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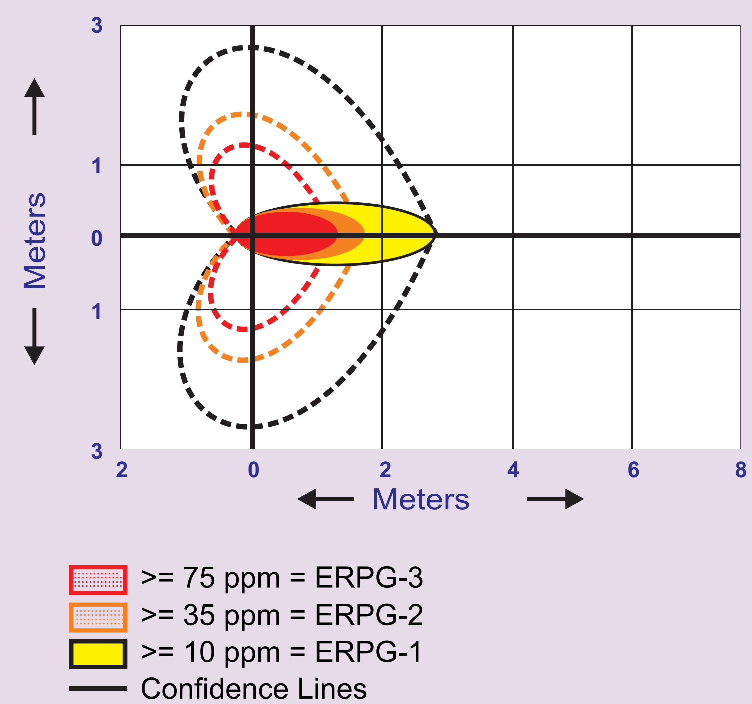
Theme – 12

Consequence Analysis: A Vital Need for Emergency Planning

industrial Disaster Risk Management



DMI Bhopal
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Since inception, DMI has built vast experience in preparation of both On-site and Off-site Emergency Management Plans, Safety Audit, Risk Analysis and Risk Assessment, Hazard and Operability Studies (HAZOP), etc.
The National Disaster Management Authority (NDMA) constituted under the chairmanship of the Prime Minister selected DMI as a member of the Core Group for preparation of the National Disaster Management Guidelines- Chemical Disaster.
It is a matter of pride that NDMA has selected DMI for conducting Mock Exercises on chemical (industrial) Disaster Management at key industrial locations in the country.
The Ministry of Environment and Forests, InWEnt and gtz-ASEM Germany have recognized DMI as a Nodal Training Institutes for capacity building in industrial Disaster Risk Management.

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Contents

Consequence analysis of the released hazardous chemicals into the environment is one of the vital parts of the overall emergency management. The module tries to highlight the important consideration for consequence modelling and insists that consequence analysis should be done by considering all possible variables, as one variable may change the impact zones.

A few examples have been taken for certain chemicals to show how the consequence analysis should be carried out. One chemical may result in different impacts zones hence analysis at one place should not be copied for the other places.

1. Introduction

When a hazardous material escapes from its normal container due to some reason, it leads to the formation of gas, vapour, liquid or two-phase release. If the escaping fluid is combustible and an ignition source is present, a fire may occur. The situation may produce pool fire, jet fire, Boiling Liquid Expanding Vapour Explosion (BLEVE) etc. depending on the situation. If the ignition source is not present, the cloud gets diluted and blows off slowly. If the liquid is toxic, all living objects in the path of the cloud are exposed to toxic cloud.

The nature of the damage resulting from an accidental release of a chemical depends on several factors viz., nature of the material, storage condition, release condition, atmospheric condition etc. The best way of understanding and quantifying the physical effects of any accidental release of chemicals from their normal containment is by means of mathematical modelling, called Consequence Analysis (CA). Consequence analysis deals with the study of effects of potential dangers involved in accidental release of regulated chemicals. As far as chemical industries are concerned, there are two types of consequence analysis: On-site CA and off-site CA. Worst case release scenario and alternative case release scenario are the two basic elements of Consequence Analysis.

A flow chart for consequence analysis is shown as Fig -1.

2. Worst-case release scenarios

2.1 Definition

The Environmental Protection Agency (EPA), USA has defined a worst-case release as

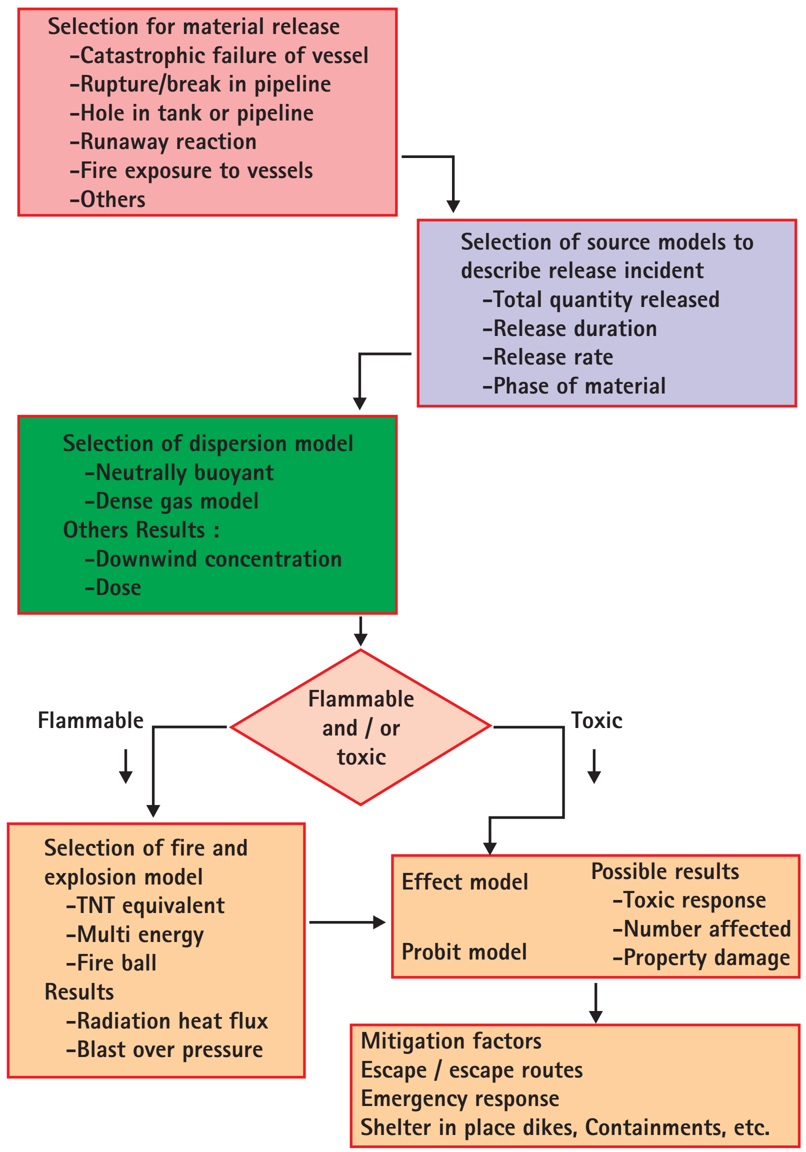


Fig-1 Flow chart for consequence analysis

the release of the largest quantity of a regulated substance that results in the greatest distance from the point to a specified end-point. For substances in vessels, release of the largest amount in a single vessel; for substances in pipes, release of largest amount in a pipe should be assumed. Actually the largest quantity should be determined taking administrative controls into account .

Administrative controls are written procedures that limit the quantity of a substance that can be stored or processed in a vessel or pipe at any one time, or alternatively, occasionally allow a vessel or pipe to store larger than usual quantities (e.g. during turnaround). It is not necessary to consider the possible causes of the worst-case release or the probability that such a release might occur; the release is simply assumed to take place.

2.2 Worst-case releases of toxic substances

For the worst-case release analysis for toxic substances, several assumptions are used. These assumptions are very conservative; the results likely will be very conservative.

2.2.1 Modeling assumptions

(a) End-points: in the definition of worst-case analysis for toxic substances, the end-points are the concentrations below which it is believed nearly all individuals could be exposed for one-half to one hour without any serious health effects. The distance to the end-point estimated under worst-case conditions should not be considered a zone in which the public would likely be in danger, instead, it is intended to provide an estimate of the maximum possible area that might be affected in the unlikely event of catastrophic conditions.

(b) Release height: all releases are assumed to take place at ground level for the worst-case analysis. Even a ground-level release is unlikely at the site, we must use this assumption for the worst-case analysis.

(c) Wind speed and atmospheric stability: meteorological conditions for the worst-case scenario are defined as atmospheric stability class F (very stable atmosphere) and wind speed of 1.5 m/s. If we can demonstrate a higher minimum wind speed or less stable atmosphere over three years, these minimums may be used.

(d) Temperature and Humidity: The highest daily maximum temperature that occurred in the previous three years and the average humidity for the site should be used. Small differences in temperature and humidity are unlikely to have a major effect on results.

(e) Topography: Two choices are provided for topography for the worst-case scenario.

If the site is located in an area with a few buildings or other obstructions, we should assume open (rural) conditions. If the site is in an urban location, or is in an area with many obstructions, we should assume urban conditions.

(f) Gas or Vapour Density: For the worst-case scenario analysis, we must use a model appropriate for the density of the released gas or vapour. Generally, for a substance that is lighter than air or has a density similar to that of air, we would use a model for neutrally buoyant vapours. For a substance that is heavier than air, we would generally use a dense gas model.

Required parameters for modelling worst-case scenarios
For toxic substances, use the endpoint of STEL.
For explosive substances, use the endpoint of an over pressure of 1 pound per square inch (psi) for vapour cloud explosions.
For flammable substances, use the endpoint of an heat flux of 4.5 kW/sqm.

Wind speed/stability
Use wind speed of 1.5 meter per second and F stability class unless the local meteorological data applicable to the site show a higher minimum wind speed or less stable atmosphere at all times during the previous three years. If the site demonstrates a higher minimum wind speed or less stable atmosphere over three years, these minimums may be used.
Ambient temperature/humidity
For toxic substances, use the highest daily maximum temperature during the past three years and average humidity for the site.

Height of release
For toxic substances, assume a ground level release.
Topography
Use urban or rural topography, as appropriate.
Temperature of released substance
For liquids (other than gases liquefied by refrigeration), use the highest daily maximum temperature, based on data for the previous three years, or at process temperature, whichever is higher.
Assume gases liquefied by refrigeration at atmospheric pressure are released at their boiling points.

2.2.2 Identification of Worst-case release scenario

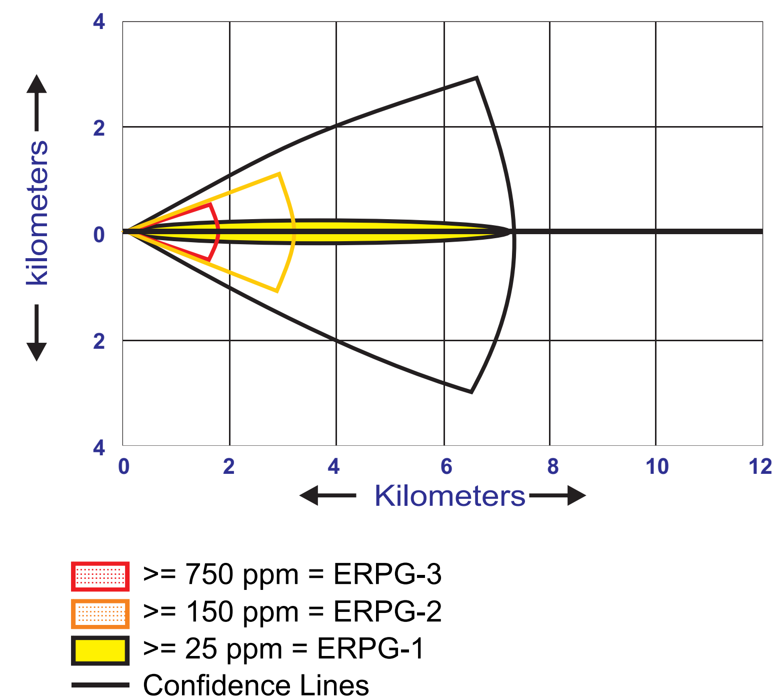
For the identification of worst-case scenario of toxic substances, we have to analyse more than one scenario, because the distances depend on more than simply the

quantity in a process. For example, for toxic liquids, distances depend on the magnitude of the toxic end point, the molecular weight, volatility of the substance and the temperature of the substance in the process, as well as quantity. A smaller quantity of a substance at an elevated temperature may give a greater distance to the end-point than a larger quantity of the same substance at ambient temperature. In some cases, it may be difficult to predict which substance and process will give the greatest worst-case distance.

The following cases will throw more light to understand the worst case sceanarios:

Case 1

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
Wind : 1.5 meters/second from west direction at 3 meters
Ground Roughness : open country
Cloud Cover : 5 tenths
Air Temperature : 45° C
Stability Class : F
No Inversion Height
Relative Humidity : 50%

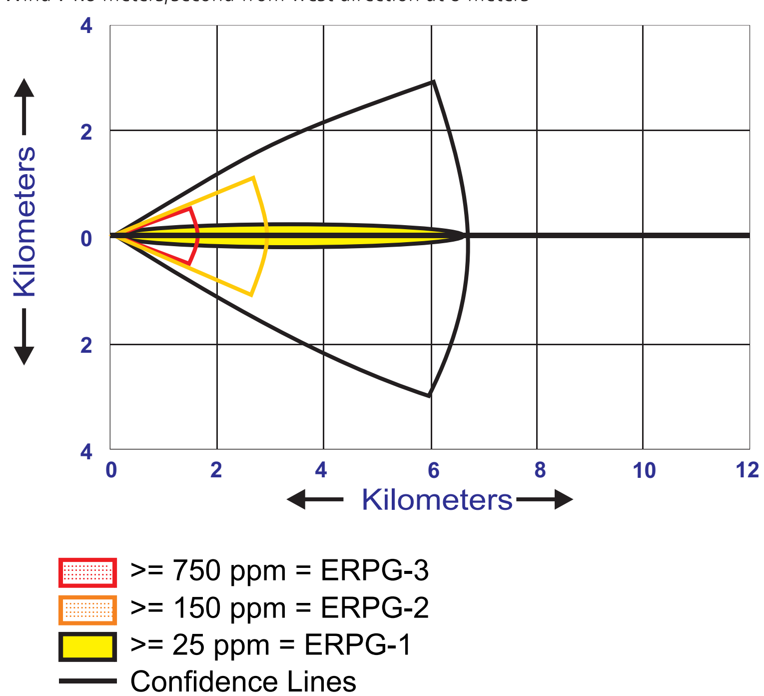


SOURCE STRENGTH :
Direct Source : 1000 kilograms Source Height: 0
Release Duration : 1 minute
Release Rate : 16.7 kilograms/sec
Total Amount Released : 1,000 kilograms
Note : This chemical may flash boil and/or result in two phase flow.

THREAT ZONE :
Model Run : Gaussian
Red : 1.7 kilometers --- (750 ppm = ERPG-3)
Orange : 3.3 kilometers --- (150 ppm = ERPG-2)
Yellow: 7.3 kilometers --- (25 ppm = ERPG-1)

Case 2

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 1.5 meters/second from west direction at 3 meters



Ground Roughness : open country Cloud Cover: 5 tenths
Air Temperature : 5° C Stability Class: F
No Inversion Height Relative Humidity: 50%

SOURCE STRENGTH:
Direct Source : 1000 kilograms Source Height: 0
Release Duration : 1 minute
Release Rate : 16.7 kilograms/sec
Total Amount Released : 1,000 kilograms
Note : This chemical may flash boil and/or result in two phase flow.

THREAT ZONE :
Model Run : Gaussian
Red : 1.6 kilometers --- (750 ppm = ERPG-3)
Orange : 3.1 kilometers --- (150 ppm = ERPG-2)
Yellow : 6.9 kilometers --- (25 ppm = ERPG-1

Case 3

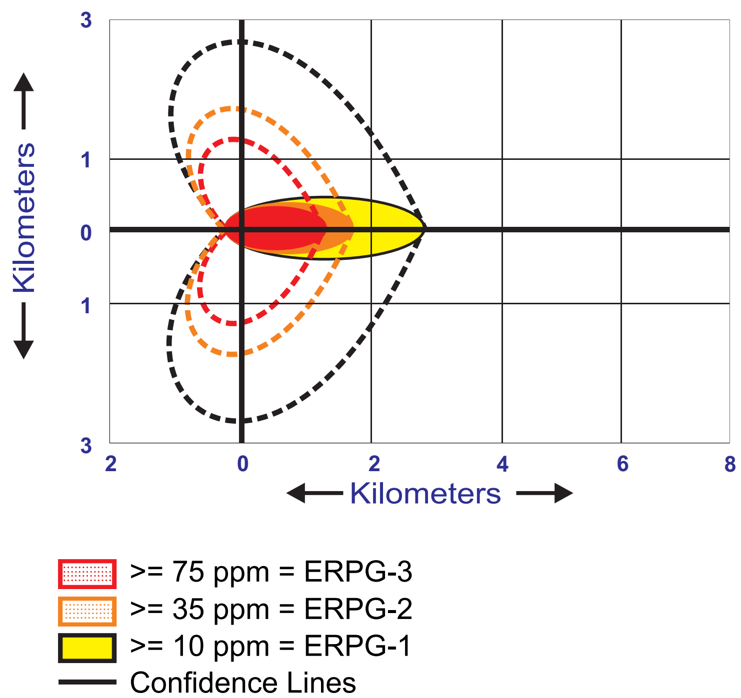
ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind: 1.5 meters/second from west direction at 3 meters
Ground Roughness : open country Cloud Cover: 5 tenths
Air Temperature : 45° C Stability Class: B
No Inversion Height Relative Humidity: 50%

SOURCE STRENGTH :
Direct Source : 1000 kilograms Source Height: 0
Release Duration : 1 minute
Release Rate : 16.7 kilograms/sec
Total Amount Released : 1,000 kilograms

THREAT ZONE:
Model Run : Heavy Gas
Red : 1.4 kilometers --- (75 ppm = ERPG-3)
Orange : 1.8 kilometers --- (35 ppm = ERPG-2)
Yellow : 2.8 kilometers --- (10 ppm = ERPG-1)

Modelling discussed in the module should not be copied for real purpose because for application in ONSEMP and OffSEMP the following parameters need to be addressed:

-Vessels type and their dimensions
-Temperature of atmosphere and storage conditions of the chemical
-Sun exposure and humidity, etc.



Case 4

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)

Wind : 1.5 meters/second from west direction at 3 meters

Ground Roughness : open country

Cloud Cover : 5 tenths

Air Temperature : 5° C

Stability Class : B

No Inversion Height

Relative Humidity : 50%

SOURCE STRENGTH:

Direct Source : 1000 kilograms

Source Height : 0

Release Duration : 1 minute

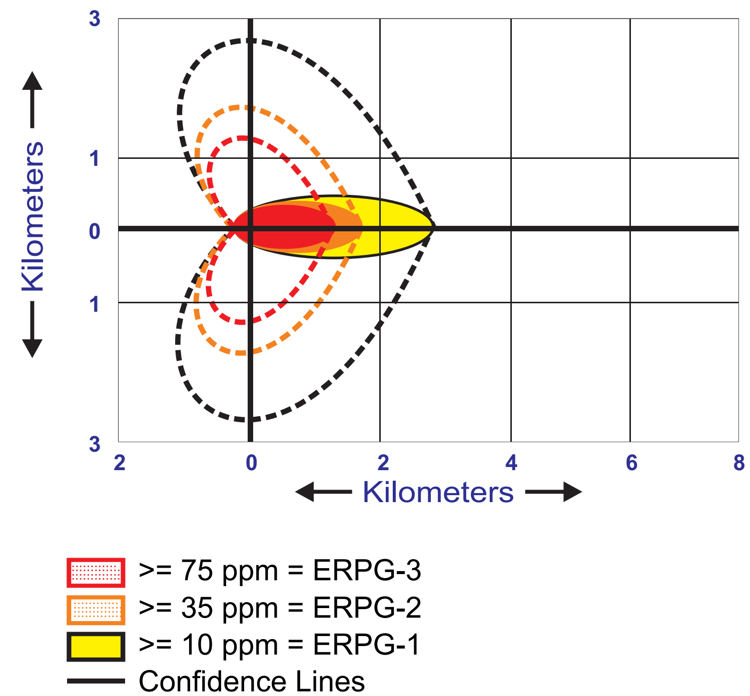
Release Rate : 16.7 kilograms/sec

Total Amount Released : 1,000 kilograms

THREAT ZONE:

Model Run : Heavy Gas

Red : 1.3 kilometers --- (75 ppm = ERPG-3)
Orange : 1.7 kilometers --- (35 ppm = ERPG-2)
Yellow : 2.7 kilometers --- (10 ppm = ERPG-1)



2.3 Worst-case releases of Flammable substances

For the worst-case scenario involving a release of a regulated flammable substance, the following aspects are considered:

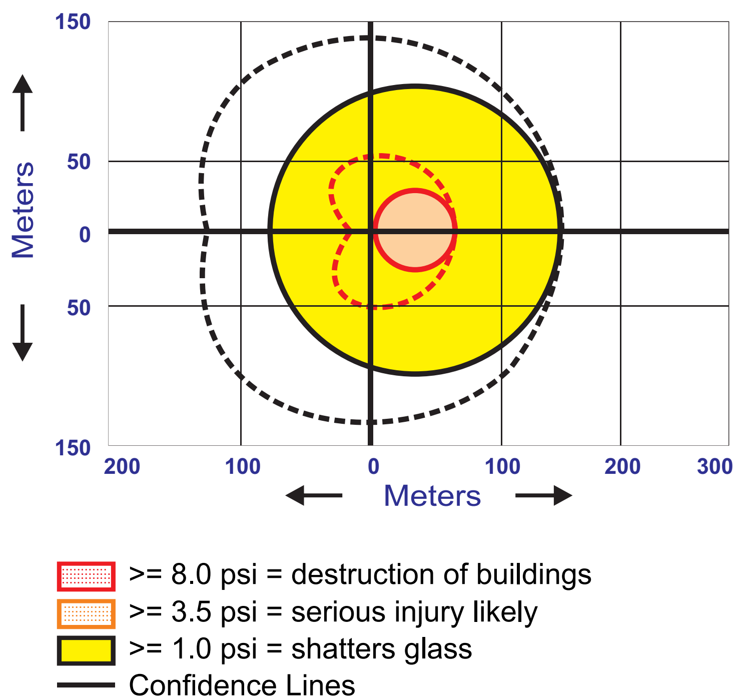
(a) Quantity of the flammable substance is released into a vapour cloud and that a vapour cloud explosion results. Generally we estimate the distance to an end point to an overpressure level of 1 psi from the explosion of the vapour cloud and heat radiation intensity of 4.5 kW/sqm.

(b) If the flammable substance is normally a gas at ambient temperature and handled as gas or liquid under pressure or, if the flammable substance is a gas handled as a refrigerated liquid and is not contained when released or the contained pool is one centimeter or less deep, we must assume the total quantity is released as a gas and is involved in a vapor cloud explosion.

(c) If the flammable substance is a liquid or a refrigerated gas released into a containment area with a depth greater than one centimeter, we may assume that the quantity that volatilises in 10 minutes is involved in a vapour cloud explosion.

Case 5

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 1.5 meters/second from west direction at 3 meters
Ground Roughness : open country   Cloud Cover : 5 tenths
Air Temperature : 5° C   Stability Class : B
No Inversion Height   Relative Humidity : 50%



SOURCE STRENGTH :
Direct Source : 1000 kilograms   Source Height : 0
Release Duration : 1 minute
Release Rate : 16.7 kilograms/sec
Total Amount Released : 1,000 kilograms

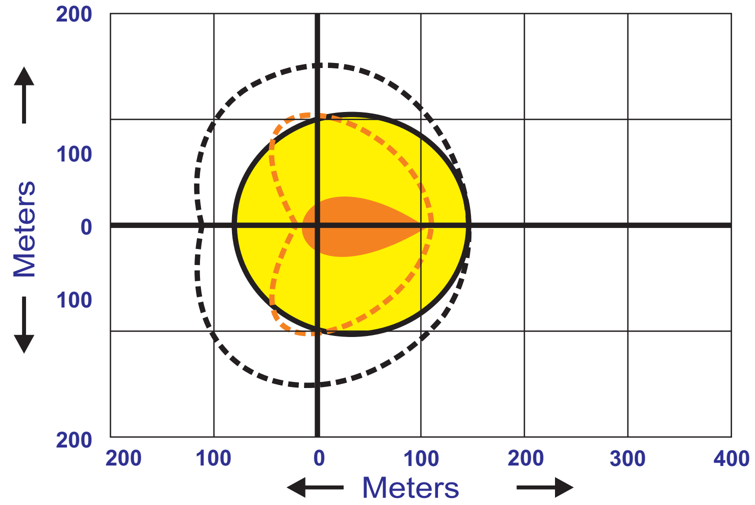
THREAT ZONE :
Threat Modeled : Overpressure (blast force) from vapour cloud explosion
Time of Ignition : 1 minutes after release begins
Type of Ignition : ignited by spark or flame
Level of Congestion : congested
Model Run : Heavy Gas
Explosive mass at time of ignition : 661 kilograms
Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange : 59 meters --- (3.5 psi = serious injury likely)
Yellow : 140 meters --- (1.0 psi = shatters glass)

Case 6

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind: 1.5 meters/second from west direction at 3 meters
Ground Roughness: open country   Cloud Cover : 5 tenths
Air Temperature : 5° C   Stability Class : B
No Inversion Height   Relative Humidity : 50%

SOURCE STRENGTH :
Direct Source : 1000 kilograms   Source Height : 0
Release Duration : 1 minute
Release Rate : 16.7 kilograms/sec
Total Amount Released : 1,000 kilograms

THREAT ZONE :
Threat Modeled : Overpressure (blast force) from vapour cloud explosion
Type of Ignition : ignited by spark or flame
Level of Congestion : congested
Model Run : Heavy Gas
Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange : 115 meters --- (3.5 psi = serious injury likely)
Yellow : 165 meters --- (1.0 psi = shatters glass)



>= 8.0 psi = destruction of buildings
>= 3.5 psi = serious injury likely
>= 1.0 psi = shatters glass
Confidence Lines

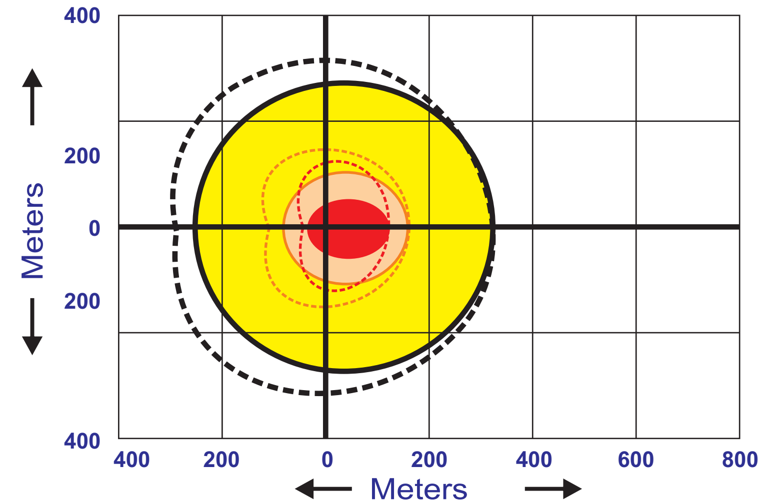
Case 7

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 1.5 meters/second from west direction at 3 meters
Ground Roughnes : open country
Cloud Cover : 5 tenths
Air Temperature : 5° C
Stability Class : B
No Inversion Height
Relative Humidity : 50%

SOURCE STRENGTH :
Direct Source : 1000 kilograms
Source Height: 0
Release Duration : 1 minute
Release Rate : 16.7 kilograms/sec
Total Amount Released : 1,000 kilograms

THREAT ZONE :
Threat Modeled : Overpressure (blast force) from vapour cloud explosion
Type of Ignition : ignited by detonation

Model Run : Heavy Gas
Red : 128 meters --- (8.0 psi = destruction of buildings)
Orange : 162 meters --- (3.5 psi = serious injury likely)
Yellow : 327 meters --- (1.0 psi = shatters glass)



>= 8.0 psi = destruction of buildings
>= 3.5 psi = serious injury likely
>= 1.0 psi = shatters glass
Confidence Lines

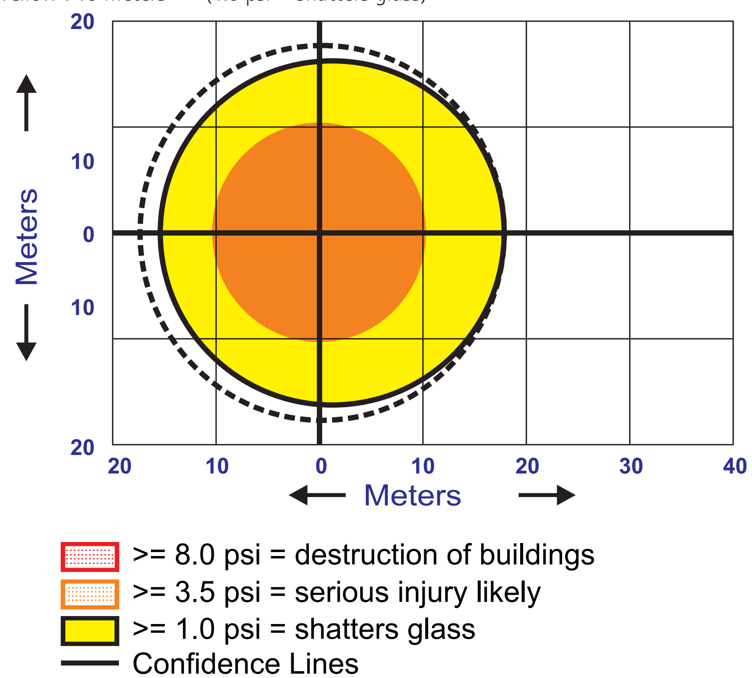
Case 8

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 1.5 meters/second from west direction at 3 meters
Ground Roughness : open country
Cloud Cover: 5 tenths
Air Temperature : 5° C
Stability Class: B
No Inversion Height
Relative Humidity: 50%

SOURCE STRENGTH :
Direct Source : 1000 kilograms
Source Height: 0
Release Duration : 1 minute

Release Rate : 16.7 kilograms/sec
Total Amount Released : 1,000 kilograms

THREAT ZONE:
Threat Modeled : Overpressure (blast force) from vapour cloud explosion
Time of Ignition : 1 seconds after release begins
Type of Ignition : ignited by spark or flame
Level of Congestion : congested
Model Run : Heavy Gas
Explosive mass at time of ignition : 2.39 kilograms
Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange : less than 10 meters(10.9 yards) --- (3.5 psi = serious injury likely)
Yellow : 19 meters --- (1.0 psi = shatters glass)



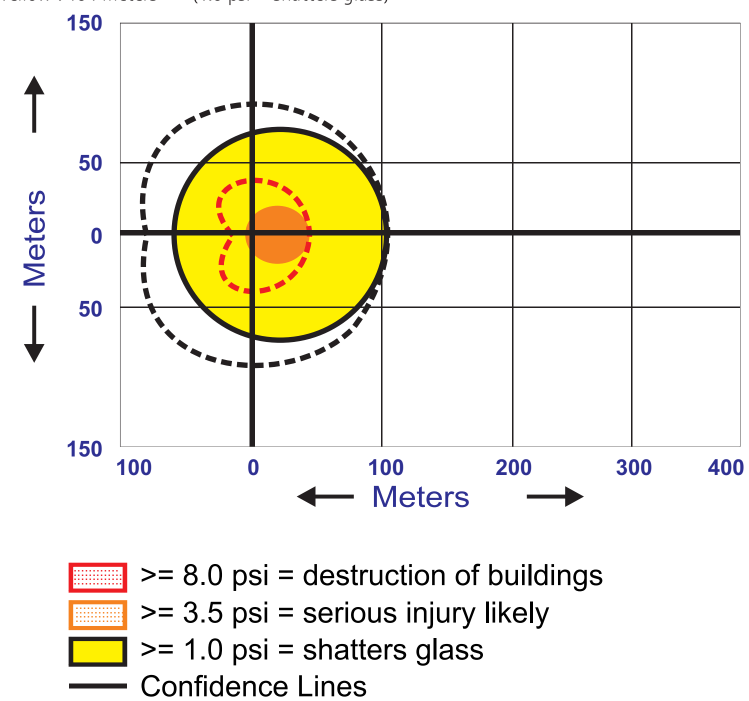
Case 9

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 1.5 meters/second from west direction at 3 meters

Ground Roughness : open country
Air Temperature : 5° C
No Inversion Height
Cloud Cover: 5 tenths
Stability Class: B
Relative Humidity: 50%

SOURCE STRENGTH:
Direct Source : 1000 kilograms
Source Height: 0
Release Duration : 1 minute
Release Rate : 16.7 kilograms/sec
Total Amount Released : 1,000 kilograms

THREAT ZONE :
Threat Modeled : Overpressure (blast force) from vapour cloud explosion
Time of Ignition : 30 seconds after release begins
Type of Ignition : ignited by spark or flame
Level of Congestion : congested
Model Run : Heavy Gas
Explosive mass at time of ignition : 324 kilograms
Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange : 40 meters --- (3.5 psi = serious injury likely)
Yellow : 104 meters --- (1.0 psi = shatters glass)

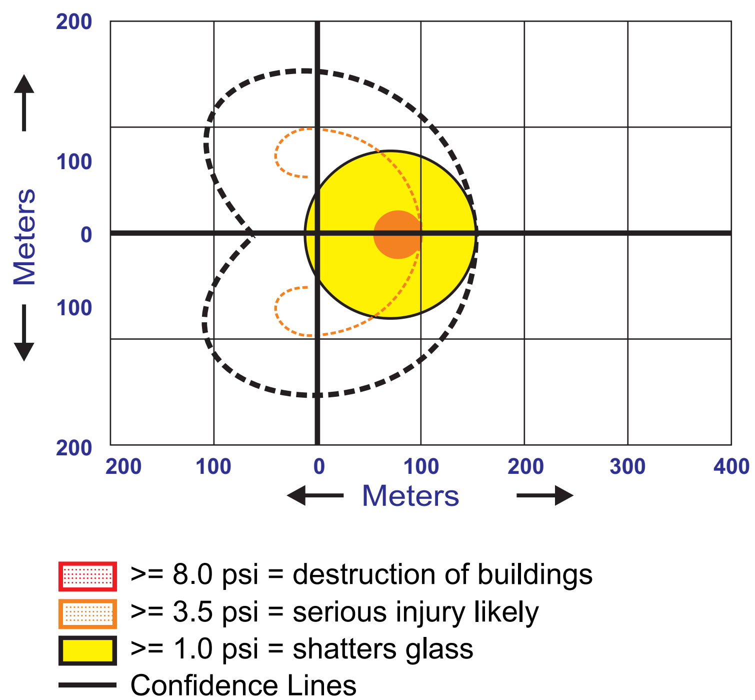


Case 10

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 1.5 meters/second from west direction at 3 meters
Ground Roughness : open country — Cloud Cover : 5 tenths
Air Temperature : 5° C — Stability Class : B
No Inversion Height — Relative Humidity : 50%

SOURCE STRENGTH :
Direct Source : 1000 kilograms — Source Height : 0
Release Duration : 1 minute
Release Rate : 16.7 kilograms/sec
Total Amount Released: 1,000 kilograms

THREAT ZONE :
Threat Modeled : Overpressure (blast force) from vapour cloud explosion
Time of Ignition : 120 seconds after release begins



Type of Ignition : ignited by spark or flame
Level of Congestion : congested
Model Run : Heavy Gas
Explosive mass at time of ignition : 285 kilograms
Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange : 103 meters --- (3.5 psi = serious injury likely)
Yellow : 164 meters --- (1.0 psi = shatters glass)

3. Alternative-case release scenarios

The acceptable alternative scenario for a covered process must be one that is more likely to occur than the worst-case scenario and that reaches an endpoint offsite, unless no such scenario exists. It is not necessary to demonstrate greater likelihood of occurrence or carry out any analysis of probability of occurrence; we only need to use reasonable judgement and knowledge of the process. If, using a combination of reasonable assumptions, modelling of a release of a regulated substance from a process shows that the relevant endpoint is not reached offsite, we can use the modelling results to demonstrate that a scenario does not exist for the process that will give an endpoint offsite.

Generally five-year accident history and failure scenarios are considered in process hazard analysis in selecting alternative release scenarios for regulated toxic or flammable substances (e.g., we might choose an actual event from our accident history as the basis of our scenario). We also may consider any other reasonable scenarios.

The alternative scenarios should be such for which we can explain to emergency responders and the public as a reasonable alternative to the worst-case scenario. For example, we could pick a scenario based on an actual event, or we could choose a scenario that we worry about, because circumstances at our site might make it a possibility. If we believe that there is no reasonable scenario that could lead to offsite consequences, we may use a scenario that has no offsite impacts for our alternative analysis. We should be prepared to explain our choice of such a scenario to the public.

3.1 Number of release scenarios

A few release scenarios may be as follows:
- Transfer hose releases due to splits or sudden uncoupling;
- Process piping releases from failures at flanges, joints, welds, valves and valve seals and drains or bleeds;
- Process vessel or pump releases due to cracks, seal failure, drain bleed, or plug failure;

-Vessel overfilling and spill, or over de-pressurization and venting through relief valves or rupture disks; and
-Shipping container mishandling and breakage or puncturing leading to a spill.

3.2 Mitigation systems for alternative release scenarios

We may consider active mitigation systems, such as interlocks, shutdown systems, pressure relieving devices, flares, emergency isolation systems, etc. Mitigation systems considered must be capable of withstanding the event that triggers the release while remaining functional.

3.3 Alternative releases of toxic substances

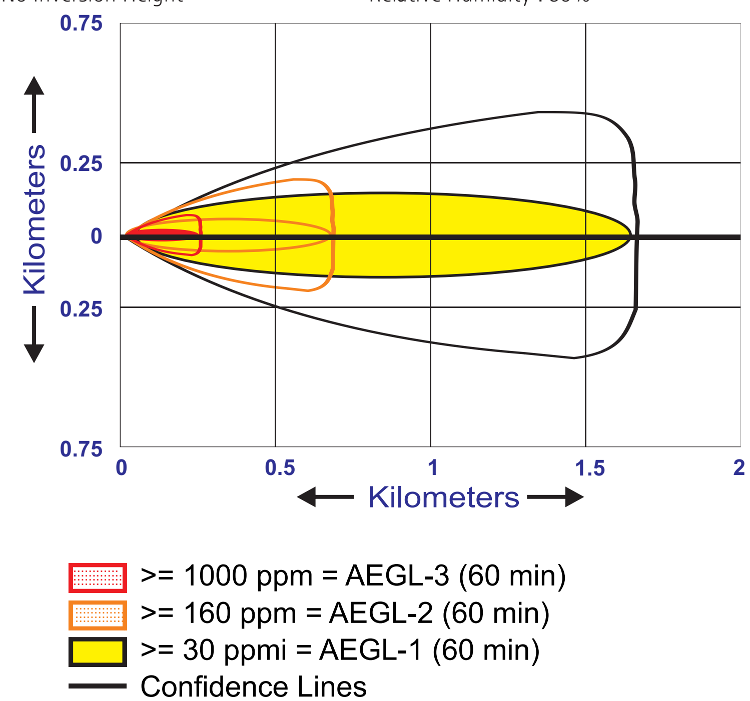
Although alternative scenarios are intended to be more likely than worst-case scenarios, the analysis of alternative scenarios should not be expected to provide realistic estimates of areas in which the public might be endangered in case of a release. The same conservative, protective endpoints are used for alternative release analysis as for worst-case analysis. These endpoints are intended to represent exposure levels below which most members of the public will not suffer any serious health effects. The endpoints are based on exposures for longer periods than may be likely in an actual release. In addition, modelling carried out to estimate distances to these endpoints, even when based on more realistic assumptions than used for the worst-case modelling, likely will provide results with a high degree of uncertainty. These estimated instances should not be considered a necessarily accurate prediction of the results of an actual release.

3.3.1 Modelling assumptions

(a) Quantity: EPA has not specified any assumptions we must make concerning quantity released for an alternative release scenario. We could consider any site-specific factors in developing a reasonable estimate of quantity released (e.g., The quantity that could be released from a sheared pipe in the time it would take to shut off flow to the pipe).
b) Release Height: We may assume any appropriate release height for our alternative scenarios. For example, we may analyse a scenario in which a regulated substance would be released at a height well above ground level.
(c) Wind Speed and Atmospheric Stability: We should use typical meteorological conditions at our site to model alternative scenarios. To determine typical conditions, we may need to obtain local meteorological data that are applicable to our site. If we do not keep weather data for our site (most sources do not), we may call another nearby source, such as an airport to determine wind speeds for our area. Our airport or other source will be able to give information on cloud cover.

Case 11

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 5 meters/second from west direction at 10 meters
Ground Roughness : open country — Cloud Cover : 5 tenths
Air Temperature : 5° C — Stability Clas s: C
No Inversion Height — Relative Humidity : 50%



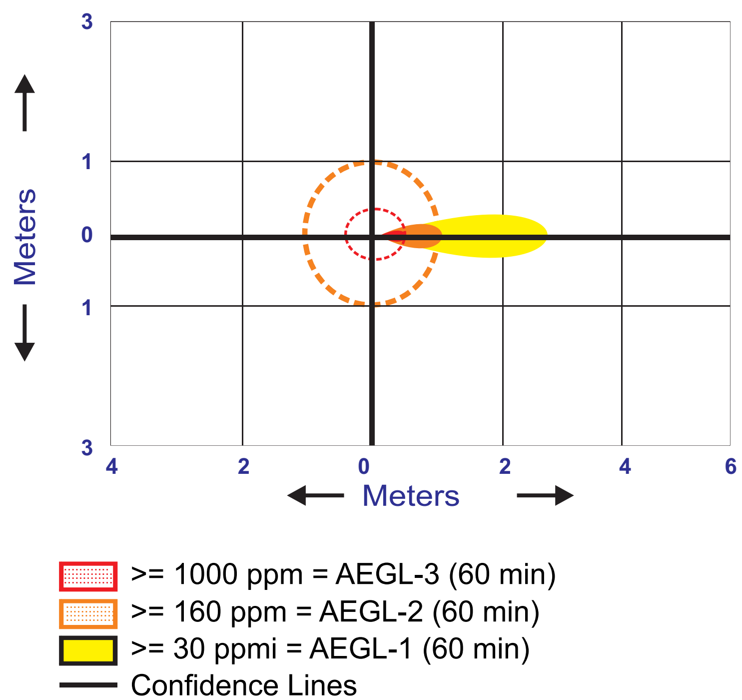
SOURCE STRENGTH :
Flammable gas escaping from pipe (not burning)
Pipe Diameter : 20 centimeters — Pipe Length : 200 meters
Unbroken end of the pipe is connected to an infinite source
Pipe Roughness : smooth — Hole Area : 314 sq cm
Pipe Press : 3 atmospheres — Pipe Temperature : 5° C
Release Duration : 1 hour
Max Average Sustained Release Rate : 338 kilograms/min
(averaged over a minute or more)
Total Amount Released : 20,266 kilograms

THREAT ZONE :
Model Run : Gaussian
Red : 249 meters --- (1100 ppm = AEGL-3(60 min))
Orange : 673 meters --- (160 ppm = AEGL-2(60 min))
Yellow : 1.7 kilometers --- (30 ppm = AEGL-1(60 min)

Case 12

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 1 meters/second from west direction at 10 meters
Ground Roughness : open country Cloud Cover : 5 tenths
Air Temperature : 45° C Stability Class : B
No Inversion Height Relative Humidity : 50%

SOURCE STRENGTH:
Flammable gas escaping from pipe (not burning)



Pipe Diameter : 20 centimeters Pipe Length: 200 meters
Unbroken end of the pipe is connected to an infinite source
Pipe Roughness : smooth Hole Area: 314 sq cm
Pipe Press : 3 atmospheres Pipe Temperature: 45° C
Release Duration : 1 hour
Max Average Sustained Release Rate : 316 kilograms/min
(averaged over a minute or more)
Total Amount Released : 18,949 kilograms

THREAT ZONE :
Model Run: Gaussian
Red : 382 meters --- (1100 ppm = AEGL-3(60 min))
Orange : 1.0 kilometers --- (160 ppm = AEGL-2(60 min))
Yellow : 2.4 kilometers --- (30 ppm = AEGL-1(60 min))

3.4 Alternative releases of flammable substances

Alternative release scenarios for flammable substances are somewhat more complicated than for toxic substances because the consequences of a release and the endpoint of concern may very. For the worst case, the consequence of concern is a vapor cloud explosion, with an over pressure endpoint. For alternative scenarios involving fires rather than explosions, other endpoints than over pressure (e.g., heat radiation) may need to be considered. The rule specifies endpoints for fires based on the heat radiation level that may cause second-degree burns from a 40-second exposure and the lower flammability limit (LFL), which is the lowest concentration in air at which a substance will burn.

3.4.1 Some possible scenarios

Some possible scenarios involving flammable substances are discussed below.

- **Vapor cloud fires (flash fires):** may result from dispersion of a cloud of flammable vapor and ignition of the cloud following dispersion. Such a fire could flash back and could represent a severe heat radiation hazard to anyone in the area of the cloud. Vapor cloud fires may be modeled using air dispersion modeling techniques to estimate distances to a concentration equal to the LFL.
- A **pool fire**, with potential radiant heat effects, may result from a spill of a flammable liquid. The endpoint for this type of fire is a radiant heat level of 5 kilowatts per square meter (kW/m2) for 40 seconds; a 40-second exposure to this heat level could cause second degree burns.
- A **Boiling Liquid Expanding Vapour Explosion (BLEVE)**, leading to a fireball that may produce intense heat, may occur if a vessel containing flammable material ruptures explosively as a result of exposure to fire. Heat radiation from the fireball is the primary

hazard; vessel fragments and over pressure from the explosion also can result. BLEVEs are generally considered unlikely events. However, if we think a BLEVE is possible at our site, we should estimate the distance at which radiant heat effect can cause second degree burns. The point of offsite consequence analysis is to determine how far away from the point of release effects of concern could occur, so we should estimate the distance for BLEVEs even if they do not last for 40 seconds. We also may want to consider models or calculation methods to estimate effects of vessel fragmentation, although we are not required to analyse such effects.

- For a **Vapor Cloud Explosion (VCE)** to occur, rapid release of a large quantity of flammable material, turbulent conditions (caused by a turbulent release or congested conditions in the area of the release, or both), and other factors are generally necessary. Vapor cloud explosions generally are considered unlikely events; however, if conditions at our site are conducive to vapor cloud explosions, we may want to consider vapor cloud explosion as an alternative scenario. The 1 psi over pressure endpoint still applies to a vapor cloud explosion for purposes of analysing an alternative scenario, but we could use less conservative assumptions than for the worst-case analysis, including any reasonable estimate of the quantity in the cloud and the yield factor. A vapor cloud defloration, involving lower flame speeds than detonation and resulting in less damaging blast effects, is more likely than a detonation. We may assume a vapor cloud deflagration for the alternative scenario, if we think it is appropriate, and use the radiant heat endpoint (adjusted for duration).
- A **jet fire** may result from the puncture or rupture of a tank or pipeline containing a compressed or liquefied gas under pressure. The gas discharging from the hole can form a jet that "blows" into the air in the direction of the hole; the jet then may ignite. Jet fires could contribute to BLEVEs and fireballs if they impinge on tanks of flammable substances. A large horizontal jet fire may have the potential to pose an offsite hazard. We may consider a jet fire as an alternative scenario, if appropriate for our site.

3.4.2 Modeling Assumptions

(a) Quantity: EPA has not specified any assumptions we must make concerning quantity released for an alternative scenario analysis for flammable substances. We may consider any site-specific factors in developing a reasonable estimate of quantity released, as for toxic substances (e.g., the quantity that could be released from a ruptured pipe in the time it would take to shut off flow to the pipe).

(b) Release Height: We may assume any appropriate release height for our alternative scenarios for flammable substances.

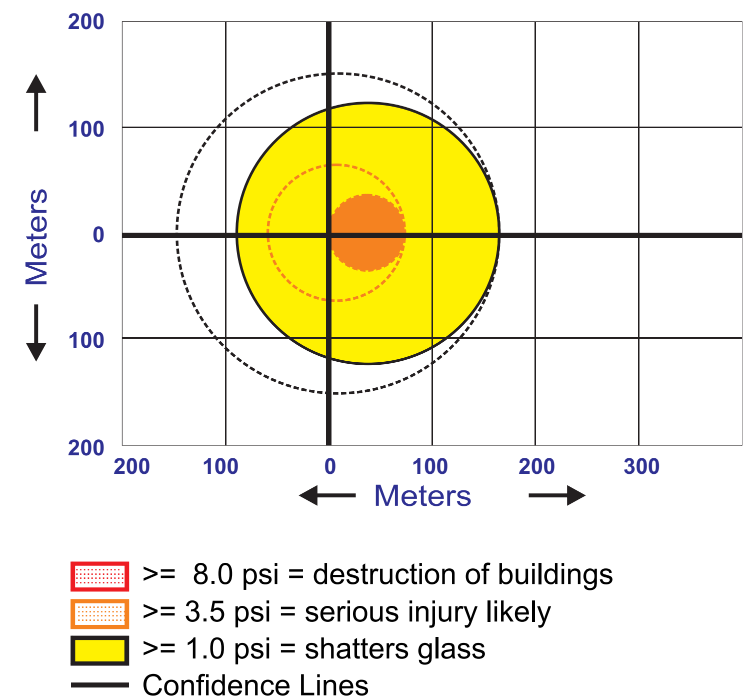
(c) Wind Speed and Atmospheric Stability: Meteorological conditions may have little effect on some scenarios for flammable substances (e.g., vapor cloud explosions and BLEVEs scenarios but may have a relatively large effect on others

(e.g., a vapor cloud fire resulting from down wind dispersion of a vapor cloud and subsequent ignition). We should use typical meteorological conditions at our site to model appropriate alternative scenarios. To determine typical conditions, we may need to obtain local meteorological data that are applicable to our site, as discussed above.

Case 13

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 1 meters/second from west direction at 10 meters
Ground Roughness : open country — Cloud Cover : 5 tenths
Air Temperature : 45° C — Stability Class : B
No Inversion Height — Relative Humidity : 50%

SOURCE STRENGTH :
Flammable gas escaping from pipe (not burning)
Pipe Diameter : 20 centimeters — Pipe Length : 200 meters



Unbroken end of the pipe is connected to an infinite source
Pipe Roughness smooth | Hole Area : 314 sq cm
Pipe Press : 7 atmospheres | Pipe Temperature : 45° C
Release Duration : 1 hour
Max Average Sustained Release Rate : 1,180 kilograms/min
(averaged over a minute or more)
Total Amount Released : 70,227 kilograms

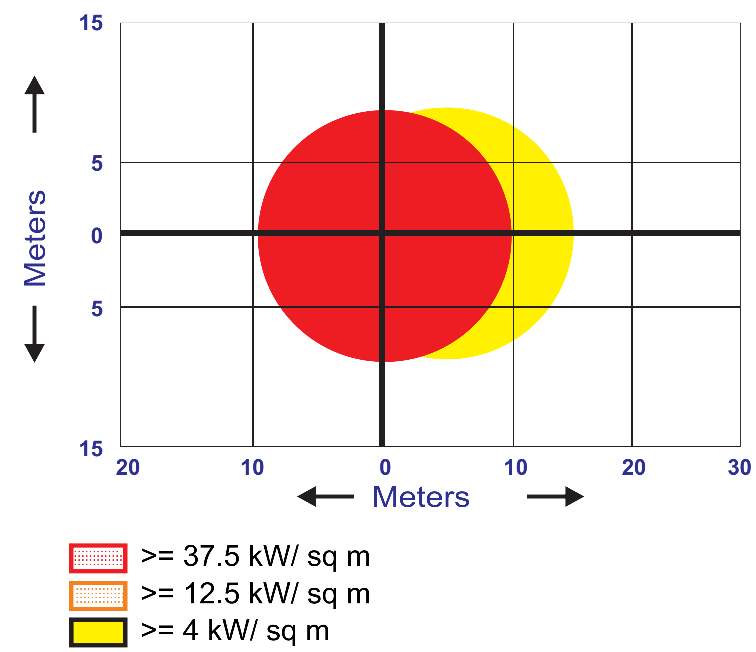
THREAT ZONE :
Threat Modeled : Over pressure (blast force) from vapor cloud explosion
Time of Ignition : 120 seconds after release begins
Type of Ignition : ignited by spark or flame
Level of Congestion : congested
Model Run : Heavy Gas
Explosive mass at time of ignition: 885 kilograms
Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange : 72 meters --- (3.5 psi = serious injury likely)
Yellow : 173 meters --- (1.0 psi = shatters glass)

Case 14

ATMOSPHERIC DATA : (MANUAL INPUT OF DATA)
Wind : 3 meters/second from west direction at 10 meters
Ground Roughness : open country | Cloud Cover : 5 tenths
Air Temperature : 5° C | Stability Class : C
No Inversion Height | Relative Humidity : 50%

SOURCE STRENGTH :
Flammable gas is burning as it escapes from pipe
Pipe Diameter : 20 centimeters | Pipe Length : 200 meters
Unbroken end of the pipe is closed off
Pipe Roughness : smooth | Hole Area : 314 sq cm
Pipe Press : 3 atmospheres | Pipe Temperature : 5° C
Flame Length : 26 meters | Burn Duration : 30 seconds
Burn Rate : 17.7 kilograms/sec
Total Amount Burned : 24.5 kilograms

THREAT ZONE :
Threat Modeled : Thermal radiation from jet fire
Red : 10 meters --- (37.5 kW/(sq m))
Orange : 10 meters --- (12.5 kW/(sq m))
Yellow : 15 meters --- (4 kW/(sq m))



3.4.3 Estimating distance to the endpoint

We may use any appropriate model to estimate the distance to the specified endpoint for alternative scenarios for regulated flammable substances. Several possible consequences of releases of flammable substances are discussed below.

(i) Vapor cloud fire: We may use any appropriate model to estimate distances for a vapor cloud fire. The LFL endpoint would be appropriate for vapour cloud fires. We may use air dispersion modelling to estimate the maximum distance to the LFL. We may want to consider, however, whether it is likely that a flammable gas or vapor could disperse to the maximum distance to the LFL before reaching an ignition source. The actual dispersion distance before ignition might be much shorter than the maximum possible distance.

(ii) Pool fire: Any appropriate model may be used for pool fires of flammable liquids. The applicable endpoint for the heat radiation level of 4 kW/m^2.

(iii) BLEVE: If a fireball from a BLEVE is a potential release scenario at our site, we may use any model or calculation method to estimate the distance to a radiant heat level that can cause second degree burns (a heat "dose" equivalent to the specified radiant heat endpoint of $5kW/m^2$ for 40 seconds).

(iv) Vapour cloud explosion: If we have the potential at our site for the rapid release of a large quantity of a flammable vapor, particularly into a congested area, a vapour cloud explosion may be an appropriate alternative release scenario.

3.4.4 Number of Scenarios

It is necessary to analyse at least one alternative release scenario for each listed toxic substance above its threshold quantity. Even if we have a substance above the threshold in several processes or locations, we need only analyse one alternative scenario for it. Similarly, to analyse one alternative release scenario representing all regulated flammable substances; we do not need to analyse an alternative scenario for each flammable substance above the threshold.

For example, if we have five listed substances chlorine, ammonia, hydrogen chloride, propane, and acetylene above the threshold quantity, we will need to analyse one alternative scenario each for chlorine, ammonia, and hydrogen chloride (toxic substances) and a single alternative scenario to cover propane and acetylene (flammable substances). In addition, no alternative scenario analysis is required for any process that does not contain more than a threshold quantity of a regulated substance, even if we believe such a process is a likely source of a release.

4. Estimating Off-site and On-site receptors

Generally we estimate residential populations within the circle defined by the endpoint for our worst-case and alternative release scenarios (i.e., the center of the circle is the point of release and the radius is the distance to the endpoint).

If there are any schools, residences, hospitals, prisons, public recreational areas or arenas, or commercial or industrial areas within the circle, we must report that, we must simply check off that one or more such areas are within the circle. Most receptors can be identified from local street maps. We have to consider environmental receptors also. Environmental receptors are defined as natural areas such as national or state parks, forests, or monuments; officially designated wildlife sanctuaries, preserves etc.

Facilities like administrative building, guest house, process areas, utilities should be identified in the high vulnerability area and proper training need to given to persons working in the areas to protect themselves in emergency situations. The high vulnerable zones should be considered for the future development of Off-site and On-site.

5. Conclusion

On-site and Off-site Emergency Management Plans should be based on consequence analysis and it should be ensured by industries and civil authorities respectively.

The following points should be examine by State Disaster Management Authorities (SDMAs) and District Disaster Management Authorities (DDMAs):-

1. All OnSEMP and OffSEMP must have vulnerable zones of fire, explosion and toxic concentration. These vulnerable zones should be projected on map by using remote sensing techniques.

2. Consequence analysis should be done by competent persons or institutions having proven past histories.

3. Authentic computer software must be used if mathematical calculations are not applied.

4. OnSEMP should use these consequence analysis in developing assembly points, escape routes, fire fighting facilities, etc. Mock drills should also be based on these analysis.

5. OffSEMP should use these consequence analysis in developing shelter points, escape routes, Incident Command Post, relief camp, etc. Mock drills should also be based on these analysis.

6. SDMA should use these consequence analysis in the future master plans of the cities and rural areas and appropriate directions should be ensured to Town and Country Planning.

7. Central and **State Environmental Impact Assessment (EIA)** committees, notified under **Environmental Impact Assessment Notification 2006,** should ask the coming and proposed industries to submit such consequence analysis before granting the site clearances for the new as well proposed industries. These committees must appoint experts in their appraisal committees who can examined the consequence analysis.

6. Glossary

1. AEGL: Acute Exposure Guideline Levels (AEGLs) are Toxic Levels of Concern (LOCs) is used to predict the area where a toxic gas concentration might be high enough to harm people. The AEGLs are under development by the National Research Council's National Advisory Committee on AEGLs of USA. AEGLs take into account sensitive individuals and are meant to protect nearly all people. As of October 2005, the final AEGL values for more than 20 chemicals have been released, interim AEGL values for more than 60 additional chemicals have also been established, and proposed AEGL values for more chemicals are under review. The committee's objective is to define AEGLs for the 300+ extremely hazardous substances. The guidelines define three-tiered AEGLs as follows:

AEGL-1: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

AEGL-2: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

AEGL-3: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

2. Cloud cover : Cloud cover, the proportion of the sky that is covered by clouds, in order to estimate the amount of incoming solar radiation at the time of a chemical release. Solar radiation is an important influence on puddle evaporation rate because heat from the sun can warm a puddle and speed up evaporation.

3. ERPG: The Emergency Response Planning Guidelines (ERPGs) are Toxic Levels of Concern (LOCs) that you can use in ALOHA to predict the area where a toxic gas concentration might be high enough to harm people. The ERPGs were developed by the ERPG committee of the American Industrial Hygiene Association. The ERPGs were developed as planning guidelines, to anticipate human adverse health effects caused by exposure to toxic chemicals. The

ERPGs are three-tiered guidelines with one common denominator: a 1-hour contact duration. Each guideline identifies the substance, its chemical and structural properties, animal toxicology data, human experience, existing exposure guidelines, the rationale behind the selected value, and a list of references.

ERPG 1: The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odour.

ERPG 2: The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

ERPG 3: The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

4. Stability class: Meteorologists have defined six atmospheric stability classes, each representing a different degree of turbulence in the atmosphere. When moderate to strong incoming solar radiation heats air near the ground, causing it to rise and generating large eddies, the atmosphere is considered unstable (relatively turbulent). Unstable conditions are associated with atmospheric stability classes A and B. When solar radiation is relatively weak or absent, air near the surface has a reduced tendency to rise and less turbulence develops. In this case, the atmosphere is considered stable (less turbulent), the wind is weak, and the stability class would be E or F. Stability classes D and C represent conditions of more neutral stability (moderately turbulent). Neutral conditions are associated with relatively strong wind speeds and moderate solar radiation.

5. Threat zone: Threat zone represents the area within which the hazard level (toxicity, flammability thermal radiation, or overpressure) is predicted to exceed your Level of Concern (LOC) at some time after a release begins.

7. References

1. Hazard Identification and Risk Analysis Code of Practice, BIS IS 15656: 2006, Bureau of Indian Standards.

2. ALOHA software for consequence analysis developed by US EPA.

3. Center for Process Safety of the American Institute of Chemical Engineers (AIChE). Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs. New York: AIChE, 1994.

4. Center for Process Safety of the American Institute of Chemical Engineers (AIChE). Guidelines for Use of Vapor Cloud Dispersion Models, Second Ed. New York: AIChE, 1996.

5. Center for Process Safety of the American Institute of Chemical Engineers (AIChE). International Conference and Workshop on Modeling and Mitigating the Consequences of Accidental Releases of Hazardous Materials, September 26-29, 1995. New York: AIChE, 1995.

6. Technical background document for offsite consequence analysis for anhydrous aqueous ammonia, chlorine, and sulphur dioxide , Chemical emergency preparedness and prevention office, U.s. Environmental protection agency, April 1999.

Notes