MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

19th Annual International Symposium
October 25-27, 2016 • College Station, Texas

An Overview of Worldwide Risk Tolerability Criteria for Chemical Process Industries

Authors:

Jordi Dunjó, Ph.D., Principal Consultant, ioMosaic Corporation

Neil Prophet, Senior Partner, ioMosaic Corporation

Marcel Amorós, Consultant, ioMosaic Corporation

Abstract

Quantitative risk assessment is accepted as a process safety management tool in many countries throughout the world. Risk-based legislation is implemented by national governmental bodies. These organizations are often under public scrutiny, which indicates a high degree of societal endorsement of the values. There are at least three themes that are commonly used in the development of many generally accepted and recognized risk criteria: (1) a comprehensive risk management program must address both individual and societal risk; (2) risk criteria for the public must be lower, i.e. more conservative, than those for the workforce since the workforce risk is considered to be voluntary; and (3) with respect to individual risk, new facilities should be held to a higher level of risk performance than existing facilities. For new facilities many opportunities exist to apply new/advanced risk reduction technologies. In contrast, societal risk criteria are universally identical for new and existing situations; i.e., where a potential exists for major accident events affecting large numbers of people, most regulators have judged that older facilities must meet the same standards as newer facilities.

This paper evaluates various international risk criteria in use today, and evaluates their respective merits. It also provides suggestions for companies or countries considering implementing their own risk tolerability criteria.

Keywords: risk assessment, QRA, individual risk, risk contours, societal risk, FN curve, ALARP

Table of Contents

I. Abstract ..... **i**

II. Introduction to Risk Assessment **3**

A. Individual Risk Definition and Characterization 5

B. Societal Risk Definition and Characterization 6

III. Some Thoughts on Risk Tolerability **8**

A. Evaluating Risk Tolerability 9

1. Qualitative Approach 9

2. Quantitative Approach 10

IV. Overview of Risk Tolerability Criteria State-of-the-Art **12**

V. Summary of Worldwide Tolerability Risk Criteria **17**

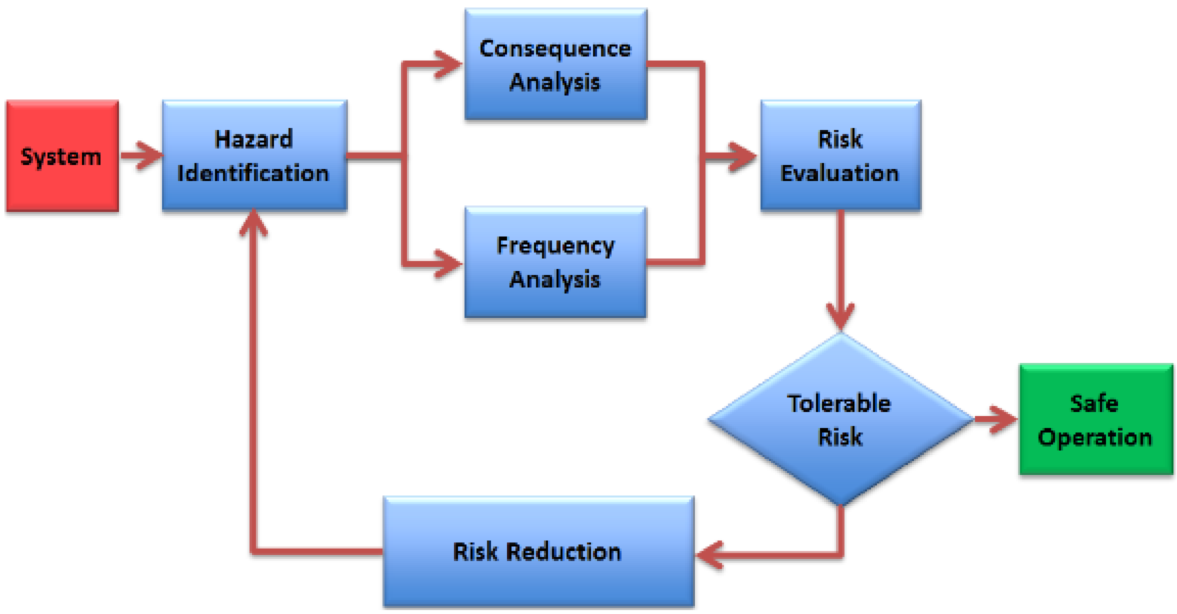
VI. Conclusions **24**

VII. References **25**

Introduction to Risk Assessment

Risk is defined in ISO 17776 **[1]** as the combination of the frequency of occurrence of an event and the consequences of that event. Accordingly, a risk-based approach considers both the frequency of occurrence and associated consequences of all outcomes that could lead to explosions, fires, and flammable and toxic dispersions in a hazardous process facility. Thus, this type of approach balances the results of a consequence-based approach by quantifying the frequencies of events leading to various consequences. The main purpose of a risk-based assessment, known as Quantitative Risk Analysis (QRA), is to answer the following key questions: (1) What can go wrong? (2) How likely is it? (3) What are the impacts; (4) Is the risk tolerable?, and (5) If not, which are the most appropriate safeguards for reducing risk to a tolerable level?. **Figure 01** illustrates a simplified QRA flowchart **[2]**.

Figure 01: Simplified Quantitative Risk Assessment Flowchart



The following contents describe the minimum criteria for conducting the four main steps during a QRA. Note that even though the main purpose of this paper is to address and provide guidance on risk tolerability criteria, it is important to define the following steps that describe the QRA process:

- **Hazard Identification:** Loss Of Containment (LOCs) scenarios are identified via systematic unit-by-unit Process Hazard Analysis (PHA). The LOCs to be identified include any piece of equipment or piping capable of leading to or from a hazardous material or energy source.

- **Frequency Analysis:** This is based on the estimation of the likelihood of occurrence of all LOCs identified during the hazard identification step. The frequency analysis can be conducted using historical data, specific plant data (if available), worldwide references with generic process equipment failure rates **[3-6]**, and also developing detailed fault trees for defining specific LOCs; i.e., top events.

- **Consequence Analysis:** Consequence modeling is performed in order to quantify the effects of LOCs previously identified. It is characterized based on: (1) the release sources of material or energy associated with the hazard being analyzed; and (2) the quantification of the impacts on a target of interest. To model the consequences of these events, the source strength, duration, and phase must be accurately determined. These quantities are functions of storage/process conditions and the thermo-physical properties of the chemical(s) in question and can be determined from fluid flow equations. Note that consequence analysis includes the identification and quantification of ALL potential outcomes that a hazardous release may cause. The Event Tree Analysis (ETA) methodology is a valuable tool for identifying and quantify all potential outcomes.

- **Risk Evaluation:** The risk evaluation (or Quantification of Risk) is both a function of the likelihood of occurrence (i.e., frequency analysis) of possible undesired events (i.e., hazard identification) and the magnitude of their associated consequences (i.e., consequence analysis). This step involves the characterization and estimation of individual and societal risk for both workers and public. These risk estimates should consider toxicity, thermal radiation, and overpressure hazards.

- **Risk Tolerability Criteria:** Risk tolerability criteria for individual and societal risk is compared between the actual risk identified and the target risk to be achieved according to the ALARP (As Low As Reasonable Practicable) principle.

***ALARP:** the term ALARP arises from UK legislation, particularly the Health and Safety at Work etc. Act 1974 **[7]**, which requires "*Provision and maintenance of plant and systems of work that are, so far as is reasonably practicable, safe and without risks to health*". The phrase "So Far As is Reasonably Practicable" (SFARP) in this and similar clauses are interpreted as leading to a requirement that risks must be reduced to a level that is "As Low As is Reasonably Practicable". The key question in determining whether a risk is ALARP is the definition of "*reasonably practicable,*" which is interpreted to mean: "*Risk must be averted unless there is a gross disproportion between the costs and benefits of doing so*".

- **Risk Reduction:** recommendations have to be proposed with the aim to minimize the actual risk level of the facility under analysis and comply with the applicable risk criteria. Additionally, recommendations intended to ensure effective management procedures, and recommendations that could improve the effectiveness and/or reliability of the system may also be considered.

As a result, the individual risk and the societal risk are two key concepts defined below.

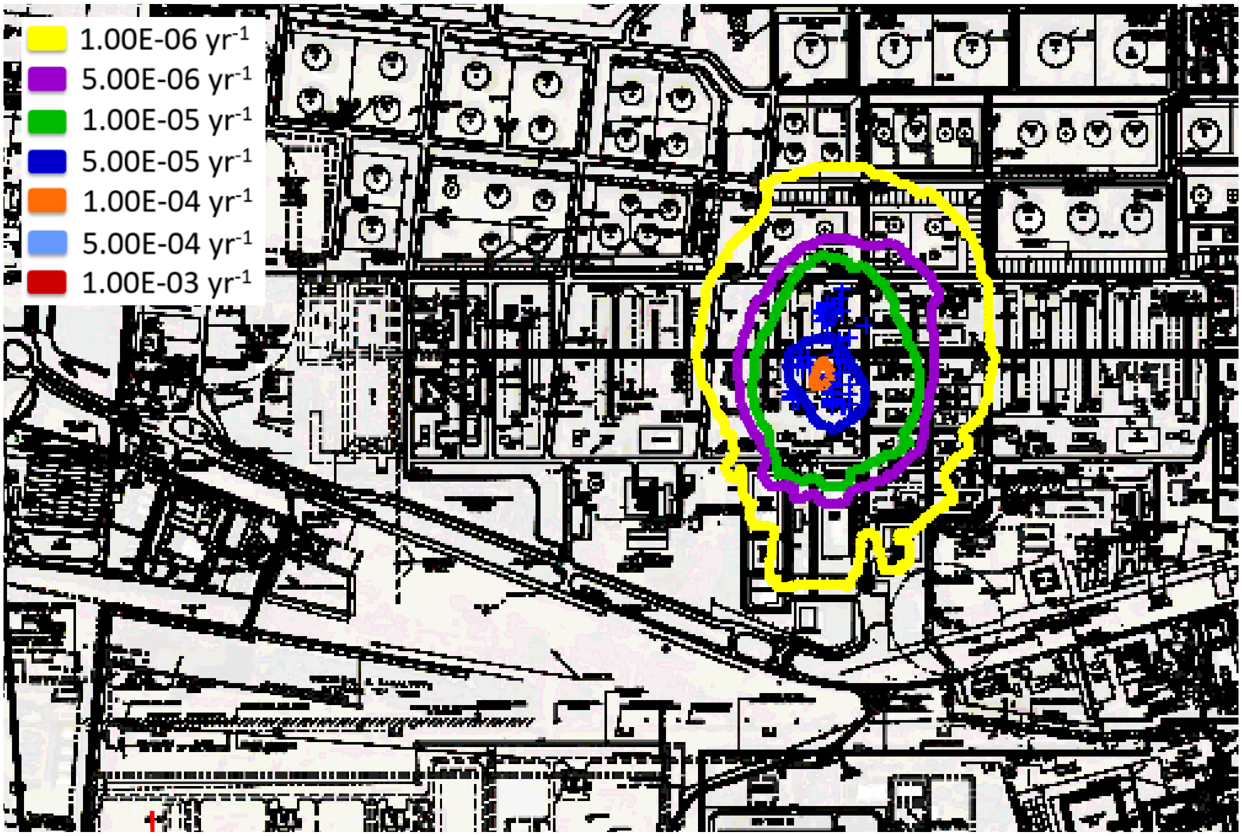
Individual Risk Definition and Characterization

The individual risk concept can be defined as the risk which considers the acceptability of a particular level of risk to an exposed individual; i.e., it is not a function of the total number of individuals placed in a given location. The individual risk can be graphically represented with Individual Risk Contours (**IRCs**) and it can be expressed as a single number or index, for example, for comparison purposes. When the goal is to determine the contribution level to the overall individual risk by one or more process units or by a specific type of hazard, the index Total Individual Risk (**IR_{TOT}**) is sometimes used.

- **Individual Risk Contours (IRC)**: Iso-risk lines are overlaid on the site topography at locations where a hypothetical individual staying there for 24 hours per day and 365 days per year is subject to a defined probability of harm due to exposure to hazards from a LOC, or multiple LOCs. Risk contours are drawn by connecting points of equal risk where the risk is calculated by determining the consequences and frequency from a number of scenarios. By adopting certain criteria for harm (most often fatality) and by using, for example, the so-called probit equation for toxic substances, thermal radiation from fires, and explosion overpressure, effect distances can be determined from the origin of an event. Based on incident frequencies, presence of ignition sources, and effects from meteorological conditions (i.e., wind direction, wind speed, Pasquill stability distribution) the contribution from each scenario/event to a point at a distance from the event can be calculated. By creating a grid over the facility being analyzed and summing the contribution from all scenarios for each grid point, a three-dimensional graphical representation can be developed. This three-dimensional rendering is then reduced to a two-dimensional representation by connecting points of equal risk. **Figure 02** illustrates an example of IRCs **[8]**.

- **Total Individual Risk (IR_{TOT})**: This index represents the results of the individual risk contours in a single number. The IR_{TOT} is calculated by summing all individual risk values for each cell within the computational domain. This index is a good tool, for example, for quantifying the contribution percentage of individual process units in a hazardous chemical facility. This procedure favors the statistical analysis of the individual risk results and helps the risk mitigation decision-making process by identifying the key process units that significantly influence the total risk of the site under analysis.

Figure 02: Example of Risk Contours Representing Predicted Risk Levels

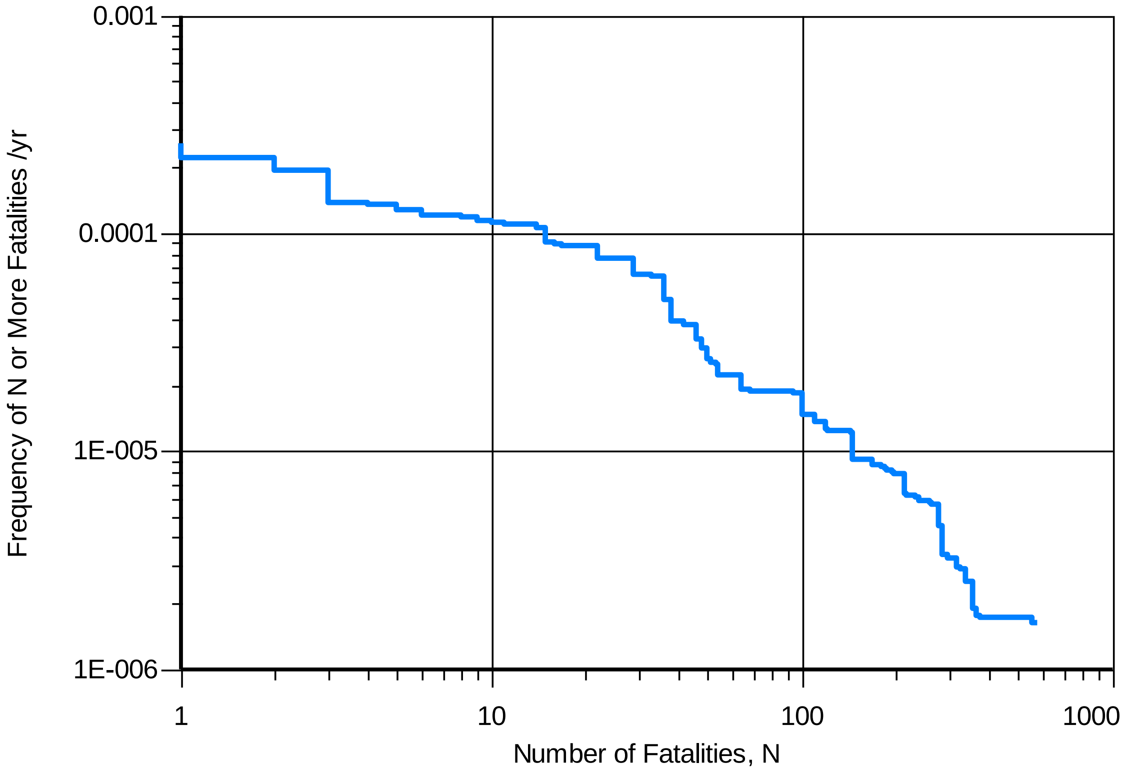


Societal Risk Definition and Characterization

The societal risk concept addresses the society's aversion to accidents which can result in multiple fatalities; i.e., the societal risk takes into account the actual population present in a given area. The societal risk can be graphically represented by F-N Curves (i.e., Frequency – Number of fatalities curves) and it can be expressed using a single number or index. When the goal is to determine the contribution level to the overall societal risk by one or more process units or by a specific type of hazard, the indices "Potential Loss of Life" (PLL) or "Average Rate of Death" (ROD) are sometimes used. Note that PLL and ROD, defined below, are considered equivalent indices:

- **F-N Curves (FN):** Societal risk is often depicted on a cumulative graph called an F-N curve. The horizontal axis is the number of potential fatalities. The vertical axis is the cumulative frequency F per year of N or more fatalities occurring. F-N curves are an indicator used by authorities as a measure of social disruption in case of large accidents. Because it is a cumulative curve, the curve always drops away (or has a negative slope) with increasing N. **Figure 03** illustrates and example of FN Curve **[9]**.

Figure 03: Example of FN Curve



Potential Loss of Life (PLL) or **Average Rate of Death (ROD)**: PLL or ROD is defined as the expected value of the number of fatalities per year (or over the life time of a project). PLL is a type of risk integral, being a summation of risk as expressed by the product of frequency and consequences; i.e., number of fatalities. The integral is summed over all the potential events that can occur. It is mainly used to compare options and enables the inclusion of different risk types like process, transport, and workplace hazards in one number.

After introducing the individual and societal risk concepts, the following contents provide guidance and knowledge on worldwide risk tolerability criteria applicable to the Chemical Process Industry (CPI).

Some Thoughts on Risk Tolerability

As the examination of risks presented by potentially hazardous facilities has advanced, so has the concept of what constitutes an acceptable risk. The phrase “acceptable risk” is widely used in QRA literature. However, it is a somewhat misleading phrase and it is more meaningful to talk about “risk tolerability”. Individuals may “accept” risk of an activity on a voluntary basis if they deem it is low enough and if they derive a benefit from it. For example, driving an automobile poses a small risk but most people are willing to “accept” that risk. However, when a risk from an activity is imposed on an individual on an involuntary basis and there are no perceived benefits that the individual gets from the activity, then no risk is truly “acceptable”, no matter how small. For involuntary risks imposed on individuals the appropriate concept for decision makers is: “is the risk small enough to be tolerable?”. Accordingly, concepts used by various jurisdictions in the United States and elsewhere on what constitutes a “tolerable” risk are presented in this section. In particular, the interest is to define if a major chemical facility presents tolerable or intolerable risk to its surroundings. Almost all human endeavors entail some level of risk, so the decision to tolerate a risk will be balanced against the benefit derived. However, there must be some levels of risk which historically have been considered either tolerable or intolerable. These levels of risks vary between communities and individuals and depend on a number of factors. The most important causes that influence the decisions to be made on risk tolerability are:

- **Economic benefit**: Individuals or communities who will receive direct economic benefit from an industrial site through increased employment or income will be more tolerant of the associated risk. Those who see no economic benefit are generally less tolerant. The cost of reducing risk by modifying the site influences the level of tolerable risk. If significant improvements can be achieved without losing too much of the economic benefit, these enhancements are normally required. Unfortunately, the perception of economic benefit and cost varies between individuals, local communities, safety authorities, governments and developers.

- **Amenities:** Individuals and communities are generally intolerant of activities that will be visually intrusive, noisy, and smelly or pollution threats. Improved amenities, such as better roads or public transport, usually have no influence on risk tolerability.

- **Voluntary or involuntary risk**: Individuals who move into an area have generally made a voluntary decision to accept the existing risk, provided the risk has been previously identified. Additional risk associated with new developments are frequently considered involuntary risks that can only be avoided at a great cost, such as by moving away from the area. Consequently, involuntary risk is much less tolerable than voluntary risk.

- **“Visible risk”**: Where risk is concentrated in a local area, for example in a coal mining community, the impact of an accident will be very visible and deeply felt. This can be contrasted with road accidents, or disease, where isolated individuals are affected and there is little concentration of risk on communities. Generally, society will expend greater efforts to reduce the visible risks despite the fact that more lives are lost by other causes.

- **Size of potential accidents:** Accidents which injure or kill large numbers of people attract more interest than individual incidents that kill the same number of people. Likewise, activities which have the potential to cause multiple injuries/fatalities are less likely to be tolerated, even if the probability of such an accident is extremely low.

Evaluating Risk Tolerability

Two basic approaches exist to evaluate risk tolerability criteria. The more traditional approach, used by numerous industries, is policy-driven and qualitative in nature. The other approach, used more extensively in Europe in various industries and under consideration in the United States by some major chemical companies, is quantitative and involves the development of numerical criteria for measuring risk tolerability. Although both approaches have certain advantages and disadvantages, the quantitative approach contains the characteristics that lead to a sound and long-term risk management program.

Qualitative Approach

Evaluation of qualitative risk tolerability can be based on the principle-based approach, or the procedural or checklist approach.

On one hand, the principle-based approach typically centers on a formalized code of ethics that allows all levels of decision making within an organization to use the same guidelines when judging risk. Examples of statements that might be included in such a code are:

- The company will not expose its employees or neighbors to risks that are considered intolerable, based on general practices and available technology.

- The company will comply with all applicable regulations and guidelines related to acute risks, and will adopt its own standards where regulations do not exist or are inadequate or incomplete.

- Any system or part of a system which failing can lead directly to fatalities or major injuries, and will be considered to be critical to safety and will undergo more rigorous analysis. Furthermore, risk reduction measures will be applied if it is deemed necessary.

A serious disadvantage of this approach is that principles such as those listed above are subject to broad interpretation, resulting in an inconsistent decision-making process.

On the other hand, the checklist approach involves developing an exhaustive list of factors that must be qualitatively examined in all risk-tolerability decisions. Such factors are usually correlated with: (1) activities; (2) demographics of the area of operations; or (3) issues such as public perception. Examples of activity related factors are: (a) Chemicals used and produced and the degree of hazard for each; (b) Number of required loading/unloading, movements, and transfers; (c) Total volume of hazardous material stored; (d) Type of activities involved (e.g., testing, training).

The checklist approach officially considers most areas and issues correlated with risk. However, it does not provide enough guidance or control over how thorough these areas/issues are addressed or understood.

Generally, qualitative approaches to risk-tolerability evaluation have a good chance of acceptance both within the organization and externally because the goals are broad and uncontentious. In addition, existing operations are likely to be found compliant with such goals. However, compliance does not necessarily mean that the public or the applicable control agencies will find such operations tolerable in terms of the risks they perceive. Thus, qualitative approaches can fail in important ways: (1) Qualitative goals generally do not provide any assistance in managing risk levels, particularly for existing operations; i.e., they cannot indicate how safe is safe enough; (2) They can be circumvented during the evaluation process; (3) They do not ensure consistency in risk decision making; and (4) They may tend to become methodologies for qualitative support of risk decisions, rather than actual policies for sound risk management.

Quantitative Approach

The quantitative approach to evaluate risk tolerability involves developing a set of numerical criteria that can be used with the standard representations of risk contours, F-N curves, and individual risk estimates to determine whether additional mitigation measures are needed. A QRA is used to determine the overall risk levels, which are then compared to the applicable risk tolerability criterion. QRA is a methodology that identifies potential mishaps, determines their expected chances of occurrence, evaluates their potential impact, and then translates all this information into overall risk results. Numeric criteria for human safety is often based on fatalities rather than injuries, largely because the data on fatalities is considered more accurate. The Health and Safety Executive **[10]** adopted a criterion based on *dangerous dose*, which attempts to address the problem of estimating fatality rates from an incident. Numeric criteria such as these must be applied with caution because they represent goals or targets, rather than universally accepted limits, standards, or requirements. Therefore, any judgment regarding the tolerability of a risk must also: (1) Consider the uncertainty of the risk estimate; and (2) Address the various qualitative issues affecting public perception.

Quantitative risk-tolerability criteria may be applied absolutely or relatively. With absolute applications, numerical criteria are treated as standards with which operations within an organization must comply. With relative applications, risks are evaluated against numerical criteria on a case-by-case basis. Compared with absolute applications, relative applications are less rigid and allow room for judgment. Even with this element of subjectivity, relative applications, if done prudently, can avoid inconsistencies and result in sound decisions. Furthermore, decisions made on the basis of relative applications of numerical criteria may be less subject to external criticism. This is mostly because the specific factors to be considered are not as identifiable as factors to be taken into account in absolute applications.

The quantitative approach to evaluate risk tolerability has several advantages and disadvantages when compared to qualitative evaluations, as listed in **Table 01** below.

Table 01: Advantages and Disadvantages of Quantitative Approach

Advantages of Quantitative Approach	Disadvantages of Quantitative Approach
It is an explicit statement of policy	The public has not yet demonstrated complete confidence in the use of numerical criteria for assessing the tolerability of risks and may criticize a particular number.
The full site of an organization can be measured for compliance with the criteria.	Existing operations may not be able to meet such specific criteria as easily as new ones
The allocation of resources to reduce risk is based on objective decision making.	The implementation of numerical criteria may require more resources as it may require extra effort to be used in risk reduction
The development and implementation of such criteria can put an organization in a better position to deal with future regulations.	

Finally, it is important also to mention that there are many low level unavoidable risks (sometimes referred to as "residual risks") that may be caused by nature or be man-made. The risk of being injured or killed in a hurricane or an earthquake represents low level unavoidable risks. Similarly, with today's technology, living near a large tank which stores a hazardous material is also considered a low level risk, based on the fact that a spontaneous large scale failure of the tank is not likely to occur, and if it does, it would be as a result of a major natural event such as an earthquake. These unavoidable background risks should be considered when examining the tolerability of living in the vicinity of a hazardous chemical facility.

Overview of Current Risk Tolerability Criteria

Numerous risk criteria have been established by government agencies and private industry. Below is a discussion of various risk criteria used in the US, Europe, UK, Canada, Hong Kong and. The section "Summary of Worldwide Tolerability Risk Criteria" in this paper illustrates detailed numeric risk criteria for these mentioned areas, and other worldwide entities and organizations.

The US federal government has no specific risk based criteria. The Federal Clean Air Act **[11]** and Risk Management Program (RMP) **[12]** define worst case zones which are used for emergency response planning, but not correlated with land use planning decisions. The following contents are examples of some criteria established in California:

- Los Angeles County Fire Department (LACFD) defines criteria for significant risks associated with their RMP program **[13]**, which has been superseded by the statewide California Accidental Release Program (CalARP) program **[14]**. It should be noted that the LACFD criteria do not meet the specific requirements of the California Environmental Quality Act (CEQA) **[15]** for the evaluation of worst-case events.

- The County of Santa Barbara established public safety thresholds in 2000 addressing the types of development that would require detailed risk analysis and the thresholds which would define significance under the CEQA **[15]**. The Santa Barbara thresholds are based on F-N curves and define acceptable frequency as a function of the number of persons affected (i.e., a sloped line on an F-N curve).

- Under the County of Santa Barbara Safety Element **[16]**, the following definitions are used to categorize public risk: (1) Red Zone: Unacceptable for all land use planning; (2) Amber Zone: Acceptable for "general" urban development. However, the amber zone is also defined as unacceptable for highly sensitive land uses and high density residential areas; and (3) Green Zone: Acceptable for all land use planning.

- As a final illustrative example of risk criteria that may be applicable to US, the NFPA (National Fire Protection Agency) developed a standard **[17]** intended to provide the minimum fire protection, safety, and related requirements for the location, design, construction, security, operation, and maintenance of liquefied natural gas (LNG) plants. This document provides individual risk criteria as listed in **Table 02**.

Table 02: Specific Individual Risk Criteria for LNG Plants – NFPA 59A

Criterion Annual Frequency	Remarks
Zone 1 Risk ≤ 1.00E-05	**Not Permitted:** residential, office, and retail **Permitted:** occasionally occupied development (e.g., pump houses, transformer stations)

Criterion Annual Frequency	Remarks
Zone 2 1.00E-06≤ Risk ≤ 1.00E-05	**Not Permitted:** shopping centers, large-scale retail outlets, restaurants, etc. **Permitted:** work places, retail and ancillary services, residences in areas of 28 to 90 people/hectare density
Zone 3 3.00E-07≤ Risk ≤ 1.00E-06	**Not Permitted:** churches, schools, hospitals, major public assembly areas, and other sensitive establishments **Permitted:** all other structures and activities

Europe, particularly the United Kingdom (UK) and the Netherlands, have been developing risk criteria for the last 40 years. These are detailed in the report "Societal Risks" **[18]**, and are summarized below. In 1996, the European Union Council Directive on the control of major-accident hazards (the so-called Seveso Directive **[19]**) was adopted. Member States had two years to meet the regulations set by the Directive. Since 1999, these regulations have become mandatory for the industry, and public authorities of Member States are now responsible for the implementation and enforcement of this Directive.

The UK has published a number of documents correlated with risk criteria, and the levels that are considered "tolerable" have been constantly changing since 1970. The HSE (Health and Safety Executive) published the "Tolerability of Risk Criteria" document **[20]**, which addresses some levels for fixed facilities and transport activities. The UK HSE has also published the PADHI (Planning Advice for Developments near Hazardous Installations **[21]**) levels report, which describes acceptable criteria as listed below in **Table 03** and **Table 04**.

Table 03: UK HSE Planning Advice for Developments near Hazardous Installations

Sensitivity	Description and Examples	Criteria
Level 1	Based on normal working population – parking areas, warehouses, non-retail, less than 100 occupants, minor transportation links.	Ok in all zones < 1.00E-05
Level 2	Based on the general public – at home and involved in normal activities – residential units less than 40 per hectare, hotels, motels up to 100 beds, major transport links, retail less than 5000 m2, gatherings of less than 100 people.	Ok in middle and outer zones only < 1.00E-06
Level 3	Based on vulnerable members of the public (children, those with mobility difficulties or those unable to recognize physical danger) – more than 100 beds, more than 40 units	Ok in outer zone only <3.00E-07

Sensitivity	Description and Examples	Criteria
	per hectare, more than 100 people outdoors, hospitals 24 hr care < 0.25 hectare prisons.	
Level 4	Large examples of Level 3 and large outdoor examples of Level 2 – theme parks, stadiums, open air areas with more than 1000 people, hospitals > 0.25 hectare, daycare larger than 1.4 hectare.	Not ok in any zone

Table 04: UK HSE Consultation Zones

Frequency	Zone	Description
< 1.00E-05	Inner Zone	Receiving a “dangerous dose” or worse.
< 1.00E-06	Middle Zone	Receiving a “dangerous dose” or worse.
< 3.00E-07	Outer Zone	Receiving a “dangerous dose” or worse. This criterion is appropriate for highly vulnerable or very large public facilities.

The Netherlands adopted specific risk criteria around 1980 and later updated it in 1996. These criteria are shown from **Table 07** through **Table 10**, and **Figure 04**. These levels are based on three regions: an unacceptable region, a region where reductions are desired, and an acceptable region. Note that the Santa Barbara County policy described above is based on the Netherlands policy.

In response to the expansion and development of oil / LPG terminals in Tsing Yi Island, and the residential development nearby, the Hong Kong government developed specific risk criteria in 1988, later updated in 1993. These criteria are shown from **Table 07** through **Table 10**, and **Figure 04**.

The criteria in France only considers the “worst credible” consequences of accidents, and is used to define the safety distance around hazardous establishments. Zone distances are based on the distance which produces a 1% fatality rate (for the inner zone) and the distance to which irreversible health effects occur (for the outer zone). Inner zone areas do not allow any additional development that could lead to a population increase. The zone between the inner and outer zones allows limited and low density housing development. All development is allowed beyond the outer zone, as listed in **Table 05** below.

Table 05: Risk Criteria Used in France

Type of Risks and Facilities	Type of Accident Scenario
Risks linked to liquefied combustible gas facilities (fixed, semi-mobile or mobile)	**Scenario A:** BLEVE (Boiling Liquid Expanding Vapor Explosion) **Scenario B:** VCE (Vapor Cloud Explosion)
Risks linked to vessels containing liquefied or non-liquefied toxic gases where the containment is not designed to resist	**Scenario C:** Total instantaneous loss of containment

Type of Risks and Facilities	Type of Accident Scenario
external damage or internal reactions of products	
Risks linked to vessels containing toxic gases where the containment is designed to resist external damage or internal reactions of products	**Scenario D:** Instantaneous rupture of the largest pipeline leading to the highest mass flow
Risks linked to large vessels containing flammable liquids	**Scenario E:** ▪Fire in the largest tank ▪Explosion of the gas phase for fixed roof tanks ▪Fireball and projection of burning product due to boil-over
Risks linked to use or storage of explosives	**Scenario F:** Explosion of the largest mass of explosive present or explosion due to a reaction

The Major Industrial Accidents Council of Canada (MIACC **[22]**) was dissolved in the fall of 1999. Their risk criteria were based on frequency and land use types as listed in **Table 06**.

Table 06: Risk Criteria used in Canada

Frequency Level	Type of Zone	Allowed Land Uses
>1.00E-04	Buffer zone	None
>1.00E-05	Municipality transition zone	Manufacturing, open spaces, golf courses
>1.00E-06	Municipality transition zone	Commercial, low density residential
<1.00E-06		All other uses

Summary of Worldwide Tolerability Risk Criteria

Numerous risk criteria established by government agencies and private industry for both public and workers are summarized from **Table 07** through **Table 10**. Furthermore, **Figure 04** illustrates different societal risk criteria for public from several worldwide entities. Most of these numeric criteria have been extracted from reference **[23]**.

It is important to clarify the meaning of the following two concepts illustrated below from **Table 07** through **Table 10**:

- Upper limit: defined as the high risk region limit (i.e., intolerable risk level if the actual risk is above this limit); and

- Lower limit: defined as the negligible risk region (i.e., broadly acceptable risk level if the actual risk is below this limit).

The concepts of upper and lower limits can be understood via the definition of ALARP provided by HSE **[20]** as follows:

- **Unacceptable Region:** Except under extraordinary circumstances, control measures must be undertaken to reduce the risk to a level deemed tolerable irrespective of the cost/benefit.

- **Tolerable Region:** In this region, the residual risk must be at an ALARP level. A proposed control must be implemented if the investment (e.g., in money, time, trouble of cost) is not in gross disproportion to the benefits achieved by implementing this control (e.g., the reduction in risk). What constitutes "gross disproportion" will depend on the level of risk (i.e., for a given level of benefit, the higher the associated level of residual risk, the greater the degree of disproportion necessary for it to be considered ALARP).

- **Broadly Acceptable Region**: Residual risk is generally regarded as insignificant and adequately controlled. Risk controls should still be implemented in those cases where the benefits still outweigh the costs.

Table 07: Individual Risk to the Public – Entities having two-limit system: Upper & Lower Limit Values

Upper Limit [Fatality·yr^{-1}]	Lower Limit [Fatality·yr^{-1}]	Entities/Applications	Comments
1.00E-04	1.00E-05	State of Sao Paulo, Brazil/Pipelines	No comments
1.00E-04	1.00E-05	State of Rio Grande do Sul, Brazil/Pipelines	No comments
1.00E-04	1.00E-06	UK HSE/Fixed facilities and dangerous goods transport	No comments
1.00E-04	1.00E-06	International Maritime Organization (IMO)/Existing ships	**Upper and Lower Limits:** applies to both passengers and public ashore
1.00E-05	1.00E-07	State of Victoria, Australia	**Upper Limit:** New facilities. If risk exceeds 1.00E-05 fatality/year at the boundary of an existing facility, risk reduction measures must be taken. Non-mandatory, can be used as part of safety case **Lower Limit:** non-mandatory, can be used as part of safety case
1.00E-05	1.00E-6	State of Sao Paulo, Brazil/Fixed installations	**Upper and Lower Limits:** New installations and significant modifications to existing
1.00E-05	1.00E-06	State of Rio Grande do Sul, Brazil/Fixed installations	**Upper and Lower Limits:** New installations
1.00E-05	1.00E-06	Hungary	No comments
1.00E-05	1.00E-06	International Maritime Organization (IMO)/New ships	**Upper and Lower Limits:** Applies to both passengers and public ashore.

Table 08: Individual Risk to the Public – Entities having single-limit system: Upper Limit Values

Upper Limit [Fatality·yr^{-1}]	Entities/Applications	Comments
5.00E-5	Australia, State of Queensland	Specifies that 5.00E-05 fatality/year risk contour must not extend beyond site boundary for new facilities. For existing facilities, risk reduction is to be "encouraged" if 5.00E-5 fatality/year risk contour extends beyond site boundary.
5.00E-5	Singapore	Specifies that the 5.00E-05 fatality/year risk contour may only extend into industrial development zones.
1.00E-05	Hong Kong	New installations. Existing installations exceeding this value should seek risk reductions
1.00E-05	Netherlands	Applies to vulnerable objects. Existing situations. Interim value, existing situations must meet value for new situations (1.00E-06 fatality/year, see below) by 2010
1.00E-05	Canada, Major Industrial Accidents Council of Canada (MIACC)	Uses this value for low density residential, and lower value (1.00E-06 fatality/year) for high density residential.
1.00E-05	Czech Republic	Limit for existing installations. Risk reduction must be carried out for facilities above this limit.
1.00E-05	State of Rio de Janeiro, Brazil/Fixed installations and pipelines	For existing facilities
5.00E-06	Singapore	Specifies that the 5.00E-06 fatality/year risk contour may only extend into industrial and commercial development zones.

Upper Limit [Fatality·yr^{-1}]	Entities/Applications	Comments
1.00E-06	Netherlands	Applies to: (1) new permits for fixed installations, (2) new land use plans, and (3) transport of dangerous goods, including transport by pipelines
1.00E-06	State of Western Australia, Australia	New installations. Higher limits are established for industrial and non-industrial developments. Lower limits (5.00E-07 fatality/year) are established for "sensitive" exposures. Existing installations are to seek risk reductions to meet requirements for new installations.
1.00E-06	State of New South Wales, Australia	Higher limits are established for industrial and nonindustrial developments. Lower limits (5.00E-07 fatality/year) are established for "sensitive" exposures.
1.00E-06	State of Queensland, Australia	Higher limits are established for industrial and nonindustrial developments. Lower limits (5.00E-07 fatality/year) are established for "sensitive" exposures.
1.00E-06	State of Rio de Janeiro, Brazil/Fixed installations and pipelines	For new facilities
1.00E-06	Czech Republic	For new facilities
1.00E-06	US DOD/Explosives handling activities	No comments
1.00E-06	California, Santa Barbara County	Used as a screening value. Risk in excess of this value requires a risk assessment examining the societal risk from the facility
1.00E-06	Singapore	Specifies that the 1.00E-06 fatality/year risk contour may only extend into industrial, commercial, and park developments zones.

Upper Limit [Fatality·yr^{-1}]	Entities/Applications	Comments
1.00E-06	Malaysia	Malaysia: higher risk criteria established for those on industrial facilities, exposed from outside source.
1.00E-07	US NRC/Risk of "prompt" fatalities from nuclear power accidents	Calculated from the criterion that risks should not exceed 0.1% of prompt fatality risks from all other accidental sources, assuming an accidental fatality rate of 1.00E-04 fatality/year

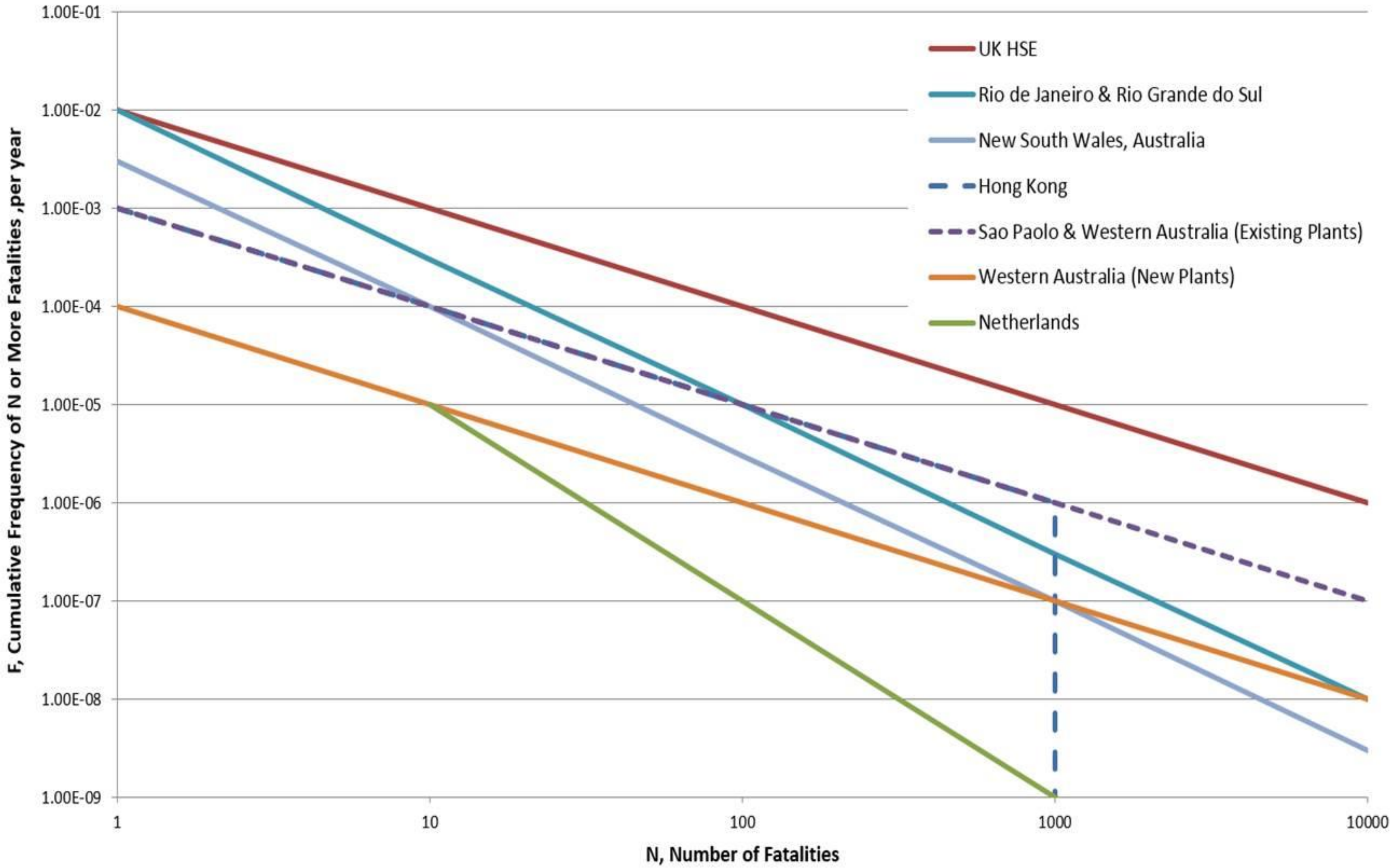
Table 09: Individual Risk to Workers – Entities having two-limit system: Upper & Lower Limit Values

Upper Limit [Fatality·yr^{-1}]	Lower Limit [Fatality·yr^{-1}]	Entities/Applications	Comments
1.00E-03	1.00E-06	UK HSE	No comments
1.00E-03	1.00E-06	International Maritime Organization (IMO)/Existing ships	**Upper Limit:** for crew members on existing ships **Lower Limit:** for crew members on new or existing ships
1.00E-03	1.00E-04	State of Western Australia, Australia	**Upper Limit:** proposed for existing facilities. Where an existing facility exceeds 1.00E-03 fatality/year, a risk reduction program with an agreed time frame must be implemented to achieve 1.00E-03 fatality/year **Lower Limit:** proposed for new and existing facilities
5.00E-04	1.00E-04	State of Western Australia, Australia	**Upper Limit:** proposed for new facilities **Lower Limit:** proposed for new and existing facilities
1.00E-04	1.00E-06	International Maritime Organization (IMO)/New ships	**Upper Limit:** for crew members on existing ships **Lower Limit:** for crew members on new or existing ships

Table 10: Individual Risk to Workers – Entities having single-limit system: Upper Limit Values

Upper Limit [Fatality·yr^{-1}]	Entities/Applications	Comments
1.00E-04	US DOD/Explosives handling activities	No comments

Figure 04: Summary of Relevant Maximum Tolerable Societal Risk Criteria



Conclusions

Risk criteria should be defined in order to achieve and implement an objective decision-making process. In many countries around the world, regulatory requirements for performing a Quantitative Risk Assessment (QRA) have not yet been established. In these cases, internationally recognized methods required for implementing a QRA, and used by major international oil companies, should be considered. The criteria to be implemented for both individual and societal risk should contain the following three key characteristics: (1) Up-to-date; (2) Applicable to the Chemical Process Industry (CPI); and (3) Applicable to existing and new facilities.

Regulatory and government agencies, and/or industry associations, working together with the affected public and workforce can best recommend what levels of risk are tolerable, and when no further risk reduction actions are required. Most of the relevant quantitative risk criteria have been issued by worldwide governmental bodies, often with significant public input and/or scrutiny, indicating a high degree of societal endorsement of the values. As a result, the risk criteria values to be proposed or followed in risk assessments need to be based on worldwide regulatory and industry publications. There are at least three key aspects that are commonly used in the development of many generally accepted and recognized risk criteria:

- A comprehensive risk management program must address both individual and societal risk;

- Risk criteria for the public must be lower, i.e. more conservative, than those for the workforce since the workforce risk is considered to be voluntary.

- With respect to individual risk, new facilities should be held to a higher level of risk performance than existing facilities. For new facilities many opportunities exist to apply new/advanced risk reduction technologies. To the contrary, societal risk criteria are universally identical for new and existing situations. If a potential exists for major accident events affecting large numbers of people, most regulators have judged that older facilities must meet the same standards as newer facilities.

References

[1] ISO 17776 (2000); "Petroleum and natural gas industries -- Offshore production installations - Guidelines on tools and techniques for hazard identification and risk assessment".

[2] Dunjó, J. (2010). "New Trends for Conducting HAZard & OPerability (HAZOP) Studies in Continuous Chemical Processes" Ph.D. Thesis manuscript.

[3] VROM (2005), "Guidelines for Quantitative Risk Assessment". Publication Series on Dangerous Substances. (CPR-18E; "Purple Book").

[4] API-581 (2016). "Risk Based Inspection Base Resource Document", American Petroleum Institute, Third Edition.

[5] OREDA (2015). "Offshore and Onshore Reliability Data, Volume I: Topside Equipment"; and "Offshore and Onshore Reliability Data, Volume II: Subsea Equipment".

[6] UK HSE (2012). "Failure Rate and Event Data for use within Risk Assessments", Health and Safety Executive, 2012. http://www.hse.gov.uk/landuseplanning/failure-rates.pdf

[7] UK HSE (1974). "Health and Safety at Work etc. Act 1974", Health and Safety Executive, 1974. http://www.legislation.gov.uk/ukpga/1974/37/pdfs/ukpga_19740037_en.pdf

[8] ioMosaic Corporation (2016). "SuperChems™ Expert 8.2 Individual Risk Contour Example", ioMosaic Corporation. Salem, New Hampshire.

[9] ioMosaic Corporation (2016). "SuperChems™ Expert 8.2 FN Curve Example", ioMosaic Corporation. Salem, New Hampshire.

[10] HSE (1989). "Risk Criteria for Land-Use Planning in the Vicinity of Major Industrial Hazards". Health and Safety Executive; HMSO.

[11] US Federal Clean Air Act, US Environmental Protection Agency. https://www.epa.gov/laws-regulations/summary-clean-air-act

[12] Risk Management Program (RMP), US Environmental Protection Agency. https://www.epa.gov/rmp/risk-management-plan-rmp-rule-overview

[13] County of Los Angeles Fire Department, LAFD, 1991. http://www.lafd.org/

[14] CalARP (1997). "California Accidental Release Prevention (CalARP) Program". http://www.caloes.ca.gov/cal-oes-divisions/fire-rescue/hazardous-materials/california-accidental-release-prevention

[15] California Environmental Quality Act (CEQA). http://resources.ca.gov/ceqa/

[16] County of Santa Barbara Seismic Safety and Safety Element.
http://www.santabarbaraca.gov/services/planning/plan.asp

[17] NFPA 59A (2016). "Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)"; National Fire Protection Association

[18] Ball, F. (1998), "Societal Risk", UK Health and Safety Executive, HMSO.

[19] Seveso Directive (1982, 1996). Council Directive 82/501/EEC of 24th June 1982 on the Major Accident Hazards of certain industrial activities, Official Journal of the European Communities, 1982 (OJ No: L 230), and Council Directive 96/82/EC of 9th December 1996 on the control of major-accident hazards involving dangerous substance, Official Journal of the European Communities, 1997 (OJ No: L 10).

[20] Health and Safety Executive (HSE) (1989), "Risk Criteria for Land-Use Planning in the Vicinity of Major Industrial Hazards" HMSO.

[21] UK HSE (2002). "PADHI Planning Methodology". Planning Advice for Developments near Hazardous Installations UK Health and Safety Executive.

[22] MIACC (1995). "Risk-based Land Use Planning Guidelines". Major Industrial Accidents Council of Canada

[23] AIChE/CCPS, Guidelines for Developing Quantitative Safety Risk Criteria; New York; American Institute of Chemical Engineers / Center for Chemical Process Safety, 2009.