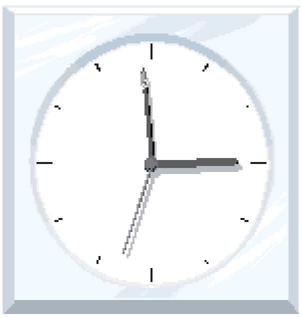
Technical Dialogue

Evacuate or Shelter in Place

by Dr. John Nordin, Ph.D.

A chemical spill accident or a terrorist incident has occurred or there is a very high probability that it will occur. Should civil authorities order an evacuation or have the public shelter-in-place, in their homes or where ever they happen to be?

Time is a Crucial Factor



Most incidents happen without prior warning. There is insufficient time to evacuate. The toxic chemical cloud or plume passes over the area before an orderly evacuation can occur. The public should be instructed to shelter-in-place (remain in their homes or offices, or seek shelter inside if they happen to be outdoors) rather than try to out run the toxic cloud.

Obviously there are overriding circumstances where evacuation is necessary. If there is smoke and fire or danger of buildings collapsing the public must be evacuated. Evacuation rather than shelter-in-place was the proper order for the World Trade terrorist incident of September 11, 2001.

An evacuation may be ordered if fire is threatening a tank farm or other location where chemicals are stored. Pressure can build up inside chemical tanks or drums due to the heat of a fire causing them to explode. Large chemical storage tanks have pressure release valves and secondary containment, but safety systems can fail and many chemicals form toxic gases in a fire. A propane tank in a fire can explode sending shrapnel a half mile from the source.

A public evacuation may be ordered in case of a transportation accident, especially a train car derailment, involving hazardous chemicals even though the chemical is contained. This is a precaution in case the tank is breached. Cleanup could involve transfer of hazardous chemicals to other tanks resulting in vaporization of hazardous chemicals even under ideal circumstances. Even though the tank is not leaking, the tank itself or valves may be damaged.

Evacuations may be ordered even during an incident as a precaution in case of wind shifts. Depending upon meteorology, the toxic cloud could be several miles long but only a few blocks wide. Changing wind patterns could cause the plume to shift or meander in another direction.

Evacuations may be ordered even after the toxic cloud has passed if there is danger of residual contamination or possible secondary releases or explosions. A terrorist release of a “dirty bomb” or chemical or biological warfare agent is an example. A ‘dirty bomb” incident is the use of explosives to disperse radioactive material over wide area. The public is instructed to shelter-in-place during and perhaps for some time after the incident. At some later time, the public is evacuated because of residual radioactive dust, or anthrax spores, etc., in the area. People might then be sent through a DECON station.

Communication is Important

Incidents happen without warning. Emergency responders need to have in place methods of communication to the public.

The train derailment incident on January 18, 2002, in Minot, North Dakota is a study on communication. The derailment occurred during the middle of the night (1:34 AM) in which 8 of the 15 derailed cars containing anhydrous ammonia were breached releasing about 230,000 gallons of anhydrous ammonia. The resulting ammonia vapor cloud was 5 miles long, 2.5 miles wide, 350 feet high, and enveloped more than 40% of the city of Minot, affecting 15,000 people. Temperatures outside were –6°F with winds from the southwest at 6 or 7 mph. Communication systems were overwhelmed with more than 2800 calls to 911 on January 18. More than 330 people were treated initially and 1605 people were treated for recurring ailments. Eleven people experienced serious injuries. There was one fatality. Details of 911 calls, how communication was handled, and public reactions may be obtained from the website,

http://www.in-forum.com/specials/minot/index5.cfm

Timely evacuation or rescue was not possible leaving shelter-in-place as the only option, but emergency responders were not able to communicate this information to the public. Because of power failure, TV stations were off the air. Radio stations played piped-in programming. It was at least 90 minutes after the incident before any emergency instructions were broadcast to the public over radio and TV. Sirens were sounded initially but not all of them worked. The sirens were not resounded for fear that the public, upon hearing the sirens, would go outside to see what was going on. There were incidents where people thinking that the vapor cloud was smoke from a fire went outside and were overcome or experienced injury not knowing what was going on. There was another incident where a motorist drove around a roadblock into the toxic cloud. With people overwhelming the 911 system, dispatchers were prevented from controlling radio traffic for firefighters and police personnel. The fact that almost everybody in the toxic cloud path "sheltered-in-place" was probably due to the extremely cold weather and that the event occurred during the night into early morning.

The Minot incident did demonstrate the value of shelter-in-place, but David Waind, Minot City Manager commented, "It took an event like this to see the shortcomings of our notification system".

Another incident took place 13 years ago in a area of southern California populated by various ethnic groups mostly Hispanic. A fire occurred in a chemical storage area producing toxic hydrogen chloride and chlorine in the resulting smoke. Orders were given in various neighborhoods to evacuate as the toxic chemicals developed in the smoke cloud and wind began to shift. However the orders, over police loud speaker, were given in English and were not understood by Spanish-speaking residents.

Other Incident Studies

Specific case studies on whether it is better to evacuate the public or shelter-in-place has been reviewed in a paper published by the National Institute for Chemical Studies, June 2001. The paper (approximately 50 pages long) can be downloaded from the Internet at http://www.nicsinfo.org/shelter%20in%20place.pdf

The conclusion of the paper is "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, then sheltering in place is a good way to protect the public during chemical emergencies".

What Should a Person Do if a Chemical Release Takes Place?

Most likely people will be notified by the emergency alert system. There will be a banner at the bottom of the television screen, a notice given on the radio, or civil defense sirens will sound. However, some people will be close to the accident. The only warning might be a strange sound like an explosion, a strange cloud, and perhaps a strange odor. Immediate action is required especially if people feel nauseous or have burning or tearing eyes. If it is obvious that people can safely evacuate the immediate area, do it, but in most situations where fire is not a threat the best option is to shelter in a building. A nearby school, church, or store are good options if his/her house is not nearby.

How to "Shelter-in-Place

A chemical spill has occurred releasing a toxic chemical gas or vapor. Shelter-in-Place means that you go inside your home or other nearby building before the toxic gas cloud reaches you. The windows and doors should be closed. Any ventilation fan that exchanges outside air with inside air should be turned off. The concentration of toxic chemical that a person is exposed when indoors should be much less than if he/she were outdoors.

The two things that determine the concentration of the toxic chemical inside the building is the building air exchange rate and the duration of the cloud outside. Fortunately for most chemical releases the cloud duration is short, that is, it passes over quickly. If there is a fire producing acrid smoke (toxic chemicals within the smoke), the cloud may last much longer, and evacuations might be ordered. While a person does not have control of the cloud duration, he or she can take steps to reduce chemical infiltration.

The most obvious steps that a person can take is to close the windows and doors and shut off any fans that exchange inside and outside air. The U.S. Army completed a study of how fast tracer gas entered various types of buildings. The study found that air exchange rates in residential houses (closed windows) varied from 0.16 to 0.86 per hour with 0.33 being typical for older residential houses. However if one room of the house were sealed up with duct tape and plastic, the amount of chemical within the room after one hour was $1/7^{th}$ to $1/17^{th}$ of what the chemical was outside. Another Army study showed that sealing up the house not only limited the contaminated air coming into the house but also filtered out some of the harmful chemicals. Sheltering in place cannot completely eliminate exposure to the chemical but can keep the exposure to below dangerous levels.

Once inside the home, the person should:

- close doors and windows
- turn furnace fan off
- turn off ventilation fans
- make sure the clothes dryer is off
- close dampers on fireplace (if there is a fire in the fireplace, let it burn down without closing the dampers)
- pick one room in the house to use as a shelter room. A bathroom is a good choice because water and toilet is available if needed. A master bedroom is a good choice if it has a bathroom and phone. An upstairs room may be a better choice than a basement room because many chemicals are heavier than air and tend to sink near the ground. Bring in a battery powered radio, cordless phone, some water, some food, duct tape, towels, and plastic sheeting or plastic bags.
- once everyone is inside, seal up the windows and doors using plastic sheeting or plastic bags and duct tape and/or damp towels
- listen to radio or TV for instructions
- Don't call 911 unless there is an emergency like a fire or serious injury

If the person is outside and cannot make it to a building, if possible he/she should try to move crosswind to the chemical cloud. If a person is in his/her car and cannot drive away from the cloud or get to a building safely, he/she should turn off the ventilation system, make sure that the windows and vents are closed, and tune in a local radio station.

Eventually some chemical will seep into the building and even the shelter room. The toxic chemical may remain inside the building even after the air has cleared outside. Emergency response personnel will need to give instructions to the public as to what to do, which could be to ventilate the building or even order an evacuation.

Example Calculation

Consider the following hypothetical example. A railcar containing anhydrous ammonia is breached as the result of a large rupture forming a gaseous ammonia cloud somewhere east of Denver, Colorado. The nearest residential structures are 1 km (0.62 miles) downwind. Wind speed is estimated to be 1 meter/sec. We don't know whether a liquid pool forms which continues to evaporate or how long the ammonia cloud will last or exactly where it will go, but sirens are sounded and emergency instructions are given to remain indoors, shut windows, and shelter-in-place. What ammonia concentrations can be expected indoors and outdoors 1 km downwind?

Discussion: The Immediately Dangerous to Life and Health (IDLH) concentration is 300 parts per million (ppm) ammonia in air. The level-2 Emergency Response Planning Guideline (ERPG-2) concentration is 150 ppm; ERPG-2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

The recommended maximum 8-hour exposure level (time-weighted average) for workers is 25 ppm.

The PEAC tool can be used to estimate the concentration outdoors. For Denver Colorado, early morning (7 AM), flat terrain, wind speed 1 meter/sec, and a large rupture on a railcar, the PEAC tool displayed a downwind distance of 1.9 km corresponding to the default entry of 300 ppm, which is the IDLH concentration. This downwind distance displayed was greater than 1 km. We need to do a reverse calculation and ask the PEAC tool what is concentration in the cloud at 1 km downwind. This can be done surprisingly fast by inserting different concentrations into the PEAC tool until 1 km (1000 meters) is displayed. The concentration that results in a 1 km protective action distance is 860 ppm ammonia. This concentration is much higher than the IDLH value.

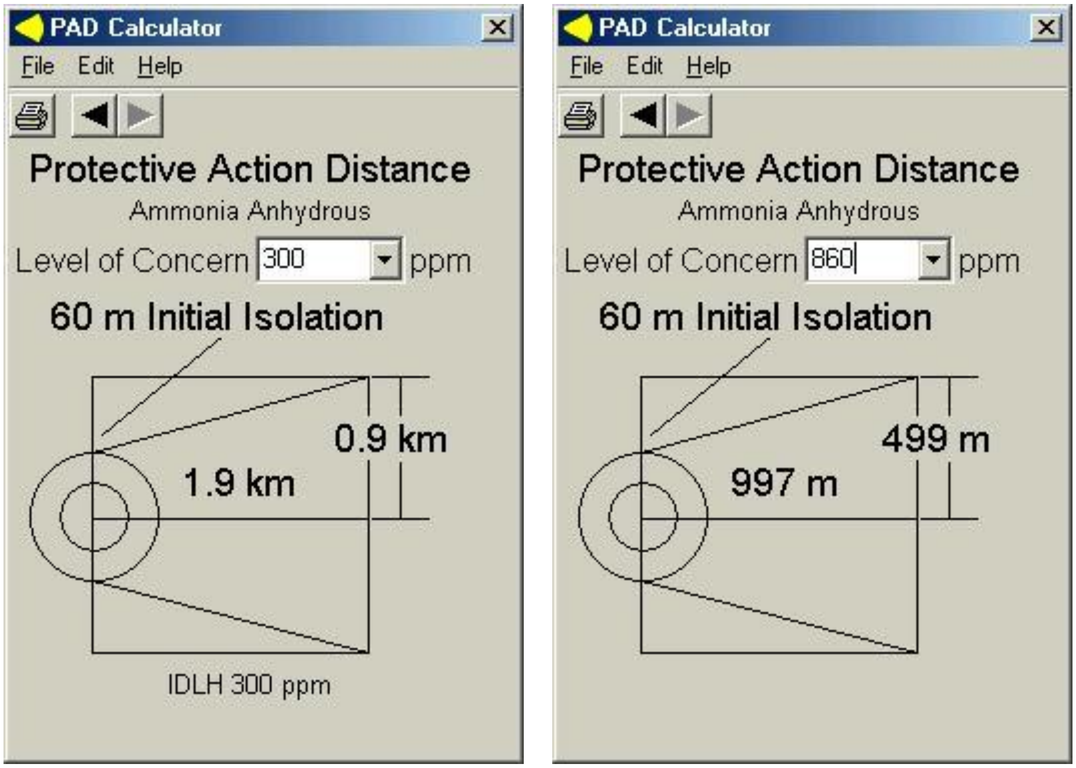
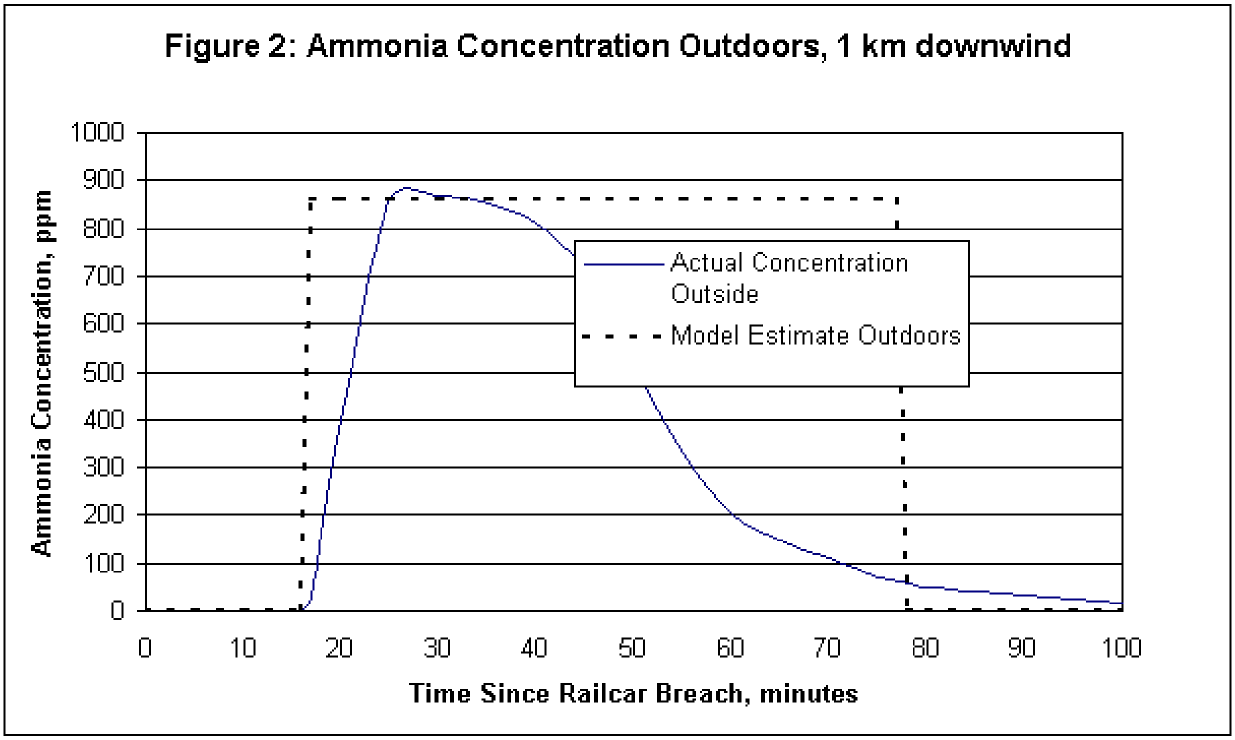


Figure 1: PEAC Displays for Outdoor Concentrations

At a wind speed of 1 meter/sec, it will take about 17 minutes for the toxic cloud to reach residences 1 km away. Probably several minutes have already past before any sirens or warning is given and there is no time to evacuate. The duration of the cloud is unknown but we will assume one hour. One hour is also the default time for the cloud duration if the continuous release mode is selected for the ALOHA model used in CAMEO.

Figure 2, below, might represent the actual plot of the highest concentration for a point one kilometer downwind superimposed on our quick model guess. Emergency Responders will not know what the actual concentration will be and have only the model estimate. The model result of 860 ppm for one hour is superimposed onto figure 2.



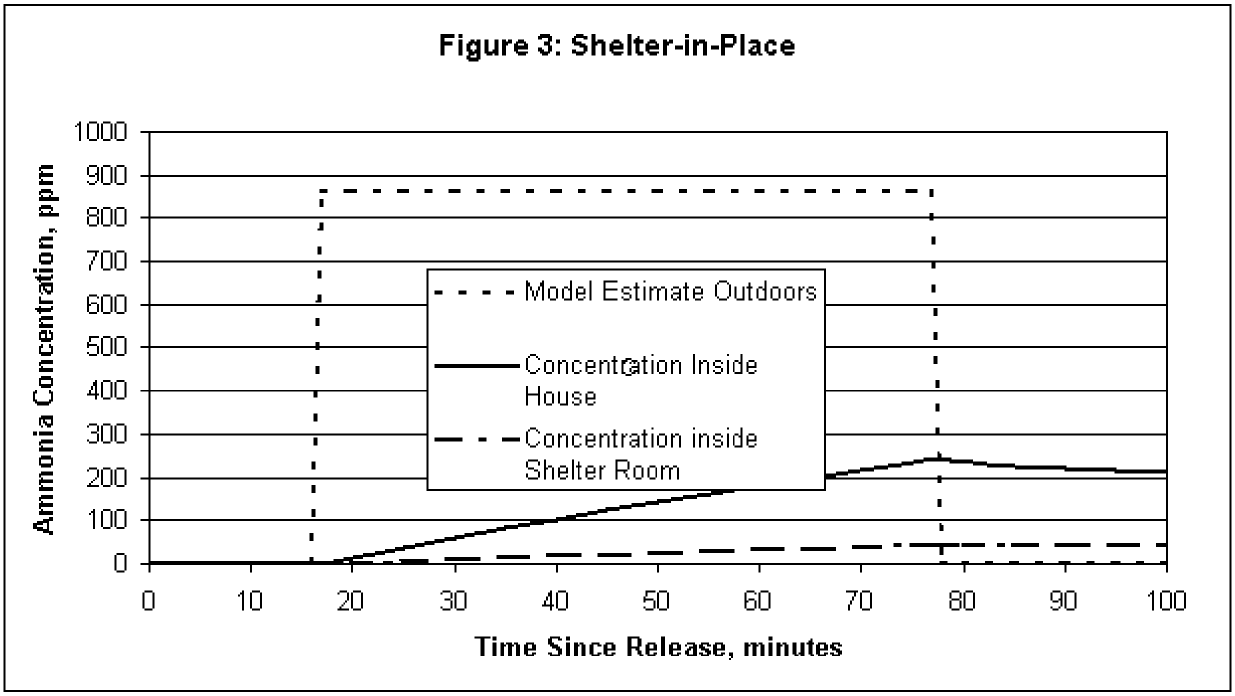
What ammonia concentration can be expected inside the residences? We will assume that the doors and windows are closed, and all fans have been turned off. We will also assume that the family retreats to a shelter room and is able to seal up the cracks with duct tape and plastic and wet towels, whatever is handy. Figure 3 might represent the concentrations indoors and in the shelter room assuming that the model estimates the concentration outdoors.

Note that the estimated concentrations inside the house and inside the sealed shelter room are much less than the concentrations outdoors. Of course, the numbers depend upon the air exchange rate between the shelter room, inside house air, and the outdoors. In the example, we assumed an air exchange rate between the house and outside of 0.33 house volumes per hour, which is typical of older residences. For the sealed shelter room, we assumed an effective air exchange rate between the outside of 0.05 volumes per hour. The concentration of ammonia at any time T (since the start of the release) is

$C = C_o (1 - e^{-V(T - t)})$ between T = 18 minutes to 78 minutes

where C_o is the concentration outdoors (860 ppm), V = volume exchanges per unit time, T= time since the railcar breach, t = travel time for cloud to reach residence 1 km downwind.

Note that after the toxic cloud has passed, some residual ammonia still remains in the shelter room and in the residence. Emergency responders need to instruct people what to do.



While the numbers (air exchange rate and cloud duration) can be debated, the example does show the value of shelter-in-place at reducing exposure to a toxic chemical if there is insufficient time to evacuate people.