Technically Speaking
A Look at the Isolation Distance and the PAD
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INITIAL ISOLATION AND PROTECTIVE ACTION DISTANCES, PLUME MODELING

Users of the Emergency Response Guidebook will see a section that lists initial isolation and protective action distances in case of a spill of a chemical that is toxic by inhalation. The Emergency Response Guidebook is published jointly by the governmental agencies in Canada, United States, and Mexico, which regulate transport of hazardous or dangerous materials. We will take a look at these distances, including how the numbers are computed and why different reference sources or models give different answers for evacuation distances. But first, let us look at some definitions.

The 2004 edition of the Emergency Response Guidebook can be downloaded at: http://hazmat.dot.gov/gydebook.htm#fullversion.

Definitions

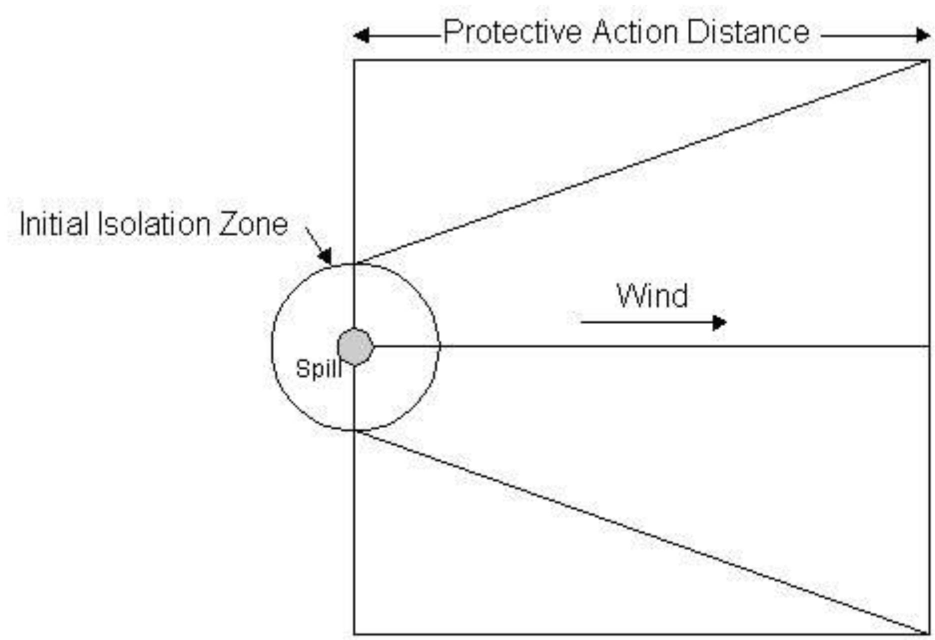

Figure 1. Defining Initial Isolation Zone and Protective Action Distances

The Emergency Response Guidebook (ERG) presents tables which lists initial isolation and protective action distances for various chemicals if spilled. There are different categories depending upon whether it is a small spill (<55 gallons or 200 liters) or large spill (> 55 gallons) or daytime or nighttime conditions. In the sketch above (figure 1), the spill is represented by the small grey circle in the center. The initial isolation zone is represented by a larger circle within which the public must be evacuated and not be permitted to enter (except response personnel with appropriate personal protective equipment). The radius of the initial isolation zone is the initial isolation distance listed in the tables. The initial isolation distance extends equally in all directions from the spill, even upwind.

Why evacuate upwind? Experience has shown that the backwash created by buildings and terrain will result in some of the toxic chemical vapors or gases to be carried upwind. Tests at the Nevada Test Facility where a toxic simulant gas was released at ground level showed some travel of the gas upwind due to the natural turbulence created by the wind. Also, when experiments performed under near windless, nighttime conditions, the toxic dense gas stimulant spread out in all directions from the source near the ground. Another reason for evacuating the public in all directions is that emergency response personnel need space to work.

As expected, the bulk of the toxic gas or vapor plume cloud will be carried downwind. The Protective Action Zone is defined by a square whose length and width is the same as the Protective Action Distance listed in the tables. The crosswind evacuation distance is half of the downwind evacuation distance. This zone is the area where people are at risk of harmful exposure if the chemical is inhaled and therefore, should be evacuated.

If there is a steady wind blowing, the toxic plume cloud may be long and narrow. The June 19, 1988 chlorine fire plume cloud at Springfield MA under about 8 mph wind conditions was only a few city blocks wide but several miles long. Under a clear nighttime, low wind condition, the toxic cloud may be several miles long and almost as wide as it is long. Winds can also shift direction. Buildings and uneven terrain can broaden the cloud or channel the cloud in a direction different from the prevailing wind. Rather than try to account for these differences in cloud width, the Emergency Response Guidebook takes a “one size fits all” approach and defines a standard protective action distance for evacuation downwind and crosswind from the spill.

The Emergency Response Guidebook does consider differences between daytime and nighttime spills in estimating Protective Action Distances (PADs). The PADs for nighttime conditions are greater than for daytime conditions. During the day, solar heating of the ground takes place. The air near the ground heats up creating air turbulence which helps to disperse the toxic chemical cloud. During nighttime conditions, the air is generally more stable and the cloud travels further downwind without dispersing. The ‘worst-case’ condition is the so-called “F” atmospheric condition, which occur during a cloudless night when winds are less than about 2 mph. Under the “F” condition, the cloud can spread out for great distances crosswind and downwind and take a very long time to disperse.

What Determines Initial Isolation and Protective Action Distances?

The distances listed in the Emergency Response Guidebook are determined by:

- How toxic the material is by inhalation
- The amount of the release
- How the release takes place (e.g. a slow leak or evaporating liquid from a pool vs all of the material released to the air at once as in a explosion or aerosol)
- Weather conditions
- Whether the material is spilled in water producing toxic gases.

This is a very complex subject. The various editions (e.g., 1996, 2000, 2004) of the Emergency Response Guidebooks reflect changes in the listed distances as more information becomes available and methodology is improved and refined.

The distances listed assume that the chemical is spilled in an open, outdoor location and does not consider release in a confined location as in an airplane or building, or a chemical cloud channeled by terrain.

Toxic Inhalation Hazard materials (TIH)

The Emergency Response Guidebook classifies hazardous materials into TIH materials and non-TIH materials. Even a non-TIH material spill or accident may have an isolation distance specified under the “PUBLIC SAFETY” section under the Guide Number associated with the UN (United Nations) Shipping Number. This isolation distance is specified in the interest of public safety. Materials which are toxic by inhalation [TIH materials] have both initial isolation and protective action distances listed, and the toxicity of the material is a major factor determining what distances is listed. The Emergency Response Guidebook looks at LC50 numbers published for the chemical (e.g. see the government Hazardous Substance Data Base at http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB0). LC50 is the airborne concentration that results in death of 50% of the test animals, usually a rat, when the animals are exposed to the chemical for 1-hour. The assumption is made that humans experience the same level of toxicity as the test animals. The Emergency Response Guidebook further subdivides LC50 numbers of TIH materials into Hazard Zones, as follows:

- Hazard Zone A: LC50 of gases or vapors less than or equal to 200 ppm
- Hazard Zone B: LC50 less than or equal to 1000 ppm but greater than 200 ppm
- Hazard Zone C: LC50 greater than 1000 ppm and less than or equal to 3000 ppm
- Hazard Zone D: LC50 greater than 3000 ppm but less than or greater than 5000 ppm

The Hazard Zones do not represent areas or distances but are assigned on the basis of LC50 values.

The American Industrial Hygiene Association (AIHA) publishes Emergency Response

Planning Guideline (ERPG) levels for various chemicals. Guideline development is a slow, peer-reviewed process. ERPG levels have been published for about 110 chemicals to date, with about 7 new chemicals added each year. ERPG levels current as of 2004 is at http://www.aiha.org/Committees/documents/erpglevels.pdf. If an ERPG level 2 (EPRG-2) value has been published, the Emergency Response Guideline uses this number for setting the PAD. If a ERPG-2 value has not been established, the PAD is set at 0.01 x LC50. If several different LC50 numbers appear in the literature, the most conservative (i.e. the lowest) value is selected. The definition of ERPG-2 is:

ERPG-2: 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 Initial Isolation Distance is usually based on ERPG-3 values if available, but may be based on NIOSH's published IDLH [Immediately Dangerous to Life and Health] values or on 0.1 x LC50 and other safety considerations. The IDLH is either based on 10% of the Lower Explosive Limit or on toxicity considerations (no injury or irreversible health effects for a 30-minite exposure) or severe respiratory or eye irritation, whichever is most stringent.

Table 1. Initial Isolation and PADs for Example Chemicals

Chemical	ERPG-2 ppm	LC50 ppm	Small Spills, Initial isolation Distance, km	Small spills, PAD, Daytime, km	Small Spills, PAD, Nighttime km	Large Spills, Initial Isolation Distance, km	Large Spills, PAD, Daytime, km	Large Spills, PAD, Nighttime, km
Ammonia	150	7338	0.03	0.1	0.1	0.06	0.6	2.2
Chlorine	3	293	0.03	0.2	1.2	0.24	2.4	7.4
HCl	20	3124	0.03	0.1	0.4	0.36	3.6	10.4
Phosgene	0.2	100	0.09	0.9	4.1	0.8	6.6	11+
Trifluorochloroethylene	100	8568	0.03	0.1	0.1	0.06	0.4	0.8
Pentaborane	Not pub.	10	0.09	0.9	3.3	0.6	5.3	11
Compressed gas, toxic inhalation hazard zone A	Not pub.	< 200	0.12	1.2	5.1	1	8.7	11+
Compressed gas, toxic inhalation hazard zone B	Not pub.	200 to 1000	0.03	0.2	1.2	0.42	4.0	10.8
Compressed gas, toxic inhalation hazard zone C	Not pub.	1000 to 3000	0.03	0.2	0.8	0.24	2.4	6.4
Compressed gas, toxic inhalation hazard zone D	Not pub.	3000 to 5000	0.03	0.1	0.2	0.09	0.8	2.4
Ethyl isocyanate	Not pub.	28	0.06	0.6	2.1	0.8	6.2	11+
GB (when used as a weapon)	Not pub.	25	0.15	1.7	3.4	1	11+	11+
Boron tribromide (land spill)	30 mg/m^3	387	0.03	0.2	0.5	0.06	0.5	1.3

Boron tribromide (water spill)	Not pub.	HBr	0.03	0.1	0.5	0.09	0.7	2.6

Note: Ammonia ERPG-2 basis was 200 ppm in 2000 Emergency Response Guidebook

To convert km to miles, multiply by 0.62.

Examination of **Table 1** shows that generally the more toxic chemicals have the greater initial isolation and protective action distances. But it is not a direct proportional relationship. This is because other factors enter in such as amount of material spilled, degree to which the material disperses into the air, reactivity with water, and meteorology.

Amount Spilled, Release to Atmosphere, Meteorology

The U.S. Department of Transportation used a statistical approach when developing initial isolation and protective action distances. This means that they looked at historical accidents, meteorological observations over 5 years at 120+ locations in Canada, United States, and Mexico, container sizes likely to be used when shipping hazardous materials, and most probable accident release scenarios. The vapor cloud plume concentrations were modeled as a function of distances downwind to the toxic level of concern (e.g. the latest ERPG-2 or 1% of LC50 or other criteria) to get a PAD. When considering all of these different release situations for a particular chemical, a 90% statistical criteria rule was adopted for establishing a PAD for the Emergency Response Guidebook, that is, 90% of the many scenarios modeled had PADs equal to or less than the PAD selected for listing. In other words, for 90% of the accidents where toxic chemicals are released, the concentrations at the PAD should be less than ERPG-2 or 1% of LC50. But what about the other 10%? There is some conservatism built into selection of the hypothetical cases and subsequent modeling, but there still could be a “worst case” situation [a large amount of toxic chemical released at once under an “F” atmospheric stability] where the distances predicted in the Emergency Response Guidebook are too small.

The Emergency Response Guidebook (ERG) defines small spills as less than 55 gallons. A slow leak from a large container is still considered a small spill. But the ERG does not make mention of what container sizes were used in the modeling scenarios for the chemical.

Details on the container sizes used in the modeling scenarios in the 2000 ERG are detailed in *Brown, F.F. et al, 2000*. “Development of the Table of Initial Isolation and Protective Action Distances for the 2000 Emergency Response Guidebook”, Argonne National Laboratory, Argonne, IL, report ANL/DIS-00-1. This report is available at http://hazmat.dot.gov/anl-dis-00-1.pdf.

Small and large releases as applied to chemical warfare agents vary depending upon the agent. For Sarin (GB), a small release for the purpose of modeling is 2 kg. A large release is 100 kg. The term “when used as a weapon” with Sarin means that that the material is released quickly as a spray or explosive release. For hydrogen cyanide (AC), a small release for the purpose of modeling is 60 kg and a larger release is 30000 kg. The term “when used as a weapon” with hydrogen cyanide or AC means a sudden release by equipment sabotage.

PEAC tool Modeling for Protective Action Distance

The PEAC tool adopts the same concept of the Initial Isolation and Protective Action Distances as in the ERG. The Initial Isolation Distance is the same, but the user has the option of modeling a PAD for the specific circumstance of the accident or terrorist incident. The user may specify that the chemical is released all at once as in explosion (whether from an accident or terrorist activity) or slowly as in an evaporating pool. The user can specify the size of the container or mass released. The user can specify a PAD based on ERPG-2 or any other level of concern. The user can model the plume cloud based on meteorology. All this gives the first responder more control over the decision making process for ordering public evacuations. For example, in the case of a hydrogen chloride (HCl) nighttime release, there is a big difference in ordering evacuation 10.4 km downing as opposed to ordering an evacuation 0.4 km downwind (compare small and large release, table 1). The ERG tables for initial isolation and PADs are, of course, in the PEAC tool, but the PEAC tool also gives the user the option of adapting the PAD for the particular circumstance rather than depend on information developed for a 90% statistical average.

Example: January 2005 Chlorine Release from Railcar Accident at Graniteville S.C. Killing 9 People.

For newspaper accounts and photos of the accident site visit:

http://www.cnn.com/2005/US/01/07/train.wreck/
http://www.augustachronicle.com/stories/010605/lat_train.shtml
http://home.hamptonroads.com/stories/story.cfm?story=80666&ran=171463
http://www.citizen-times.com/cache/article/editorial/73787.shtml
http://pubs.acs.org/cen/news/83/i03/8303notw1.html

EPA Photo 6 Jan

On 6 January 2005, at 2:39 AM (another report said 2:30AM), a Norfolk Southern freight train carrying 42 cars struck a parked train at a crossing siding near the Avondale Mills textile plant in Graniteville, South Carolina. A track switch in the wrong position diverted the freight train to the siding. The freight train included three cars carrying chlorine; one of the cars began to leak chlorine gas at the time of the accident. An evacuation order was issued for residents within 1 mile from the site, affecting 5400 people; many residents already experienced eye irritation and breathing difficulties at the time of the evacuation order. Nine deaths occurred to chlorine inhalation. About 350 people were initially treated at the county medical center for chlorine inhalation. The deaths included 6 workers at Avondale Mills, the train engineer (it is not clear whether the train engineer died from chlorine inhalation or from wounds sustained from the crash), another person found dead in a nearby home, and another in his truck in the parking lot near the plant. No one was in the parked train. A worker at the textile plant at the time of the accident reported “I saw a green mist coming towards me… I ran to my supervisor who said to get them [the workers] out”. Others reported a greenish-yellow fog that rolled in and smelled powerfully like bleach, searing eyes and making them cough and gasp. Some workers escaped to the roof of the textile plant. A volunteer firefighter who was one of the first to arrive at the scene saw workers lying on the ground outside but without protective respiratory equipment could not do anything to help, and he himself had difficulty breathing and had to leave. The amount of chlorine released was not determined, but a Lt. sheriff interviewed the next day said that the rail car had a 90 ton liquid chlorine capacity, and the 30 to 40 percent of its contents still remained in the tank and was still leaking from the car. An initial EPA report (http://www.epa.gov/Region4/waste/errb/granitvillepolrep3.pdf) had estimated the release even higher. There was a report of some liquid chlorine entering a storm drain at the site, and fish kills were also reported where the drain emptied into a pond.


Aitkin Co Sheriff Dept. photo, used by AP

As of January 10, 29 people remained hospitalized with four in critical condition. A South Carolina Department of Health and Environmental spokesman estimated that 60 tons of chlorine escaped from the warped rail car and that another 30 tons remained. A temporary polyethylene patch was used to plug the hole in the rail car on 9 January, which was described as the size of a fist. A steel patch was fabricated which was installed at 3:30 PM on 12 January. Cleanup crews used sodium hydroxide to mop up the chlorine. Norfork Southern began transfer operations from the other two rail cars (about 90 tons per tank car) involved in the accident. Hulcher Services was contracted to perform containment and cleanup services. This highest ambient chlorine reading among 26 monitoring units placed at the crash site (readings 12 January) was 1.9 ppm. The mandatory one-mile evacuation zone continued in effect, plus a 6PM to 7AM curfew within 2 miles from the site, until the chlorine was removed from the tank cars. Most residents were allowed to return on 14 January.

Our Analysis:

- The 2004 Emergency Response Guidebook lists 0.8 miles (1.2 km) as a PAD for small spills and 4.6 miles (7.4 km) for large spills for a nighttime release of chlorine. The initial isolation zone is listed as 100 feet (0.03 km) for small spills and 800 feet (0.24 km) for large spills. Available newspaper accounts make mention of a “hot zone” at the site and an evacuation zone of one mile radius plus a nighttime curfew extending two miles from the site. The evacuation and curfew zones imposed by local authorities are in effect PADs but extended in all directions from the site.
- The 90-ton capacity rail car indicates that this is a large spill, but the release did not occur all at once. There was still about 30 tons left in the rail car after several days, at least until a polyethylene patch was used to plug a fist-sized hole in the tank car on January 9. There was probably an initial fairly large release of liquid under pressure [reports spoke of some liquid chlorine reaching a drain] at the time of the accident. Thereafter, the chlorine was released slowly from the tank as a gas as the liquid remaining in the tank evaporated.
- Considering that chlorine leaked from the tank car over a several day period and that there were still two 90-ton rail cars at the accident site, authorities were wise

in extending the evacuation zone and curfew in all directions rather than "downwind" as winds can easily shift.

- Available newspaper accounts indicated that the Avondale Mills employees on night shift responded quickly in getting people away from the chlorine plume at the time of the accident which probably save many more lives.
- We [Aristatek] were unable to determine what the weather conditions (wind speed and direction and sky cover) were at the time of the accident making modeling of the chlorine cloud difficult. An unofficial report was that the weather was overcast, little or no wind, and possibly a light rain. Weather conditions the following morning were described as gusty strong winds from the southwest. Ambient chlorine readings the next morning were low out in the open but were described as "off scale" at some locations at the site where the winds did not scour out the air. Strong chlorine odors were reported along highway 1 during the night of 9 January when an air inversion took place.
- Modeling of the release using the PEAC tool suggests that the situation could have been much worse. If the entire 90 ton contents were released quickly (e.g. through a 3" diameter hole at the bottom of the tank) under clear nighttime, low wind conditions, lethal concentrations of chlorine would have extended more than 1 mile from the accident site, and a PAD distance based on ERPG-2 concentrations in excess of 10 miles would need to be established.
- The accident demonstrates the need to have information in the hands of first responders to make decisions to save lives.