"Impact Assessment of Fire and Explosion using Source and Dispersion Models"

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Abstract

Fire and explosion are unplanned events in the workplaces, especially where the handling, transportation, and storage of hazardous material took place. The existence of this results in huge losses in terms of human life, machinery and environment.

In this work provides guidance for assessors of Fire and Explosion Risk Assessment by using source and dispersion model in oil and gas industry. Fire and Explosion have been identified as major potential hazards for Oil and Gas Production Storage area and pose risk to personnel, assets and the environment. Current fire and explosion assessment tools like source and dispersion models and others engineering practice. This tool features built-in calculations for fire and explosion impact assessment for jet and pool fire size estimation for gas/liquid release in a spherical and cylindrical storage area. Fire and Explosion impact assessment is an important part to calculate risks present in any storage area of oil and gas industry. Impact assessment analysis provides decisions support to safety based operations.

In this work, I first review fire and explosion safety-related regulations and assessment framework for evaluating safety against fire and explosion hazard in tank shell area of oil and gas industry. It also covers the two topics, emphasizing definition and calculation method for estimating and consequences of fire and explosions. The purpose of dispersion and source models solve conservation of mass, momentum and energy equation, and can use to model the dispersion of clouds in presence of obstacles even of complex geometry. Moreover, they can deal with heavy, natural or light gas dispersion.

Keywords*:* Dispersion Model, Impact assessment, Fire and Explosion, Engineering practice, Jet & pool fire.

1. Introduction

Chemicals present a substantial hazard in the form of fires and explosions. The combustion of one gallon of toluene can destroy an ordinary chemistry laboratory in minutes; persons present may be killed. The potential consequences of fires and explosions in pilot plants and plant environments are even greater. The three most common chemical plant accidents are fires, explosions, and toxic releases, in that order. Organic solvents are the most common source of fires and explosions in the chemical industry.

Chemical and hydrocarbon plant losses resulting from fires and explosions are substantial, with yearly property losses in the United States estimated at almost $300 million (1997 dollars). Additional losses in life and business interruptions are also substantial. To prevent accidents resulting from fires and explosions, engineers must be familiar with the fire and explosion properties of materials, the nature of the fire and explosion process and Procedures to reduce fire and explosion hazards.

The Distinction between Fires and Explosions- The major distinction between fires and explosions is the rate of energy release. Fires release energy slowly, whereas explosions release energy rapidly, typically on the order of microseconds. Fires can also result from explosions, and explosions can result from fires.

A good example of how the energy release rate affects the consequences of an accident is a standard automobile tire. The compressed air within the tire contains energy. If the energy is released slowly through the nozzle, the tire is harmlessly deflated. If the tire ruptures suddenly and all the energy within the compressed tire releases rapidly, the result is a dangerous explosion.

Explosion behavior is difficult to characterize. Many approaches to the problem have been undertaken, including theoretical, semi-empirical, and empirical studies. Despite these efforts, explosion behavior is still not completely understood. Practicing engineers, therefore, should use extrapolated results cautiously and provide a suitable margin of safety in all designs.

2. Source Model:

Source models are constructed from fundamental or empirical equations representing the physicochemical processes occurring during the release of materials. For a reasonably complex plant, many source models are needed to describe the release. Some development and modification of the original models are normally required to fit the specific situation. Frequently the results are only estimates because the physical properties of the materials are not adequately characterized or because the physical processes themselves are not completely understood. If uncertainty exists, the parameters should be selected to maximize the release rate and quantity. This ensures that a design is on the safe side.

Release mechanisms are classified into wide and limited aperture releases. In the wide aperture case, a large hole develops in the processing unit, releasing a substantial amount of material in a short time. An excellent example is the overpressuring and an explosion of a storage tank.

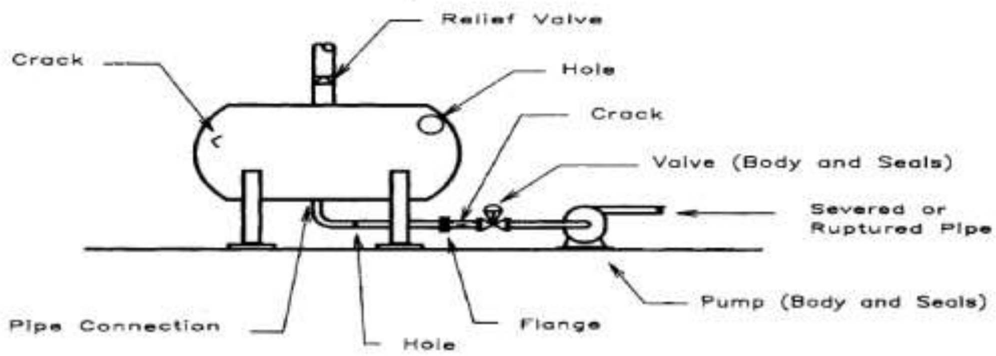


Fig. 1 Various types of limited aperture releases

For the limited aperture, case material is released at a slow enough rate that upstream conditions are not immediately affected; the assumption of constant upstream pressure is frequently valid. Limited aperture releases are conceptualized in Figure. For these releases, the material is ejected from holes and cracks in tanks and pipes, leaks in flanges, valves, and pumps, and severed or ruptured pipes. Relief systems, designed to prevent the overpressuring of tanks and process vessels, are also potential sources of released material. The Figure shows how the physical state of the material effects.

2.1 Dispersion Model

During an accident, process equipment can release toxic materials quickly and in significant enough quantities to spread in dangerous clouds throughout a plant site and the local community. A few examples are explosive rupture of a process vessel as a result of excessive pressure caused by a runaway reaction, rupture of a pipeline containing toxic materials at high pressure, rupture of a tank containing toxic material stored above its atmospheric boiling point, and rupture of a train or truck transportation tank following an accident.

Serious accidents (such as Bhopal) emphasize the importance of planning for emergencies and of designing plants to minimize the occurrence and consequences of a toxic release. Toxic release models are routinely used to estimate the effects of a release on the plant and community environments.

Dispersion models describe the airborne transport of toxic materials away from the accident site and into the plant and community. After a release, the airborne toxic material is carried away by the wind in a characteristic plume or a puff. The maximum concentration of toxic material occurs at the release point (which may not be at ground level). Concentrations downwind are less, because of turbulent mixing and dispersion of the toxic substance with air.

3 Fires and Explosions

Fire & explosions are the most serious “unpredictable” issues affecting life and business losses in the hydrocarbon and chemical industries today. The issues have existed since the inception of industrial-scale petroleum and chemical operations during the middle of the last century. Chemicals present a substantial hazard in the form of fires and explosions. The combustion of one gallon of toluene can destroy an ordinary chemistry laboratory in minutes; persons present may be killed. The potential consequences of fires and explosions in pilot plants and plant environments are even greater. The three most common chemical plant accidents are fires, explosions, and toxic releases, in that order. Organic solvents are the most common source of fires and explosions in the chemical industry.

The real cause of most incidents is what is considered the human error. The insurance industry has estimated that 80 percent of incidents are directly related to, or attributed to, the individuals involved. Most individuals have good intentions to perform a function properly, but it should be remembered that where shortcuts, easier methods or considerable (short-term) economic gain opportunities present themselves, human vulnerability usually succumbs to the temptation. Therefore it is prudent in any organization, especially where high-risk facilities are operated, to have a system in place to conduct considerable independent checks, inspections and safety audits of the operation, maintenance, design and construction of the installation. To prevent accidents resulting from fires and explosions, engineers must be familiar with the fire and explosion properties of materials, the

nature of the fire and explosion process and Procedures to reduce fire and explosion hazards.
Explosion behavior depends on a large number of parameters. Explosion behavior is difficult to characterize. Many approaches to the problem have been undertaken, including theoretical, semi-empirical, and empirical studies. Despite these efforts, explosion behavior is still not completely understood. Practicing engineers, therefore, should use extrapolated results cautiously and provide a suitable margin of safety in all designs. An explosion results from the rapid release of energy. The energy release must be sudden enough to cause a local accumulation of energy at the site of the explosion. This energy is then dissipated by a variety of mechanisms, including the formation of a pressure wave, projectiles, thermal radiation, and acoustic energy. The damage from an explosion is caused by the dissipating energy. If the explosion occurs in a gas, the energy causes the gas to expand rapidly, forcing back the surrounding gas and initiating a pressure wave that moves rapidly outward from the blast source. The pressure wave contains energy, which results in damage to the surroundings. For chemical plants, much of the damage from explosions is due to this pressure wave. Thus, in order to understand explosion impacts, we must understand the dynamics of the pressure wave. A pressure wave propagating in air is called a blast wave because the pressure wave is followed by a strong wind. A shock wave or shock front results if the pressure front has an abrupt pressure change. A shock wave is expected from highly explosive materials, such as TNT, but it can also occur from the sudden rupture of a pressure vessel. The maximum pressure over ambient pressure is called the peak overpressure.

3.1 Types of Explosions

Confined Explosions- A confined explosion occurs in a confined space, such as a vessel or a building. The two most common confined explosion scenarios involve explosive vapors and explosive dust. Empirical studies have shown that the nature of the explosion is a function of several experimentally determined characteristics.
Vapor Cloud Explosions- The accident at Flix borough, England, is a classic example of a VCE. A sudden failure of a 20-inch cyclohexane line between reactors led to vaporization of an estimated 30 tons of cyclohexane. The vapor cloud dispersed throughout the plant site and was ignited by an unknown source 45 seconds after the release. The entire plant site was leveled and 28 people were killed. A summary of 29 the period 1974-1986 shows property losses for each event of between $5,000,000 and $100,000,000 and 140 fatalities (an average of almost 13 per year).VCE have increased in number because of an increase in inventories of flammable materials in process plants and because of operations at more severe conditions. Any process containing quantities of liquefied gases, volatile superheated liquid or high-pressure gases is considered a good candidate for a VCE.

Fig. 2 Vapor Cloud Explosion

VCE is difficult to characterize, primarily because of a large number of parameters needed to describe an event. Accidents occur under uncontrolled circumstances. Data collected from real events are mostly unreliable and difficult to compare. Some of the parameters that affect VCE behaviors are quantity of material released, fraction of material vaporized, probability of ignition of the cloud, distance travelled by the cloud before ignition, time delay before ignition of cloud, probability of explosion rather than fire, existence of a threshold quantity of material, efficiency of explosion, and location of ignition source with respect to release.
Boiling Liquid Expansion Vapor Explosion- A boiling-liquid expanding-vapor explosion (BLEVE) is a special type of accident that can release large quantities of materials. If the materials are flammable, a VCE might result; if they are toxic, a large area might be subjected to toxic materials. For either situation, the energy released by the BLEVE process itself can result in considerable damage. A BLEVE occurs when a tank containing a liquid held above its atmospheric pressure boiling point ruptures, resulting in the explosive vaporization of a large fraction of the tank contents. BLEVEs are caused by the sudden failure of the container as a result of any cause. The most common type of BLEVE is caused by fire. The steps are as follows: A fire develops adjacent to a tank containing a liquid then the fire heats the walls of the tank after that the tank walls below liquid level are cooled by the liquid, increasing the liquid temperature and the pressure in the tank, if the flames reach the tank walls or roof where there is only vapor and no liquid to remove the heat, the tank metal temperature rises until the tank loses it structural strength as a result of the tank ruptures, explosively vaporizing its contents.

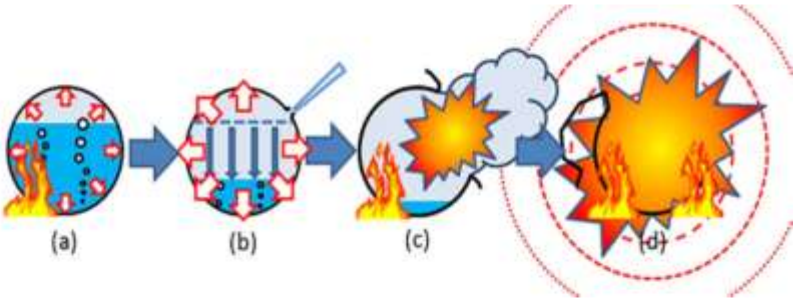


Fig. 3 Representation of BLEVE

If the liquid is flammable and a fire is the cause of the BLEVE, the liquid may ignite as the tank ruptures. Often, the boiling and burning liquid behave as a rocket fuel, propelling vessel parts for great distances. If the BLEVE is not caused by a fire, a vapor cloud might form, resulting in a VCE. The vapors might also be hazardous to personnel by means of skin burns or toxic effects. When a BLEVE occurs in a vessel, only a fraction of the liquid vaporizes; the amount depends on the physical and thermodynamic conditions of the vessel contents.

4. Source and Dispersion Models

Most accidents in chemical plants result in spills of toxic, flammable, and explosive materials. Source models are an important part of the consequence modeling procedure. Accidents begin with an incident, which usually results in the loss of containment of material from the process. The material has hazardous properties, which might include toxic properties and energy content. Typical incidents might include the rupture or break of a pipeline, a hole in a tank or pipe, runaway reaction, or fire external to the vessel. Once the incident is known, source models are selected to describe how materials are discharged from the process. The source model provides a description of the rate of discharge, the total quantity discharged (or total time of discharge), and the state of the discharge (that is, solid, liquid, vapor, or a combination). A dispersion model is subsequently used to describe how the material is transported downwind and dispersed to some concentration levels. For flammable releases, fire and explosion models convert the source model information on the release into energy hazard potentials, such as thermal radiation and explosion overpressures.

Effect models convert these incident-specific results into effects on people (injury or death) and structures. Environmental impacts could also be considered, but we do not do so here. Additional refinement is provided by mitigation factors, such as water sprays, foam systems, and sheltering or evacuation, which tend to reduce the magnitude of potential effects in real incidents. Release mechanisms are classified into wide and limited aperture releases. In the wide aperture case, a large hole develops in the processing unit, releasing a substantial amount of material in a short time. An excellent example is the overpressuring and an explosion of a storage tank. For the limited aperture, case material is released at a slow enough rate that upstream conditions are not immediately affected; the assumption of constant upstream pressure is frequently valid.

For gases or vapors stored in a tank, a leak results in a jet of gas or vapor. For liquids, a leak below the liquid level in the tank results in a stream of escaping liquid. If the liquid is stored under pressure above its atmospheric boiling point, a leak below the liquid level will result in a stream of liquid flashing partially into vapor.

Small liquid droplets or aerosols might also form from the flashing stream, with the possibility of transport away from the leak by wind currents. A leak in the vapor space above the liquid can result in either a vapor stream or a two-phase stream composed of vapor and liquid, depending on the physical properties of the material.

There are several basic source models that are used repeatedly and will be developed in detail here. This source models are-

1. Flow of liquid through a hole,
2. Flow of liquid through a hole in a tank,
3. Flow of liquids through pipes,
4. Flow of vapor through holes,
5. Flow of gases through pipes,
6. Flashing liquids

5. Dispersion Models

Dispersion models describe the airborne transport of toxic materials away from the accident site and into the plant and community. After a release, the airborne toxic material is carried away by the wind in a characteristic plume, or a puff, as shown in Figure. Concentrations downwind are less, because of turbulent mixing and dispersion of the toxic substance with air.

Plume Mode

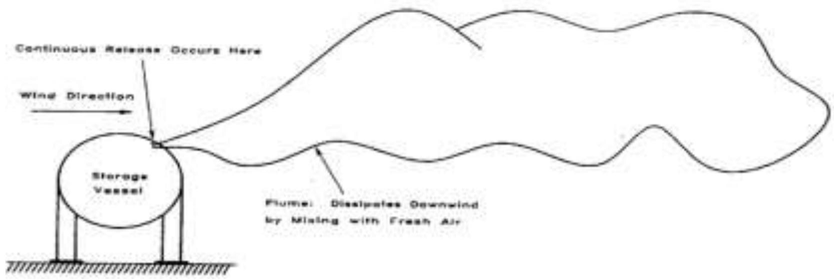


Fig. 4 Plume mode made by release of material

Puff Mode

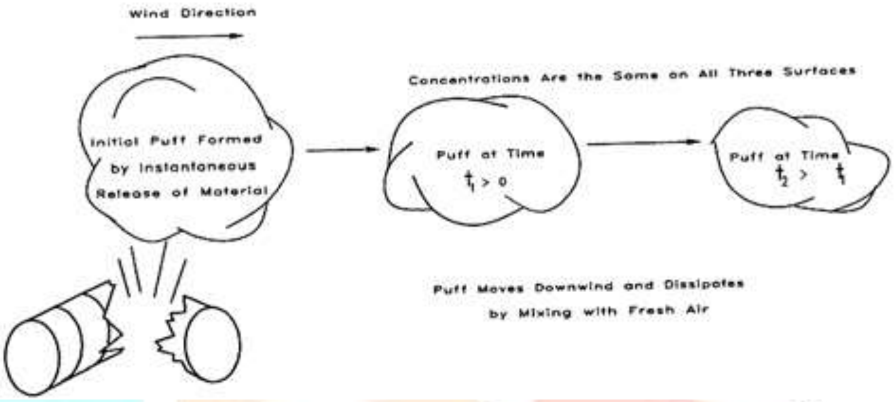


Fig. 5 Puff mode made by release of material

During an accident, process equipment can release toxic materials quickly and in significant enough quantities to spread in dangerous clouds throughout a plant site and the local community. A few examples are explosive rupture of a process vessel as a result of excessive pressure caused by a runaway reaction, rupture of a pipeline containing toxic materials at high pressure, rupture of a tank containing toxic material stored above its atmospheric boiling point, and rupture of a train or truck transportation tank following an accident.

Wind Speed- As the wind speed increases, the plume in figure - becomes longer and narrower; the substance is carried downwind faster but is diluted faster by a larger quantity of air.

Atmospheric Stability- Atmospheric stability relates to vertical mixing of the air. During the day, the air temperature decreases rapidly with height, encouraging vertical motions. At night the temperature decrease is less, resulting in less vertical motion. Temperature profiles for day and night situations are shown in Figure. Sometimes an inversion occurs. During an inversion, the temperature increases with height, resulting in minimal vertical motion. This most often occurs at night because the ground cools rapidly as a result of thermal radiation.

Atmospheric stability is classified according to three stability classes: unstable, neutral, and stable. For unstable atmospheric conditions, the sun heats the ground faster than the heat can be removed so that the air temperature near the ground is higher than the air temperature at higher elevations, as might be observed in the early morning hours. This results in unstable stability because the air of lower density is below air of greater density. This influence of buoyancy enhances atmospheric mechanical turbulence. For neutral stability the air above the ground warms and the wind speed increases, reducing the effect of solar energy input, or insulation. The air temperature difference does not influence atmospheric mechanical turbulence. For stable atmospheric conditions, the sun cannot heat the ground as fast as the ground cools.

The temperature near the ground is lower than the air temperature at higher elevations. This condition is stable because the air of higher density is below air of lower density. The influence of buoyancy suppresses mechanical turbulence.

Ground Conditions- Ground conditions affect the mechanical mixing at the surface and the wind profile with height. Trees and buildings increase mixing, whereas lakes and open areas decrease it.The Figure shows the change in wind speed versus height for a variety of surface conditions.

6. Analysis and Methodologies

An excellent safety program strives to identify the problem before they occur. So we need to cover the entire problem. And we have to make a solution for all of them.

With the help of our study on Toxic Release & Dispersion Modeling, we have prepared -

- Dispersion Modeling.
- Model on Toxic Release
- Divide area according to Potential Hazards(Zoning)
- Develop an emergency response.

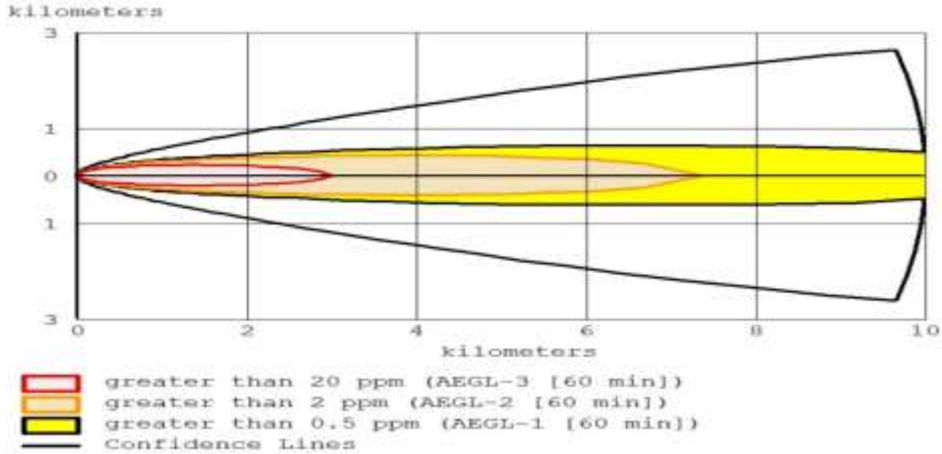
Methodology Used:

1) ALOHA (Aerial location of Hazardous Atmosphere)
2) Pasquill Gifford Dispersion Model

7. Result and Discussion.

Release Scenario 1- Chlorine Leakage

At 13:30 hours, July 27, 2016, RIL Jamnagar Manufacturing Division, Jamnagar, Gujarat, A leakage occurred in common header line. The ambient temperature was 38 degrees C, with the wind speed of 6 meters per second from NE direction at 2-meter header diameter of 10 m length.

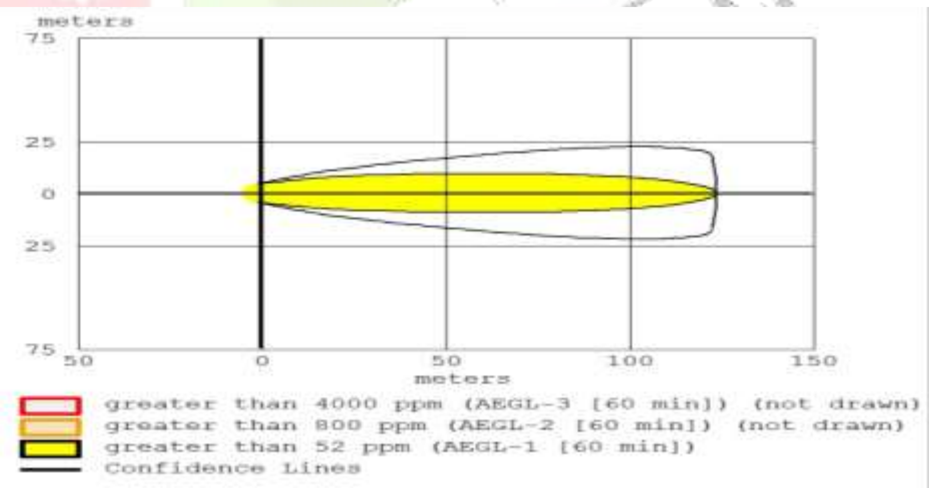


Aerial depiction of hazardous atmosphere in Chlorine Release

In the above threat zone aerial depiction of chlorine leakage, “The Red Zone” extends up to 3.0 kilometer from the point of release with the Acute Exposure Guideline Limit [AEGL] of 20 ppm. Furthermore, “The Orange Zone” extends up to 7.4 kilometers from the point of release with AEGL level of 2 ppm and lastly, “The Yellow Zone” is the least exposure zone extending up to 10 kilometers with AEGL level of 0.5 ppm.

Scenario 2 - Benzene Leakage

At 15:30 hours, August 2, 2016, Jamnagar Manufacturing Division, Jamnagar, Gujarat. A leakage occurred in common header line. The ambient temperature was 30 degrees C, with the wind speed of 6 meters per second from NE direction, the diameter of 4 meters & height of tank was 10 meter. The Diameter of opening is 2 cm. The Hole is at 4 meters above the bottom of the tank.



Aerial depiction of hazardous atmosphere in Benzene Release

In the above threat zone an aerial depiction of Benzene leakage, “The Red Zone” extends up to a range of fewer than 10 meters (10.9 yards) from the point of release with the Acute Exposure Guideline Limit [AEGL] of 4000 ppm. Furthermore, “The Orange Zone” extends up to 17 meters from the point of release with AEGL level of 800 ppm but in this aerial depiction, the threat zone was not drawn because effects of near-field patchiness make dispersion predictions less reliable for short distances and lastly “The Yellow Zone”, which is the least exposure zone extending up to 124 meters with AEGL level of 52 ppm.

Conclusion

In this paperwork, I have adopted an analytical approach in which real-life data from our training location is used to create a hypothetical scenario depicting release of hazardous chemicals (Chlorine and Benzene). Simulating that data in the ALOHA software as well as using Pasquill- Gifford Model, we have determined the threat zones according to the type and means of hazardous release.

Calculating all of the information by hand at the time of a chemical incident would be too time- consuming to help a response, even if the firefighter or emergency responder had the training and education to make all of these calculations. ALOHA, Areal Location of Hazardous Atmospheres is an air-dispersion model used to evaluate hazardous chemical scenarios and determine the likely "footprint" of such spills. ALOHA software is also very much useful in creating almost a precise release scenario and its effects in the surrounding atmosphere, so as to enable the firefighters and responsible authority to develop a thorough off-site emergency plan.

The purpose of impact assessment is to improve community preparedness for off-site releases. It is a mechanism to initiate public protective actions and facilitate effective unified incident management. The plan affects the facility, local emergency response agencies, and external supporting facilities and entities. The key to using the plan effectively is to understand its purpose, intent, content, and limitations and to exercise with it pre-incident. The plan includes an off-site release consequence methodology that prescribes a theoretical vulnerability zone. This is important to identify population exposure and special-needs facilities. In the event of a release, the plan should include a notification tree of what information the facility must report and to which agencies it must report. If the incident requires off-site assistance, the plan outlines the role and responsibilities of key stakeholders and provides a mechanism for establishing a unified command structure.

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