The Benefits of a Risk-Based Approach to Facility Siting

Neil Prophet, Senior Partner
ioMosaic Corporation
2401 Fountain View Drive, Ste. 850
Houston, TX 77057
prophet.n.tx@iomosaic.com

Prepared for Presentation at
8th Global Congress on Process Safety
Houston, TX
April 1 – 4, 2012

UNPUBLISHED

The Benefits of a Risk-Based Approach to Facility Siting

Neil Prophet, Senior Partner

ioMosaic Corporation

2401 Fountain View Drive, Ste. 850

Houston, TX 77057

prophet.n.tx@iomosaic.com

Keywords: Facility Siting, Risk, QRA, Consequence

Abstract

Facility siting has come under increasing scrutiny in recent years and is an important aspect of process safety for plant personnel and their contractors. In December 2009, API issued the Third Edition of the Recommended Practice 752, "Management of Hazards Associated with Location of Process Plant Permanent Buildings," which incorporated much of what has been learned from catastrophic incidents since their Second Edition was published in 2003. In addition, API RP 753, "Management of Hazards Associated with Location of Process Plant Portable Buildings," was developed and issued in June 2007.

API RP 752 outlines three basic facility siting assessment approaches that can be utilized: a consequence-based approach, a quantified risk assessment approach, and a spacing tables approach. This paper summarizes how a risk-based approach to facility siting can provide the best understanding of onsite risks and can enable the most cost-effective resolution of facility siting issues.

1. Introduction

Facility siting is the assessment and management of explosion, fire, and toxic-release hazards to occupants of buildings located in close proximity to process plants. Facility siting is no new issue. As Table 1 shows, there have been numerous incidents highlighting the importance of facility siting. In addition to those incidents listed, many other incidents have occurred which could also have been mentioned.

Table 1. Historical List of Facility Siting Incidents

Date	Location	Fatalities	Description
2006	Danvers, MA	0	Heptane and alcohols
2005	Texas City, TX	18	Pentane/hexane release
2005	Point Comfort, TX	0	Propylene release
2002	Pascagoula, MS	0	Mononitrotoluene release
1999	Allentown, PA	5	Hydroxylamine decomposition
1998	Mustang, NV	4	High explosives
1992	La Mede, France	6	LPG Leak
1989	Pasadena, TX	23	Isobutane and ethylene release
1988	Norco, LA	7	Propane leak
1984	Mexico City	542	LPG line rupture
1978	Texas City, TX	7	Isobutane sphere failure
1974	Flixborough, UK	28	Cyclohexane release

The development of facility siting techniques and guidelines has been a gradual one. OSHA's PSM rule (29 CFR 1910.119, Section (e)), which was introduced in 1992, includes facility siting as part of a facility's process hazards analysis (PHA) requirements.

In response to this requirement, various guideline and best practice documents have been developed to provide facility siting methodologies. These include:

- API Recommended Practice 752, "Management of Hazards Associated with Location of Process Plant Permanent Buildings"
    - First Edition: 1995
    - Second Edition: 2003
    - Third Edition: 2009
- API Recommended Practice 753, "Management of Hazards Associated with Location of Process Plant Portable Buildings"
    - First Edition: 2007
- Center for Chemical Process Safety (CCPS), "Guidelines of Evaluating Process Plant Buildings for External Explosions and Fires"
    - First Edition: 1996
    - Second Edition: In progress

The continued development and implementation of these guideline documents is a crucial step for each facility wishing to maintain the best practices for facility siting.

2. Facility Siting Standards

2.1 API RP 752

API's Recommended Practice 752, "Management of Hazards Associated with Location of Process Plant Permanent Buildings," Third Edition, was issued in December 2009 and was significantly revised compared to earlier editions.

Exclusions include portable or modular buildings, which are now covered under API RP 753, and also soft-sided buildings such as tents, with the focus of the Third Edition being specifically about permanent buildings. It is also interesting to note that API 752 applies to "refineries, petrochemical and chemical operations, natural gas liquids extraction plants, and other facilities covered by OSHA PSM Standard 29 CFR 1910.119", thereby eliminating any confusion regarding which facilities may be considered covered or not covered.

The Third Edition of API RP 752 discusses the need for a phased-in mitigation approach based on a prioritization list of all buildings that fail to meet the building "Siting Evaluation," and has guiding principles for hierarchy of mitigation options. The document also directly refers to API 753 for portable facilities, to clarify understanding of which practice applies to each structure type (i.e., blast resistant, fixed, tent). Also new, is a prescriptive set of topics that must be included in documentation for building facility siting, as described below.

The three basic assessment approaches that API 752 describes are: a consequence-based approach (CBA), a quantified risk assessment (QRA) approach, which would include a risk-based assessment that utilizes numerical values for both consequences and frequencies, and a spacing-tables approach.

While practical guidance on the possible assessment approaches is provided, guidance on understanding how to execute the QRA approach is not provided on the basis that this guidance can be obtained elsewhere.

API 752 proposes consideration of a maximum credible event (MCE). This is an event that is a hypothetical explosion, fire, or toxic event that has maximum consequence to the occupants of the building. Each building should have its own set of MCEs. This edition attempts to ensure more global thought was provided on MCEs by indicating a variety of possible scenarios should be considered before selecting the MCE, including the potential for a dust explosion.

Each location's documentation for facility siting is required to include each of the following:

1. Assessment approach
2. Scenario selection basis
3. Analysis methodology

4. Applicability of analysis methodology
5. Data sources used in the analysis
6. Applicability of data sources
7. Building siting criteria
8. Results
9. Documentation of mitigation plans (for existing facilities), which includes a prioritization list

The Third Edition of API 752 redefines how occupancy criteria is handled. There are no thresholds, only a definition associated with "intended for occupancy." If a building has personnel assigned, or a building is utilized on a recurring basis, it is "intended for occupancy" and it must be included in the assessment. Some buildings are to be evaluated on a case-by-case basis, such as smoke shacks and storm shelters. Another area that is specifically emphasized in the Third Edition of API RP 752, is issues associated with management of change (MOC). Employers should have provisions to address changes to the facility siting assessment when variables such as the number of personnel or time spent inside the building increases. The provisions shall also manage changes when a facility converts from "not intended for occupancy" to "intended for occupancy" or there are modifications to existing facilities, etc.

When addressing explosions, the methods of acceptable analysis for explosions are listed, and specifically exclude the simplified "TNT" model. The analysis is dependent on the building's response to blast load. It is made clear that tools designed for dynamic analysis methods shall be utilized for detailed blast analysis. New facilities and modifications to existing facilities are now required to have a detailed structural analysis.

API 752 considers options and analysis for building siting evaluation for fire. Spacing tables for fire exposure are readily available in multiple resources, and there is discussion of the need to model the different types of fires. Fire modeling may needed to include pool fires, jet fires, or flash fires. The recommended practice discusses two protective concepts for fire: shelter-in-place and evacuation. Owners must implement at least one of these concepts.

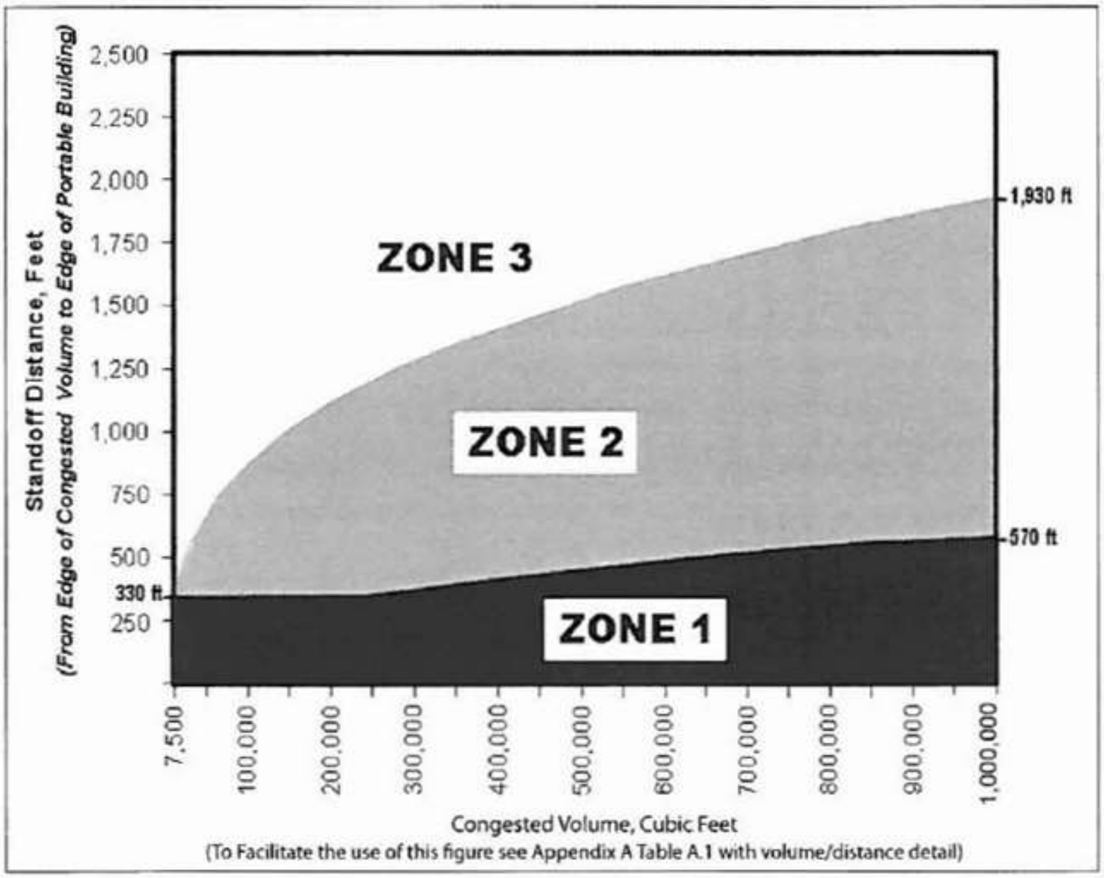
The guidance for evaluation of toxic hazards is similar to fire, in that there is a requirement to understand dispersion for each building. Owners also need to select at least one of the same protective concepts: shelter-in-place or evacuation.

API 752 provides flexibility in the approach, ensuring that employees working in facilities in close proximity to highly-hazardous substances are properly protected in the workplace.

2.2 API RP 753

API's Recommended Practice 753, "Management of Hazards Associated with Location of Process Plant Portable Buildings" is relatively prescriptive in terms of requirements and methodologies when compared to API RP 752. A three-zone method is applied for locating portable buildings. Each zone is based on the size of the congested process area and the distance from the edge of this congested area to the portable building. These zones are shown in Figure 1, which comes directly from API 753.

Figure 1: Portable Buildings Location Distance



Congested volumes, regardless of the material handled, should be considered as potential explosion sources, as a released vapor cloud may drift from adjacent facilities. Additionally, the operating status of a process unit does not exempt it from assessment. As before, a vapor cloud may drift into an offline unit.

For the three zones identified in Figure 1, light wood trailers intended for occupancy should not be located in Zone 1. Other portable buildings require a detailed analysis before being placed in Zone 1. All portable buildings within Zone 2 require a detailed analysis. Finally, any portable buildings may be located in Zone 3 without a detailed analysis. A detailed analysis may either be a consequence analysis or quantitative risk analysis.

3. Consequence Analysis Approach

The consequence-based approach must take into consideration the maximum credible events (MCEs) that could lead to explosions, fires, or toxic releases. This is an event that is a hypothetical explosion, fire, or toxic event that has maximum consequence to the occupants of the building. It should be considered realistic, with a reasonable probability of occurring during the lifetime of the facility. For example, a realistic MCE for most modern well-run facilities is usually a failure of a major transfer line; or for high-integrity piping systems, an MCE could be a failure of a fitting on the line.

Upon selection of the MCEs, a comprehensive list of hazard scenarios, along with all the required data, is taken to the consequence analysis stage. A comprehensive list of the required data for each scenario is provided below:

- Scenario Name
- Process Flow Diagram/Piping & Instrumentation Diagram
- Fluid Conditions (Temperature, Pressure, Phase, Composition, Explosion Reactivity, Toxicity)
- Release Flow Rate
- Release Coordinates
- Equipment Type and Size
- Hole Diameter(s)
- Piping Length (if applicable)
- Release Duration
- Release Geometry (1D, 2D, 2.5D, 3D)
- Degree of Confinement

Meteorological conditions which are representative to the site should be applied. Generally two or three sets of wind speed, humidity, and atmospheric stability data are selected.

In the consequence analysis method, hazard levels must be selected for:

Radiant Heat from Fires – Generally, levels for injury and fatality are required and are set by considering an exposure time based on how long it might take someone to escape or reach a safe haven. Typical values are $5 kW/m^2$ for injury and $12.5 kW/m^2$ for death. When considering flammable effects, jet fires, pool fires, and internal flash fires should be considered. Fireballs and flash fires outside buildings are typically of short duration and not normally considered in facility siting studies.

Overpressure – Overpressure should take into consideration how injuries could be sustained. Very low overpressures can shatter standard windows potentially causing injury to anyone inside the building. It requires a higher overpressure to cause structural damage that could result in building collapse and potentially fatal injury. Very high levels of overpressure are required to directly cause fatal injury, but lower levels can throw a person against equipment causing serious or fatal injury.

Toxic Exposure – The toxic response of humans is extremely complex and difficult to model. A number of simple concentration dependent data also exist, for example, immediately dangerous to life and health (IDLH) and emergency response planning guidelines (ERPG) limits are published by a number of authorities, including several regulators. Other available data include lethal concentration (LC) and lethal dose (LD) data, usually expressed in terms of a particular percentage of fatality for specified exposure duration.

In each case, the consequence analysis should consider building internal environmental degradation (i.e., when it may be unable to support life). It is therefore important to consider influences such as air conditioning, positive air pressure, temperature rise inside or ignition of building, ingress of flammable or toxic vapors, ingress of smoke and fumes, or thermal radiation impact to personnel located near windows or personnel who choose to evacuate.

4. Quantitative Risk Analysis Approach

A facility siting QRA can typically be divided into the following primary tasks:

- Identify plant buildings, construction type and population
- Identify credible hazard scenarios (including maximum credible events)
- Determine consequence of event
- Determine frequency of event
- Determine vulnerability of occupants
- Calculate risk to an individual
- Calculate the aggregate risk to building occupants
- Compare calculated risk with company's risk-acceptance criteria

some of the main facility siting steps (hazard identification (identification of maximum credible events) and consequence analysis) have already been discussed in this paper. The remaining step in a quantitative risk analysis is to apply a frequency to the hazard scenarios, and therefore determine the risk.

A simplified risk equation could be represented by:

$$Risk = Consequence \times Frequency$$

A risk analysis is the development of a quantitative estimate of risk, based on engineering evaluation and mathematical techniques for combining estimates of incident consequences and frequencies.

There are several effective methods that can be used to establish consequence-frequency pairs for detailed QRA studies including (a) fault or event tree analysis, (b) historical failure rate data, and (c) layer of protection analysis (LOPA).

In fault or event trees analysis, one describes in a systematic fashion the logical sequence of events (fault or event trees) that can lead to a hazard scenario. The trees are then quantified to provide an estimate of the hazard scenario frequency.

The use of historical failure rate data approach is good for “generic” failures, but is not recommended for “non-generic” process-related failures or venting from stacks or relief devices. In addition, one cannot easily consider the impact of Safety Instrumented Systems (SISs) on risk reduction.

The frequency analysis of scenarios can also be conducted using the LOPA technique that is described in the CCPS publication, “Layer of Protection Analysis, Simplified Process Risk Assessment.”

Combining the consequences of the hazards with a calculated frequency enables the risk to be determined. Typically, both individual and societal/aggregate risk results are modeled. Results can be presented for daytime population, nighttime population, and a combined average. Additional onsite risk statistics can also be calculated showing the highest individual risk, average individual risk, fatal accident rate, and rate of death.

The facility siting QRA approach allows a variety of results to be generated, which enables detailed analysis and understanding of the facility siting risks involved. Typical risk results, as defined by CCPS (1989), are as follows:

Individual Risk – “The risk to a person in the vicinity of a hazard. This includes the nature of the injury to the individual, the likelihood of the injury occurring, and the time period over which the injury might occur”. This can be displayed graphically or numerically. An example of graphical individual risk contours is provided in Figure 2.

Average Individual Risk – “The average of all individual risk estimates over a defined population”. Fatal accident rate (FAR) is calculated from the average individual risk, and is normally used as a measure of employee risk in an exposed population. This is the number of fatalities occurring during 1,000 working lifetimes (10^8 hours).

The **Fatal Accident Rate (FAR)** is calculated from the average individual risk, and is normally used as a measure of employee risk in an exposed population. It has units of fatalities per 10^8 man hours of exposure.

Societal Risk – Societal risk measures the risk to a group of people (CCPS, 1989). Societal risk measures estimate both the potential size and likelihood of incidents with multiple adverse outcomes. In this example, the adverse outcome considered is immediate fatality resulting from fire, explosion, or exposure to toxic vapors. Societal risk measures are important for managing risk in a situation where there is a potential for accidents impacting more than one person. Societal risk results can be presented graphically or numerically. An example of a graphical societal risk F-N curve is provided in Figure 3.

Average Rate of Death (ROD) is the estimated average number of fatalities in the population from all potential incidents.

Aggregate Risk – Facility siting commonly uses aggregate risk as a tool for managing the risk associated with occupied buildings in a process plant. Aggregate risk can be defined as "societal risk applied to a specific group of people within a facility". (CCPS, 1996)

Figure 2: Sample QRA Result: Individual Risk Contours

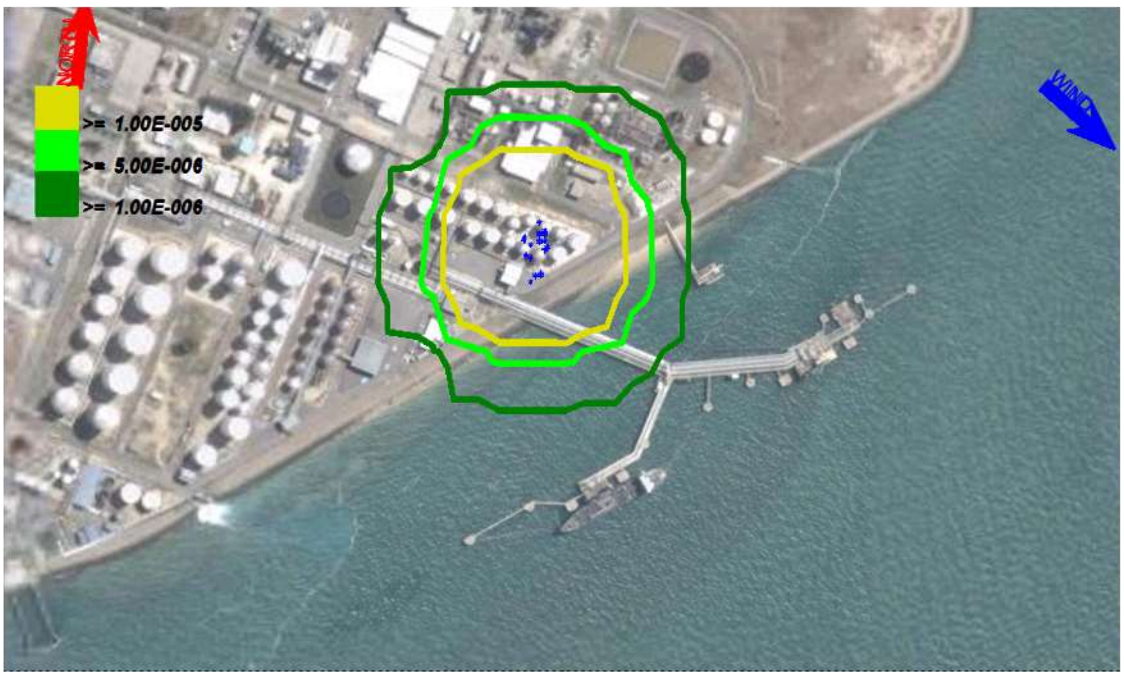
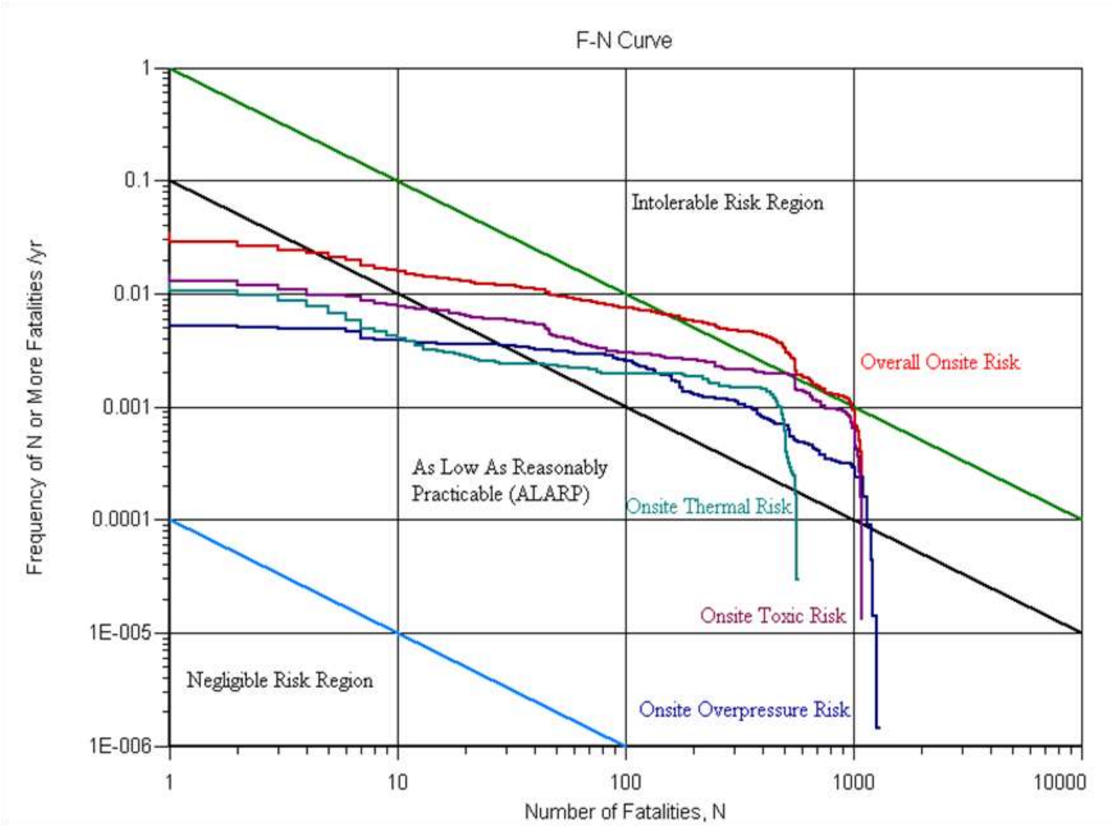


Figure 3: Sample QRA Results: Societal Risk F-N Curves



5. Benefits to the QRA Approach

The QRA approach gives a far greater understanding of the main contributors to risk, as it allows for significant segmentation of the risk. Variations of risk results can include:

- Overall risk contours
- Overpressure risk contours (risk filtered to show only risk from vapor cloud explosion overpressure)
- Thermal radiation risk contours (risk filtered to show only risk from thermal radiation effects)
- Toxic impact risk contours (risk filtered to show only risk from toxic effects)
- Risk ranking of scenarios (all hazard scenarios, including MCEs, sorted to show scenarios which generate the greatest risk)
- Risk ranking of impacted buildings (all buildings within the study, sorted to show buildings which are seeing the greatest risk)

In addition to risk being expressed in terms of fatalities, risk can also be expressed in financial terms. The F-N curve can be replaced with a $-N curve instead, thereby enabling a cost-benefit analysis approach to any mitigation options being considered.

Using a QRA approach, while the consequences of a MCE may be severe, it may occur at a sufficiently low frequency to deem that the risk is acceptable. Additionally, the QRA approach generates all the typical consequence results which would be expected during a consequence-analysis approach.

When considering a facility siting QRA, it is also possible to develop a table showing overpressure risk frequencies for each building considered within the scope. This table can show overpressure frequencies for specific overpressure levels, relevant to building type and structure. An example of such a table is provided as Table 2.

Table 2: Sample Overpressure Frequency Table

Description / Function	Overpressure Risk Frequency / yr		
	≥ 1 psi	≥ 3 psi	≥ 5 psi
Lab	6.84E-05	7.36E-06	2.15E-06
Substation	8.21E-05	9.72E-06	2.85E-06
Operator Shelter	8.32E-05	7.16E-06	2.95E-06
Operator Shelter	1.14E-04	2.95E-05	5.29E-06
Office	1.74E-05	1.00E-06	2.93E-07
Substation	9.75E-05	2.81E-06	5.10E-07
Maintenance Building	5.12E-05	1.07E-05	3.38E-06

Using the overpressure frequency table approach, an acceptable frequency level can be established (e.g., less than 1 E-04), whereby frequencies of overpressure exceeding the acceptable value are deemed an unacceptable level of risk for a specific building. In this way, at-risk buildings can easily be identified and priorities established to mitigate these risks.

6. Conclusions

When conducting a facility siting study, all onsite buildings should be reviewed to verify if they are intended for occupancy. As with any process safety study, hazard identification is a crucial step, and facility siting is no exception. It is of critical importance to ensure that all potential hazards are identified and considered.

The QRA approach to facility siting provides a greater understanding of onsite hazards affecting buildings and personnel. The ability to segment, filter, sort, and compare risk results enables easy identification of problem areas and can also be used to incorporate a cost-benefit analysis into the study.

Having identified any buildings which fail to meet the evaluation criteria, a prioritized list of buildings, together with a mitigation plan, should be developed and implemented. Any mitigation options should be implemented in order of decreasing reliability.

The level of effort required when setting up a QRA facility siting study, does not differ greatly from the consequence analysis approach, while providing a great deal of extra useful information for the risk analyst.

6.1 References:

1. API Recommended Practice 572, Third Edition, “Management of Hazards Associated with Location of Process Plant Permanent Buildings” (2009)
2. API Recommended Practice 573, First Edition, “Management of Hazards Associated with Location of Process Plant Portable Buildings” (2007)
3. CCPS, “Guidelines for Chemical Process Quantitative Risk Analysis”, AIChE/CCPS, New York (1989)
4. CCPS, “Layer of Protection Analysis – Simplified Process Risk Assessment,” AIChE/CCPS, New York (2001)
5. CCPS, “Guidelines for Facility Siting and Layout,” AIChE/CCPS, New York (2003)
6. CCPS, “Guidelines for Evaluating Process Plant Buildings for External Explosions and Fires,” AIChE/CCPS, New York (1996)