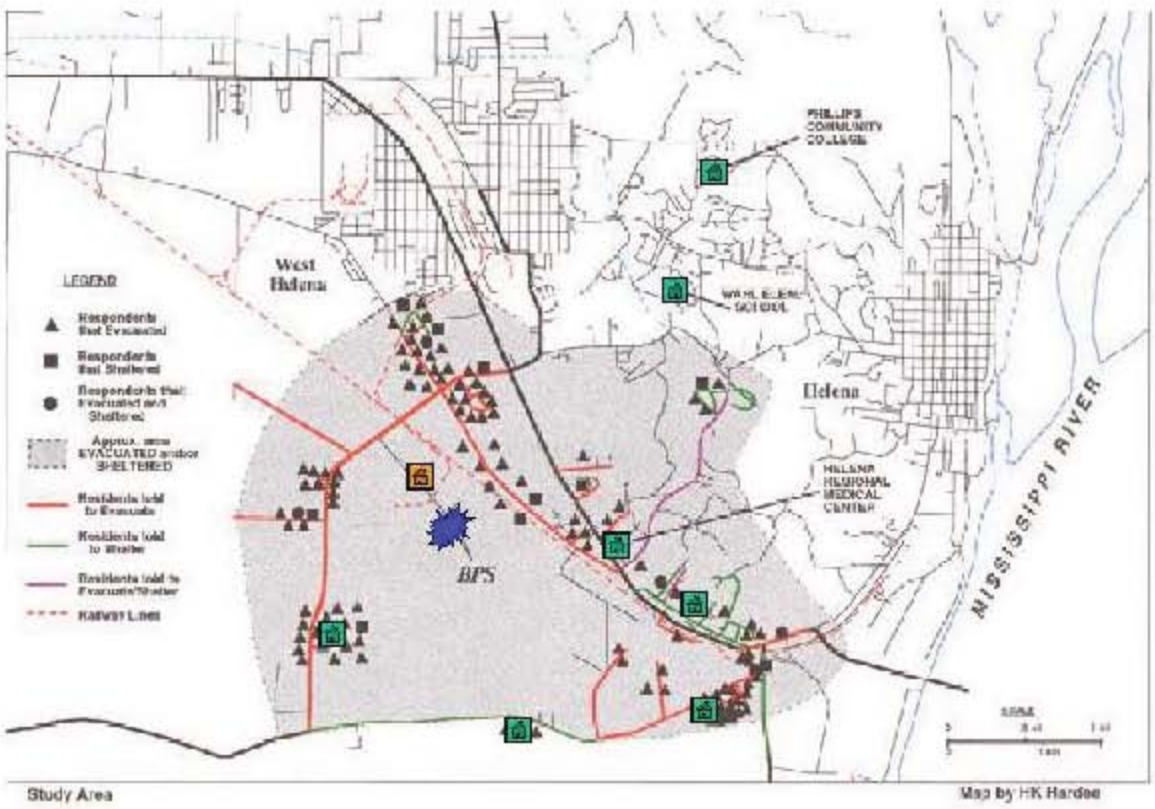
Residents typically reported that they complied with the instructions of the authorities, many upwind of the plant did not perceive any danger and chose not to evacuate.

Emergency Response Capabilities: The West Helena Arkansas Fire Department did not have operational level HAZMAT capability. The Helena Arkansas Fire Department was asked to take over command for this incident at the time of the explosion.

The facility was active in the Local Emergency Planning Committee and had supplied the fire department with pre-incident planning assistance for their facility including maps and material safety data sheets. A walk through tour of the facility had been conducted just one month prior to the incident.

The medical center had a recently updated and evaluated evacuation plan in place and a drill had been conducted six months prior to the incident. The plan seemed to work well and the entire evacuation of the medical facility took just 55 minutes to complete.

Site Map


West Helena
Helena
BPS
MISSISSIPPI RIVER
PHILLIPS COMMUNITY COLLEGE
HELENA REGIONAL MEDICAL CENTER
LEGEND
Study Area
Map by HK Hardee

Runaway Chemical Reaction and Vapor Release
Paso Robles, California
November 12, 1991

Basis of Study: Research of incident, review of agency incident reports and anecdotal reports of responders

Citation: Paso Robles Department of Emergency Services, Incident Report # 97-1748, (sections) Incident Commanders Review, Incident, Narrative, Evacuation Group Log, Update-Hazardous Materials Incident of 11/12/91, Paso Robles, California

Protective Actions: Evacuation and Shelter-In-Place

Abstract: A runaway chain reaction in a chemical process sent clouds of potentially toxic smoke over a relatively rural area of California, as well as several schools and a California Youth Authority detention facility. The incident was ongoing for some 30 hours prior to any request for assistance from the local emergency response community. Several logistical and operational problems were encountered. The incident resulted in numerous evacuations of residents and their livestock, as well as the sheltering in place of over 800 inmates held in the minimum to maximum-security detention facility.

Incident Description: The first request for assistance (via 911) came from the Chemron Corporation in Paso Robles, California at 4:05 AM on November 12, 1997. The caller reported that "a runaway chemical reactor" was causing the plant problems and that a vapor release had occurred. While responding, the Incident Commander noted a gray colored cloud in the vicinity of the plant from approximately two miles way and confirmed this with other responding units prior to arrival.

Plant personnel had been evacuated prior to the arrival of the fire department. The Incident Commander made a decision early in the incident that all responding units would assume a defensive posture. Since there were no lives directly endangered, the incident would be dealt with from a distance and no firefighters should be placed at risk.

It was soon learned that the chemical reactor involved had been experiencing varying degrees of problems since approximately 7:00 PM on Monday November 10th, some 30 hours prior to the emergency call to

911. The mixing operation that was underway had been completed over 100 times in the past without incident.

However, on this occasion the temperature in the chemical reactor rapidly rose from 150 degrees F (normal operating temperature) to over 400 degrees F. At first, this runaway reaction was being controlled by plant employees and was not considered to be a problem. Employees used water hoses to attempt to cool the chemical mixture. This was continued until approximately 4:05 AM on Wednesday, November 12th, when the water hose split open and caused the chemical reactor to generate a cloud of vapor that was released into the air. At this time, the call to 911 was placed.

At first, plant representatives were not initially available for the fire department to question about the incident or the materials involved. This caused concern, as responders were unsure of the materials involved and the exact nature of the circumstances and events prior to the release. At 4:45 AM, a plant representative was able to identify the involved product as toluene-2, 4 diisocyanate, a class B poison. Given this information and the fact that the incident had been ongoing for over a day and a half, the Incident Commander ordered that area residents and businesses evacuate the downwind corridor as a precaution. He also ordered the California Youth Authority to shelter in place its entire population, confining them to their living wards. At this time, additional technical resources such as the San Luis Obispo HAZMAT team were requested to respond to the scene, as were several law enforcement agencies to handle the evacuation.

Once the incident scenario was better understood and technical experts consulted, it was determined that the reaction would run its course in twelve hours. At that time, readings would be taken of both the atmosphere and temperature near the involved vessels and chemicals. Based on the information gathered at that time, decisions would then be made as to reducing or modifying the evacuation boundaries.

Later in the incident it was learned that two other chemicals were involved polyethylene glycol and trimetholpropane. This information was significant, however, it did not require any change in response tactics or evacuation considerations.

From early in the incident, the fire department assumed a “worst case” scenario due to lack of information. Based on this approach five

"evacuation zones" were developed and plans to shelter in place the youth detention facility were made.

At 7:45 AM, an uncontrolled release occurred which caused a large black-gray cloud to cover the area immediately adjacent to the facility. This release forced the command post to relocate and evacuation of three of the five "evacuation zones" were ordered as the vapor cloud spread to the populated area.

Entry was made into the facility at 2:11 PM for the purpose of temperature and atmospheric monitoring. It was found that no detectable levels of toxic vapor could be found outside the facility and that the temperature of the product in the chemical reactor since it was last measured had decreased over 100 degrees F.

The emergency response phase of this incident was terminated by the fire department at 3:44 PM and incident command was turned over to Environmental Health. All emergency services activity, including those of the Emergency Operations Center related to this incident, ceased at 4:00 PM

Incident Timeline:

11/10/97	10:00 pm	Incident begins
11/12/97	4:05 am	First call to 911
11/12/97	4:20 am	Employees moved
11/12/97	4:45 am	Chemron states that the Incident is "out of control"
11/12/97	6:05 am	County EOC activated
11/12/97	7:45 am	Uncontrolled release of vapors
11/12/97	8:00 am	Zones 1, 4, & 5 ordered to evacuate
11/12/97	8:30 am	Detention center ordered to shelter in place
11/12/97	2:38 pm	Zones 4 and 5 and some of zone 1 reopened to the public
11/12/97	3:44 pm	Fire Department terminates operations
11/12/97	4:00 pm	County EOC closed

Hazardous Materials Involved: The initial report indicated that only one chemical, toluene-2, 4 diisocyanate was involved in the reaction. However, it was later learned that two additional chemicals were in the chemical reactor as well. This misinformation caused some initial concern to responders, but they learned that the additional chemicals

were unlikely to require a change in operational tactics or to have any adverse affect on the outcome of the incident.

Toluene-2, 4 diisocyanate is toxic chemical with a DOT hazard class of poison B. Generally it is sold and stored in solid form. However, in the process of blending the chemical with two other chemicals in a steam heated pressure vessel, the chemical is in a vapor form. The other chemicals in the blending vessel at the time of the incident were polyethylene glycol, a mild irritant and trimetholpropane, a non-irritating, non-toxic product. The eventual use of the mixture was in the manufacture of polyurethane foam. When mixed, these three chemicals are known to generate a great deal of heat.

The initial vapor release was traveling with the wind in the general direction of the populated area. The chief concern with toluene-2, 4 diisocyanate vapor is the inhalation hazard which can cause respiratory compromise and irritation. The other chemicals presented minimal health problems.

Population at Risk: The immediate area of the release was an airport industrial park with limited employee exposure on the night shift. In the downwind corridor, there was a residential area, several schools and a California Youth Authority Juvenile detention facility.

Several residents in the evacuation areas owned high value pets and livestock and refused to evacuate without them. A decision was made by the Evacuation Coordinator that no animals would be evacuated by emergency response personnel due to manpower limitations. However, an accommodation was made at a nearby fairground to house any animals that residents removed themselves.

The detention facility housed approximately 800 “youth” inmates (13 to 26 years in age), with 150 of those being maximum security inmates on 23 and a half hour a day “lock down”. These inmates were housed in approximately 80 wards with a centralized feeding and education/ recreation facilities on a large compound. Each ward housed 10-15 inmates.

Several logistical problems were noted in the decision to shelter-in-place at the detention facility. Since the facility was located wholly within the boundaries of an evacuation zone, workers that would normally report in the morning for normal shift changes were unable to do so. This problem was further compounded by the fact that several of the on-duty (night

shift) personnel were already working a third shift and had not planned on being at the facility beyond normal shift change. Staffing for the overnight shift is reduced when compared to day shift and concerns regarding control of the inmates were raised particularly if the incident continued longer
then the anticipated 12 hour window of risk that had been established.

Once it became apparent that meals would be required due to the duration of the incident, logistical problems occurred in terms of how to get the inmates to the centralized feeding facility or get meals to them in their wards without creating an exposure hazard. Also, if the incident ran longer then anticipated at the outset, concern over how to restock the centralized feeding facility was raised.

The limited supplies on hand for expedient sheltering modifications, such as duct tape and sealing film, were quickly exhausted with no means for replenishment.

Meteorological Conditions: The impact of the weather was minor in this incident, as it was mild for the time of year with a temperature of 45 degrees and a light but variable wind speed and direction. The sky was clear and no precipitation was anticipated.

Time Factors: Early in the response, the Incident Commander noted a large gray cloud as being visible from two miles away. This cloud later grew in magnitude when a substantial escalation of the incident occurred. The vapor cloud was propelled only by the winds at the scene.

The time of the incident made residential warning difficult as most residents were sleeping. At the time of significant escalation, the public was generally awake and aware of the incident and the potential need to evacuate. However, schools had already begun their sessions, and this complicated the evacuation and necessitated a shelter in place posture for the schools.

The need for protective action went from a potential need to evacuate, to an actual evacuation and shelter-in-place in approximately 15 minutes, once the incident grew in magnitude.

Communications Capabilities: Communications capabilities were generally not an issue during this event. A separate frequency was available and dedicated to the evacuation operation

so as not to interfere with the tactical operations. Some difficulty was noted in that the scene lacked fax capacity. Several dead spots were observed with regard to the use of cell phones.

Minor issues did arise with respect to interagency communications with regional response units that were called to the scene for technical expertise.

In his "Incident Commanders Review and Summary of Actions" the Incident Commander reported that public information provided by the Public Information Unit "though articulate, was in some cases taken out of context or exaggerated"

One key to communications issues at the detention facility was constant communications between the internal Emergency Operations Center and the wards themselves. Many inmates later stated that they felt as if the facility staff was genuinely concerned for the inmates welfare. This was attributed to the relative calm in the wards during the shelter in place activity.

Emergency Response Capabilities: The initial response consisted of three complete fire stations and a Chief Officer. One unmanned fire station which would normally respond to this incident based on location was enveloped in the vapor cloud at the time of the 911 call and alternate units had to be dispatched.

At the time of the incident, none of the responding units had any state certified HAZMAT Technicians on shift. The responding Chief Officer requested that two of the six HAZMAT technicians on the department be called at home to respond.

HAZMAT units were requested from the San Luis Obispo County Fire department and other mutual aid resources were requested, to respond to this incident and to provide for routine fire protection in the area during this incident.

Several local, county and state law enforcement agencies responded to assist in the evacuation of the area. Units from state and federal environmental agencies were called to the scene for technical assistance and support.

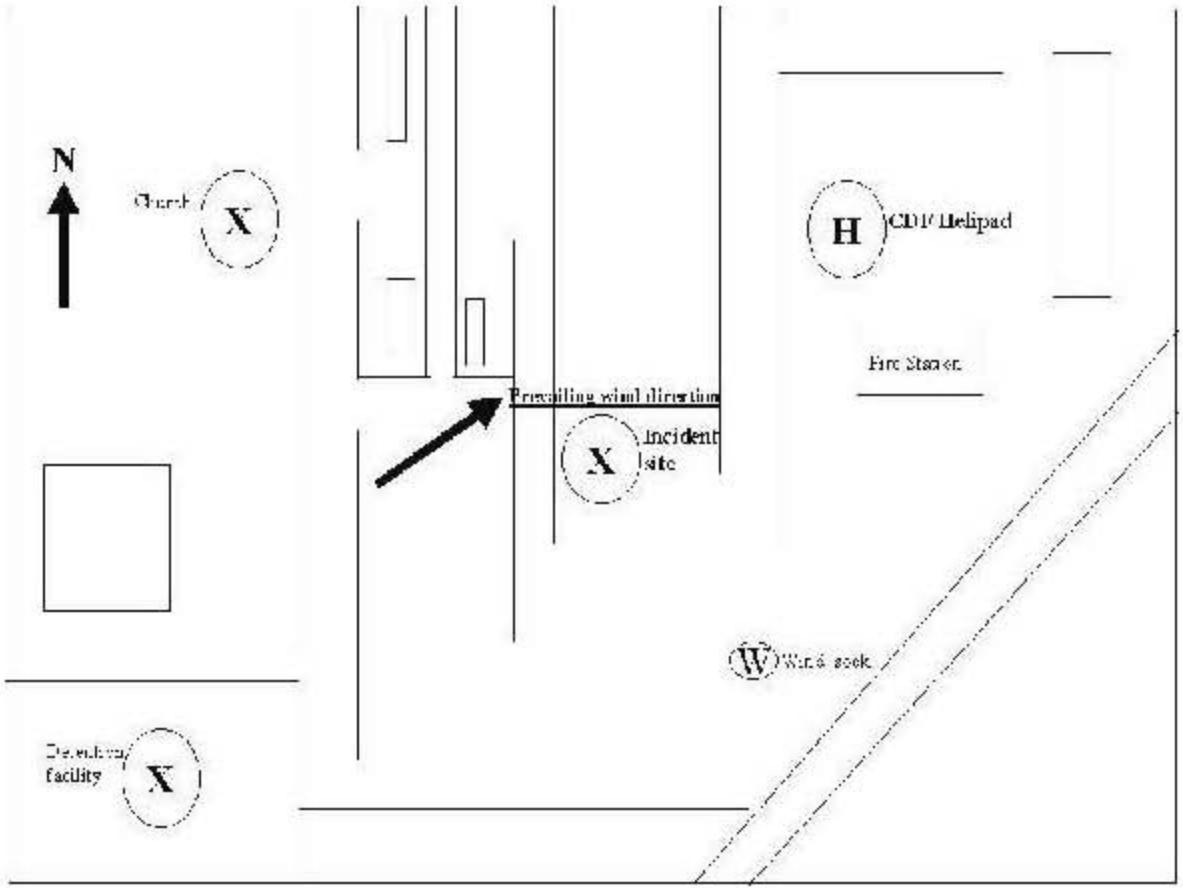
The California Youth Authority activated its internal emergency operations center for the duration of the incident. Existing plans were in

place for both shelter-in-place and evacuation. However, the liaison from the Authority was unaware that an evacuation plan existed.

The primary reason the evacuation plan was in place for the detention facility was the proximity of a nuclear power station to the facility. The evacuation plans included transportation, security and reception center issues that had been resolved in planning, but had never been tested other than a table top exercise.

While the detention facility management staff was very confident that the facility could have been safely and effectively evacuated in a reasonable period of time without incident, other staff members were not as confident on that point.

Site Map:


N
Church
X
H
CDO Helipad
Fire Station
Prevailing wind direction
X
Incident site
W
Wind sock
X

Chemical Plant Release
Nitro, WV
December 5, 1995

Basis of Study: Research of incident, review of agency incident reports and anecdotal reports of responders

Citation: Incident report, Kanawha Putnam Emergency Planning Committee , interviews

Protective Actions: Shelter in Place

Abstract: A process vessel at a chemical plant overpressurized and released a phosphorus chloride compound into the diked area around the vessel. In the rain, a hydrochloric acid cloud was formed which drifted offsite into an adjacent office and commercial area.. More than 800 employees of a neighboring chemical plant and several offices sheltered in place while the plume passed over the area. No injuries were reported. Businesses in the area had been trained in sheltering for employees.

Incident Description: At about 1:00 pm on December 5, 1995, a process unit at a chemical plant in a business/industrial park became overheated and began to overpressurize. An alarm at the unit malfunctioned and failed to warn operators that pressure was building in the vessel. A pressure relief valve opened and allowed 1,470 pounds of phosphorus trichloride to spill into the diked area around the vessel. Light rain had been falling and the air was very moist. The moisture reacted with the phosphorus compound. A cloud of hydrochloric acid formed and drifted slowly toward an adjacent chemical plant. Workers at the second plant noted the cloud and called 911 and the emergency response coordinator at the plant where the cloud originated.

A shelter in place recommendation was issued over the community's warning system. Sirens were sounded and the emergency alert system activated. The cloud was slowing moving to the northwest toward the rest of the business/industrial park and the adjacent interstate. Because of the proximity of the two chemical plants, the other businesses in the park had been trained in sheltering in place and had implemented shelter in place plans. The West Virginia Department of Environmental Protection main offices are located in the park. There are also a number of other businesses including a soft drink cannery, trucking companies, warehouses and a piping/valve company.

Nitro Fire and Police personnel implemented the traffic diversion plant and limited access into the threatened area. The main street through Nitro was blocked and other law enforcement agencies blocked the interstate and directed traffic through alternate routes.

The release and subsequent mitigation activities lasted for about four hours. An estimated 800 gallons of phosphorus trichloride discharged to the diked area. Emergency response by plant personnel during that time limited the amount of hydrogen chloride that formed. Sodium bicarbonate was applied to the phosphorus trichloride in the diked area. If all of the phosphorus trichloride would have reacted with water the maximum amount of hydrogen chloride formed would have been about 8,000 pounds.

Hazardous Material Involved: Hydrogen chloride is an acid that can form aerosol clouds. Inhalation of hydrochloric acid can cause serious respiratory problems. It is classified as an extremely hazardous substance by the U.S. Environmental Protection Agency. The hydrochloric acid cloud formed when moisture in the air reacted with the phosphorus trichloride that spilled into the diked area. Light winds slowly moved the cloud out of the plant toward an adjacent chemical plant, a business/industrial park and I-64 to the northeast.

Hydrochloric acid is corrosive and in sufficient concentration is an irritant to eyes, nose, throat and larynx. It can also cause skin burns. The cloud that traveled into the business/industrial park was sufficient to cause irritation to the eyes, nose and throat. An employee of a nearby gas station who ignored the shelter in place advisory said her nose burned a little when she went outside to take readings on the gas pumps.

Based on the amount of phosphorus trichloride released and emergency response mitigation activities, the company reported that significantly less than the maximum release of about 8,000 pounds of hydrogen chloride actually occurred.

Population at Risk: The immediate area of the release was the chemical plant where the chemical leaked. Immediately downwind was another chemical plant, and in the downwind corridor were several businesses. These businesses are in a business/industrial park adjacent to I-64 to the northwest. Other populations potentially at risk included parts of the Nitro business district and a few residences.

Because of the chemical plants, commercial residents of the business/industrial park have been trained in sheltering in place. The West Virginia Department of Environmental Protection has a multi-story office building in the park. Employees conduct shelter in place drills on a regular basis. A piping/valve business with warehouses has taken measures to provide warehouse and pipe yard workers with a secure place to shelter. In one of the warehouses, the company constructed a room with sufficient space to house all of the workers. Their shelter plan allows three minutes for workers to enter the safe room. They have drilled the activity and know that all workers in the warehouse and pipe yard can make it into the shelter room in that time.

The cloud was heading toward the interstate, so traffic was diverted as a precaution. The main road through Nitro (State Route 25) runs parallel to the business/industrial park. Some of the businesses along this road have shelter in place plans, but many of the establishments are retail and fast food services which have not implemented shelter in place policies. Before local public safety personnel could block Route 25, some residents drove through the area. One woman reported an itching rash on her arms and neck. Otherwise, no injuries were reported.

Meteorological Conditions: Weather was a significant factor in this incident. Rain that had fallen prior to the release caused standing water in the diked area. When phosphorus trichloride leaked into the diked area, hydrogen chloride was formed. During the course of the event, intermittent light rain fell and also reacted with the phosphorus trichloride. Although wind measurements were not available, individuals from public safety agencies reported very light winds that were heading generally in a northwest direction.

Time Factors: The release occurred in the middle of the work day. The business/industrial park was fully populated. The slow movement of the cloud allowed emergency warnings to reach the companies in the park in time to take protective action. The cloud was also visible which alerted some people of a problem. The shelter in place lasted for about 2 hours.

Communications Capabilities: Communications capabilities were generally not an issue during this event. Minor issues did arise with respect to interagency communications in implementing traffic diversion. Mostly this was due to heavy traffic on one radio frequency. Communication with the public was effective with the Emergency Alert System, sirens and cable intercept.

Emergency Response Capabilities: The chemical plant where the leak occurred has its own emergency response team.. Non-essential personnel at the site were evacuated. The emergency response team was able to effectively mitigate the accident by spreading sodium bicarbonate over the spilled material.

The 911 Center appropriately alerted local responders and the public. The community's emergency warning system activated through it's siren system, EAS, and the ability to interrupt cable television programming. The Kanawha-Putnam Emergency Planning Commitee emergency response plan was activated. Nitro public safety personnel and WV State Police provided access control to the affected area and temporarily diverted traffic from I-64 to alternate routes.

Overturned Tank Truck
Marin County, California
July 14, 1999

Basis of Study: Research of incident, review of agency incident reports and anecdotal reports of responders

Citation: Marin County Sheriff's Department, Office of Emergency Services, After Action Report for incident # NF99002203, San Rafael, California

Protective Actions: Shelter-in-place

Abstract:. At 7:42 AM on the morning of July 14, 1999, a traffic accident occurred involving a tractor-trailer carrying two incompatible chemicals. The truck overturned, and the chemicals mixed and reacted. This caused a lingering vapor cloud to form that threatened to envelop sections of highway that became impassable due to stranded motorists. Several hundred motorists were trapped on the highway in their cars in mid-July. The motorists were advised to shelter-in-place from the vapor cloud by remaining in their cars.

Incident Description: At 7:42 AM, a call reporting an accident involving an overturned truck at the intersection of Highway 101 and Highway 37 in the Novato section of Marin County, California was received by the Marin County Sheriff's Department. A complete HAZMAT team was dispatched The Incident Commander reported that a full sized tractor-trailer was overturned and that a vapor cloud 15' X 10' was visible at the rear of the truck. The roads were immediately shut down, and it became apparent that several hundred motorists would be stranded in their cars on the highway.

A shelter in place order for people trapped in their cars was given at approximately 8:30 AM. By this time, several motorists had exited their cars and wandered through the area near the accident, potentially becoming exposed to possible contamination.

With several hundred motorists stranded ,the California Highway Patrol was used to conduct an orderly evacuation of the cars by turning each one and having it drive the wrong way on the road to the previous exit. The effort was massive. By the time it began, traffic was backed up for nearly six miles in both directions.

At approximately 1:00 PM, a wind shift occurred causing concern for a number of motorists who had been upwind of the incident. Further shelter-in-place orders were issued to these motorists.
At approximately 8:00 PM, the highway was able to be reopened and all motorists were allowed to leave the area.

There were no significant exposures and no one was injured or needed any medical treatment other then the truck driver who had a minor knee injury from impact of the accident.

Hazardous Materials Involved: The shipping papers indicated that the tractor trailer was carrying 288 gallons of hydrochloric acid, 3,168 gallons of sodium hypochlorite and 400 pounds of sodium thiosulfate. The sodium thyosulfate was not spilled and none was released; the hydrochloric acid and sodium hypochlorite did spill and mixed causing a reaction which generated chlorine gas that enveloped the vehicle. The driver was not seriously injured and was able to assist with product identification. The materials were released in the back of the trailer with the door still shut. A vapor cloud was slowly generated and was beginning to envelop the trailer upon arrival of responders. The primary health concern was the chlorine content of the vapor cloud. The vapor can cause skin, eye and throat irritation in low doses and longer term pulmonary complications can occur with exposure to larger doses.

Population at Risk: At the time of the accident, several hundred cars were trapped behind the incident. Several drivers left their vehicles with most leaving the area. However, a few actually approached the incident to the point of walking near the trailer where the materials might be leaking. Once traffic was stopped, the back up rapidly became massive, reaching as far as six and a half miles from the incident scene. Some cars were abandoned on the roadway. No resources were available for providing water to the drivers of the vehicles.

Initially there were no at-risk populations other then the stranded motorists, until a wind shift occurred and caused concern for homes that were adjacent to the scene. Several person were observing the incident from their yards and might have been endangered if spill mitigation activities caused a rapid generation of a larger vapor cloud. Plans were made to deal with the new at-risk population.

Meteorological Conditions: At one point, a wind shift occurred causing concern that motorists that were in the upwind area might now be in a down wind corridor from the scene. Plans to shelter-in-place were readied, but not immediately implemented.

The responders had access to extremely accurate point source weather data from an on-board collection system carried on the HAZMAT team vehicle.

Time Factors: The incident occurred the height of rush hour. The initial spill generated a vapor cloud that was approximately 10' X 15' in diameter directly to the rear of the trailer doors. As time wore on, the cloud grew at a slow pace and was dissipating at the same time.

Initial actions were directed at removing the trapped motorists from the area. Then product identification and hazard analysis were undertaken.

Communications Capabilities: Interagency communications were not an issue in this incident as the use of the mobile command post and the emergency operations center was well practiced.

Communications with the public in their cars presented a problem and much of this communication had to be done on a face to face basis. A recommendation was made in the after action report for securing the use of mobile radio stations such as those used for traffic construction for emergency broadcasts.

The media presented some challenges as they monitored responder communications via scanners and misunderstood the term shelter-in-place as to mean that shelters had been opened. When they were told that this was not the case, they questioned responders as to why not. This forced the Public Information Officers from the various agencies to "teach" the media about the concept of shelter-in-place while trying to deal with the emerging incident itself.

Another media problem was that, because the incident was on two highways, the media had units located both north and south of the incident. However, the public Information Officer was only located on the north end of the incident. In the absence of guidance from agencies on-scene, the media on the southern end of the incident began to interview anyone in the area. This allowed for some misinformation to be made public.

Emergency Response Capabilities: From the outset of the incident, a full HAZMAT response and relatively large law enforcement response was made. This was mostly due to the initial reports of the release coupled with the rush hour time frame.

The HAZMAT team was able to rapidly identify the product and begin to formulate cleanup plans.

Summary of other sheltering cases

Shelter in Place is used across the country as a protective action for the public. But even before formal sheltering in place was common, examples of the effectiveness of staying indoors during chemical emergencies exist. Following are examples from around the United States. Information was gathered from news reports and other printed materials, Lexis/Nexis news service, the federal Chemical Safety Board website (www.csb.gov) and from Risk Management Plans (RMPs) filed with the Environmental Protection Agency. Where there are no citations, the data were collected from RMPs

- Houston, TX on May 11, 1976
  A tank truck carrying anhydrous ammonia wrecked on an exit ramp and toppled onto a freeway below. On impact, the tank ruptured and released about 7,500 gallons of ammonia. The ammonia immediately vaporized and formed a thick plume. With winds of about 7 mph, most of the ammonia cloud had dispersed after 5 minutes. The cloud surrounded the nearby Houston Post newspaper building – birds on the roof were killed. For people within 1,000 feet of the release point, 78 were hospitalized for symptoms of ammonia exposure, 100 were treated for less severe injuries, and 4 died as a result of ammonia exposure. The National Transportation Safety Board (NTSB) investigation concluded that people who sheltered and stayed inside buildings (including workers in the Houston Post building) received no harm from the ammonia release. NTSB also concluded that people who stayed in their cars generally received less severe injuries that those who left their cars and tried to escape.[7]

- Pensacola, FL on November 9, 1977
  A railroad tank car carrying anhydrous ammonia derailed and was punctured resulting in a release of ammonia vapors. Two deaths and 46 injuries were reported for those who were evacuated. In six houses that were very close to the accident site, there was no time to evacuate. Those residents closed their windows and doors and stuffed towels under doors and around windows. NTSB concluded that a breathable and survivable atmosphere was maintained in those houses where the residents were not harmed.[8]

- Miamisburg, OH on July 8, 1986
  A CSX rail tank car derailed releasing liquid phosphorus. About 30,000 people were evacuated from the surrounding area. However, a local hospital near the accident site was unable to evacuate. The hospital staff and patients sheltered in place and were not injured. (Information from a telephone interview on 12-15-97 with Lt. Andy Harp, Miamisburg Fire Department, one of the first responders on the scene, as reported by East Harris, TX Manufacturers Association)

- Texas City, TX on October 30, 1987
  An accident at a Marthon Oil refinery released a large amount of hydrogen fluoride (HF). About 3,000 people evacuated. Of those, 500 were treated for burns and respiratory problems. People who stayed in their homes and refused to evacuate were not injured by the HF. In addition, pets and plants that were left inside the homes that were evacuated were not injured while pets and plants left outside perished. (Interview with Texas City Fire Chief Ken Jones on 12-16-98, as reported by East Harris County, TX Manufacturers Association)

- Planquemine, LA in 1987
  A Dow Chemical Company accident released chlorine. All of the employees who stayed in buildings were unaffected. Two employees who tried to evacuate from the cafeteria suffered respiratory problems from inhaling the chlorine. Trees near the gate of the facility were damaged, while houseplants in offices near the accident site were not.

- Henderson, NV on May 6, 1991
  Corrosion in a steel piping system caused a failure that released 70 tons of chlorine gas. Two hundred people were hospitalized. Investigators from the U.S. Fire Administration concluded that people who evacuated were exposed to greater risk than those who stayed indoors. (Cited in a Michigan State Police report)[9]

- Ludington, MI on February 7, 1993
  Michigan State Police reported that a pipe fitting failed releasing bromine gas. Shelter in place was utilized successfully for 3 hours with no injuries. Michigan State Police concluded that in this incident, sheltering in place was an effective protective action and that it was preferred to risking exposure during an evacuation.[8]

- Richmond, CA on July 26, 1993
  A tank car carrying oleum overheated and ruptured sending a cloud of sulfur trioxide into the air. The Contra Costa County Health Services Department reported that 22,000 people in the community sought medical attention, 22 were hospitalized. Employees of a nearby plant, in the direct path of the plume, sheltered in place and were not injured. Followup health studies by the Agency for Toxic Substances and Disease Registry (ATSDR) concluded that persons with observable symptoms such as wheezing and vomiting were more likely to have been outdoors during the release or did not shelter in place as advised.[8]

- Fort Rucker, AL on November 8, 1994
  Chlorine gas (150 lbs.) escaped from a sewage treatment facility at the U.S. Army Aviation Center and Fort Rucker. The release occurred in the early evening, 6:10 pm, and lasted for about 2 hours. According to the RMP filed by the facility, 128 people sheltered and 128 people evacuated. This resulted in 21 public responders being hospitalized , 22 workers being injured and injury to one member of the public who was onsite at the time. The chlorine release also damage plants in the area. Stability conditions of F meant that the cloud of chlorine gas dispersed very slowly; temperature was 65 F and wind at 3 knots from the south.

- Westlake, LA on January 24, 1995
  Vinyl chloride (6,516 lbs.) and hydrochloric acid (2,754 lbs.) were released from a process vessel at a Georgia Gulf facility at around 9:15 am. Local officials requested a shelter in place for about 1,000 people who lived in the vicinity. The cloud dispersed slowly in the 44°F temperature. Wind speed was about 4.5 mph. Local officials reported no injuries.

- Westlake, LA on March 10, 1995
  A process vessel at a Georgia Gulf facility overpressurized which resulted in the release of ethylene, vinyl chloride, propylene, and hydrochloric acid. Although the primary threat from the first three of these chemicals is flammability, 5000 people in the community sheltered in place. Weather conditions during the 7:40 am release were 47°F with winds from the north at 6 mph. No injuries were reported.

- Newport, TN on September 11, 1995
  A malfunction at a Great Lakes Chemicals facility resulted in the loss of 475 pounds of phosphorus oxychloride from a storage container. The release occurred at 1:40 pm and lasted for 2 hours 40 minutes. The weather was warm, 85° F, with winds from the east at 6.7 mph. On-site, 13 employees were injured. In the community, 400 people were evacuated while 200 people sheltered in place. One member of the community received medical treatment.

- Nitro, WV on December 5, 1995
  A process vessel at an FMC chemical plant overpressurized and released phosphorus trichloride into the diked area around the vessel. In the rain, a hydrochloric acid cloud was formed which drifted offsite into an adjacent office and commercial area.. More than 800 employees of a neighboring chemical plant and several offices sheltered in place while the plume passed over the area. No injuries were reported. Businesses in the area had been trained in sheltering for employees.[10]

- Glendale, AZ on January 16, 1996
  At Cholla Water Treatment Plant, approximately 100 pounds of chlorine was released when a manifold ruptured. The release lasted for a nearly 2 hours. Approximately 700 residents of the area sheltered in place. No injuries were reported.

- Overland Park, KS on June 24, 1996
  The Johnson County wastewater treatment plant suffered an equipment failure which released 1,100 pounds of chlorine into the air. Fifty people in the community sheltered in place with no reported injuries. Plants in the surrounding community were damaged. One worker was injured

- Hammond, IN on February 20, 1997
  At a Rhodia, Inc. hazardous waste facility, chloroform (117 lbs.) and hydrogen chloride (1,447 lbs.) were released from a flare on a storage vessel at 1:19 pm. In the community, 2,000 people sheltered in place, 23 people sought medical treatment and 2 were hospitalized. During the more than 6 hours of the release, temperatures were in the upper 30s with wind from the NNW at 5 m/sec.

- Baton Rouge, LA on March 17, 1997
  During near flood conditions on the Mississippi River, a barge carrying 420,000 gallons of pyrolysis gasoline capsized and began leaking. The pyrolysis gasoline was 40% benzene and also contained significant amounts of toluene. The accident and subsequent clean-up activities resulted in the forced evacuation of 65 residents and 75 inmates from a work-release center and at least five separate shelter in place recommendations. More than 380 residents were treated at area emergency rooms. There were no injuries reported from those who sheltered in place.[11]

- Westlake, LA on June 5, 1997
  An overpressurized process vessel at a Georgia Gulf facility released 533 pounds of vinyl chloride and 21,400 pounds of hydrochloric acid at 10:25 am. Weather conditions were good for dispersal of the plume. The temperature was at 79°F with winds from the east at 7 mph. About 1,000 members of the community sheltered in place. No injuries were reported.

- Pittsburg, CA in 1998
  At a refinery, an accident released 900 pounds of chlorine. About 7,000 people in the immediate community were alerted to shelter in place. One employee was injured in the incident, but no injuries were reported from offsite.

- Rodeo, CA on January 7, 1998
  A leak in a refinery unit designed to clean sulfur from diesel fuel led to a fire in a ground flare system. The burning flare produced billowing black smoke that contained hydrogen sulfide. The leak occurred at 9:05 am and lasted for two minutes. Emergency management officials were notified of the leak at 9:15 am. The emergency alert system was not activated until 9:26 am because officials were unsure of the direction the fumes were heading. A nearby elementary school sheltered 1,000 children prior to the warning because they saw the smoke and flames and could smell the hydrogen sulfide. Many residents ignored the warning sirens and shelter in place advisories. Health officials said that the amount of hydrogen sulfide released was well below hazardous levels. One possible injury was reported from a resident who complained of respiratory problems.[12]

- Huntington, WV on June 20, 1998
  A train derailed and spilled 30,000 gallons of formaldehyde at about 12:37 pm near Huntington, WV. About 100 families closest to the railroad were evacuated. Six residents and the train's conductor complained of breathing difficulties and were treated and released by a local hospital. River traffic was closed for about 40 minutes and local highway traffic was diverted until the cleanup was completed. Evacuated residents were not allowed back into their homes until air tests confirmed that the air was clear. Residences about a mile away were warned to shelter in place for about 1.5 hours. None of these residents reported injuries. [13, 14]

- Carlyss, LA on August 7, 1998
  Two acids mixed by mistake at a Calcasieu Parish chemical plant sent a brown cloud of nitrogen dioxide into the air. The leak lasted from about 11:00 am until noon. Residents living within two miles of the plant were advised to shelter in place. Late that afternoon, the shelter order was lifted after officials tested the air and found no significant levels of the gas near the plant. [15]

- Bayport, TX on August 28, 1998
  A trimethyl chloride release from a chemical plant drifted into local communities and prompted school officials to order a shelter in place. After an all-clear signal was given, children who went back outside were exposed to lingering traces of the toxic gas and complained of sore throats and nausea. A total of 130 people were treated at area hospitals for breathing problems, chest pains, throat and eye irritation and nausea.[16]

- Baton Rouge, LA on June 20, 1998
  A tanker truck overturned on a city street releasing about 2,000 gallons of molten sulfur from a "lid that popped open". Hydrogen sulfide gas rose from the spill and moved toward I-110 and to the north. The accident occurred at 9:55 am on a Saturday. Before emergency management officials could notify the public, at least 13 people were exposed and reported skin irritation from exposure to the gas cloud.. Seven of those were treated at local hospitals and released. The others were treated at the scene by paramedics. The Community Alert system notified 276 residences within a half-mile

radius of the spill to shelter in place. None of those residents reported any injuries. The shelter in place lasted from about 10:30 am to 12:30 pm while the spill was mitigated and the truck turned upright.[17]

- St.Gabriel, LA on March 2, 1999
  An ammonia leak at a fertilizer plant prompted local emergency management to order two neighboring prisons and one school to shelter in place at about 8:30 am until 10:15 am. A total of 176 pounds of ammonia were lost in a plume that was pushed to the west at 3 mph. The plume was headed for an elementary school, the Hunt Correctional Center and the Louisiana Correctional Institute for Women. Odor response teams that were sent into the area reported no trace of ammonia which led to the shelter order being lifted.[18]

- Baton Rouge, LA on March 2, 1999
  Hydrogen chloride gas leaked from an Allied Signal plant at 10:13 pm. Initially, the plant believed that the cloud would not leave the plant boundary. Ten minutes later, the plant updated its report saying that the leak would be noticeable in the surrounding community. A local Fire Department Hazmat Unit arrived at 10:40 pm and notice a white haze moving south into a residential neighborhood. About 500 nearby residents were advised to shelter in place. After air tests were conducted in the area and showed no detectable levels of hydrogen chloride, theshelter in place order was lifted at around 11:45 pm. No injuries were reported.[13]

- Gallipolis Ferry, WV on April 8, 1999
  Ethylene oxide was released from the premature rupture of a pressure release device in a process unit. The ethylene oxide vaporized in the 80° F temperature. A cloud was dispersed over the rural community from winds of about 7 mph. Some 250 people sheltered in place. No injuries were reported.

- Texas City, TX on June 25, 1999
  At a petrochemical plant, steam was released that contained methyldiethanolamine, a solvent, at about 7:30 pm. A disruption in a sulfur-recovery unit occurred just prior to the release. The steam stayed high in the air at first but a wind shift brought it to ground level. Residents in a 35-block area were advised to shelter in place until 12:20 am on June 26. Sixty people went to a local

hospital for treatment of skin and eye irritation and shortness of breath. Most of these people were not sheltered in their homes.[19]

- Valdosta, GA on June 29, 1999
  A valve in an ammonia piping system at an Archer Midlands Daniel facility failed and released 7,780 pounds of ammonia. Five workers were injured in the accident. In the surrounding community, 500 people were evacuated, but 20 residents closer to the facility sheltered in place. The potential impact of the accident was minimized due to weather conditions. Although the weather was hot (85° F), it was raining and the wind was blowing at about 10 mph. No offsite injuries were reported.

- Baton Rouge, LA on August 2, 1999
  A leaking chemical truck on I-12 near Baton Rouge led to closure of the interstate and protective actionws for nearby residents. Boron trifluoride, a corrosive gas, was leaking from pressurized tubes. Residents within a 1/4 mile radius of the truck were asked to shelter in place at about 12:30 pm while firefighters "knocked down" the cloud of harmful chemicals. The leak could not be patched so the remainder of the chemical was off-loaded through a portable scrubber system. Since this process was somewhat risky and would take several hours, 11 families closest to the truck were evacuated. No one was injured.[20]

- Pearl River, LA on October 15, 1999
  Pressure in a process vessel at a polymers plant increased to a level that caused a valve blow-out. This released 1,800 pounds of various chemicals including allyl chloride and dimethylamine gas. Twenty-three local residents were treated at local hospitals. One resident close to the accident complained of injuries from previous accidents due to fumes that leaked into the house during a mandatory shelter in place.[21]

- Institute, WV on October 15, 1999
  A small hole developed in a vessel within a pesticide production unit and a small amount of phosgene was released into the air. Initially, the chemical was misidentified because company workers thought the leak occurred at a valve very near the hole in the vessel. The leak occurred at about 9 pm on a Friday night. A shelter in place advisory was issued for communities around the plant and highways on both sides of the river were closed. Within the shelter in place advisory area, a high school football game was

underway. When the sirens sounded, the football game was halted. Spectators, players and coaches hurriedly entered the adjacent school where shelter in place procedures were implemented. The leak rapidly dissipated and air monitoring verified that the air was clear. The roads were reopened and the shelter in place order lifted at about 10:15 pm. No injuries were reported.[22, 23]

- Corruna, Ontario, Canada on March 16, 2000
  A flare went out on a stack at a Shell Canada refinery releasing hydrogen sulfide and mecaptans into the air. The flare was out about 10 minutes. Although fire officals advised area residents to shelter in place, some people were exposed before the advisory was issued. About 200 employees of a call center near the refinery complained of nausea and sore throats, and 21 people were taken to the hospital because of those complaints and dizziness.[24]

- Phoenix, AZ on August 3, 2000
  A warehouse explosion and fire created smoke containing pesticides, fertilizers and cyanide into a nearby community. Several residents who were evacuated to community shelters complained of headaches and respiratory problems. Residents who could see and smell the smoke were advised to shelter in place. None of these residents reported injuries.[25]

Lessons Learned

Examination of news reports, federal databases, incident reports and other data clearly indicates that sheltering in place, either alone or in conjunction with evacuation, is used effectively by emergency managers across the United States. The available data, however, generally lack sufficient detail to draw clear conclusions about effectiveness. To clearly demonstrate effectiveness, one would need to know whether a toxic gas cloud of sufficient concentration to be harmful entered a populated area. It would also be important to know whether the population received warning in a timely manner, whether residents were clear on steps to take to shelter effectively, and whether residents implemented sheltering techniques prior to arrival of the toxic plume.

Only in a few cases can it be determined that a cloud of toxic gas entered an area in sufficient concentrations to be harmful. And in even fewer cases are details of shelter in place education and implementation available. However, the body of available cases lends strong support to the scientific evidence that sheltering in place can be effective and should be a tool in the emergency manager's protective action toolbox.

The three key criteria that determine how effective sheltering in place can be are: 1) the behavior of the public; 2) the characteristics of the structure and its immediate environment; and 3) the characteristics of the chemical.

- **Behavior of the public** - Perhaps the most important factor in determining how effectively shelter in place protects the public is how the threatened public behaves when advised to take protective action. In order to maximize the effectiveness of sheltering in place, individuals must immediately go inside (or stay inside) when the warning is received. As quickly as possible, all windows and doors of the structure should be closed and locked. If a fireplace is in the home, the damper should be closed. Any air handling equipment such as heating, cooling or ventilating systems should be turned off. This is "normal" sheltering and can be accomplished in a very short time.

  If the population has been trained to take additional measures, individuals should go to their safe room and implement "expedient" sheltering in place techniques. The safe room should be a room with few or no windows and should have a radio or television to monitor emergency messages. Plastic sheeting should be installed

over windows and vents with long strips of duct tape to enhance air tightness. The edges of any doors should also be covered with long strips of duct tape. If the space of the bottom of the door is unable to be sealed by duct tape, a towel should be stuffed into the space. Tape can also be placed over electrical outlets, especially over those on outside walls.

Finally, when instructed by emergency management officials, sheltered individuals must terminate sheltering. Sheltering in place minimizes exposure, but does not avoid exposure to hazardous gases that may surround the structure. Small amounts of gases enter the structure through small cracks and pores. When the outside air is clear, it is important that sheltered individuals open all doors and windows and turn on air moving equipment to ventilate the structure. For most incidents, individuals should then go outside until the structure is well ventilated. If people stay sheltered after the outside air is clear, they will continue to be exposed to whatever amount of hazardous gases may have entered the structure.

There are several potential impediments to the public implementing protective actions in a timely manner. Social research has indicated that people need to believe that the threat is real and that the recommended protective action is effective. They must also believe in the credibility of emergency response decision-makers and spokespersons. Emergency response jurisdictions must have effective mechanisms for public warning and instruction. The population must have knowledge on how to effectively implement the protective action. Finally, people will try to assure themselves of the safety of other family members before implementing protective actions. All of these potential impediments can interfere with immediate implementation of protective actions by the threatened public.

Most of these impediments to appropriate public behavior in implementing protective actions can be reduced by effective public education and information programs. Public information programs are especially important for sheltering in place. Evacuation has a longer history as a public protective action and is more intuitive to people. The natural instinct when danger threatens is to get away from the source of the danger. Public education about sheltering in place is more challenging because of the need to provide instruction on techniques and explanations of effectiveness. Strong

public information programs can also build credibility and trust. Communities that learn about emergency plans and the people who are responsible for emergency management develop a greater sense of trust in those plans an d emergency managers. Effective public education about emergency plans for schools and other institutions can also lessen the anxiety for family members' safety.

In the shelter in place events reviewed for this study, public information campaigns are a hallmark of communities that use shelter in place for public protection. Many of the cases in this report are from communities in California, Louisiana, Texas, and West Virginia where petroleum refineries, chemical facilities and transportation of hazardous materials are common. Communities in these chemical-producing regions have undertaken strong and ongoing public information programs to include sheltering in place as an effective alternative to evacuation. These areas are also characterized by strong emergency planning in the school systems and protective action education activities with students. Information about these public education activities is not usually available from databases, but can often be captured from news reports, incident reports and personal interviews with emergency response managers.

- **Characteristics of the structure and its immediate environment** - Clearly, the type of structure to be used in a shelter in place action has a large impact on how effective sheltering in place will be in protecting the public. Modern, energy efficient homes are more airtight than older homes with single pane windows and little if any insulation. But even older homes can be effective shelters if the safe room is made more airtight by caulking obvious air infiltration points and using expedient sheltering techniques.

  For most of the cases of sheltering in place examined in this study, it is difficult to determine the how airtight potentially exposed structures are. However, descriptions of communities in news stories can often allow an estimate of building tightness and air exchange rates. For instance, low income communities around industrial facilities often consist of older frame homes that may have infiltration rates much higher than optimal for sheltering. In these cases, special care must be taken by emergency management officials to inform and educate these communities about expedient sheltering in place techniques.

The primary immediate environment of the structure is weather conditions. Weather can have a major effect on sheltering in place success. From a physical standpoint, weather can affect air infiltration rates. When there is a great difference in indoor and outdoor temperatures, infiltration of air into the structure increases. Wind also can increase infiltration of toxic gases into a structure. However, wind can also be helpful in a toxic gas release since higher winds will disperse gases quickly. Dispersed gases will be in much lower concentration and be much less likely to cause harm. Studies have shown that selection of a safe room on the leeward side of a house can increase the protective value of sheltering in place.[26]

Weather can also have an effect on public behavior regarding sheltering in place. When temperatures are extreme, safe rooms can reach uncomfortable temperatures. The longer a shelter in place action lasts under these conditions, the more likely people are to terminate the protective action before the outside air is clear. Emergency response managers must take weather conditions into account while managing public protective actions. Termination of the shelter in place order should be advised as soon as the safety of the outside air is determined.

In the cases examined for this report, termination decisions and times were not always apparent. Sheltering in place should only be used for toxic releases of limited duration – a few hours at most. The cases rarely noted both the time of the shelter in place advice and the "all clear" or terminate shelter order. In many cases, there was no mention of terminating the shelter in place.

- **Characteristics of the chemical** - The physical state of a hazardous materials influences the choice and effectiveness of protective actions. Clearly, gases and aerosols are the most likely to enter structures when sheltering in place. Typically, materials with higher volatility are more likely to enter structures than those with low er volatility. Another characteristic that is important to sheltering in place as an effective technique is whether or not the chemical is flammable and/or explosive. Chemicals that have the potential to ignite or create a vapor explosion generally call for evacuating populations that may be in or near a potential vapor explosion or fire.

> Reports gathered from all sources provided the name of the chemical released. In some cases, an estimate of the amount released into communities was also provided. Although there were no reports of vapor explosions or fires in communities as a result of chemical accidents, there were several reports of sheltering in place being used with releases of chemicals whose primary hazard was flammability. There were insufficient data to determine if the plume was sufficiently concentrated to create a substantial fire or explosion threat. However, emergency managers should be aware of the primary threats of chemicals that may be released in their jurisdictions. Some chemicals are both flammable and toxic, and, in some cases, flammability is a greater threat to the public than toxicity.

In order to implement and manage a successful shelter in place action, emergency management jurisdiction must be able to meet these requirements: 1) a mechanism to alert, warn and instruct the public; 2) structures capable of closure; 3) personnel and equipment to control access to the affected area; 4) a way to determine when the affected areas are free of hazardous gases; and 5) a way to ventilate and/or exit the structure after the emergency is over.

For every case in this study, local emergency managers have the Emergency Alert System (EAS) available to them. In most of the chemical-producing communities, siren systems have been installed and are used for both chemical and natural emergencies. These two mechanisms for alerting, warning and instructing the public are often mentioned in news reports of chemical emergencies. Databases do not provide this information. Other public alert and warning systems used in communities where shelter in place is used are telephone ring-down systems and cable-intercept. Telephone ring-down systems use computer-based dialing to call households in pre-determined sectors with warning and instructions. Cable-intercept systems allow EAS messages to be broadcast on cable channels as well as local, over-the-air stations. Information about these warning systems can sometimes be found in news reports, but was most often discovered during interviews. One issue that arose in one community regarding the EAS system was the computer-generated voice used in the new digital EAS. The computer voice was difficult to understand by many citizens. The LEPC in that jurisdiction is working with the National Weather Service to either improve the computer-generated voice or to use a human voice to tape the emergency warning and instruction message.

The availability of structures was usually found in reports on chemical accidents that used shelter in place as a protective action. Houses were the most commonly used shelters, but office buildings, industrial facilities, schools and prisons were also noted. Structure issues arise with people at recreational facilities such as golf courses, football games, festivals and the like. While an adjacent school might be available for sheltering spectators and participants in football games, it is unlikely that sufficient structures will be available for golfers and other participants in outdoor activities. And in these cases, none of these outdoor populations were mentioned except for a football game where an adjacent school was used to shelter in place. Emergency managers should be aware of outdoor activities in their community and plan accordingly.

Most of the reports also discussed the closing of roads and other transportation modes to prevent access to the areas affected by the chemical release. Some reports, however, were silent on whether access to the area was restricted. Access restriction is important to prevent people from entering an area where chemical exposure is possible. Generally, sheltering in place requires fewer resources to control access than does an evacuation..

Sheltering in place events where the termination of sheltering was discussed usually mentioned that the area was “all clear.” For some cases, the way of determining when it was clear and when people should ventilate structures was not apparent. For others, however, the news reports indicated that either public emergency responders or industrial facility personnel went into the community to monitor air quality. The timing of termination of sheltering in place is critical. Emergency responders need to be sure that the air is safe for people to ventilate their homes. However, the longer the terminate shelter order is delayed, the longer people will be exposed to whatever chemicals may have seeped into their homes. Typically, emergency responders are more concerned about verifying that the outside air is clear and prefer to have monitoring results before declaring an end to sheltering in place by the public.

Conclusions

Sheltering in place is an appropriate public protection tool in the right circumstances. For chemical releases of limited duration, it is faster and usually safer to shelter in place than to evacuate. For all the cases examined during this study, there were no fatalities associated with sheltering in place. There were a few cases where injuries were reported in situations where sheltering in place was ordered. Unfortunately, it was impossible to determine whether or not the injured parties actually sheltered in place. For the vast majority of events that have led to the public sheltering in place, there have been no reported injuries. In fact, for a very few cases, clouds of toxic materials of sufficient concentration to cause harm have entered communities and, because sheltering in place has been accepted by the community and was successfully implemented, no one was injured. The body of evidence suggests that if there is insufficient time to complete an evacuation, or the chemical leak will be of limited duration, or conditions would make an evacuation more risky than staying in place, sheltering in place is a good way to protect the public during chemical emergencies.

Appendix A

General Shelter In Place Instructions

Before an accident occurs, select a room in your house as a shelter location. The best sheltering location is a room with few windows and doors. It should also have a telephone.

Prepare a shelter in place kit. A shelter in place kit should contain plastic sheeting to cover any windows or vents, duct tape for installing the plastic and taping around doors, towels for placing at the bottom of doors, water for wetting the towels and for drinking, a battery operated radio and fresh batteries, snacks and games for any children. A flashlight with fresh batteries may be needed if the electricity fails, and a first-aid kit should be included.

Sheltering in place is a technique for minimizing exposure to chemicals that have been released into the air. Sheltering in place is most appropriate for chemical leaks of short duration.

When notified that a shelter in place has been recommended:

1) Go inside your home. Bring pets inside.

2) Shut and lock all exterior windows and doors. Locking provides a tighter seal.

3) Turn off any fans, air conditioners, vents or heating equipment. Shut fireplace dampers.

4) Enter your sheltering room. Shut and lock the door.

5) Tape plastic over any windows in the room. Use long strips of duct tape to make a continuous seal. Overlap tape where necessary. Use long strips of tape to seal the top, bottom and sides of the door. If the space at the bottom of the door is too wide to cover effectively with tape, wet the towels and place them at the bottom of the door.

6) Turn on the radio or TV to listen for emergency instructions. Do not use the telephone unless you have an emergency.

7) When the chemical accident is over, and you hear that an “All Clear” has been issued, leave your shelter room and ventilate your home. Open doors and windows, turn on air handling equipment to move air out of your home.

8) Go outside until your home has been ventilated.

It is very important to leave your home and to ventilate it as soon after a shelter in place has ended as possible. If your house was enclosed in a cloud of chemicals, small amounts of the chemicals may have entered your house. By turning on window fans or the fan on your heating system, you can exchange the air in your house with the clean air outside.

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