U.S. DOT PHMSA

Final Report No. 16-092

# Paper Study on Risk Tolerance

Stephanie Flamberg, Susan Rose (Kiefner/Applus-RTD)
Bob Kurth, Cedric Sallaberry (EMC$^2$)

June 30, 2016

0339-1501

Intentionally blank

Final Report No. 16-092

**Final Report**

on

# PAPER STUDY ON RISK TOLERANCE

to

## U.S. DEPARTMENT OF TRANSPORTATION

## PIPELINE AND HAZARDOUS MATERIALS SAFETY ADMINISTRATION

## OFFICE OF PIPELINE SAFETY RESEARCH AND DEVELOPMENT PROGRAM

**June 30, 2016**

**Prepared by**


_____

**Susan Rose**
**Principal Engineer**


**Approved by**


_____

**Dyke Hicks**
**Senior Principal Engineer**

**Kiefner and Associates, Inc.**
**4480 Bridgeway Avenue, Suite D**
**Columbus, OH 43219**


0339-1501

## DISCLAIMER

This document presents findings and/or recommendations based on engineering services performed by employees of Kiefner and Associates, Inc. The work addressed herein has been performed according to the authors' knowledge, information, and belief in accordance with commonly accepted procedures consistent with applicable standards of practice, and is not a guaranty or warranty, either expressed or implied.

The analysis and conclusions provided in this report are for the sole use and benefit of the Client. No information or representations contained herein are for the use or benefit of any party other than the party contracting with Kiefner. The scope of use of the information presented herein is limited to the facts as presented and examined, as outlined within the body of this document. No additional representations are made as to matters not specifically addressed within this report. Any additional facts or circumstances in existence but not described or considered within this report may change the analysis, outcomes and representations made in this report.

## TABLE OF CONTENTS


1 INTRODUCTION ..... 1
2 RESEARCH SUMMARY ..... 2
2.1 Quantitative Risk Criteria ..... 5
2.1.1 Societal Risk Criteria ..... 5
2.1.2 Individual Risk Criteria ..... 7
2.1.3 Pipeline Specific Risk Criteria ..... 10
2.1.4 Impact Risk Criteria ..... 10
2.2 Qualitative or Semi-Quantitative Risk Criteria ..... 11
2.3 Summary ..... 11
3 BACKGROUND ..... 20
4 RISK ASSESSMENT REGULATIONS FOR PIPELINES ..... 21
5 RISK TOLERANCE CONCEPTS ..... 23
5.1 Considerations When Developing Risk Tolerability Criteria ..... 24
5.2 Types of Risk Tolerability Criteria ..... 27
5.2.1 Qualitative Risk Criteria ..... 28
5.2.2 Semi-Quantitative Risk Criteria ..... 31
5.2.3 Quantitative Risk Criteria ..... 32
6 RESULTS ..... 35
6.1 Countries ..... 35
6.1.1 United Kingdom ..... 36
6.1.2 Netherlands ..... 41
6.1.3 Australia ..... 45
6.1.4 Brazil ..... 53
6.1.5 Hong Kong ..... 57
6.1.6 France ..... 59
6.1.7 Switzerland ..... 60
6.1.8 Canada ..... 62
6.1.9 Malaysia ..... 64
6.1.10 Singapore ..... 64
6.1.11 Norway ..... 65
6.1.12 Venezuela ..... 67
6.1.13 Czech Republic ..... 69

6.1.14 Hungary ..... 71
6.1.15 Germany ..... 71
6.1.16 International Maritime Organization (IMO) ..... 71
6.2 U.S. Government Agencies ..... 73
6.2.1 Department of Defense (DOD) ..... 73
6.2.2 Department of the Interior (DOI) ..... 76
6.2.3 Department of Transportation (DOT) ..... 79
6.2.4 Environmental Protection Agency (EPA) ..... 80
6.2.5 Food and Drug Administration (FDA) ..... 85
6.2.6 Occupational Safety and Health Administration (OSHA) ..... 85
6.2.7 Santa Barbara County, California ..... 86
6.2.8 Nuclear, Aeronautical, and Aerospace Industries ..... 88
6.3 C-FER IR and SR Criteria ..... 98
6.3.1 C-FER Technologies RBDA Societal Risk Criteria ..... 98
6.4 Pipeline Companies ..... 102
6.4.1 Industry Survey Questions ..... 102
6.4.2 Summary of Responses ..... 102
7 REFERENCES ..... 115
APPENDIX A – INDUSTRY SURVEY QUESTIONS ..... 120
APPENDIX B – INDUSTRY SURVEY RESPONSES ..... 121

## LIST OF FIGURES

Figure 1. Summary of Individual Risk (IR) Criteria – New Hazardous Facilities ..... 9
Figure 2. Summary of Individual Risk Criteria – Existing Hazardous Facilities ..... 9
Figure 3. Summary of Individual Risk Criteria – Workers ..... 10
Figure 4 Risk Acceptability Framework ..... 24
Figure 5. Example Qualitative Risk Matrix [CCPS 1992] ..... 29
Figure 6. Evolution of Maximum Tolerable Societal Risk Criteria in the UK (derived from CCPS, 2009) ..... 38
Figure 7. IGE/TD/1 Sample FN Criterion ..... 39
Figure 8. Example Site Specific Gas Pipeline Risk Based on HSE Zone Concept UK ..... 41
Figure 9. Evolution of Maximum Tolerable Societal Risk Criteria in the Netherlands (derived from CCPS, 2009) ..... 43
Figure 10. Maximum Tolerable and Broadly Acceptable Societal Risk Criteria in the NSW and Victoria, Australia (derived from CCPS, 2009) ..... 48

Figure 11. Maximum Tolerable and Broadly Acceptable Societal Risk Criteria in the NSW and Victoria, Australia (derived from CCPS, 2009) ....50
Figure 12. Background Risk and ANCOLD IR Criteria[109] ....52
Figure 13. ANCOLD Maximum Tolerable Risk Criteria for Dams[110] ....53
Figure 14. Maximum Tolerable and Broadly Acceptable Societal Risk Criteria for Three States in Brazil (derived from CCPS, 2009) ....57
Figure 15. Hong Kong Societal Risk Criteria (derived from CCPS, 2009) ....58
Figure 16. Switzerland Societal Risk Criteria ....61
Figure 17. Example Semi-Quantitative Risk Criteria (Risk Matrix) ....63
Figure 18. Venezuelan Societal Risk Criteria ....69
Figure 19. Czech Republic Maximum Tolerable Societal Risk Criteria ....70
Figure 20. IMO Maximum Tolerable Societal Risk Criteria ....73
Figure 21. DOD Test Range Societal Risk Criteria ....74
Figure 22. DOD Risk Assessment Matrix ....76
Figure 23. Bureau of Reclamation Risk Tolerability Guidelines ....78
Figure 24. Bureau of Reclamation Decision Matrix[160] ....78
Figure 25. Representation of Threshold used for Yucca Mountain with an Illustrative Example of Mean Annual Dose ....82
Figure 26. Representation of Regulatory Threshold for WIPP with an Illustrative CCDF ....84
Figure 27. Santa Barbara Societal Risk Criteria[174] ....87
Figure 28. FAA Semi-Quantitative Risk Criteria Example ....92
Figure 29. Fundamental Principles of Adequate Safety ....97
Figure 30. C-FER RBDA Societal Risk Criteria ....99
Figure 31. Reliability Targets Based on Population Density ....101
Figure 32. Reliability Targets Based on Location Class ....101
Figure 33. Pipeline Mileage by Product Represented in Survey Responses ....103
Figure 34. Pipeline Mileage by Pipeline Type Represented in Survey Responses ....103
Figure 35. Hazardous Liquid Products Represented in Survey Responses ....104
Figure 36. Uses of Risk Assessment Represented in Survey Responses ....105
Figure 37. Scope of Risk Assessments Represented in Survey Responses ....105
Figure 38. Segmentation for Pipeline Risk Assessments Represented in Survey Responses ....107
Figure 39. Risk Assessment Types Represented in Survey Responses ....107
Figure 40. Risk Assessment Models Represented in Survey Responses ....108
Figure 41. Risk Assessment Consequence Categories Represented in Survey Responses ....108

Figure 42. Methods Used to Communicate Risk Tolerance Levels Represented in Survey Responses ..... 110
Figure 43. Risk Tolerance Levels Represented in Survey Responses ..... 111
Figure 44. Individuals Involved in Defining Risk Tolerance Levels Represented in Survey Responses ..... 112

## LIST OF TABLES

Table 1. Advantages and Disadvantages of Risk Tolerability Criteria Techniques ..... 11
Table 2. Summary of Individual Risk (IR) Tolerance Practices ..... 13
Table 3. Summary of Societal Risk (SR) Tolerance Practices ..... 17
Table 4. Example Consequence Categories – Qualitative Risk Matrix ..... 29
Table 5. Example Frequency Categories – Qualitative Risk Matrix ..... 29
Table 6. Example Risk Ranking/Response Categories – Qualitative Risk Matrix ..... 30
Table 7. Example Consequence Categories – Semi-Quantitative Risk Matrix ..... 31
Table 8. Example Frequency Categories – Semi-Quantitative Risk Matrix ..... 31
Table 9. Summary of UK IR Criteria for New and Existing Facilities ..... 40
Table 10. Summary of Dutch IR Criteria for New and Existing Facilities ..... 45
Table 11. Summary of Western Australia IR Criteria for New Facilities ..... 46
Table 12. Summary of NSW IR Criteria for New Facilities ..... 47
Table 13. Summary of Queensland IR Criteria for New Facilities ..... 49
Table 14. Summary of Victoria IR Criteria for New Facilities ..... 49
Table 15. Summary of ANCOLD IR Criteria for Dams ..... 52
Table 16. Summary of São Paulo IR Criteria ..... 54
Table 17. Summary of Rio de Janeiro IR Criteria ..... 55
Table 18. Summary of Rio Grande do Sul IR Criteria for New Facilities ..... 56
Table 19. Summary of Hong Kong IR Criteria for New and Existing Facilities ..... 59
Table 20. French Decision Matrix for Permitting New or Modified Facilities ..... 60
Table 21. Summary of Canadian IR Criteria ..... 62
Table 22. Summary of Malaysian IR Criteria ..... 64
Table 23. Summary of Singapore's IR Criteria ..... 65
Table 24. Summary of the Czech Republic IR Criteria ..... 70
Table 25. Summary of the IMO IR Criteria ..... 72
Table 26. Individual and Societal Risk Criteria for DOD Test Range Operations ..... 74
Table 27. Individual and Societal Risk Criteria for DOD Explosives Handling Operations ..... 75

Table 28. Summary Various Individual Risk Criteria Used by the EPA (as of 1996) .....80

Table 29. Comparison of Flight Crew Limits for the Proposed New FAA FAR Part 117 to the Current Rule.....93

# Acronyms

| | |
|---|---|
| ALARA | As Low As Reasonably Achievable |
| ALARP | As Low As Reasonably Practicable |
| ASARP | As Safe As Reasonably Practicable |
| ANCOLD | Australian National Committee on Large Dams (Australia) |
| API | American Petroleum Institute |
| CSChE | Canadian Society for Chemical Engineering (Canada) |
| CCPS | Center for Chemical Process Safety |
| CHEM | Chemical Hazards and Emergency Management Services (Queensland, Australia) |
| COMAH | Control of Major Accident Hazards regulation (UK) |
| CCDF | Complementary Cumulative Distribution Function |
| CETSEB | Companhia de Tecnologia de Saneamento Ambiental (São Paulo, Brazil) |
| DOD | Department of Defense (US) |
| DOE | Department of Energy (US) |
| DOI | Department of the Interior (US) |
| DOP | Department of Planning (NSW, Australia) |
| EPA | Environmental Protection Agency (US) |
| EPA | Environmental Protection Authority (Western Australia) |
| EPD | Environmental Protection Department (Hong Kong) |
| FAA | Federal Aviation Administration (US) |
| FDA | Food and Drug Administration (US) |

| | |
|---|---|
| F-N | Frequency-number (curve) |
| FEEMA | Fundação Estadual de Engenharia do Meio Ambiente (Rio de Janeiro, Brazil) |
| FEPAM | Fundação Estadual de Proteção Ambiental (Rio Grande do Sul, Brazil) |
| FRA | Federal Railroad Administration (US) |
| FSA | Formal Safety Assessment |
| GAO | Government Accountability Office (US) |
| HCA | High Consequence Area |
| HSC | Health and Safety Commission (UK) |
| HSE | Health and Safety Executive (UK) |
| IM | Integrity Management |
| IMO | International Maritime Organization |
| IR | Individual Risk |
| ISS | International Space Station |
| IZ | Inner Zone |
| LBB | Leak Before Break |
| LOPA | Layer of Protection Analysis |
| MEM | Minimum Endogenous Mortality |
| MIACC | Major Industrial Accidents Council of Canada (Canada) |
| MZ | Middle Zone |
| NASA | National Aeronautics and Space Administration (US) |
| NSW | New South Wales |
| NRC | Nuclear Regulatory Commission (US) |

| | |
|---|---|
| NSW | New South Wales, Australia |
| NTSB | National Transportation Safety Board (US) |
| OSHA | Occupational Safety and Health Administration (US) |
| OZ | Outer Zone |
| PCD | Pollution Control Department (Singapore) |
| PDVSA | Petróleos de Venezuela, S.A. (Venezuela) |
| PHMSA | Pipeline and Hazardous Materials Safety Administration (PHMSA) |
| PRA | Probabilistic Risk Assessment |
| PRAM | Practical Risk Assessment Methodology |
| PSM | Process Safety Management |
| PWSCC | Primary Water Stress Corrosion Cracking |
| QRA | Quantitative Risk Assessment |
| RAC | Risk Assessment Code |
| RAIRS | Railroad Accident/Incident Reporting System |
| RIRIP | Risk-Informed Regulation Implementation Plan |
| RPP | Risk-Informed, Performance-Based Plan |
| RSSG | Royal Society Study Group |
| SR | Societal Risk |
| SRP | Standard Review Plan |
| UKOPA | United Kingdom Onshore Pipeline Operators Association |

# Glossary

**Aggregate risk:** Societal risk for on-site workers in occupied buildings (uniquely applied to facility siting studies, as described in [CCPS 1996] and [API 2003]).

**Aleatory uncertainty:** Inherent randomness in the properties or behavior of the system under study. Aleatory uncertainty cannot be reduced based on increased knowledge of the system under study or the inability to increase the understanding of the uncertainty due to funding or institutional constraints. It should be a major component of any risk analysis (see Kaplan/Garrick ordered triple representation of risk). See "Epistemic uncertainty" for the other category of uncertainty.

**Anchor point:** A single F-N pair which, along with the slope, defines and F-N risk criterion curve.

**Apportionment:** The subdividing of a risk criterion among a number of risk sources (for example, among all process units at an operating site). The concept of risk apportionment can apply to both individual and societal risk, but at different levels in the enterprise.

**As Low As Reasonably Achievable (ALARA):** A concept equivalent to *As Low as Reasonably Practicable.*

**As Low As Reasonably Practicable (ALARP):** The concept that efforts to reduce risk should be continued until the incremental sacrifice (in terms of time, effort, cost, or other expenditure of resources) is grossly disproportionate to the value of the incremental risk reduction achieved.

**Average individual risk (exposed hours/worked hours):** The individual risk for an activity, calculated for the duration of the activity, or averaged over the working day.

**Average individual risk (exposed population):** The individual risk averaged over the population which is exposed to risk from the facility.

**Average individual risk (total population):** The individual risk averaged over a predetermined population, without regard to whether or not all people in that population are actually exposed to the risk.

**Average rate of death:** A measure of societal risk expressed as the average number of fatalities that might be expected per unit time from all possible incidents.

**Consequence:** The undesirable result of an incident (can be measured in health and safety effects, environmental impacts, loss of property, equipment damage, and business interruption costs).

**Damage tolerant analysis:** This is the aeronautical industries response to excluding the initiation of cracks from their risk analysis since it is the largest source of uncertainty. In this analysis known events are used to back calculate the initial damage. This information is then

combined in a probabilistic tool to insure that the probability of the event is below an acceptable risk level before N inspections have occurred.[1]

**De minimis risk:** A level of risk that would be perceived by most to be broadly acceptable, and not requiring further reduction.

**Epistemic uncertainty:** Uncertainty related to the lack of knowledge or confidence about the system under analysis. It is produced by a lack of knowledge regarding the inputs or models under consideration. It is usually considered as reducible uncertainty as increased knowledge should reduce it. See the entry "Aleatory uncertainty" for the other category of uncertainty.

**Fatal accident rate:** A measure of individual risk expressed as the estimated number of fatalities per $10^8$ exposure hours (roughly 1000 employee working lifetimes).

**F-N curve:** A plot of cumulative frequency versus consequences (typically expressed as number of fatalities).

**High Consequence Area (HCA):** U.S. Pipeline safety regulations use the concept of "High Consequence Areas" (HCAs) to identify specific locales and areas where a release could have the most significant adverse consequences. Once identified, operators are required to devote additional focus, efforts, and analysis in HCAs to ensure the integrity of pipelines.

HCAs for natural gas transmission pipelines focus solely on populated areas. (Environmental and ecological consequences are usually minimal for releases involving natural gas.) Identification of HCAs for hazardous liquid pipelines focus on populated areas, drinking water sources, and unusually sensitive ecological resources.

**High Population Area.** An urbanized area, as defined and delineated by the U.S. Census Bureau, which contains 50,000 or more people and has a population density of at least 1,000 people per square mile. High population areas are considered high consequence areas.

**Incident:** An event, or series of events, resulting in one or more undesirable consequences, such as harm to people, damage to the environment, or asset/business losses. Such events include fires, explosions, releases of toxic or otherwise harmful substances, and so forth.

**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. (Often expressed in terms of fatalities per year)

**Layer of Protection Analysis (LOPA):** An approach that analyzes one incident scenario (cause/consequence) at a time, using predefined values for the initiating cause frequency, independent protection layer failure probabilities, and consequence severity, in order to compare an order-of-magnitude scenario risk estimate to tolerable risk goals for determining where additional risk reduction or more detailed analysis is needed. Scenarios are identified

---

[1] Kurth, R. E. (1994). Probabilistic Damage Tolerant Analysis to Improve Aging Aircraft Maintenance and Inspection Schedules. 1994 ASME International Mechanical Engineering Congress and Exposition. Chicago, IL: ASME.

elsewhere, typically using a scenario-based hazard evaluation procedure such as a HAZOP study.

**Likelihood:** A measure of the expected frequency with which an event occurs. This may be expressed as a frequency (e.g., events per year), a probability of occurrence during a time interval (e.g., annual probability), or a conditional probability (e.g., probability of occurrence, given that a precursor event has occurred).

**Preventive and Mitigative Measures.** Activities designed to prevent or reduce the likelihood of an incident/failure (preventive) and/or mitigate the consequences of the incident/ failure (mitigative). In the context of pipeline systems, examples of preventive measures include enhanced damage prevention practices, conducting periodic close interval surveys, or inspecting pressure relief devices more frequently. Examples of mitigative measures include the installation of emergency flow restricting devices, improving leak detection system capability, or conducting drills with local emergency responders.

**Probability:** A measure of the likelihood that an event will occur within some unit of time.

**Probabilistic Risk Assessment (PRA):** is a methodology used to assess risk for any complex system. It consists in identifying and quantifying the risks and associated uncertainties, propagating them through the complex system and analyzing the consequences. Often a Monte Carlo approach is used to propagate the uncertainty and provide the material to statistically assess the consequences.

**Risk:** A measure of the likelihood that an adverse event could occur and the magnitude of the expected consequences should it occur. Risk = Likelihood x Consequence

**Risk Assessment:** The process of identifying, defining, and analyzing risks. A risk analysis can be qualitative, semi-quantitative, or quantitative.

**Risk contour:** Lines that connect points of equal risk around the facility ("isorisk" lines).

**Risk criteria:** Criteria can be established on the basis of health and safety, environmental damage, equipment/property damage, business loss, litigation costs, etc.

**Risk management:** The process by which an organization understands, makes decisions, and takes action to reduce the risk of a facility it operates.

**Risk matrix:** A tabular approach for presenting risk tolerance criteria, typically involving graduated scales of incident likelihood on the Y-axis and incident consequences on the X-axes. Each cell in the table (at intersecting values of incident likelihood and incident consequences) represents a particular level of risk.

**Risk tolerance criteria:** A predetermined measure of risk used to aid decisions about whether further efforts to reduce the risk are warranted.

**Risk tolerance:** This has been described as "willingness by society as a whole to live with a risk so as to secure certain benefits in the confidence that the risk is one that is worth taking

and that it is being properly controlled. However, it does not imply that ... everyone would agree without reservation to take this risk or have it imposed on them." [HSE 2001]

**Safety factors (SF):** represent a margin of security against risks and can be seen as structural strength of a system when subjected to conditions beyond the expected design.

**Societal risk:** A measure of risk to a group of people. It is most often expressed in terms of the frequency distribution of multiple casualty events. F-N curves are broadly used: expected annual frequency (F) of the number (N or more) of casualties. Used to evaluate the risk of fixed facilities to the general public. Many corporations have also adopted this method for internal evaluation of the relative risk of projects, plants and businesses, setting their own criteria.

# Paper Study on Risk Tolerance

Stephanie Flamberg, Susan Rose (Kiefner/Applus-RTD)
Bob Kurth, Cedric Sallaberry (EMC$^2$)

## 1 INTRODUCTION

Pipeline organizations have always included risk management principals in some manner in the design, construction, and operation of their systems. However, as these systems age, new materials are introduced, differing damage mechanisms are discovered, and so forth, pipeline organizations are being forced to rethink and redesign their risk management practices to manage the risk and to remain safe and reliable operators for transportation of hydrocarbons, hazardous materials, carbon dioxide, and ammonia for example. The focus of developing risk tolerance criteria should be on the control of risk as the system ages and non-design basis scenarios develop. This change in risk can stem from the increasing likelihood of a failure, e.g. crack growth in welds, or due to changes in the consequences, e.g. increased population and construction which would increase both the initiating event probability (for example, third-party damage) and the consequences (for example, greater population density).

Approaches to risk management differ considerably across pipeline companies. Particular risk assessment methodologies are chosen to make the best use of available data and resources while still providing assurance of pipeline safety. Regardless of the particular risk assessment approach, all pipeline companies must identify risks, prioritize them, and implement strategies to reduce the risk. But risk reduction comes at a cost and setting and communicating risk criteria can be challenging. Ultimately, defining risk tolerability criteria is a means for helping decision makers objectively evaluate risks based on the company's risk tolerance.

This purpose of this project is to provide an overview of risk tolerance practices used by relevant industries to serve as a basis for comparison and discussion for the pipeline industry to use in their risk management programs. This includes the oil and gas, chemical manufacturing, transportation (air, rail, vehicles) and aerospace as well as U.S. government agencies (DOD, DOE, DOI, DOT, EPA, FAA, FDA, NASA, NRC, OSHA) and other regulatory bodies around the world (UK, Canada, Australia, The Netherlands, Hong Kong, Venezuela, Brazil).

Studying how others have approached risk-based decision making provides valuable perspective to those attempting to define their own risk tolerance criteria. This project does not intend to propose or recommend specific criteria for the pipeline industry. Instead, the content of this report is to inform pipeline organizations on how others have developed the basis for their risk tolerance criteria so that similar thought processes can be understood by others. There are a

number of approaches for defining risk tolerance criteria and the degree of risk tolerance varies from government agency to government agency and from company to company depending on the concerns of each organization. Moreover, the formulation of risk tolerance criteria cannot be done in a vacuum and must be accomplished within the context of a variety of considerations (e.g., societal, environmental, legal, business, and perhaps, regulatory) that are unique to each organization.

Our approach to this program is to conduct a literature search to understand what other regulatory bodies and industries have done to define risk tolerance criteria (Task 1). This information will be supplemented with data gathered from a survey of pipeline industry members about their risk management decision-making process (Task 2). Together, these activities will identify methods for defining risk tolerability criteria and highlighting practices used across the pipeline industry (Task 3 – final report). The overall program is guided by a Technical Advisory Committee comprised of pipeline operators.

This project is one of three R&D projects funded by PHMSA aimed at improving the risk management process for pipeline operators. The other two complementary projects include 1) a "Critical Review of Candidate Pipeline Risk Models" by C-FER Technologies and 2) a "Paper Study on Review of Approaches for Preventing Catastrophic Events" by GTI. Collectively, these three research projects will provide valuable information to PHMSA and the pipeline industry for improving risk management practices and ultimately the safety and reliability of the nation's pipeline infrastructure.

# 2 RESEARCH SUMMARY

Many regulatory agencies in the U.S. and abroad require some form of risk assessment to be performed for new and existing hazardous facilities to assure public safety. Defining and understanding the safety of hazardous facilities is one thing but ultimately, these regulatory agencies need to establish what they consider is safe enough. Efforts to answer this question have resulted in various methods for establishing risk tolerability criteria. Some of the more proactive regulatory bodies in this area include, but are not limited to: The European Union (EU) through the Seveso 3 Directive, The United Kingdom (UK) through the Health and Safety Executive (HSE), Hong Kong, The Netherlands, various Australian States, and The United States through various government entities.

Risk criteria are generally set with an understanding that no aspect of living can be risk free but that any imposed risk should be very small in the context of generally accepted background risk. Various levels of risk are tolerated on a daily basis, both to individuals and to society as a

whole[2]. The UK and the Netherlands are two countries that have pioneered the use of individual and societal risk criteria in response to country specific drivers. Both countries have tackled risk criteria from different angles (experience-based in the UK verses technology-driven in the Netherlands), but in general, recommend similar approaches. For the most part, the other countries reviewed in this study use the criteria established by the UK and Netherlands as the basis for their risk tolerability criteria with slight modifications for country or state specific concerns (e.g. Hong Kong is concerned about densely populated cities near large LPG storage facilities and landslide risks), societal risk values (e.g. risk aversion; risk perception), and/or risk scale (i.e. single hazardous facilities versus multiple hazardous facilities versus linear assets like pipelines). Whereas many of the U.S. agencies base risk tolerance on latent cancer risks, like the EPA, FDA, OSHA, and NRC or on impact zones to specific consequence endpoints.

Current U.S. DOT pipeline safety regulations for gas pipelines use class locations to differentiate risk along gas pipelines and provide an additional safety margin for more densely populated areas. Class locations, defined in 49 CFR §192.5, range from 1 (sparsely populated) to 4 (densely populated) and specify the maximum allowable operating pressure (MAOP) of the pipeline segment in each class location.

The Pipeline Integrity Management (IM) regulations introduced the concept of High Consequence Areas (HCAs) to identify specific locales and areas where a release could have the most significant adverse consequences. Once identified, operators are required to devote additional focus, efforts, and analysis in HCAs to ensure the integrity of pipelines.

HCAs for natural gas transmission pipelines focus solely on populated areas (environmental and ecological consequences are usually minimal for releases involving natural gas.) The identification of HCAs for hazardous liquid pipelines focus on populated areas, drinking water sources, and unusually sensitive ecological resources. The specific regulations are defined in 49 CFR §192.905 for gas pipelines and in 49 CFR §195.452 for hazardous liquid pipelines.

C-FER Technologies[3] has developed two approaches for quantification of maximum tolerable societal risk criteria related to pipelines: 1) societal risk with fixed expectation; and 2) societal risk with aversion function.[4] (Refer to Section 0 for further detail). The maximum tolerable

---

[2] Hazardous Industry Planning Advisory Paper No 4, Risk Criteria for Land Use Safety Planning, New South Wales (NSW) Government, January 2011.

[3] The information in the C-FER Technologies, Guidelines for Reliability Based Design and Assessment of Onshore Natural Gas Pipelines is based on the following papers: 1) Nessim, M.A., Zhou, W., Zhou, J., Rothwell, B., and McLamb, M. Target Reliability Levels for Design and Assessment of Onshore Natural Gas Pipelines (Paper IPC04-0321), Proceedings, International Pipeline Conference, Calgary, Alberta, 2004; and 2) Nessim, M.A. and Zhou, W. Target Reliability Levels for the Design and Assessment of Onshore Natural Gas Pipelines. Gas Research Institute Report 04/0230, 2005. This methodology is also laid out in CSA Z662, Appendix O.

[4] C-FER Technologies, Guidelines for Reliability Based Design and Assessment of Onshore Natural Gas Pipelines, Submitted to Pipeline Research Council, International, Inc. October 2011.

societal risk criteria proposed by C-FER Technologies for reliability targets (not absolute risk targets) were generated by calibration to existing codes and regulations, including ASME B31.8, ASME B31.8S, and 49 CFR 192.327.

C-FER Technologies takes a slightly different approach to individual risk (IR) criteria than other organizations that have established IR criteria for pipelines. Instead of defining criteria for new and existing pipelines or for sensitive populations, they use the regulatory Class definitions to define the degree of tolerable IR. Class locations are used by DOT to differentiate risk along gas pipelines and provide an additional safety margin for more densely populated areas.

The pipeline industry requires that risk assessments be performed as part of the company's integrity management program. The results are used to prioritize integrity assessments and guide decisions on preventive and mitigative risk reduction measures. A main objective of this study was to determine the extent to which pipeline companies have established risk tolerance levels as part of their risk assessment process. A survey was sent to approximately 100 pipeline operators with a total of 24 survey responses received. The responses cover a representative cross section of liquid and natural gas (transmission, distribution, and gathering) with some respondents having assets in more than one category. The following is a brief summary of the results of our survey.

- About half of the risk assessments are performed using purchased software models, often tailored to suit the individual company. A number of companies use non-software models such as risk matrices or process hazards analysis (PHA) techniques such as what-if analyses, checklists, and/or Hazard and Operability Studies (HAZOPs).

- There are ranges of risk modeling approaches being used with most using semi-quantitative techniques (i.e. risk matrices with numerical ranges for likelihood and/or consequences) to evaluate risk. Companies are also using relative risk/index models where likelihood and consequence variables are assigned to each pipeline segment resulting in relative risk scores. The variables are typically weighted to reflect their relative impact. The variables are typically based on the pipeline integrity threats identified in ASME B31.8S standard and by PHMSA. A few companies are implementing quantitative/probabilistic risk assessment approaches.

- Almost half of those surveyed have defined an unacceptable / intolerable level of risk.

- Relative risk/index models and risk matrices are the most common methods of presenting risk tolerance levels, followed by comparison criteria and individual risk (IR). For respondents that use index-based risk models or risk matrices, risk criteria are generally defined by the index score or category. In some cases historical data has been

used, in other cases the limits are subjective. One example of quantified tolerability levels from our survey (for natural gas pipelines) is provided risk criteria levels are presented in terms of both individual and societal risk.

- Multiple risk criteria have been established by some companies, differentiating between product type (liquid versus gas) and asset type (pipeline or facility).
- Risk criteria have been established on a system-wide level, on a unit-length basis, as well as facility level. Safety levels equivalent to code compliance are also used for ILI-based decisions and engineering assessments.
- The survey results show that risk criteria levels were most often established by company senior management, SMEs, and risk analysts, with a number of companies using risk consultants.
- There were two general ideas identified for improvement: Additional guidance for developing risk-based decisions, especially risk tolerance levels and risk communication and an improved incident database that is automatically updated.

A possible future project could be to work with PHMSA and the pipeline industry to develop industry-wide guidance on defining risk tolerability criteria for the multitude of risk models used by the pipeline industry. Can a common basis be established so that all operators have a clear understanding of what is expected from them?

Our research found a mis-match between the risk tolerability criteria published across government agencies and international organizations (very quantitative in nature requiring the use of QRA) and the risk models used by the pipeline industry (relative risk-based, semi-quantitative). As a general comment it would be difficult to apply the criteria developed by these other agencies to most risk models used by the pipeline industry.

## 2.1 Quantitative Risk Criteria

A majority of the worldwide government agencies reviewed for this study rely upon quantitative risk tolerability criteria in the form of societal risk (SR) and individual risk (IR) with a few countries also specifying impact-based criteria for land use planning. A summary of the IR and SR risk tolerability criteria defined by each organization is provided in Table 2 and Table 3, respectively.

### 2.1.1 Societal Risk Criteria

All fatal accidents are a cause for concern, but society generally tends to be more concerned about multiple fatalities in a single event. While such low probability, high consequence events

might represent a very small risk to an individual, they may be viewed as unacceptable when a large number of people are exposed. Societal risk (SR) expresses "the cumulative risk to groups of people who might be affected by such events."[5] This type of SR criteria is commonly depicted as a frequency-number (F-N) diagram. Section 6 presents the maximum tolerable risk criteria defined by the various organizations reviewed in this study and also summarized in Table 3. Risk calculation values above each line represent the intolerable risk region and risk calculation values below the line represents the tolerable risk region. There are a few items to note about how the different organizations have approached defining SR criteria:

1. The slopes of the SR criteria lines vary providing insight into the risk aversion of a particular organization. The steeper the slope, the more risk averse the criteria. Organizations like the UK HSE and IMO have defined SR criteria with a shallower slope of (-1) whereas the Netherlands, Santa Barbara, CA, and Czech Republic have all defined SR criteria with steeper a slope of (-2).

2. Some organizations scale their SR criteria based on the size of the facility under evaluation. For example, the UK HSE defines one SR criterion for a single facility and another SR criterion for multiple facilities. Additionally, the Netherlands, São Paulo, Brazil, and Rio Grande Do Sul, Brazil set the SR criteria for pipelines an order of magnitude less restrictive than that set for other industrial activities. The Dutch and British governments have chosen to establish societal risk criteria based on the F-N diagram for a given length of pipe. While both countries use 1 km as the reference pipe length, they differ in how the risk criteria is used. The Dutch recommend evaluating the worst-case km within an urban area while the British recommend summing F-N pairs over the entire length of pipeline through a community and then normalizing the result to 1 km. Norway's SR criterion is established on a 10 km basis. Rio de Janeiro, Brazil SR criteria are the same as fixed facilities and does not define the basis.

3. High consequence events (generally greater than 1,000 fatalities) are unacceptable regardless of the potential likelihood in certain models. This is reflected in the abrupt drop in the maximum tolerable risk limit for Hong Kong and the Netherlands at 1,000 fatalities.

4. There is wide variation between organizations regarding what they consider to be the maximum tolerable risk level. The maximum tolerable SR criteria for IMO Passenger Roll-On/Roll-Off Ferries and the UK SR criteria for multiple facilities is 5 orders of magnitude more permissive than the SR criteria defined for sensitive land use (schools, hospitals) in Santa Barbara, CA for events involving 10 or more fatalities. This variation may be due to the scale of the risk, the risk aversion of the particular organization, the public's risk

[5] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 35.

perception (large consequence events are often viewed as unacceptable regardless of the likelihood), or combinations thereof.

5. Some organizations, like the UK HSE, NSW DOP, and Brazil environmental agencies also chose to set broadly acceptable risk levels that generally are two orders of magnitude lower than the maximum tolerable SR criterion. In between, most organizations apply as low as reasonably practical (ALARP) principles. In the Netherlands, however, they chose to abandon the concept of broadly acceptable risk to encourage risk generators to be proactive in lowering risk where practical for ALL risks below the maximum tolerable region.

6. The São Paulo CETSEB and Hong Kong EPD, have mandated use of SR criteria for evaluation of risk acceptability; however, most agencies only provide SR criteria as guidance and not as a strict mandate.

### 2.1.2 Individual Risk Criteria

IR is one of the most widely used forms of quantitative risk criteria and is defined as the annual chance that an individual will suffer a specified level of harm due to hazards to which they are exposed. IR tolerability criteria are generally set by comparing the risk associated with an industrial activity to risks posed by other activities that average individuals are exposed to on both a daily and intermittent basis, like driving a car, flying a plane, or working. The probability of fatality for these specific events or exposures is then used as guidance for setting maximum tolerable and broadly acceptable levels of IR.

Location-based IR risk calculations assume that an individual is present at that location 100% of the day without means to escape or protect themselves from the hazard. IR can also be calculated to assume an occupancy and protection factor which is known as personal-based IR. Personal-based IR is less conservative than location-based IR since it assumes an individual is not always present at that location (day versus night occupancy) and that they might be able to protect themselves should an incident occur (indoor versus outdoor; vulnerable versus less-vulnerable).

IR calculations can also consider acute versus chronic exposures. For the most part, IR calculations used for the oil & gas, petrochemical, and chemical industries are based on acute IR where only the immediate effects (thermal dose, overpressure, toxic dose) of a hazard are considered[6]. However, in the nuclear industry as well as other government agencies concerned about individual exposure to waste materials, pollutants, additives, and other carcinogens, the

[6] There are some exceptions to this statement, especially related to carcinogens like benzene, where the IR from chronic exposure becomes more of a concern.

IR risk from chronic exposures (risk of developing cancer over a lifetime) is often used to determine risk tolerability.

Figure 1 and Figure 2 summarize the IR criteria used by various organizations for the development of (and around) new and existing hazardous facilities. The data used in these charts are also summarized in Table 2. There are some items to note when looking at these figures:

1. Generally, existing facilities are allotted a higher maximum tolerable IR level (usually one-half to one order of magnitude greater). Most likely, this is to account for the fact that new facilities can benefit from newer technologies that lower the risk of hazardous processes and activities. Moreover, populations may have grown up around the existing facility that were not there when the facility was originally constructed making it difficult to meet IR criteria established for new facilities.

2. Victoria, Australia; the UK HSE; São Paulo and Rio Grande do Sul Brazil, Venezuela define both a maximum tolerable IR criterion and a broadly acceptable IR criterion. In between these criteria ALARP principles are applied requiring risk generators to reduce risk where feasible (costs are not grossly disproportionate to the benefit received). Other organizations only define a maximum tolerable IR criterion. For risk below this single criterion, risk generators are encouraged to be proactive in lowering risk where practical for ALL risks below the maximum tolerable region.

3. The UK and Canada are the least risk adverse defining the maximum tolerable IR criterion level at one fatality in ten thousand per year ($1 \times 10^{-4}$ fatality/year) whereas the Netherlands, Malaysia, Santa Barbara County, CA, Rio de Janeiro, Brazil are more risk averse defining a maximum tolerable IR level two orders of magnitude lower at one fatality in a million per year (1 x 10-6 fatality/year).

4. Only a few organizations define maximum tolerable IR criteria for workers. Those that do, generally set the maximum tolerable IR level an order of magnitude higher for workers since workers have a general awareness of the risks to which they are exposed and risk acceptance is higher because the benefit is higher. In the case of the UK, the upper bound value of one fatality in a thousand per year ($1 \times 10^{-3}$ fatality/year) reflects the highest risk that is generally accepted by workers under modern conditions in high risk jobs such as deep sea fishing.

5. As shown in Table 2, several organizations define separate IR criteria for sensitive populations (schools, hospitals, nursing homes, etc.), residential developments, commercial developments (office buildings, restaurants, retail centers, etc.), and open active spaces. These criteria range from a half order of magnitude to two orders of magnitude lower than the IR criteria set for the facility boundary (industrial facility IR). The greater risk aversion reflects the vulnerability of specific populations groups as well as their ability to willingly accept and protect themselves from the risks imposed on them.

Figure 3 presents a summary of individual risk criteria for workers.

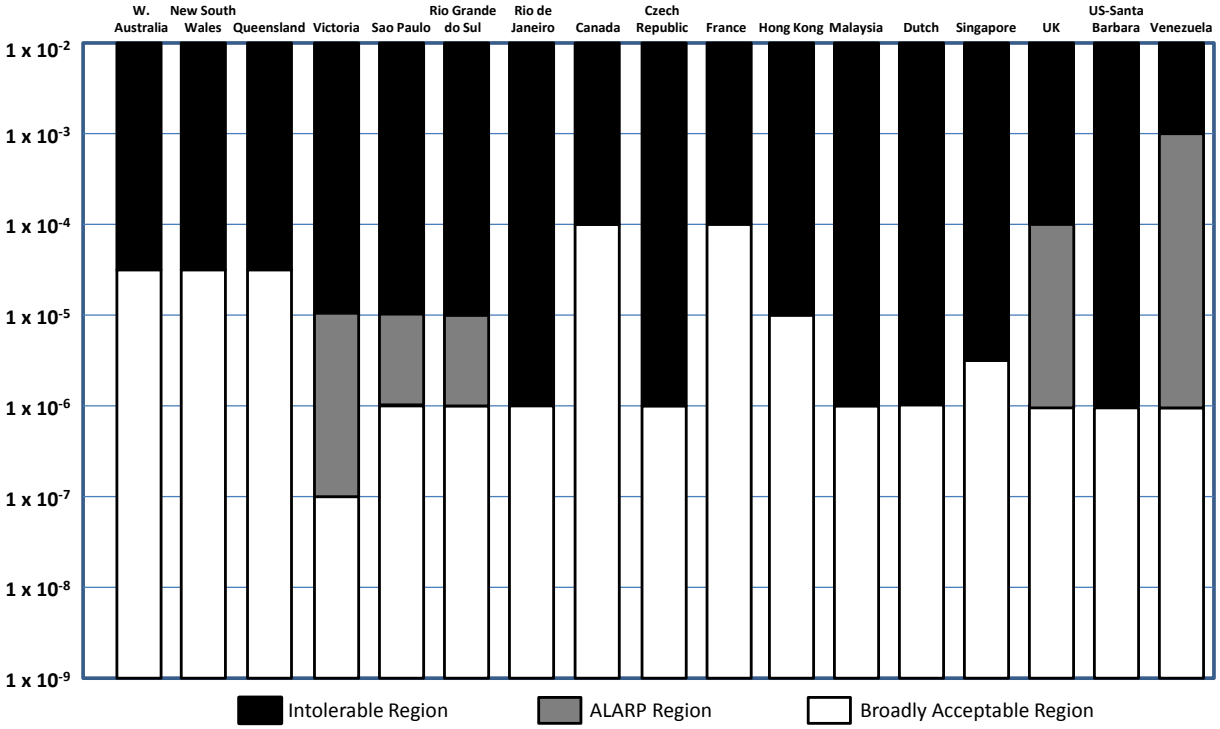



**Figure 1. Summary of Individual Risk (IR) Criteria – New Hazardous Facilities**

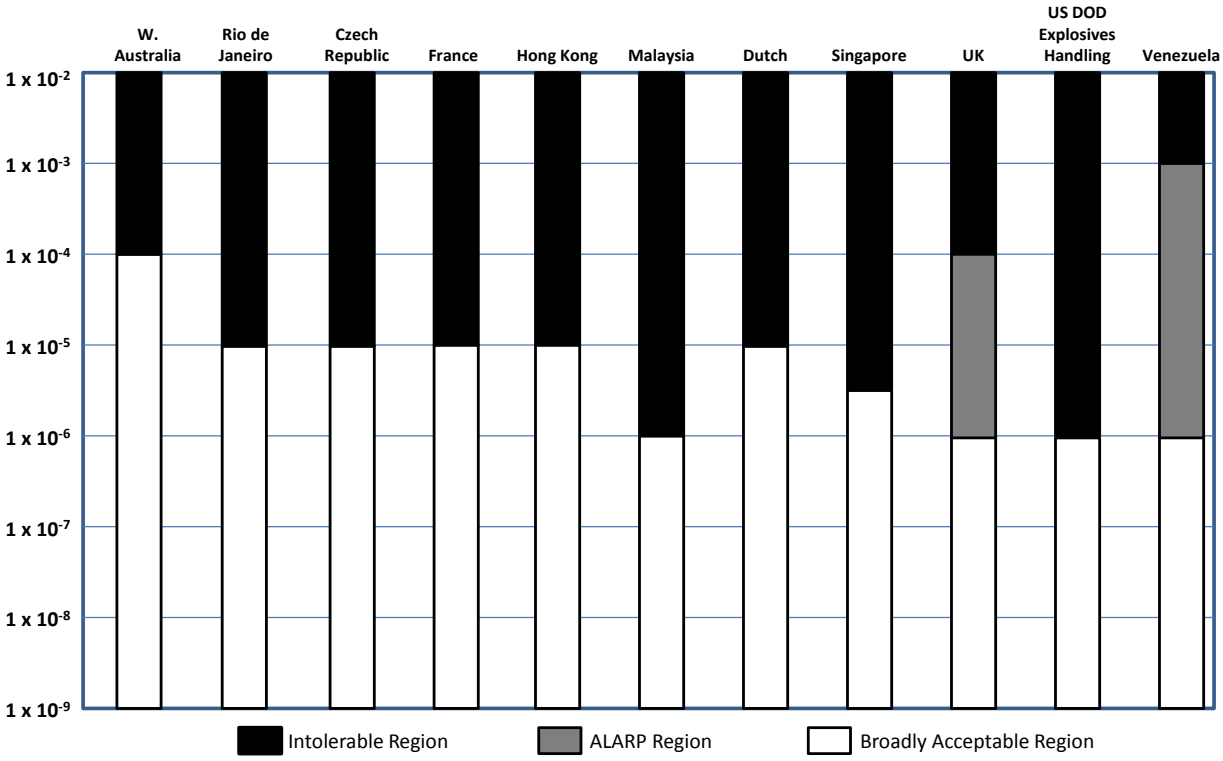



**Figure 2. Summary of Individual Risk Criteria – Existing Hazardous Facilities**

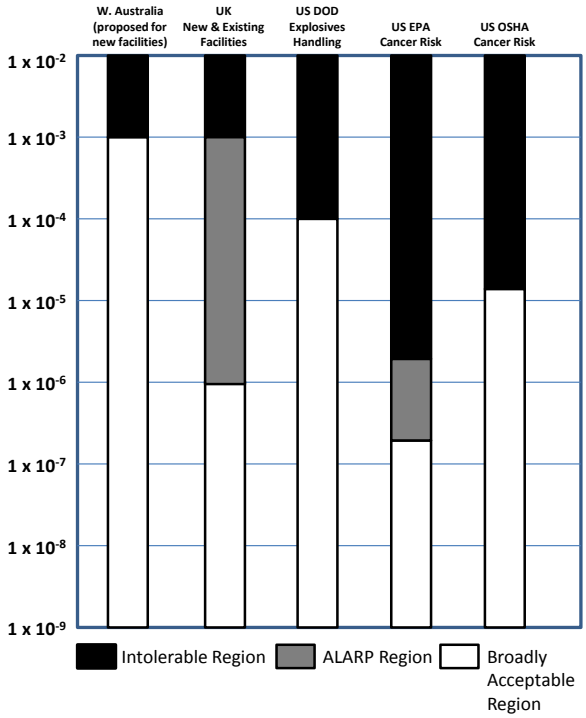



**Figure 3. Summary of Individual Risk Criteria – Workers**

### 2.1.3 Pipeline Specific Risk Criteria

There have been a few regulatory bodies that have specifically addressed risk criteria for hazardous pipelines. In general, these agencies have defined either individual risk criteria (e.g. Brazil, The Netherlands) or societal risk criteria (e.g. The Netherlands, UK) for pipelines. The Dutch and British governments have chosen to establish societal risk criteria based on the F-N diagram for a given length of pipe. While both countries use 1 km as the reference pipe length, they differ in how the risk criteria is used.[7] The Dutch recommend evaluating the worst-case km within an urban area while the British recommend summing F-N pairs over the entire length of pipeline through a community and then normalizing the result to 1 km. For the most part, these regulatory bodies set the risk tolerability criteria for pipelines at an order of magnitude less restrictive than for other industrial activities.

### 2.1.4 Impact Risk Criteria

Several regulatory bodies also use impact criteria (also known as consequence endpoint criteria) to define risk tolerability. Impact criteria is an off-shoot of individual and societal risk criteria in which it only considers consequence distances resulting in a specified impact (fatality, injury, property damage). This type of criteria is used by the U.S. EPA as part of their risk management plan (RMP) regulation as well as DOT PHMSA, in some respect, with the definition

[7] Schork, J. M. and Lutostansky, E. M., Societal Risk Criteria and Pipelines, Global Congress on Process Safety, 2012.

of high consequence areas (HCAs) and the additional integrity requirements for pipeline segments within HCAs. At an extreme, Germany specifies that no risk is to be imposed on people or the environment outside of the facility boundary[8]. Singapore also specifies that specific thermal radiation, overpressure, fireball, and toxic levels must remain within the facility boundaries. Consequence endpoint criteria evaluate worst-case impact distances without consideration of the likelihood of such an event. This type of criteria can lead to overly conservative intolerable risk ranges.

## 2.2 Qualitative or Semi-Quantitative Risk Criteria

France and Canada as well as the U.S. FAA use semi-quantitative risk matrices to determine risk tolerability. Each organization defines specific categories for consequence and likelihood – some focus solely on health risk categories while others include categories for environmental damage, property damage, business impacts, etc. They then define a risk matrix where the combination of consequence and likelihood provides an indication of risk for which different actions are undertaken to reduce the risk.

## 2.3 Summary

Table 1 provides a list of advantages and disadvantages for use of different risk tolerability criteria techniques. Ultimately, those considering development of risk criteria need to clearly define the basis behind the criteria, match the scope of the risk assessment with the criteria, be able to make reasonable decisions using the criteria, communicate those decisions to stakeholders, and avoid bias in the manner that risk-based decisions are made.

**Table 1. Advantages and Disadvantages of Risk Tolerability Criteria Techniques[9]**

| Technique | Advantages | Disadvantages |
|---|---|---|
| Qualitative and Semi-Quantitative Risk Criteria | • Relatively quick and easy to use<br>• Can provide information beyond likelihood and health and safety consequences such as environmental impacts, property damage, financial losses, vulnerabilities, damage to reputation, etc.<br>• Is easily understood by all stakeholders who may not be trained in quantitative risk assessment techniques<br>• Methodologies can be tailored to meet the needs of the study | • Risk assessment is subjective and can result in inconsistent use of qualitative techniques<br>• Tendency to make decisions based on the practitioners personal experience rather than what could potentially happen<br>• Is imprecise – risk events that fall into the same risk level can represent substantially different amounts of risk.<br>• Generally applied on scenario basis which can be difficult to compare with QRA results<br>• Difficult to numerically aggregate or address risk interactions and correlations<br>• Difficult to standardize frequency definitions and reliability of safeguards |

[8] Trbojevic, V.M., Risk criteria in EU, Risk Support Limited, London, U.K.
[9] The information provided in this table was adapted from Guidelines for Developing Quantitative Safety Risk Criteria written for the Center for Chemical Process Safety (CCPS), 2009 and http://www.coso.org/documents/COSOAnncsOnlineSurvy2GainInpt4Updt2IntrnlCntrlIntgratdFrmwrk%20-%20for%20merge_files/COSO-ERM%20Risk%20Assessment%20inPractice%20Thought%20Paper%20OCtober%202012.pdf

| Technique | Advantages | Disadvantages |
|---|---|---|
| | | • Provides limited ability to perform cost-benefit analysis |
| Quantitative Risk Criteria | • Provides the total risk and allows numerical aggregation which can account for risk interactions<br>• Permits cost-benefit analysis to compare the effectiveness of risk reduction options<br>• The greater level of detail required for analysis adds to the understanding of the process evaluated<br>• Useful for addressing high consequence, low frequency events<br>• If ALARP principles are used, encourages risk generators to drive risk downward | • Can be time-consuming and costly<br>• Requires a greater level of expertise for effective decision-making<br>• Must define units of measure (e.g. fatalities and/or dollar amounts) and annual frequency which may overlook qualitative impacts (e.g. reputation damage).<br>• Use of numbers may imply greater precision than the uncertainty of inputs warrants<br>• Assumptions may not be apparent<br>• Results can be difficult to understand<br>• Not enforcing the use of ALARP principles can discourage risk generators from doing more than the bare minimum to remain below the maximum tolerable level |
| Individual Risk Criteria | • Independent of the scale of the risk<br>• Can be compared with other typical activities (driving a car, flying in a plane, etc.) to communicate the level of risk to which an individual is exposed<br>• Permits evaluation of risk reduction measures using a consistent basis<br>• If personal-based IR criteria are used, the calculated risk accounts for occupancy patterns | • Focus is solely on casualties and overlooks other impacts (e.g. environmental impacts, property damage, business interruption, reputation damage).<br>• Can be overly restrictive if location-based IR criteria are used, not allowing for consideration of occupancy factors. |
| Societal Risk Criteria | • Provides a picture of the scale of an accident<br>• Permits evaluation of risk reduction measures using a consistent basis<br>• Accounts for occupancy patterns in the risk calculations | • Defining the criteria solely on number of fatalities overlooks other impacts (e.g. environmental impacts, property damage, business interruption, reputation damage).<br>• Criteria must be adjusted based on the defined scale of the risk assessment (a single facility vs multiple facilities vs pipeline route)<br>• Societal risk is sensitive to data assumptions and confidence in the data which can lead to widely varying results<br>• For pipelines, risk per defined length (i.e. 1 km) can be misleading when trying to compare different pipeline routes on a total risk basis.<br>• Too stringent criteria (such as in the Netherlands) can make compliance with the criteria difficult – especially for existing facilities.[10]<br>• May include irrational prejudice in comparison to commonly accepted risks (1000s of deaths each year from road travel vs 10s of deaths from pipeline or rail transportation).[11] |
| Impact Risk Criteria | • Easier for public stakeholders to understand<br>• Relatively easy to define and calculate impact levels | • Can be overly conservative because it does not consider the likelihood of large-scale incidents.<br>• Results may be mis-leading in terms of actual risk to public receptors. |

[10] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 71.
[11] Walker, T. Reducing Risks, Protecting People – Decision-Making on the Basis of Risk. University of Bath, School of Management. Center for the Study of Regulated Industries. January 2003.

**Table 2. Summary of Individual Risk (IR) Tolerance Practices**

| Country[12] | State | Agency | Hazardous Facility | Worker IR | Sensitive Development[13] IR | Residential Development IR | Commercial Facilities[14] IR | Non-Industrial or Active Open Spaces[15] IR | Industrial (Fixed) Facilities[16] IR | Hazardous Good Transport IR | IR Basis (Location or Personal) | Regulatory Requirement? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | fatality/year | | | | | | | | |
| Australia | Western Australia | Environmental Protection Authority (EPA) | New | None (proposed NA: > 1 x $10^{-3}$ in 2007) | NA: > 5 x $10^{-7}$ | NA: > 1 x $10^{-6}$ | NA: > 5 x $10^{-6}$ | NA: > 1 x $10^{-5}$ | Site Boundary NA: > 5 x $10^{-5}$<br>Any Facility NA: >1 x $10^{-4}$ | None | Location | Yes |
| | | | Existing | None | Seek risk reduction measures to meet new facility requirements. | | | | | None | Location | |
| | New South Wales | The New South Wales Department of Planning (DOP) | New | None | NA: > 5 x $10^{-7}$ | NA: > 1 x $10^{-6}$ | NA: > 5 x $10^{-6}$ | NA: > 1 x $10^{-5}$ | NA: > 5 x $10^{-5}$ | None | Location | Yes |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | Not defined | None | Not defined | |
| | Queensland | Chemical Hazards and Emergency Management Services (CHEM) | New | None | NA: > 5 x $10^{-7}$ | NA: > 1 x $10^{-6}$ | NA: > 5 x $10^{-6}$ | NA: > 1 x $10^{-5}$ | NA: > 5 x $10^{-5}$ | None | Location | Yes |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | Not defined | None | Not defined | |
| | Victoria | Victorian WorkCover | New | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-5}$<br>BA: $\leq$ 1 x $10^{-7}$ | None | Not defined | Yes |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | Not defined | None | Not defined | |
| | | Australian National Committee on Large Dams (ANCOLD) | New | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-5}$ | None | Not defined | No |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-4}$ | None | Not defined | No |
| Brazil | São Paulo | Companhia de Tecnologia de Saneamento Ambiental (CETSEB) | New | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-5}$<br>BA: $\leq$ 1 x $10^{-6}$ | Pipelines:<br>NA: > 1 x $10^{-4}$<br>BA: $\leq$ 1 x $10^{-5}$ | Not defined | Yes |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | Not defined | None | Not defined | |
| | Rio Grande do Sul | Fundação Estadual de Proteção Ambiental (FEPAM) | New | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-5}$<br>BA: $\leq$ 1 x $10^{-6}$ | Pipelines:<br>NA: > 1 x $10^{-4}$<br>BA: $\leq$ 1 x $10^{-5}$ | Not defined | Yes |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | Not defined | None | Not defined | |
| | Rio de Janeiro | Fundação Estadual de Engenharia do Meio Ambiente (FEEMA) | New | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-6}$ | Pipelines:<br>NA: > 1 x $10^{-6}$ | Not defined | Yes |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-5}$ | Pipelines:<br>NA: > 1 x $10^{-5}$ | Not defined | |
| Canada | | Major Industrial Accidents Council of Canada (MIACC) | Unknown | None | Not defined | NA: > 1 x $10^{-6}$ | NA: > 1 x $10^{-5}$ to 1 x $10^{-6}$ | NA: > 1 x $10^{-4}$ to 1 x $10^{-5}$ | NA: >1 x $10^{-4}$ | Same as fixed facility | Not defined | No |
| Czech Republic | | | New | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-6}$ | Not defined | Not defined | Unknown |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-5}$ | Not defined | Not defined | Unknown |

[12] A majority of the information documented in this table was derived from the Guidelines for Developing Quantitative Safety Risk Criteria written for the Center for Chemical Process Safety (CCPS), Appendix B, 2009.
[13] Various definitions apply but generally represent sensitive population groups such as those in schools, hospitals, nursing homes, and locations with high strategic value.
[14] Various definitions apply but generally represent population groups located in office buildings, hotels, retail centers, and restaurants.
[15] Various definitions apply but generally represent populations in active open spaces, like parks, that are located in buffer areas between industrial facilities and residential areas.
[16] Various definitions apply. The individual risk for a hazardous fixed facility (industrial facility) is generally defined for receptors just outside the facility boundary (also denoted as off-site). The definition for what qualifies as a hazardous facility can vary by country as well as type and quantities of hazardous substances processed at the facility.

| Country[12] | State | Agency | Hazardous Facility | Worker IR | Sensitive Development[13] IR | Residential Development IR | Commercial Facilities[14] IR | Non-Industrial or Active Open Spaces[15] IR | Industrial (Fixed) Facilities[16] IR | Hazardous Good Transport IR | IR Basis (Location or Personal) | Regulatory Requirement? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | fatality/year | | | | | | | | |
| France | | | New | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-4}$ to 1 x $10^{-5}$ depending on hazard level | Not defined | Not defined | Yes |
| | | | Existing | None | Not defined | NA: > 1 x $10^{-5}$ for very high hazard level | Not defined | Not defined | NA > 1 x $10^{-5}$ if exceeds, risk reduction can be used for very high hazard level | Not defined | Not defined | Yes |
| Germany | | | New | None | Not defined | Not defined | Not defined | Not defined | NA beyond facility boundaries | Not defined | Not defined | Unknown |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | NA beyond facility boundaries | Not defined | Not defined | Unknown |
| Hong Kong | | Planning Department and the Environmental Protection Department (EPD) | New | None | Not defined | Not defined | Not defined | Not defined | NA > 1 x $10^{-5}$ | Not defined | Personal | Yes |
| | | | Existing | None | Not defined | Not defined | Not defined | Not defined | NA > 1 x $10^{-5}$ if exceeds, risk reduction can be used | Not defined | Personal | Yes |
| Hungary | | | Unknown | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-5}$ BA: $\leq$ 1 x $10^{-6}$ | Not defined | Not defined | Unknown |
| Malaysia | | Malaysian Environmental Quality Act | New | None | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ | NA: > 1 x $10^{-5}$ with buffer zone of 500 m or to 1 x $10^{-6}$ level, whichever is greater | Not defined | Not defined | Yes |
| | | | Existing | None | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ | NA: > 1 x $10^{-5}$ with buffer zone of 500 m or to 1 x $10^{-6}$ level, whichever is greater | Not defined | Not defined | Yes |
| Netherlands | | Dutch Ministry for Housing, Spatial Planning, and the Environment | New | None | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ can be exceeded with compelling reasons | NA: >1 x $10^{-6}$ can be exceeded with compelling reasons | NA[17]: > 1 x $10^{-6}$ | Dangerous Goods NA: >1 x $10^{-6}$ | Location | Yes, only for vulnerable populations (residential and sensitive) |
| | | | Existing | None | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ | NA: >1 x $10^{-6}$ can be exceeded with compelling reasons | NA: >1 x $10^{-6}$ can be exceeded with compelling reasons | NA: > 1 x $10^{-5}$ | Dangerous Goods NA: >1 x $10^{-6}$ | Location | Yes, only for vulnerable populations (residential and sensitive) |
| Norway | | | Unknown | Risk generator is responsible for defining their own risk criteria | | | | | | | Depends | Yes for offshore industry |

[17] The Netherlands has originally defined a broadly acceptable region of 1 x $10^{-8}$, below which risks are considered acceptable. However, this criterion was eliminated in 1993 to encourage risk generators to apply as low as reasonably achievable (ALARA) principles for all individual risks below the unacceptable level.

| Country[12] | State | Agency | Hazardous Facility | Worker IR | Sensitive Development[13] IR | Residential Development IR | Commercial Facilities[14] IR | Non-Industrial or Active Open Spaces[15] IR | Industrial (Fixed) Facilities[16] IR | Hazardous Good Transport IR | IR Basis (Location or Personal) | Regulatory Requirement? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | fatality/year | | | | | | | | |
| Singapore | | Pollution Control Department (PCD) | New | None | Not defined | Not defined | NA: > 1 x $10^{-6}$ | NA: > 5 x $10^{-6}$ | NA: > 5 x $10^{-5}$ with 1 km buffer zone | Not defined | Not defined | Yes |
| | | | Existing | None | Not defined | Not defined | NA: > 1 x $10^{-6}$ | NA: > 5 x $10^{-6}$ | NA: > 5 x $10^{-5}$ with 1 km buffer zone | Not defined | Not defined | Yes |
| Switzerland | | | None | None | None | None | None | None | None | None | None | No, societal risk only |
| United Kingdom | | Health and Safety Executive (HSE) | New | NA: > 1 x $10^{-3}$<br>BA: $\leq$ 1 x $10^{-6}$ | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-4}$<br>BA: $\leq$ 1 x $10^{-6}$ | Aggregated with fixed facilities | Not defined | Yes |
| | | | Existing | NA: > 1 x $10^{-3}$<br>BA: $\leq$ 1 x $10^{-6}$ | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-4}$<br>BA: $\leq$ 1 x $10^{-6}$ | Aggregated with fixed facilities | Not defined | Yes |
| United States | California | Santa Barbara County Planning and Development Department | Unknown | None | Not defined | Not defined | Not defined | Not defined | NA: >1 x $10^{-6}$ | Not defined | Not defined | No, only used to screen if QRA required then relies on societal risk criteria |
| | New Jersey | New Jersey Air Quality Permitting Program | New | None | Not defined | Not defined | Not defined | Not defined | NA[18]: >1.4 x $10^{-6}$<br>BA[19]: $\leq$ 1.4 x $10^{-8}$ | Not defined | Incremental cancer risk | Unknown |
| United States | | Department of Defense (DOD) | Missile Test Range | NA[20]: > 1 x $10^{-6}$ individual probability of fatality | Not defined | Not defined | Not defined | Not defined | NA[21]: > 1 x $10^{-7}$ individual probability of fatality | Not defined | Not defined | Unknown |
| | | | Explosives Handling | NA: > 1 x $10^{-4}$ | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-6}$ | Not defined | Not defined | Unknown |
| | | Department of the Interior (DOI) | Bureau of Reclamation – Dam Safety Office | None | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-4}$ | Not defined | Not defined | No |
| United States | | Department of Energy (DOE) | Nuclear Facility | Not defined | Not defined | Not defined | Not defined | Not defined | NA[22]: > 2 x $10^{-6}$ risk of latent cancer fatalities (within 10 miles) | Not defined | Acute and latent cancer risk | Yes as part of 10 CFR 830 |

[18] Value defined by the New Jersey Air Quality Permitting Program as the incremental cancer risk from any contaminant over the lifetime of an individual. A lifetime is defined as 70 years. Therefore, a broadly acceptable individual cancer risk less than or equal to 1 x $10^{-6}$ fatality/lifetime is equivalent to 1.4 x $10^{-8}$ fatality/year.
[19] Value defined by the New Jersey Air Quality Permitting Program as the incremental cancer risk from any contaminant over the lifetime of an individual. A lifetime is defined as 70 years. Therefore, an unacceptable individual cancer risk greater than 1 x $10^{-4}$ fatality/lifetime is equivalent to 1.4 x $10^{-6}$ fatality/year.
[20] The value presented represents an individuals' probability of fatality per event and must therefore be multiplied by the number of missions to develop an individual risk value comparable to the other individual risk values (fatality/year) presented in this table. In addition, the value presented under 'Worker IR' actually represents the DOD definitions for mission essential personnel and critical operations personnel.
[21] The value presented represents an individuals' probability of fatality per event and must therefore be multiplied by the number of missions to develop an individual risk value comparable to the other individual risk values (fatality/year) presented in this table. In addition, the value presented under 'Industrial (Fixed) Facilities' actually represents the DOD definition for the general public which are people not critical to the mission including the public, personnel not essential to the mission, visitors, press, and persons living at the facility.
[22] As defined in Table B.18 of the CCPS Guidelines for Developing Quantitative Safety Risk Criteria: "Calculated from the criterion that risks should not exceed 0.1% of cancer fatality risks from all other causes".

| Country[12] | State | Agency | Hazardous Facility | Worker IR | Sensitive Development[13] IR | Residential Development IR | Commercial Facilities[14] IR | Non-Industrial or Active Open Spaces[15] IR | Industrial (Fixed) Facilities[16] IR | Hazardous Good Transport IR | IR Basis (Location or Personal) | Regulatory Requirement? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | fatality/year | | | | | | | | |
| | | | | | | | | | NA[23]: > 4 x $10^{-7}$ risk of acute cancer fatalities (within 1 mile) | | | |
| | | Environmental Protection Agency (EPA) | Waste sites, impurities in drinking water, etc. | NA[24]: >2.5 x $10^{-6}$ to 2.5 x $10^{-7}$ | Not defined | Not defined | Not defined | Not defined | NA[25]: >1.4 x $10^{-7}$ to 1.4 x $10^{-8}$ | Not defined | Incremental cancer risk | Yes as part of several regulations for which the EPA is responsible |
| | | Food and Drug Administration (FDA) | Cosmetics and food additives | Not defined | Not defined | Not defined | Not defined | Not defined | NA[26]: > 1.4 x $10^{-8}$ | Not defined | Incremental cancer risk | Yes |
| | | Nuclear Regulatory Commission (NRC) | Nuclear Facility | Not defined | Not defined | Not defined | Not defined | Not defined | NA[27]: > 1.4 x $10^{-7}$ | Not defined | Incremental cancer risk | Yes |
| | | Occupational Safety and Health Administration (OSHA) | Industrial Facility | NA[28]: > 2.2 x $10^{-5}$ | Not defined | Not defined | Not defined | Not defined | Not defined | Not defined | Incremental cancer risk | Unknown |
| Venezuela | | Petróleos de Venezuela, S.A. (PDVSA) | Unknown | Not defined | Not defined | Not defined | Not defined | Not defined | NA[29]: > 1 x $10^{-3}$ BA: $\leq$1 x $10^{-6}$ | Not defined | Not defined | Unknown |
| International | | International Maritime Organization (IMO) | New Ships | NA: > 1 x $10^{-4}$ BA: $\leq$ 1 x $10^{-6}$ | Not defined | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-5}$ BA: $\leq$ 1 x $10^{-6}$ | Not defined | Unknown |
| | | | Existing Ships | NA: > 1 x $10^{-3}$ BA: $\leq$ 1 x $10^{-6}$ | Not defined | Not defined | Not defined | Not defined | Not defined | NA: > 1 x $10^{-4}$ BA: $\leq$ 1 x $10^{-6}$ | Not defined | Unknown |

[23] As defined in Table B.18 of the CCPS Guidelines for Developing Quantitative Safety Risk Criteria: "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 4 x $10^{-4}$ fatality/year".

[24] The values of maximum tolerable residual risk differ by the various EPA agencies. The values presented in the table cover the range presented in "A Survey of Methods for Chemical Health Risk Assessment Among Federal Regulatory Agencies", Lorenz R. Rhomberg, PhD. The U.S. EPA generally defines these values as the upper limit value for cancer risk to a worker over the lifetime of an individual. An occupational lifetime is assumed as 40 years. Therefore, a worker's maximum tolerable cancer risk for a lifetime must be less than 1 x $10^{-4}$ fatality/lifetime or an equivalent of 2.5 x $10^{-6}$ fatality/year.

[25] The values of maximum tolerable residual risk differ by the various EPA agencies. The values presented in the table cover the range presented in "A Survey of Methods for Chemical Health Risk Assessment Among Federal Regulatory Agencies", Lorenz R. Rhomberg, PhD. The U.S. EPA generally defines these values as the upper limit value for cancer risk to the public over the lifetime of an individual. A lifetime is assumed as 70 years. Therefore, a public individual's maximum tolerable cancer risk for a lifetime must be less than 1 x $10^{-6}$ fatality/lifetime is equivalent to a yearly risk of 1.4 x $10^{-8}$ fatality/year.

[26] Value defined by the U.S. FDA as the cancer risk to the public over the lifetime of an individual. A lifetime is defined as 70 years. Therefore, a public individual's cancer risk is broadly acceptable if it is less than 1 x $10^{-6}$ fatality/lifetime which is equivalent to 1.4 x $10^{-8}$ fatality/year.

[27] Value defined by the U.S. NRC "the risk to an average individual in the vicinity of a nuclear power plant of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1 percent) of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed." Therefore, if the prompt fatality risk that the U.S. population is generally exposed to is approximately 1 x $10^{-4}$ fatality/year then the individual risk for the general public from a nuclear reactor accident is equivalent to 1.4 x $10^{-7}$ fatality/year.

[28] Value defined by the U.S. OSHA as the upper range value for cancer risk to workers over the lifetime of an individual. A lifetime is defined as 45 years. Therefore, a worker's unacceptable cancer risk should not be greater than 1 x $10^{-3}$ fatality/lifetime is equivalent to 2.2 x $10^{-5}$ fatality/year.

[29] Data obtained from the paper: Cornwell, J.B. and Meyer, M.M. Risk Acceptance Criteria or "How Safe is Safe Enough?". II Risk Control Seminar, October 13, 1997.

**Table 3. Summary of Societal Risk (SR) Tolerance Practices**

| Country[30] | State | Agency | Tolerability | Societal Risk Criteria – Frequency (F) | Societal Risk Criteria – Number of Fatalities (N) | Slope of F-N Curve | Regulatory Requirement? | Comment |
|---|---|---|---|---|---|---|---|---|
| Australia | Western Australia | Environmental Protection Authority (EPA) | See IR | None | None | None | No | A guidance document proposed generic separation distances between industrial facilities and sensitive land use ranging from 300 to 1500 meters; however it did not recommend using the generic distances for major industrial developments.<br><br>Graduated scales for IR somewhat address societal risk concerns. |
| | New South Wales | The New South Wales Department of Planning (DOP) | Maximum Tolerable | $1 \times 10^{-4}$ | 10 | -1.5 | No | NSW has a system of minimum separation distances between hazardous facilities and other types of developments intended to ensure that new developments satisfy the risk criteria. NSW allows for flexibility in applying this criterion. |
| | | | Broadly Acceptable | $1 \times 10^{-6}$ | 10 | -1.5 | No | |
| | Queensland | Chemical Hazards and Emergency Management Services (CHEM) | See IR | None | None | None | No | Although Queensland has not mandated use of societal risk criteria, they suggest that "this concept should be addressed in the case of facilities that are close to significant population centres." (CCPS)<br><br>Graduated scales for IR somewhat address societal risk concerns. |
| | Victoria | Victorian WorkCover | Maximum Tolerable | $1 \times 10^{-4}$ | 10 | -2 | No | Societal risk criteria based on F-N values suggested by the UK with the more conservative slope used by the Dutch. |
| | | | Broadly Acceptable | $1 \times 10^{-6}$ | 10 | -2 | No | |
| | | Australian National Committee on Large Dams (ANCOLD) | Maximum Tolerable | $1 \times 10^{-4}$ | 10 | -1 | No | ANCOLD applies ALARP principles. At a frequency of $1 \times 10^{-5}$ and 100 fatalities the F-N curve transitions to a horizontal line at $1 \times 10^{-5}$ indicating a minimum level of safety regardless of the consequences. |
| | | | Broadly Acceptable | $1 \times 10^{-6}$ | 10 | -1 | No | |
| Brazil | São Paulo | Companhia de Tecnologia de Saneamento Ambiental (CETSEB) | Maximum Tolerable | $1 \times 10^{-4}$ | 10 | -1 | Yes | Permit the exceedance of individual risk criteria as long as the societal risk criteria is satisfied[30] |
| | | | Broadly Acceptable | $1 \times 10^{-6}$ | 10 | -1 | Yes | |
| | Rio Grande do Sul | Fundação Estadual de Proteção Ambiental (FEPAM) | Maximum Tolerable | $1 \times 10^{-5}$ | 100 | -1.5 | No | |
| | | | Broadly Acceptable | $1 \times 10^{-6}$ | 100 | -1.5 | No | |
| | Rio de Janeiro | Fundação Estadual de Engenharia do Meio Ambiente (FEEMA) | Maximum Tolerable | $1 \times 10^{-5}$ | 100 | -1.5 | Yes, including pipelines | Requires evaluation of societal risk for pipelines which is the same criteria as that used for fixed facilities. |
| | | | Broadly Acceptable | $1 \times 10^{-6}$ | 100 | -1.5 | Yes, including pipelines | |
| Canada | | Major Industrial Accidents Council of Canada (MIACC) | See IR | None | None | None | No | Graduated scales for IR somewhat address societal risk concerns. |
| Czech Republic | | | See IR | None | None | None | No | |
| France | | | Maximum Tolerable | $1 \times 10^{-5}$<br><br>$1 \times 10^{-4}$ | Extreme for existing facilities[31]<br>Catastrophic[32] | None | Unknown | Permitting of new or modified industrial facilities is based on societal risk measures defined in a matrix format while land use planning is based on individual risk measures. |

[30] A majority of the information documented in this table was derived from the Guidelines for Developing Quantitative Safety Risk Criteria written for the Center for Chemical Process Safety (CCPS), 2009.
[31] An 'Extreme' consequence in France is defined as: 1) greater than 10 persons exposed to a significant lethal effect (5% chance of fatality); 2) greater than 100 persons exposed to a first lethal effect (1% chance of fatality); or 3) greater than 1000 persons exposed to an irreversible effect. Stringent risk reduction measures are required for existing facilities. For new facilities, any scenario with a 1 x 10-5 frequency and Extreme consequence is unacceptable.
[32] A 'Catastrophic' consequence in France is defined as: 1) between 1 and 10 persons exposed to a significant lethal effect (5% chance of fatality); 2) between 10 and 100 persons exposed to a first lethal effect (1% chance of fatality); or 3) between 100 and 1000 persons exposed to an irreversible effect. Risk reduction measures are required.

| Country[30] | State | Agency | Tolerability | Societal Risk Criteria – Frequency (F) | Societal Risk Criteria – Number of Fatalities (N) | Slope of F-N Curve | Regulatory Requirement? | Comment |
|---|---|---|---|---|---|---|---|---|
| | | | | $1 \times 10^{-3}$<br>$1 \times 10^{-2}$ | Significant[33]<br>Medium[34] | | | |
| | | | Broadly Acceptable | $\leq 1 \times 10^{-2}$<br>$< 1 \times 10^{-4}$ | Moderate[35]<br>Medium | None | Unknown | |
| Germany | | | No risk level permitted outside the facility boundary | | | | | |
| Hong Kong | | Planning Department and the Environmental Protection Department (EPD) | Maximum Tolerable | $1 \times 10^{-4}$ | 10 | -1 | Yes | Frequency of fatality no longer considered after N=1000. |
| | | | Broadly Acceptable | $1 \times 10^{-6}$ | 10 | -1 | Yes | |
| Hungary | | | See IR | None | None | None | No | |
| Malaysia | | Malaysian Environmental Quality Act | See IR | None | None | None | No | Minimum 500 meter buffer zone or distance to $1 \times 10^{-6}$ fatality/year risk contour, whichever is greater, required between boundary of hazardous industrial facility and any other development. |
| Netherlands | | Dutch Ministry for Housing, Spatial Planning, and the Environment | Maximum Tolerable (Fixed Facility) | $1 \times 10^{-5}$ | 10 | -2 | No | Credit can be taken for occupancy patterns, indoor/outdoor exposure when calculating societal risk. |
| | | | Maximum Tolerable per km (Transportation) | $1 \times 10^{-4}$ | 10 | -2 | | |
| | | | Broadly Acceptable | None | None | None | No | |
| Norway | | | Risk generator is responsible for defining their own criteria | | | | | |
| Singapore | | Pollution Control Department (PCD) | See IR | None | None | None | No | Requires a 1 km buffer zone between residences and installations such as oil refineries, petrochemical and chemical plants, and toxic industrial waste treatment facilities. Also require specific worst-case credible scenarios not extend beyond the facility boundaries or go outside industrial areas and encroach on residential areas. |
| Switzerland | | | Maximum Tolerable | $\sim 1 \times 10^{-5}$ | Disaster Value 0.3 | | Unknown | Societal risk guidelines use a disaster value for 'N' which uses equivalency factors between fatalities, injuries, environmental impact, and property damage. |
| | | | Broadly Acceptable | $\sim 1 \times 10^{-7}$ | Disaster Value 0.3 | | Unknown | |
| United Kingdom | | Health and Safety Executive (HSE) | Maximum Tolerable | Single site: $2 \times 10^{-4}$<br>Multiple sites: $2 \times 10^{-3}$ | 50<br>50 | -1<br>-1 | No | Also allow for 'risk scaling' in which the maximum tolerable line can be set an order of magnitude higher where several sites contribute to the local societal risk. Aggregates transportation risk with facility risk. |
| | | | Broadly Acceptable | $2 \times 10^{-6}$ | 50 | -1 | No | |
| United States | California | Santa Barbara County Planning and Development Department | Maximum Tolerable | $1 \times 10^{-5}$ | 10 | -2 | Unknown | For new developments, the societal risk is unacceptable if above N=10 and F=$1 \times 10^{-5}$. For new developments with sensitive land use (schools, hospitals, etc.), the societal risk is unacceptable if above N=10 and F is between $1 \times 10^{-5}$ and $1 \times 10^{-7}$.<br>Also defines risk criteria for injuries that are two orders of magnitude higher than the F-N curves. |
| | | | Broadly Acceptable | $1 \times 10^{-7}$ | 10 | -2 | Unknown | |

[33] A 'Significant' consequence in France is defined as: 1) 1 or fewer persons exposed to a significant lethal effect (5% chance of fatality); 2) between 1 and 10 persons exposed to a first lethal effect (1% chance of fatality); or 3) between 10 and 100 persons exposed to an irreversible effect. Risk reduction measures are required.
[34] A 'Medium' consequence in France is defined as: 1) 0 persons exposed to a significant lethal effect (5% chance of fatality); 2) 1 or fewer persons exposed to a first lethal effect (1% chance of fatality); or 3) between 1 and 10 persons exposed to an irreversible effect. Risk reduction measures are required.
[35] A 'Moderate' consequence in France is defined as one or less people exposed to an irreversible effect and no lethal effects outside of the facility. Risk reduction measures are required.

| Country[30] | State | Agency | Tolerability | Societal Risk Criteria – Frequency (F) | Societal Risk Criteria – Number of Fatalities (N) | Slope of F-N Curve | Regulatory Requirement? | Comment |
|---|---|---|---|---|---|---|---|---|
| United States | | Department of Defense (DOD) | Missile Test Range Max Tolerable | Public: $1 \times 10^{-7}$<br>Worker: $5 \times 10^{-7}$ | 100<br>100 | -1.5<br>-1.5 | Unknown | |
| | | | Explosives Handling Max Tolerable | $1 \times 10^{-3}$<br>$1 \times 10^{-5}$ | All workers<br>All public | | Unknown | The DOD makes allowances for increasing the frequency by an order of magnitude for workers ($1 \times 10^{-2}$) and two orders of magnitude for the public ($1 \times 10^{-3}$) if there is a significant national need. |
| | | Department of Energy (DOE) | See IR | None | None | None | No | |
| | | Department of the Interior (DOI) – Bureau of Reclamation Dam Safety Office | Maximum Tolerable | $1 \times 10^{-4}$ | 10 | -1 | No | ALARP principles apply in a region below $1 \times 10^{-6}$ annualized failure probability and greater than 1,000 fatalities. |
| | | | Broadly Acceptable | None | None | None | No | |
| | | Environmental Protection Agency (EPA) | See IR | None | None | None | No | |
| | | Food and Drug Administration (FDA) | See IR | None | None | None | No | |
| | | Nuclear Regulatory Commission (NRC) | See IR | None | None | None | No | |
| | | Occupational Safety and Health Administration | See IR | None | None | None | No | |
| Venezuela | | Petróleos de Venezuela, S.A. (PDVSA) | Maximum Tolerable | $1 \times 10^{-2}$<br>$1 \times 10^{-4}$<br>$1 \times 10^{-6}$ | 1 to 10<br>10 to 50<br>50 to 1,000 | Step Curve | Unknown | The maximum tolerable line does not extend beyond 1,000 fatalities and the broadly acceptable line does not extend beyond 10 fatalities. We have presumed, similar to the Hong Kong and earlier Dutch criteria, that for fatalities greater than 1,000 the risk is unacceptable regardless of frequency. Moreover, we have presumed that the broadly acceptable curve mimics the maximum tolerable curve, except that the values are 4 orders of magnitude lower. |
| | | | Broadly Acceptable | $1 \times 10^{-6}$<br>$1 \times 10^{-8}$<br>$1 \times 10^{-10}$ | 1 to 10<br>10 to 50 (presumed)<br>50 to 1,000 (presumed) | Step Curve | Unknown | |
| International | | International Maritime Organization (IMO) | Tankers<br>Max Tolerable<br>Broadly Acceptable | <br>$2 \times 10^{-3}$<br>$2 \times 10^{-5}$ | <br>10<br>10 | <br>-1<br>-1 | Unknown | |
| | | | Bulk and Ore Carriers<br>Max Tolerable<br>Broadly Acceptable | <br>$1 \times 10^{-3}$<br>$1 \times 10^{-5}$ | <br>10<br>10 | <br>-1<br>-1 | Unknown | |
| | | | Passenger Roll On/Off<br>Max Tolerable<br>Broadly Acceptable | <br>$1 \times 10^{-2}$<br>$1 \times 10^{-4}$ | <br>10<br>10 | <br>-1<br>-1 | Unknown | |

# 3 BACKGROUND

Recent studies conducted by the Government Accountability Office (GAO) and National Transportation Safety Board (NTSB) evaluated the effectiveness of the gas transmission pipeline integrity management program. In the GAO report[36], they examined the results of baseline assessments and reassessments and the potential impact of making the current process more risk-based. The NTSB report[37] was undertaken because of concerns about deficiencies in the application and oversight of integrity management programs and heightened concerns over gas transmission pipeline safety stemming from three major gas transmission accidents occurring within the past five years. Some of the key findings from the NTSB study were:

- Though the trend of gas transmission pipeline incidents has leveled off since implementation of the integrity management in 2004, there is no evidence that the overall incident rate in high consequence areas (HCAs) has declined.
- From 2010 to 2013, gas transmission pipeline incidents were overrepresented on HCA pipeline segments compared to non-HCA pipeline segments.
- Despite the intention of the gas integrity management regulations to reduce the risk of all identified threats, HCA incidents attributed to causes other than corrosion and material defects in pipe or weld increased from 2010 to 2013.
- Sufficient guidance is not available to pipeline operators and inspectors regarding the safety performance of the four types of risk assessment approaches allowed by regulation, including the effects of weighting factors, calculation of consequences, and risk aggregation methods.
- The study found that aspects of the operators' threat identification and risk assessment processes require improvement.

Based on these findings, the NTSB identified several areas for improvement to further enhance the safety of gas transmission pipelines in HCAs. NTSB recommendations that are directly related to the research conducted for this project include:

- Establish minimum criteria for eliminating threats and provide guidance to gas transmission pipeline operators for documenting their rationale for eliminating threats.
- Develop and implement specific risk assessment training for inspectors to verify the technical validity of risk assessments that operators use.

[36] U.S. Government Accountability Office. Gas Pipeline Safety – Guidance and More Information Needed before Using Risk-Based Reassessment Intervals. June 2013.
[37] NTSB. Safety Study – Integrity Management of Gas Transmission Pipelines in High Consequence Areas. NTSB/SS-15/01. January 27, 2015.

- Update guidance on critical components of risk assessment approaches. Include methods for setting weighting factors, factors that should be included in consequence of failure calculations, and appropriate **risk metrics** and methods for aggregating risk along a pipeline.

In September 2015, the Pipeline and Hazardous Materials Safety Administration (PHMSA) held a workshop on risk modeling methodologies to discuss ideas for continued diligence and improvements in risk analysis in response to the NTSB recommendations and a July 2011 public workshop on improving pipeline risk assessment and recordkeeping[38]. During the workshop, PHMSA highlighted areas of improvement related to risk modeling methodologies. Particularly related to risk-based decision-making, PHMSA identified the following recommendations:

- Risk models and safety management systems (SMS) need to be improved to help operators make informed decisions about the safe operation and maintenance of their pipeline systems.
- Risk evaluation approaches need to be "investigative-oriented" – more data-driven and connected to real-life decision making.
- Risk assessment approaches must tell us what can be done to reduce risk verses simply identifying which parts of the pipeline represent the highest relative risk.
- Generating risk numbers is not the end goal; a structured way to evaluate and reduce operational risk is the goal.

This report is to inform PHMSA and pipeline operators on methodologies used for risk-based decision-making, specifically risk tolerability criteria, to help progress risk management practices used across the pipeline industry.

# 4 RISK ASSESSMENT REGULATIONS FOR PIPELINES

U.S. DOT pipeline regulations for hazardous liquid pipelines (§195.452) and natural gas pipelines (§192.901- §192.951) require operators to perform risk assessments of their pipelines to:

- Ensure that integrity assessment methods (internal inspection, pressure testing, direct assessment, etc.) are employed to address significant threats on pipeline segments.
- Ensure that integrity assessments of the highest risk segments are scheduled with priority over lower risk segments.

[38] Nanney, S. and Lee, K. Presentation on Current Regulatory Requirements for Evaluation of Risk. PHMSA Pipeline Risk Modeling Methodologies Public Workshop. September 9, 2015.

- Ensure that assessments of threats and potential consequences are conducted to define, evaluate, and implement additional measures that address significant threats to the pipeline (e.g., conducting depth-of-cover surveys and correcting any deficiencies), or reduce potential consequences of failures (e.g., installing additional valves on the pipeline to reduce the amount of liquid or gas that might be released should a failure occur).

The specific regulations are listed below.

| **Natural Gas Pipelines**<br>**DOT 49 CFR 192 – Subpart O – Gas Transmission Pipeline Integrity Management** | |
|---|---|
| §192.917 | c) Risk Assessment. An operator must conduct a risk assessment that follows ASME/ANSI B31.8S, section 5, and considers the identified threats for each covered segment. An operator must use the risk assessment to prioritize the covered segments for the baseline and continual reassessments (§§ 192.919, 192.921, 192.937), and to determine what additional preventive and mitigative measures are needed (§ 192.935) for the covered segment. |

| **Hazardous Liquid and Carbon Dioxide Pipelines**<br>**DOT 49 CFR 195 – Pipeline Integrity Management in High Consequence Areas** | |
|---|---|
| §195.452 | (e) (1) An operator must establish an integrity assessment schedule that prioritizes pipeline segments for assessment (see paragraphs (d)(1) and (j)(3) of this section). An operator must base the assessment schedule on all risk factors that reflect the risk conditions on the pipeline segment. |
| | (i) (1) General requirements. An operator must take measures to prevent and mitigate the consequences of a pipeline failure that could affect a high consequence area. These measures include conducting a risk analysis of the pipeline segment to identify additional actions to enhance public safety or environmental protection. Such actions may include, but are not limited to, implementing damage prevention best practices, better monitoring of cathodic protection where corrosion is a concern, establishing shorter inspection intervals, installing EFRDs on the pipeline segment, modifying the systems that monitor pressure and detect leaks, providing additional training to personnel on response procedures, conducting drills with local emergency responders and adopting other management controls. |

| Hazardous Liquid and Carbon Dioxide Pipelines<br>DOT 49 CFR 195 – Pipeline Integrity Management in High Consequence Areas | |
|---|---|
| | (i) (2) Risk analysis criteria. In identifying the need for additional preventive and mitigative measures, an operator must evaluate the likelihood of a pipeline release occurring and how a release could affect the high consequence area. This determination must consider all relevant risk factors... |

**Notice of Proposed Rulemaking (NPRM)**

PHMSA issued a Notice of Proposed Rulemaking (NPRM) on October 13, 2015[39] concerning hazardous liquid pipeline safety issues. These proposed rules were prepared in response to certain Congressional mandates under the 2011 amendments to the Pipeline Safety Act as well as critiques from the GAO and NTSB. The Agency issued the proposal after two recent Senate hearings on pipeline safety, and as Congress prepares to consider reauthorization of the Pipeline Safety Act. The proposed changes to the Part 195 regulations would significantly extend and expand the reach of certain PHMSA integrity management (IM) requirements (i.e., periodic assessments, repairs and leak detection). In addition, the proposal would trigger new reporting requirements for certain unregulated pipelines, including all gathering lines.

# 5 RISK TOLERANCE CONCEPTS

The word "risk" is generally defined as the combination of the probability that something adverse will happen and its consequence given that it did occur. The probability that a specified undesirable event will occur depends on a host of factors that can be time dependent or time independent. Risk management comprises an estimation of the risk, deciding whether or not it is tolerable and exercising appropriate control measures to reduce the risk to tolerable levels. But the key is how to decide what risk is and is not tolerable.

Risk tolerability refers to a willingness to assume a level of risk commensurate with the benefits received from accepting that risk. To tolerate a risk means that we do not regard it as negligible or something that can be ignored, but rather as something that needs to be kept under review and still reduced further if feasible. Tolerability criteria can be established on the basis of human life, environmental damage, equipment/property damage, business loss, litigation costs, and other factors. For natural gas or volatile liquid pipelines, human life or life safety would be a driving factor, whereas a crude oil pipeline might be more impacted by environmental damages.

[39] Docket No. PHMSA-2010-0229, 80 FR 61610

Establishing risk tolerance levels provides a basis to identify where action is required. These limits can be qualitative, semi-quantitative, or quantitative. The most common framework for defining risk criteria divides risks into three levels: 1) An unacceptable level, where risks are intolerable except in extraordinary circumstances and risk reduction measures are essential; 2) An intermediate level or 'grey area' (also termed by many As Low As Reasonably Practical; ALARP) where risk reduction measures are desirable, but may not be implemented if the cost is grossly disproportionate to the benefit received; and 3) A broadly acceptable region, where risks are deemed tolerable or negligible and no further risk reduction measures are required. These concepts are depicted in Figure 4.

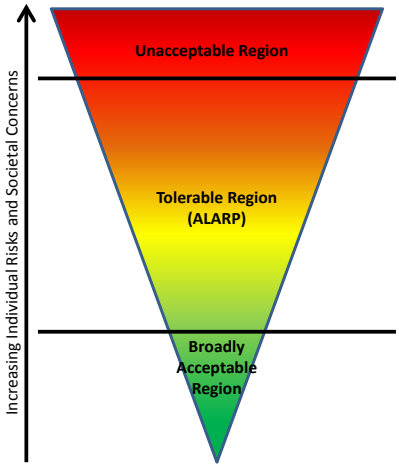



**Figure 4. Risk Acceptability Framework**

Although simple in concept, defining risk criteria is not a simple task. It requires the input and agreement among multiple stakeholders and continual monitoring and updating to reflect new and improved information. Complicating matters, the perception of acceptable versus unacceptable risks varies significantly from individual to individual and community to community.

## 5.1 Considerations When Developing Risk Tolerability Criteria

The CCPS emphasize the importance of developing risk criteria and its impact on how an organization conducts business.[41] Moreover, the NORSOK standard suggests that risk tolerability criteria must be established prior to conducting a risk assessment since it establishes the reference for evaluation of the risk assessment results.[40] Developing risk tolerability criteria requires consideration of many factors such as human health and safety, environmental protection, legal/regulatory requirements, economic objectives, stakeholder input, and risk perceptions, as examples. Several organizations have provided specific recommendations for defining risk criteria[40,41] which include but are not limited to:

1. The basis of the criteria must match the scope and methodology of the analysis to be performed (total risk at a pumping facility versus total risk for an entire pipeline system versus the total risk for all operations across the company),

2. The criteria must be unambiguous, clearly defined, and easily communicated to stakeholders,

[40] NORSOK Standard Z-013, Edition 3, October 2010. Risk and Emergency preparedness assessment. Norwegian Oil Industry Association (OLF) and the Federation of Norwegian Industry, Lysaker, Norway. 2010.
[41] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, Chapter 4.

3. The criteria must be suitable for decision-making regarding risk reducing measures,

4. The criteria must not favor any particular solution through the way in which risk is expressed, and

5. The criteria should be continuously reviewed to ensure it remains applicable to the risks being assessed.

According to the Presidential/Congressional Commission on Risk Assessment and Risk Management,

> *"A good risk management decision reduces or eliminates risks in ways that:*
>
> - *Are based on the best available scientific, economic, and other technical information.*
> - *Account for their multisource, multimedia, multichemical, and multirisk contexts.*
> - *Are feasible, with benefits reasonably related to their costs.*
> - *Give priority to preventing risks, not just controlling them.*
> - *Use alternatives to command-and-control regulation, where applicable.*
> - *Are sensitive to political, social, legal, and cultural considerations.*
> - *Include incentives for innovation, evaluation, and research…*
>
> *Decision makers must balance the value of obtaining additional information against the need for a decision, however uncertain…When sufficient information is available to make a risk management decision or when additional information or analysis would not contribute significantly to the quality of the decision, the decision should not be postponed."*[42]

***Framework for Environmental Health Risk Management (1997) – (p 37)***

It is clear that one of the first steps in any risk study is to set up a glossary to define each term exactly. This insures that the risk analysis will be constructed in an unambiguous way. Thus, every person involved starts with a common understanding of the problem.

<u>The first term that needs to be defined is **risk**</u>. In Section 3.1 of ASME/ANSI B31.8S, risk is introduced as the product of likelihood and consequences of events. While risk is often expressed in such way, this is not the only representation of risk and we think that the notion of risk needs to be expanded to encompass the broader perspective of the term. A better definition is given in *Societal Risk Assessment – How Safe is Safe Enough?*[43] where risk is defined as follows:

[42] The Presidential/Congressional Commission on Risk Assessment and Risk Management. Framework for Environmental Health Risk Management. Final Report Volume 1. 1997

[43] General Motors Research Laboratories. (1979). Societal Risk Assessment - How Safe is Safe Enough? In R. C. Schwing (Ed.), International symposium on Societal Risk Assessments. Warren (MI): Springer Science.

> *"Risk" may be defined as a compound measure of the probability and magnitude of adverse effect…*

***Societal Risk Assessment: How Safe is Safe Enough (1979) – the nature of risk (p 5)***

Such definition is consistent with the definition of risk calculation in *Pipeline Risk Analysis - Major Hazards Onshore and Offshore*[44], directly recommended for pipelines.

> *Risk is calculated by combining the likelihood of a hazardous event with its consequence and can therefore be expressed as:-*
> *Risk = f (Probability, Consequence)*

***I CHEM E symposium series 130 - Pipeline risk analysis (p 660)***

Three concepts underlie the multidimensional aspect of risk. First, there is the notion of adverse effect which is sometimes assimilated into events but can also be linked to a process that spans a long time. The first aspect of any risk study is to identify these potential effects, whether they are well known (aging process), more or less likely (incident or accident observed with a certain frequency in the past), or hypothetical (potential failure never observed yet). This first dimension can be treated as discrete (for instance a set of potential scenarios) or embedded in on global umbrella.

The two others dimensions derive from this first dimension. One characterization of any adverse effect is its likelihood. Usually, prediction of occurrences to estimate future risk is performed using a probabilistic framework. In other words, each adverse effect is associated with a probability distribution representing its likelihood of occurrence. This probability can be as a function of time, space or both (e.g. for every 100 miles of pipeline, per year for the entire pipeline, or per year and per 100 miles of pipeline). The fact that any probability may be influenced by space and time raises an important aspect of the definition of risk, the necessity to clearly define the context of the risk analysis. Some aspects of risk will change depending on the problem being considered (for example a set of pipelines versus a specific section of a pipeline, or a specific geographical configuration).

The last dimension characterizing each effect is the consequence associated with the effect. Once again, it is important to remember that the consequence is directly linked to the question asked. Some events may be of low consequence in certain aspects of risk while driving some others.

What transpired from these generic definitions is that before even listing the potential risks and characterizing each of them, it is necessary to define a priori, and as precisely as possible, the context of the analysis and the risk that needs to be considered before appropriate definitions

[44] Hill, R. T. (1992). Pipeline Risk Analysis. Major Hazards Onshore and Offshore, (pp. 657-670).

for risk tolerance can be defined. Without a clear definition of the question to be answered there cannot be a satisfying answer.

This statement is consistent with the conclusion reached by the committee on improving risk analysis approaches used by the U.S. Environmental Protection Agency and expressed in *Science and Decisions – Advancing Risk Assessment*.[45]

> *Risk assessment should continue to capture and accurately describe what various research findings do and do not tell us about threats to human health and to the environment, but only after the risk-management questions that risk assessment should address have been clearly posed.*

***Science and Decisions – Advancing Risk Assessment (2009) – Summary (p.5)***

## 5.2 Types of Risk Tolerability Criteria

In the document *Hazardous Materials Transportation Risk Assessment: State of the Practice*, the NRC is quoted "different categories of decisions require different approaches to risk analysis; strict reliance on quantitative models is not always the best approach."[46] This document further states that the types of decisions are closely tied to the decision-maker (public or private sector) where the fundamental difference in the decisions they must make leads to differences in the risk assessment approaches that they employ.[46]

Below are a set of concepts that are usually considered when defining what the question is relative to risk. The first question one has to answer is **who** or **what** is at risk. The designation of risk changes depending on the nature of:

- An individual's health (prompt or latent death, disease). The metric used to evaluate this aspect of risk is called **individual risk**. The individual is often represented as a generic individual based on median behavior or specific characteristics such as the Reasonably Maximized Exposed Individual (see 40 CFR §197.21.)
- A group of individuals of different size. Often called **Population Risk** (See for instance p 70 of *Science and Judgment in Risk Assessment*[47]) or **Societal Risk** (Institution of Chemical Engineers[48]) which has been adopted by the UK and the Netherland governments, among other concepts in *Pipeline Risk Analysis - Major Hazards Onshore and Offshore*[49]. Regulations or guidance documents then link lower probability to higher

[45] National Research Council. (2009). Science and Decisions - Advancing Risk Assessment. Washington D.C.: National Academy Press
[46] Hazardous Materials Cooperative Research Program (HMCRP). Report 12, Hazardous Materials Transportation Risk Assessment: State of the Practice. Transportation Research Board. Sponsored by Pipeline and Hazardous Materials Safety Administration. 2013.
[47] National Research Council. (1994). Science and Judgment in Risk Assessment. Washington D.C.: National Academy Press.
[48] Institution of Chemical Engineers. (1985). Nomenclature for hazard and risk assessment in the process industries. Warrington, UK: The Institution.
[49] Hill, R. T. (1992). Pipeline Risk Analysis. Major Hazards Onshore and Offshore, (pp. 657-670).

number of people affected. Societal risk can also be defined in contrast to individual risk to designate people who are not affecting their lifestyle with respect to a potential risk (e.g. general population living close to a pipeline versus workers coming to maintain a pipeline)

- Ecological damage: pollution, destruction of wildlife. The risk associated with such accident is called **environmental risk** or **ecological risk**.
- For companies, there is also an important factor which is the **economic risk** or **business risk**.

All of these risks have a different degree of importance which varies depending on the individual or organization considering them. The problem is even more complex as perceptions may be different based on the amount (and quality) of information, and also perspectives (risk aversion).

Methods for defining risk criteria are often split between qualitative, semi-quantitative, and quantitative analysis techniques. Each method is discussed in detail in Sections 5.2.1, 5.2.2, and 5.2.3.

## 5.2.1 Qualitative Risk Criteria

### 5.2.1.1 Qualitative Risk Matrices

Risk is expressed as a function of both the likelihood of an unexpected event and the undesired consequence. When using a qualitative approach, the analysts use their collective knowledge and experience to make judgments on frequency estimates and consequence severity levels.

Often risk matrices are used to document the results. The two scales on the matrix describe increasing levels of consequence and frequency. The cells of the matrix define, for each consequence/frequency pair, a relative degree of risk. For this example, four levels of risk are identified (an increasing level of risk from IV through I).

The example qualitative risk matrix shown in Figure 5 uses consequence categories for either the public or employees that are defined in Table 4 in a qualitative manner. The frequency categories described in Table 5 are also qualitative.

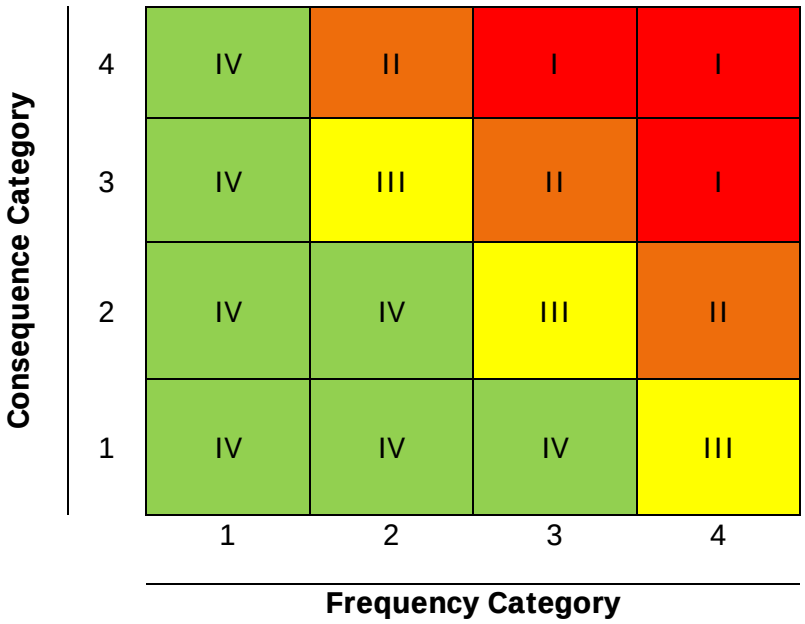



**Figure 5. Example Qualitative Risk Matrix [CCPS 1992]**

**Table 4. Example Consequence Categories – Qualitative Risk Matrix**

| Category | Description |
|---|---|
| 1 | No injury or health effects |
| 2 | Minor to moderate injury or health effects |
| 3 | Moderate to severe injury or health effects |
| 4 | Permanently disabling injury or fatality |

**Table 5. Example Frequency Categories – Qualitative Risk Matrix**

| Category | Description |
|---|---|
| 1 | Not expected to occur during life of process/system/facility |
| 2 | May occur once during life of process/system/facility |
| 3 | May occur several times during life of process/system/facility |
| 4 | Expected to occur more than once in a year |

An example of risk level categories for a qualitative risk matrix is shown in Table 6. Required responses are given for the four levels of risk displayed in the risk matrix, from “Unacceptable” for the highest risk level to “Acceptable As Is” for the lowest risk. Decisions regarding potential risk reduction actions for the moderate risk level are left up to the management discretion.

**Table 6. Example Risk Ranking/Response Categories – Qualitative Risk Matrix**

| Risk Level | Description | Required Response |
|---|---|---|
| I | Unacceptable | Immediate mitigation or termination of activity |
| II | High | Mitigation within 6 months |
| III | Moderate | Administrative Level |
| IV | Acceptable As Is | No mitigation required |

#### 5.2.1.2 Comparison Criteria

As described in the NORSOK standard, comparison criteria "is suitable in more limited studies which aim at comparing certain concepts or solutions for a particular purpose with established or accepted practice...The use of the comparison criteria requires that the basis of the comparison is expressed relatively precisely."[50] Examples of comparison criteria include:

- Implementation of an alternative design (or use of new technology) should be at least as safe as conventional technology; and
- An alternative solution should be at least as cost effective as the established practice.

As presented by Skjong, the main methods for establishing comparison criteria are[51]:

- Compare with other hazards: Risk comparisons with other relevant industries that represent a reasonable target and have well documented risk assessments to determine tolerability (e.g. pipeline risk compared to rail risk).
- Compare with natural hazards: Risk comparisons from human activity compared with risks posed by nature to determine tolerability (e.g. designed for a 100-year flood).
- Compare with risks we normally take: Risk comparisons with activities humans regularly undertake like driving or sporting activities (e.g. individual risk of living near a hazardous facility compared to driving in a car).
- Compare with previous decisions: Risk comparisons with accepted codes and standards (e.g. pipeline operating in compliance with 40 CFR 192).
- Compare with well informed decision in democratic forums: Risk evaluated by authorities to determine acceptability (e.g. land use planning decisions).

The usefulness of comparison criteria is limited but could be beneficial in situations where rapid screening of alternatives is needed to identify where more detailed analyses might be warranted.

[50] NORSOK Standard Z-013, Edition 3, October 2010. Risk and Emergency preparedness assessment. Norwegian Oil Industry Association (OLF) and the Federation of Norwegian Industry, Lysaker, Norway. 2010.
[51] Skjong, R. Risk Acceptance Criteria: current proposals and IMO position. Surface transport technologies for sustainable development. June 2002.

### 5.2.2 Semi-Quantitative Risk Criteria

The next step beyond a qualitative approach is termed semi-quantitative in that numerical definitions are provided for the consequence and frequency categories. Many find this approach is of greater value to an experienced analysis team since, based upon its collective experience, the team has at least a historical sense of how frequently an event might occur or how severe the consequences might be. Table 7 and Table 8 are examples of consequence and frequency categories based on the DOD Mil-Std-882E. These are semi-quantitative because consequence and/or frequency modeling is not necessarily used in estimating the categories, but consequence categories are expressed in terms of dollars and frequency categories are expressed in terms of orders of magnitude.

**Table 7. Example Consequence Categories – Semi-Quantitative Risk Matrix**

| Description | Category | Mishap Result Criteria |
|---|---|---|
| Catastrophic | 1 | Could result in one or more of the following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10M |
| Critical | 2 | Could result in one or more of the following: permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1M but less than $10M. |
| Marginal | 3 | Could result in one or more of the following: injury or occupational illness resulting in one or more lost work day(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $100K but less than $1M. |
| Negligible | 4 | Could result in one or more of the following: injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100K. |

**Table 8. Example Frequency Categories – Semi-Quantitative Risk Matrix**

| Description | Level | Specific Individual Item |
|---|---|---|
| Frequent | A | Likely to occur often in the life of an item, with a probability of occurrence greater than 10-1 in that life. |
| Probable | B | Will occur several times in the life of an item, with a probability of occurrence less than 10-1, but greater than 10-2 in that life. |
| Occasional | C | Likely to occur sometime in the life of an item, with a probability of occurrence less than 10-2 but greater than 10-3 in that life. |
| Remote | D | Unlikely but possible to occur in the life of an item, with a probability of occurrence less than 10-3 but greater than 10-6 in that life. |
| Improbable | E | So unlikely it can be assumed that occurrence may not be experienced, with a probability of occurrence of less than 10-6 in that life. |

### 5.2.3 Quantitative Risk Criteria

The most widely used forms of quantitative risk criteria are individual risk (IR) and societal risk criteria (SR) which evaluate expected fatalities from an individual or group of people exposed to hazardous scenario(s). Although expressing risk tolerability criteria based on number of fatalities can be informative, it also neglects other factors that enter into decision-making including business losses, property damage, environmental damage, and regulatory compliance, among others. Some government agencies have tried to include these 'other' factors in an equivalent fatality number but their use is rare unless included as part of a qualitative/semi-quantitative risk matrix type analyses[52]. More commonly, individual companies will include the full range of impacts in their risk tolerability criteria so that they have a multifaceted understanding of the risks posed by their hazardous operations for use in strategic decision-making.

#### 5.2.3.1 Individual Risk (IR)

IR is one of the most widely used forms of quantitative risk criteria and is defined as the annual chance that an individual will suffer a specified level of harm due to hazards to which they are exposed. IR tolerability criteria are generally set by comparing the risk associated with an industrial activity to risks posed by other activities that average individuals are exposed to on both a daily and intermittent basis, like driving a car, flying a plane, or working. The probability of fatality for these specific events or exposures is then used as guidance for setting maximum tolerable and broadly acceptable levels of IR.

The calculation of IR assumes that the risk to an individual from all incident scenarios at their particular location are additive. IR is often presented as risk contours showing the risk at a distance from the risk source. This type of risk is a location-based or geographic-based risk rather than the risk to a particular individual. Location-based IR risk calculations assume that an individual is present at that location 100% of the day without means to escape or protect themselves from the hazard. IR can also be calculated to assume an occupancy and protection factor which is known as personal-based IR. Obviously, personal-based IR is less conservative than location-based IR since it assumes an individual is not always present at that location (day versus night occupancy) and that they might be able to protect themselves should an incident occur (indoor versus outdoor; vulnerable versus less-vulnerable).

IR calculations can also consider acute versus chronic exposures. For the most part, IR calculations used for the oil & gas, petrochemical, and chemical industries are based on acute IR where the immediate effects of a hazard are considered. However, in the nuclear industry as

[52] It is difficult to find a common basis for comparing 'other' risk factors. Most often the common basis is monetary; however, there is unease if casualties are assessed on a monetary basis. For this reason, organizations may choose to develop two sets of criteria – one to evaluate the risk to people and the other to assess the financial impacts so as to not apply a monetary value to life.

well as other government agencies concerned about individual exposure to waste materials, pollutants, additives, and other carcinogens, the IR risk from chronic exposures (risk of developing cancer over a lifetime) is used to determine risk tolerability.

#### 5.2.3.2 Societal Risk (SR)

All fatal accidents are a cause for concern, but society generally tends to be more concerned about multiple fatalities in a single event. While such low probability, high consequence events might represent a very small risk to an individual, they may be viewed as unacceptable when a large number of people are exposed. Such incidents can significantly impact shareholder value and, in some instances, the company never recovers.[53] Societal risk expresses "the cumulative risk to groups of people who might be affected by such events."[54]

Developing risk tolerability criteria for hazards giving rise to societal concerns is difficult because they often involve a wide range of events with a range of possible outcomes.[55] Most recently, the UK Health & Safety Executive (HSE) proposed that the risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the frequency is estimated to be more than one in five thousand per year.[55] This type of SR criteria is commonly depicted as a frequency-number (F-N) diagram. The area above each line represents the intolerable risk region and the area below the line represents the tolerable risk region.

#### 5.2.3.3 Pipeline Specific Risk Criteria

There have been a few regulatory bodies that have specifically addressed risk criteria for hazardous pipelines. In general, these agencies have defined either individual risk criteria (e.g. Brazil, The Netherlands) or societal risk criteria (e.g. The Netherlands, UK) for pipelines. The Dutch and British governments have chosen to establish societal risk criteria based on the F-N diagram for a given length of pipe. While both countries use 1 km as the reference pipe length, they differ in how the risk criteria is used.[56] The Dutch recommend evaluating the worst-case km within an urban area while the British recommend summing F-N pairs over the entire length of pipeline through a community and then normalizing the result to 1 km.[56] For the most part, these regulatory bodies set the risk tolerability criteria for pipelines at an order of magnitude less restrictive than for other industrial activities.

As is evident from the above discussion, to calculate IR and SR for linear assets like pipelines, it is important to define the length of pipeline that could cause harm. The risk for all pipeline

---

[53] Sedwick, 2002. The Impact of Catastrophes on Shareholder Value, A Research Report Sponsored by Sedgwick Group, Rory F. Knight & Deborah J. Pretty, The Oxford Executive Research Briefings, 2002.
[54] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 35.
[55] HSE, Reducing risks, protecting people. HSE's decision-making process, 2001 http://www.hse.gov.uk/risk/theory/r2p2.pdf
[56] Schork, J. M. and Lutostansky, E. M., Societal Risk Criteria and Pipelines, Global Congress on Process Safety, 2012.

incidents for the defined length is what is used to calculate the IR along a transect perpendicular to the pipeline. The IR is then defined as the probability of a fatality for an individual at a specific location from the pipeline.[57]

SR criteria are also related to a specific length of pipe but consider the layout of developments near the pipeline and movement of adjacent population during the day. As reported by Penspen, for linear hazards like pipelines, where several people may be affected by an incident it is common to use IR criteria to screen high risk segments then to apply SR criteria to consider the effect on groups of people. [58]

#### 5.2.3.4 Impact (Consequence Endpoint) Criteria

Several regulatory bodies also use impact criteria (also known as consequence endpoint criteria) to define risk tolerability. Impact criteria is an off-shoot of individual and societal risk criteria in which it only considers consequence distances resulting in a specified impact (fatality, injury, property damage). This type of criteria is used by the U.S. EPA as part of their risk management plan (RMP) regulation as well as DOT PHMSA, in some respect, with the definition of high consequence areas (HCAs) and the additional integrity requirements for pipeline segments within HCAs. At an extreme, Germany specifies that no risk is to be imposed on people or the environment outside of the facility boundary[59]. Consequence endpoint criteria evaluate worst-case impact distances without consideration of the likelihood of such an event. This type of criteria can lead to overly conservative intolerable risk ranges.

#### 5.2.3.5 Other Industry Criteria

For example, in the aeronautical community the FAA, NASA, Air Force and Navy have incorporated risk in two different manners. The Air Force uses a damage tolerant approach. In this approach damage is assumed to exist at an installation but two inspections for damage are required before predicted component failure. The Navy uses a safe life approach which estimates a predicted life and then simply retires the component or aircraft at that time. The Navy's approach is being reworked because in the current budgetary atmosphere such an approach is nearly impossible. Boeing uses a combined approach of both damage tolerance and safe life. Airbus uses only a damage tolerance approach. NASA's aeronautical divisions use a damage tolerance approach but most require four inspections rather than two.

[57] http://www.penspen.com/wp-content/uploads/2014/09/comparison-of-risk-levels.pdf
[58] http://www.penspen.com/wp-content/uploads/2014/09/comparison-of-risk-levels.pdf
[59] Trbojevic, V.M., Risk criteria in EU, Risk Support Limited, London, U.K.

# 6 RESULTS

Approaches to risk management differ considerably across pipeline companies. Particular risk assessment methodologies are chosen to make the best use of available data and resources while still providing assurance of pipeline safety. Regardless of the particular risk assessment approach, all pipeline companies must identify risks, prioritize them, and implement strategies to reduce the risk. But risk reduction comes at a cost and setting and communicating risk criteria can be challenging. Ultimately, defining risk tolerability criteria is a means for helping decision makers objectively evaluate risks based on the company's risk tolerance.

To meet this challenge it is first important to understand how others have defined and used risk criteria. This review should not be limited to only the pipeline industry since there are many other government agencies and industries that have been successfully using risk criteria to facilitate risk-based decision making. Learning from where others have been allows for better informed decisions moving forward.

Many regulatory agencies in the U.S. and abroad require some form of risk assessment to be performed for new and existing hazardous facilities and/or operations to assure public safety. Defining and understanding the safety of hazardous facilities is one thing but ultimately, these regulatory agencies need to establish what they consider is safe enough. Efforts to answer this question have resulted in various methods for establishing risk tolerability criteria. Some of the more proactive regulatory bodies in this area include, but are not limited to: The European Union (EU) through the Seveso 3 Directive, The United Kingdom (UK) through the Health and Safety Executive (HSE), Hong Kong, The Netherlands, various Australian States, and The United States through various government entities.

Risk criteria are generally set with an understanding that no aspect of living can be risk free but that any imposed risk should be very small in the context of generally accepted background risk. Various levels of risk are tolerated on a daily basis, both to individuals and to society as a whole[60].

## 6.1 Countries

The UK and the Netherlands are two countries that have pioneered the use of individual and societal risk criteria in response to country specific drivers. Both countries have tackled risk criteria from different angles (experience-based in the UK verses technology-driven in the Netherlands) but in general, recommend similar approaches. The other countries discussed in

[60] Hazardous Industry Planning Advisory Paper No 4, Risk Criteria for Land Use Safety Planning, New South Wales (NSW) Government, January 2011.

this section of the report often base their risk tolerability criteria off of the criteria established by the UK and Netherlands. Each country may modify the risk tolerability criteria based on specific concerns (e.g. the Hong Kong is concerned about densely populated cities near large LPG storage facilities and landslide risks) or risk aversion but, for the most part, originate from the work initiated by the UK and Netherlands.

The following sections summarize both the criteria mandated or suggested by several different countries and associated authorities. For the most part, each country focuses on some form of individual and/or societal risk criteria with a few countries also specifying impact-based criteria for land use planning. A summary of the IR and SR criteria by country are provided in Table 2 and Table 3, respectively.

## 6.1.1 United Kingdom

### 6.1.1.1 UK Societal Risk Criteria Development

In the UK, risk criteria had its beginnings in the UK Atomic Energy Authority but did not begin to take root until after the Flixborough, UK vapor cloud explosion accident in June 1974 where 28 workers perished and another 36 workers and 53 offsite people suffered injuries.[61] An Advisory Committee on Major Hazards (ACMH), formed by the Health and Safety Commission (HSC), investigated the Flixborough accident and made recommendations for controlling risk from land-use development for industrial and non-industrial installations.[62] In the first report by the ACMH the societal risk (SR) criteria depicted in Figure 6 (UK-1976) were suggested, in which a 'serious accident' occurring at a single facility 1 in 10,000 years would be perceived by the public as just acceptable. A serious accident was inferred to involve 10 or more fatalities.[63] In this initial study, the ACMH excluded consideration of cross country pipelines even though they acknowledged the possible threats from transportation of hazardous substances.

Other UK SR criteria reflected public perceptions of the tolerability of a large number of fatalities related to nuclear incidents (UK – 1989 in Figure 6) set at 100 latent cancer deaths once every 10,000 years as the maximum tolerable risk.

In 1991, the SR criteria were modified to reflect the outcome of the Canvey Island risk study which involved the risk from multiple hazardous facilities. The risks (including risk reduction measures) defined in the Canvey Island study were deemed 'just tolerable' after extensive public and government scrutiny. [64] In that study, the frequency of a major incident (defined as 1,500 or more casualties or 500 or more fatalities) occurs once every 5,000 years. This is used

[61] http://www.hse.gov.uk/comah/sragtech/caseflixboroug74.htm
[62] Health and Safety Commission Advisory Committee on Major Hazards. First Report. 1976
[63] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 53.
[64] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 56.

as the anchor point for the societal risk curve shown in Figure 6 (UK – 1991) at a log-log slope of (-1)[65]. The slope of the curve was selected based on a worldwide review of major incidents. A broadly acceptable curve was defined three orders of magnitude lower[64] and in between the two SR lines is the ALARP region. The use of the Canvey Island study as the basis for SR criteria is when the UK first acknowledged that risk criteria should be developed such that it is proportionate to the scale of the industrial activity to which it is being applied.

In 2001, the maximum tolerable anchor point for the SR criteria was reduced to 50 or more fatalities at a frequency of once every 5,000 years to scale the risk criteria from a multiple facility basis, as reflected by the Canvey Island study, to a single industrial facility basis. The HSE also commented that the SR criteria were merely guidelines and not intended to be rigid benchmarks[66]. Later, the HSE actually set two different SR criteria, one for single industrial facilities and another for multiple industrial facilities to better account for the scale of the risk in which the risk for multiple industrial facilities is an order of magnitude higher than that for a single industrial facility (UK – 2008, single facility and UK-2008, multiple facilities in Figure 6). For both SR criteria, the broadly acceptable curve is defined as being two orders of magnitude lower.

In a 2009 briefing[67] by the Societal Risk Technical Advisory Group, the group agreed that societal risk should be accounted for in the regulation of onshore non-nuclear major hazards in both land use planning control around sites and in judgments for onsite safety measures; however there was no agreement on how to develop and implement this policy. No additional information was found at the time this report was written to indicate if this has since become a regulatory requirement for major hazardous installations. However, language on the HSE website[68] indicates that risk and sacrifice by the operator must be assessed in its social context and that the Health and Safety Commission (HSC) considers societal concerns when evaluating risk assessments.

[65] For an order of magnitude decrease in frequency (F) there is a corresponding order of magnitude increase in fatalities (N). The steeper the slope for an FN curve, the more conservative the societal risk criteria.
[66] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 58.
[67] HSE. Societal Risk: Initial briefing to Societal Risk Technical Advisory Group. Prepared by the Health and Safety Laboratory and the Health and Safety Executive. 2009.
[68] Principles and guidelines to assist HSE in its judgements that duty-holders have reduced risk as low as reasonably practicable http://www.hse.gov.uk/risk/theory/alarp1.htm

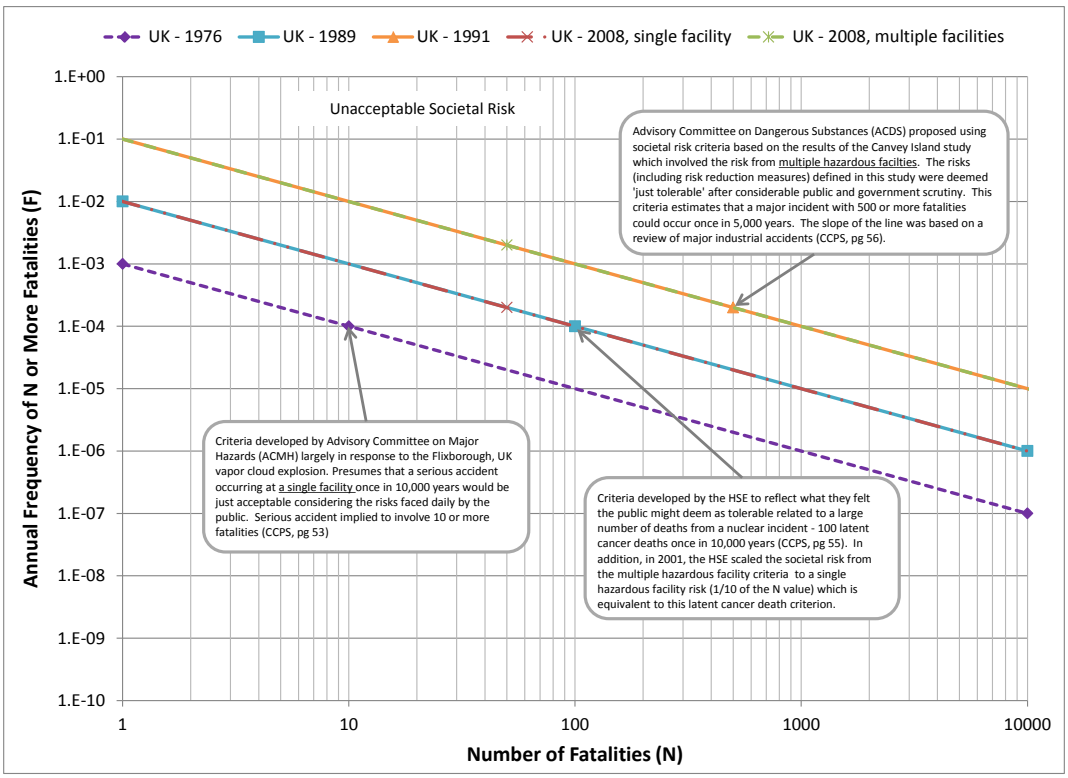



**Figure 6. Evolution of Maximum Tolerable Societal Risk Criteria in the UK (derived from CCPS, 2009[69])**

The concept of scalable risk tolerability is important to remember when defining tolerability criteria for pipeline assets. Risk criteria that use the aggregate risk of an entire pipeline network as its basis cannot be applied to decision making at the local pipeline level. Therefore, precautions must be taken to define the basis of risk tolerability criteria so that they are appropriately and logically applied.

Edition 4 of IGE/TD/1[70] includes a sample F-N criterion for natural gas pipelines as presented in Figure 7 and is defined for a 1.6 km length of pipeline. This figure was developed based on extensive application of previous editions of the IGE/TD/1 guidance document to represent the residual risk for a range of generic pipeline design cases and population densities subjected to ALARP considerations[71]. As described in IGEM/TD/2, the F-N curve is a practical representation of the 'broadly acceptable' limit typical of a code-compliant pipeline route.[72]

[69] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009.
[70] IGEM/TD/1 Edition 5. Steel pipelines and associated installations for high pressure gas transmission. The Institute of Gas Engineers and Managers.
[71] The thermal radiation dose used to determine the population effects (N) is 1800 tdu representing a 50% fatality rate.
[72] IGEM/TD/1. Application of pipeline risk assessment to proposed developments in the vicinity of high pressure Natural Gas pipelines. The Institute of Gas Engineers and Managers.

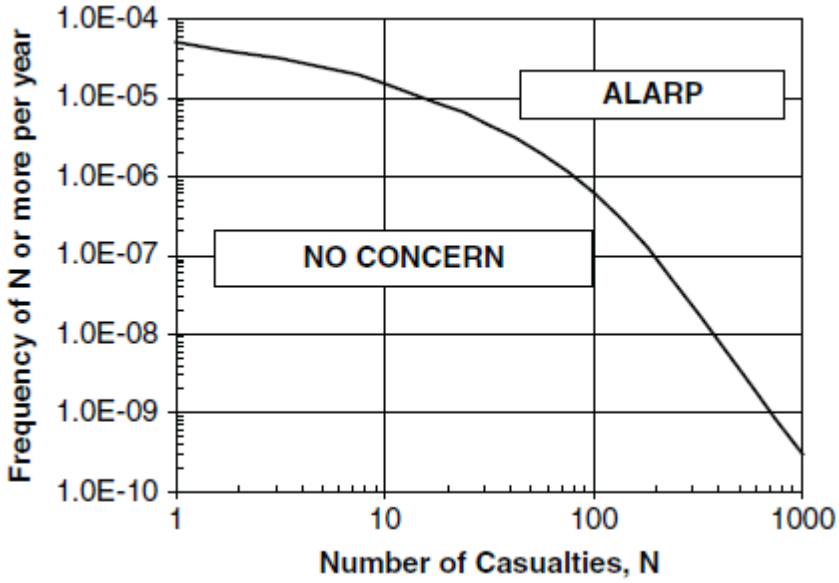



**Figure 7. IGE/TD/1 Sample FN Criterion[73]**

#### 6.1.1.2 UK Individual Risk Criteria Development

Over the decades, the UK has continued to evolve their published risk tolerability criteria to reflect changing attitudes and concepts. Specifically, in 1983, the Royal Society Study Group (RSSG) first defined individual risk (IR) criteria and concepts like as low as reasonably practicable (ALARP)[74] that the UK Health and Safety Executive (HSE) apply to this day. The RSSG proposed upper ($1 \times 10^{-3}$ fatality/year) and lower ($1 \times 10^{-6}$ fatality/year) bounds for worker individual risk criteria. The upper bound value reflects the highest risk that is generally accepted by workers under modern conditions in high risk jobs such as deep sea fishing. The lower bound is viewed as a risk so small that the general population would find it acceptable without any further precautions being taken.

Public IR criteria were defined by the HSE in 1988 with an upper bound ($1 \times 10^{-4}$ fatality/year) which is an order of magnitude lower than that for workers but maintained the lower bound ($1 \times 10^{-6}$ fatality/year) as a risk that would not cause concern to the public or alter their behavior. The HSE applies the same IR criteria for fixed facilities as it does for pipelines and other hazardous goods transport.

[73] Haswell, J. V., Goodfellow, G.D., Jackson, N.W., and McConnell, R. New UK Pipeline Risk Assessment Codes – IGEM TD/2 and PD 8010 Part 3. IChemE, 2009, pg. 308-317.

[74] The concept of as low as reasonably practicable (ALARP) takes on many different forms and definitions for various agencies and organizations. Other commonly used terms for similar principles include 'as low as reasonably achievable' (ALARA); 'globelment au momns aussi bon' (GAMAB), 'globelement au momns equivalent' (GAME) – meaning 'globally at least as good', cost-benefit analysis, value of statistical life. The UK HSE, specify the test of "gross disproportion" where measures to reduce risk can be ruled out only if the sacrifice involved in taking them would be grossly disproportionate to the benefits of the risk reduction.

The HSE also sets risk-based zones around pipelines, within which the risks to people and developments must be assessed and considered by planning authorities for new developments.[75] The HSE has currently defined three levels for IR risk consideration which include:

- An inner zone (IZ) adjacent to the pipeline and equivalent to an IR level of $1 \times 10^{-5}$ fatality/year.
- A middle zone (MZ) which applies to significant developments and is equivalent to an IR level of $1 \times 10^{-6}$ fatality/year.
- An outer zone (OZ) which applies to vulnerable or very large populations and is equivalent to an IR level of $3 \times 10^{-7}$ fatality/year.

In this case, IR calculations assume a person is permanently resident next to the pipeline (location-based IR). For the most part, the planning authority can use decision tables to quantify the risk; however, in borderline or difficult cases, quantitative risk assessment (QRA) is used to assess risk and ultimately to decide if the risk to the new developments (including risk reduction measures) is acceptable. Pipeline risk assessment codes IGEM TD/2 and PD 8010, developed by the United Kingdom Onshore Pipeline Operators Association (UKOPA) provide pipeline operators with guidance on risk analysis for site specific pipeline properties. In the example shown in Figure 8, the local planning authority would advise against the proposed housing development since it exceeds 30 residences and crosses into the MZ. With risk mitigation measures implemented, the zones shrink to a point where the development only encroaches into the outer zone which would then be accepted by the planning authority.[75]

A summary of the UK individual risk criteria is provided in Table 9.

**Table 9. Summary of UK IR Criteria for New and Existing Facilities**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | Maximum Tolerable: $1 \times 10^{-3}$<br>Broadly Acceptable: $1 \times 10^{-6}$ |
| Offsite Public IR | Maximum Tolerable: $1 \times 10^{-4}$<br>Broadly Acceptable: $1 \times 10^{-6}$ |
| Public IR near IZ of Pipeline | Maximum Tolerable: $1 \times 10^{-5}$ |
| Public IR (significant developments) near MZ of Pipeline | Maximum Tolerable: $1 \times 10^{-6}$ |
| Public IR (vulnerable and very large populations) near OZ of Pipeline | Maximum Tolerable: $3 \times 10^{-7}$ |

[75] Haswell, J. V., Goodfellow, G.D., Jackson, N.W., and McConnell, R. New UK Pipeline Risk Assessment Codes – IGEM TD/2 and PD 8010 Part 3. IChemE, 2009, pg. 308-317.

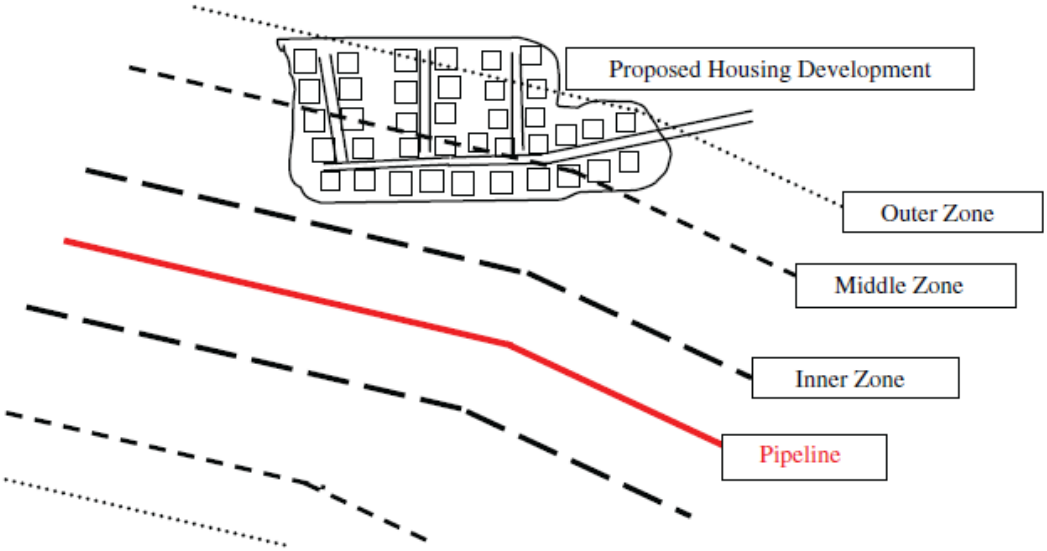



**Figure 8. Example Site Specific Gas Pipeline Risk Based on HSE Zone Concept UK[76]**

## 6.1.2 Netherlands

### 6.1.2.1 The Netherlands Societal Risk Criteria Development

Much like in the UK, SR criteria development in the Netherlands was spurred by a series of process safety incidents in the 1970s. The SR criteria developed by the Province of Groningen in 1978 (see Figure 9), was developed for single hazardous facilities and the value of 'N' was a combination of fatalities and injuries, called an equivalent fatality.[77] As you can see comparing the SR criteria between the UK and Netherlands, the just tolerable criteria of 10 equivalent fatalities occurring at a single facility 1 in 10,000 years[78] is the same as in the 1970s era UK SR criteria; however, the slope of the Netherlands SR criteria is much steeper indicating they are more risk averse.[79] Also, the Dutch consider any risk with an equivalent fatality 'N' greater than 1,000 to be unacceptable, regardless of the annual frequency 'F'. This equates to a more deterministic, consequence-based approach to risk criteria (Netherlands – 1978 in Figure 9).

In the 1980s, the Dutch government was becoming more aware of the potential consequences of an industrial accident in such a densely populated country as the Netherlands and commissioned two major risk studies. In particular, the study conducted by the Dutch Ministry for Housing, Spatial Planning, and the Environment served as the basis for the Dutch safety

[76] Haswell, J. V., Goodfellow, G.D., Jackson, N.W., and McConnell, R. New UK Pipeline Risk Assessment Codes – IGEM TD/2 and PD 8010 Part 3. IChemE, 2009, pg. 308-317.
[77] One fatality was equivalent to 10 injuries, 100 slight injuries, or 1,000 very slight injuries.
[78] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 60.
[79] For a two order of magnitude decrease in frequency (F) there is a corresponding order of magnitude increase in fatalities (N). The steeper the slope for an FN curve, the more conservative the societal risk criteria.

policy requiring the use of quantitative risk assessment (QRA) to evaluate risk and the establishment of IR and SR tolerability criteria.[80] The SR criteria slope was maintained the same as the earlier criteria developed by Groningen; however the maximum tolerable criterion was lowered an order of magnitude to 10 equivalent fatalities occurring at a single facility 1 in 100,000 years (Netherlands – 1984 and Netherlands – Fixed Facility (1996) in Figure 9). Additionally, the broadly acceptable SR criterion was defined two orders of magnitude lower than the maximum tolerable criterion with an as low as reasonably achievable (ALARA) region in between.

In the 1990s, the Dutch government eliminated the concept of broadly acceptable from their risk criteria (both SR and IR) to encourage risk generators to be proactive in lowering risk where practical for ALL risks below the maximum tolerable region. Additionally, the Dutch no longer mandated risk generators to meet the suggested SR criteria and instead encouraged local authorities to use their judgment for exceeding the maximum tolerable societal risk criterion if the benefits provided greatly outweighed the risks (e.g. economic benefits for accepting the risk).[81]

In 1996, the Dutch Ministry of Transport, Public Works, and Water Management established SR criteria for transportation of hazardous goods at an order of magnitude higher than the SR criteria for fixed industrial facilities (Netherlands – Transportation (1996) in Figure 9). The transportation SR criteria were established assuming the risks would be evaluated on a per kilometer basis.[82]

In 2004, the Dutch Ministry of Housing, Spatial Planning, and the Environment defined specific populations to be included and excluded from the societal risk calculations. Specifically, employees and visitors at a risk source and persons on roadways, train stations, and public areas were excluded while employees of nearby facilities were included with the remainder of the general public, with some exceptions based on emergency response preparedness. In addition, the Ministry affirmed that occupancy factors (i.e. indoor versus outdoor; daytime versus nighttime) could be accounted for when calculating societal risk.[83]

[80] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 61.
[81] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 64.
[82] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 64-65.
[83] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 65-66.

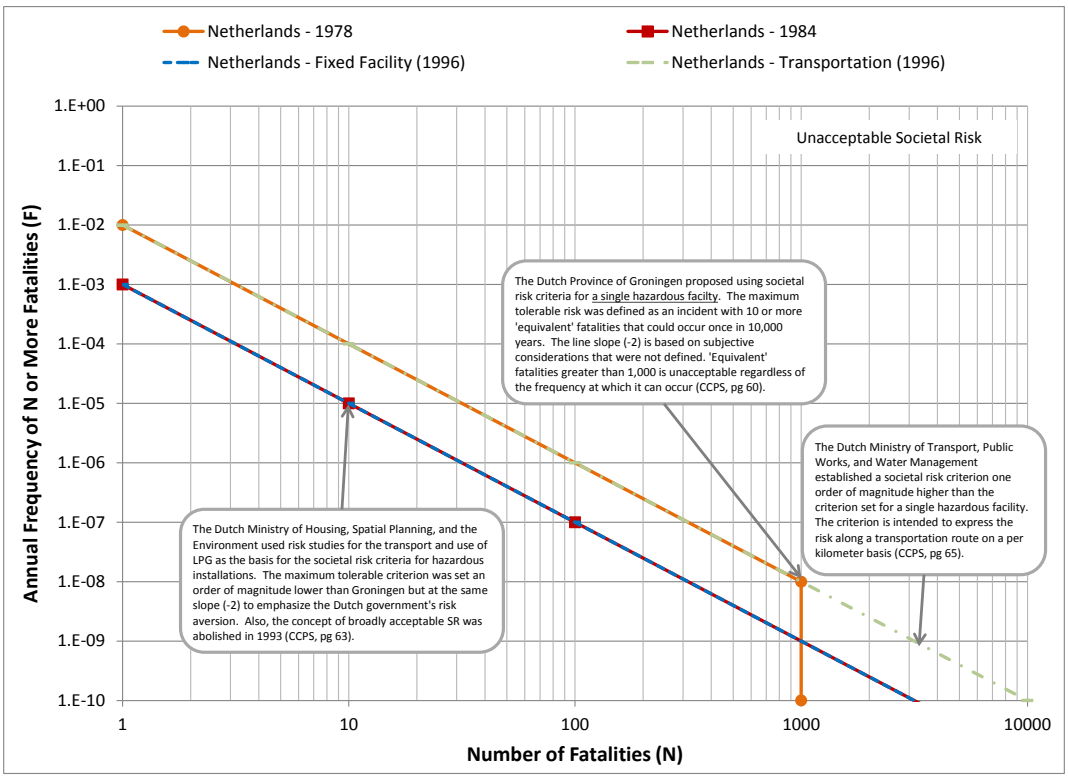



**Figure 9. Evolution of Maximum Tolerable Societal Risk Criteria in the Netherlands (derived from CCPS, 2009[84])**

### 6.1.2.2 The Netherlands Individual Risk Criteria Development

In the early 1950s, the Netherlands government considered the use of IR criteria in the design of their sea defense systems. Similar to concepts of 100-year flood events, storm events, earthquakes, etc. that are considered in the design and siting of structures, the Dutch had to make a similar decision for what was a practical storm surge event for which their sea dike protection system should be designed. With this in mind, they settled on the idea that an individual's risk or drowning from failure of a sea dike should be less than one chance in a million years (maximum tolerable level of $1 \times 10^{-6}$ fatality/year).[85] The Dutch government later (1984) established a broadly acceptable risk criterion two orders of magnitude lower ($1 \times 10^{-8}$ fatality/year) with an ALARA region in between.[86]

[84] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009.
[85] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 60.
[86] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 63.

The IR value defined by the Province of Groningen in 1978 set the IR criterion to 1 x $10^{-5}$ fatality/year which was equivalent to 1% of the total risk of accidental death for an average individual in the Dutch population.[87]

In the late 1980s, the Dutch Ministry for Housing, Spatial Planning, and the Environment retained the 1 x $10^{-6}$ fatality IR criterion; however the basis was revised to represent 1% the 'natural death risk' for 10 to 14 year old Dutch citizens. The underlying foundation is that the maximum tolerable risk for hazardous installations should only slightly add to the average risk of death for a person in the Netherlands.[88] This criterion was extended to nuclear power facilities, chronic exposures to toxic substances, and existing facilities. However, recognizing that meeting the 1 x $10^{-6}$ fatality/year IR criterion would be difficult for existing facilities, the IR criterion was increased an order of magnitude to 1 x $10^{-5}$ fatality/year for existing facilities.[89] This same distinction was not made for SR criteria.

In the 1990s, the Dutch government made several changes to their IR criterion. In 1993, the Dutch government abandoned the concept of broadly acceptable risk to encourage risk generators to apply ALARA principles to all risks below the maximum tolerable limit.[90] In 1996, the Ministry of Transport, Public Works, and Water Management set the IR criterion for dangerous goods transport to 1 x $10^{-6}$ fatality/year.[91] Then, in 1999, the Dutch Ministry for Housing, Spatial Planning, and the Environment introduced a distinction in IR criteria for vulnerable[92] verses less vulnerable[93] populations. The IR criterion for vulnerable populations was maintained at 1 x $10^{-6}$ fatality/year; however, the IR criterion for less vulnerable populations was increased by an order of magnitude to 1 x $10^{-5}$ fatality/year. These IR criteria are applied regardless if the facility is new or existing and the IR criterion for vulnerable populations is a mandatory regulatory requirement.[94] Lastly, in 2004, the Ministry affirmed that calculation of IR was intended to be a location-based risk which assumes an individual is present 100% of the time without protection from hazards at each place the risk is calculated.[95]

A summary of the Dutch individual risk criteria is provided in Table 10.

---

[87] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 60.
[88] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 63.
[89] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 63.
[90] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 64.
[91] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 65.
[92] Vulnerable populations include houses, apartment buildings, other residential objects, hospitals, medical facilities, schools, and objects with high strategic value.
[93] Less vulnerable populations include shops, department stores, hotels, restaurants, cafes, commercial and industrial buildings, office buildings, and recreational facilities.
[94] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 65.
[95] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 66.

**Table 10. Summary of Dutch IR Criteria for New and Existing Facilities**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Vulnerable Offsite Public IR (new and existing facilities) | Maximum Tolerable: $1 \times 10^{-6}$ |
| Less Vulnerable Offsite Public IR (new facilities) | Maximum Tolerable: $1 \times 10^{-6}$ |
| Less Vulnerable Offsite Public IR (existing facilities) | Maximum Tolerable: $1 \times 10^{-5}$ |
| Public IR (hazardous goods transport) | Maximum Tolerable: $1 \times 10^{-6}$ |

## 6.1.3 Australia

In Australia, risk criteria are defined by state and include Western Australia, New South Wales, Queensland, and Victoria. Each State has developed similar criteria for both IR and SR with some notable differences as described below.

### 6.1.3.1 Western Australia

#### 6.1.3.1.1 Western Australia Individual Risk Criteria Development

In consultation public stakeholders, the Environmental Protection Authority (EPA) of Western Australia first published IR criteria for evaluating the risks posed by hazardous industries in 1987.[96] These criteria specified that an individual fatality risk level of one in a million per year ($1 \times 10^{-6}$ fatality/year) for residential areas is a risk level so small as to be acceptable to the Authority. It also adopted a broadly acceptable IR level of ten in a million per year ($10 \times 10^{-6}$ per year) for residential areas. When the risk level in residential zones is in the range one in a million to ten in a million per year, the Authority calls for further evaluation of risks associated with the project.[97]

A few years later, the EPA sought input from government agencies, companies, industrial groups, community groups and the public to modify the established IR criteria. The IR criteria that the Authority settled on after years of review accounted for the vulnerability of specific populations groups and their ability to willingly accept and protect themselves from hazardous installation risks.[98] These criteria are summarized below as well as in Table 11.

- Sensitive Developments (e.g. hospitals, schools, nursing homes): Maximum tolerable IR is $5 \times 10^{-7}$ fatality/year. This level can be exceeded for intermittently occupied areas on

[96] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 135.
[97] 691_B627.pdf: Criteria for the assessment of risk from industry – expanded discussion, 1992
[98] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 136.

the grounds of these facilities, like parking lots and gardens, to a maximum of 1 x $10^{-6}$ fatality/year.

- Residential Developments: Maximum tolerable IR is 1 x $10^{-6}$ fatality/year
- Commercial Developments (offices, retail, entertainment): Maximum tolerable IR is 5 x $10^{-6}$ fatality/year
- Non-Industrial Activities or Active Open Spaces between industrial and residential: Maximum tolerable IR is 1 x $10^{-5}$ fatality/year.
- Industrial Developments: Maximum tolerable IR is 5 x $10^{-5}$ fatality/year at the site boundary and the cumulative risk imposed on an industry should not exceed 1 x $10^{-4}$ fatality/year.

The above individual risk criteria are a location-based IR in which an individual is present 100% of the time and would do nothing to avoid harm. In addition, the individual risk calculations are intended to be the summation of all risks from all hazardous facilities, existing as well as newly proposed facilities. Where the risks from existing facilities exceed these levels, risk reduction programs should be implemented so that the IR criteria for new facilities are met.

**Table 11. Summary of Western Australia IR Criteria for New Facilities**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None (proposed 1 x $10^{-3}$) |
| Offsite Public IR<br>Sensitive Developments | Maximum Tolerable: 5 x $10^{-7}$ |
| Offsite Public IR<br>Residential Developments | Maximum Tolerable: 1 x $10^{-6}$ |
| Offsite Public IR<br>Commercial Developments | Maximum Tolerable: 5 x $10^{-6}$ |
| Offsite Public IR<br>Non-Industrial Activities or Active Open Spaces between Industrial and Residential | Maximum Tolerable: 1 x $10^{-5}$ |
| Offsite Public IR<br>Industrial Developments | Maximum Tolerable: 5 x $10^{-5}$ |

6.1.3.1.2 Western Australia Societal Risk Criteria Development

The Western Australia EPA has not proposed any societal risk criteria. One guidance document does propose generic separation distances between industrial facilities and sensitive land uses – possibly to provide guidance in the absence of technical studies – but they do not recommend use of these criteria for major industrial developments.[99]

[99] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 138.

### 6.1.3.2 New South Wales (NSW)

#### 6.1.3.2.1 New South Wales Individual Risk Criteria Development

The New South Wales (NSW) Department of Planning (DOP) published IR criteria in 1990 that mimics the criteria developed by the Western Australia EPA with one exception. The maximum tolerable IR for industrial developments is capped at 5 x $10^{-5}$ fatality/year and does not allow this limit to be exceeded for the cumulative risks imposed on an industry as is allowed in Western Australia.

The DOP specified that the IR criteria is location-based (100% occupancy and no consideration of protection factors) and is to be applied for both the development of hazardous installations and land use planning around hazardous facilities. A summary of the NSW DOP IR criteria are provided in Table 12.

**Table 12. Summary of NSW IR Criteria for New Facilities**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR<br>Sensitive Developments | Maximum Tolerable: 5 x $10^{-7}$ |
| Offsite Public IR<br>Residential Developments | Maximum Tolerable: 1 x $10^{-6}$ |
| Offsite Public IR<br>Commercial Developments | Maximum Tolerable: 5 x $10^{-6}$ |
| Offsite Public IR<br>Non-Industrial Activities or Active Open Spaces between Industrial and Residential | Maximum Tolerable: 1 x $10^{-5}$ |
| Offsite Public IR<br>Industrial Developments | Maximum Tolerable: 5 x $10^{-5}$ |

#### 6.1.3.2.2 New South Wales Societal Risk Criteria Development

In 2007, NSW defined a maximum tolerable SR criterion of 10 fatalities occurring at a single industrial facility 1 in 10,000 years based on the SR criteria defined by the UK ACMH; however, they selected a slope of (-1.5). NSW also defines a broadly acceptable region two orders of magnitude below the maximum tolerable criteria. In between these two regions they apply ALARP principles.[100] These curves are shown in Figure 10.[101] Although NSW has suggested specific SR criteria, they do not strictly enforce them.

[100] HIPAP 10: Land Use Safety Planning, January 2011. http://d.planning.nsw.gov.au/Portals/0/HIPAP%2010%20Final%202011.pdf
[101] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 139-140.

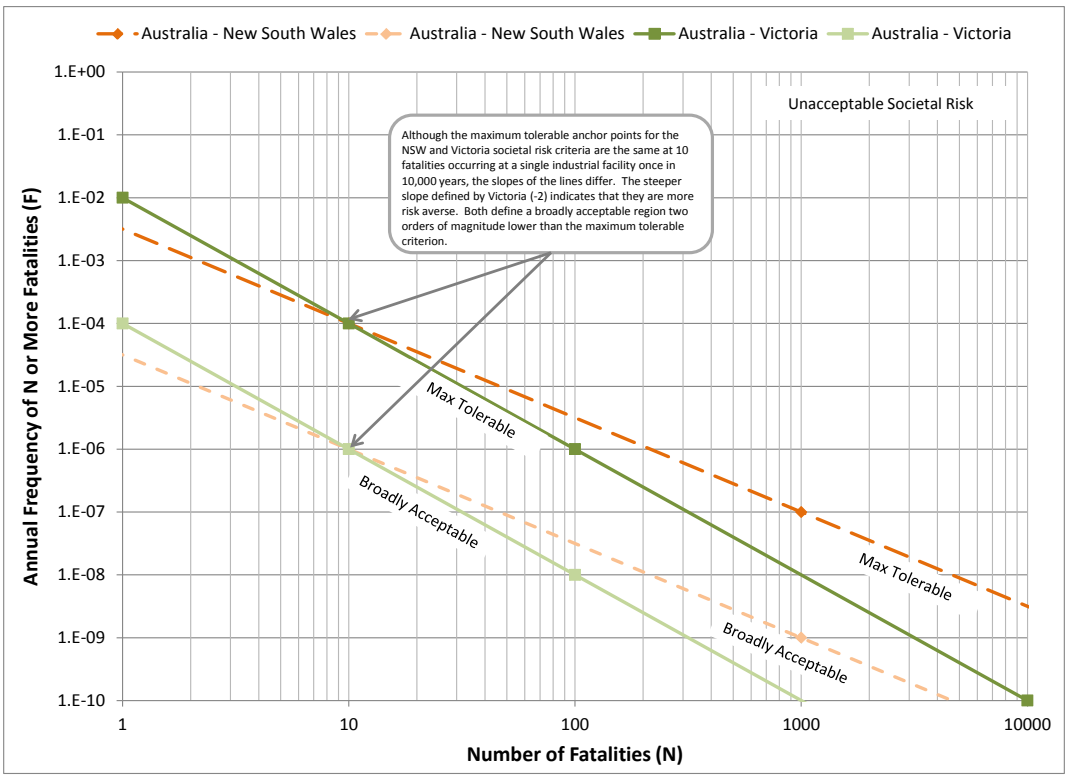



**Figure 10. Maximum Tolerable and Broadly Acceptable Societal Risk Criteria in the NSW and Victoria, Australia (derived from CCPS, 2009[102])**

6.1.3.2.3 New South Wales Environmental Risk Criteria

The NSW DOP recognizes that in addition to the risks to people, the siting of hazardous facilities must also consider risks to the environment. Even though they specify that is inappropriate to set hard and fast environmental risk criteria, they suggest that industrial development should not be sited in proximity to sensitive natural environmental areas where the consequences of more likely accident scenarios may threaten the long-term viability of the eco-system or species contained within; and/or when the likelihood of impacts is not lower than the background level of threat to the eco-system.[103]

### 6.1.3.3 Queensland

6.1.3.3.1 Queensland Individual Risk Criteria Development

In 1998 the Chemical Hazards and Emergency Management (CHEM) Services department adopted the same IR criteria defined by NSW (see Section 0) and intend for decision-makers to

[102] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009.
[103] HIPAP 10: Land Use Safety Planning, January 2011. http://d.planning.nsw.gov.au/Portals/0/HIPAP%2010%20Final%202011.pdf

apply the ALARP principle with cost-benefit considerations.[104] A summary of the Queensland IR criteria are provided in Table 13.

**Table 13. Summary of Queensland IR Criteria for New Facilities**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR<br>Sensitive Developments | Maximum Tolerable: $5 \times 10^{-7}$ |
| Offsite Public IR<br>Residential Developments | Maximum Tolerable: $1 \times 10^{-6}$ |
| Offsite Public IR<br>Commercial Developments | Maximum Tolerable: $5 \times 10^{-6}$ |
| Offsite Public IR<br>Non-Industrial Activities or Active Open Spaces between Industrial and Residential | Maximum Tolerable: $1 \times 10^{-5}$ |
| Offsite Public IR<br>Industrial Developments | Maximum Tolerable: $5 \times 10^{-5}$ |

6.1.3.3.2 Queensland Societal Risk Criteria Development

Queensland has not mandated any societal risk criteria but suggest that it should be considered for industrial facilities close to large population centers.[104]

### 6.1.3.4 Victoria

6.1.3.4.1 Victoria Individual Risk Criteria Development

As discussed in the CCPS Guidelines, IR criteria were first proposed by the Victorian WorkCover in 1995 and reaffirmed in 2006. Specifically, maximum tolerable IR at the boundary of any new facility should not exceed $1 \times 10^{-5}$ fatality/year and if it does risk reduction measures are mandatory. Additionally, the broadly acceptable IR is defined as $1 \times 10^{-7}$ fatality/year, two orders of magnitude lower than the maximum tolerable risk level. If the off-site risk lies between these values, ALARP principles apply and residential developments are to be restricted.[105] A summary of the Victoria IR criteria are provided in Table 14.

**Table 14. Summary of Victoria IR Criteria for New Facilities**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR | Maximum Tolerable: $1 \times 10^{-5}$<br>Broadly Acceptable: $1 \times 10^{-7}$ |

[104] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 141.
[105] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 142.

#### 6.1.3.4.2 Victoria Societal Risk Criteria Development

The Victorian WorkCover also defined interim SR criteria but do not mandate their use. Facilities preparing safety cases under the Victorian major hazard facilities (MHF) regulation may use the suggested criteria or develop their own. The suggested criteria sets a maximum tolerable SR criterion of 10 fatalities occurring at a single industrial facility 1 in 10,000 years based on the SR criteria defined by the UK ACMH; however, a slope of (-2) is used which indicates a greater risk aversion than both the UK and NSW. Victoria also defines a broadly acceptable region two orders of magnitude below the maximum tolerable criteria. In between these two regions they strictly apply ALARP principles but also suggest that the ALARP principle should even apply to risks falling under the broadly acceptable region.[106] The SR criteria are shown in Figure 11.

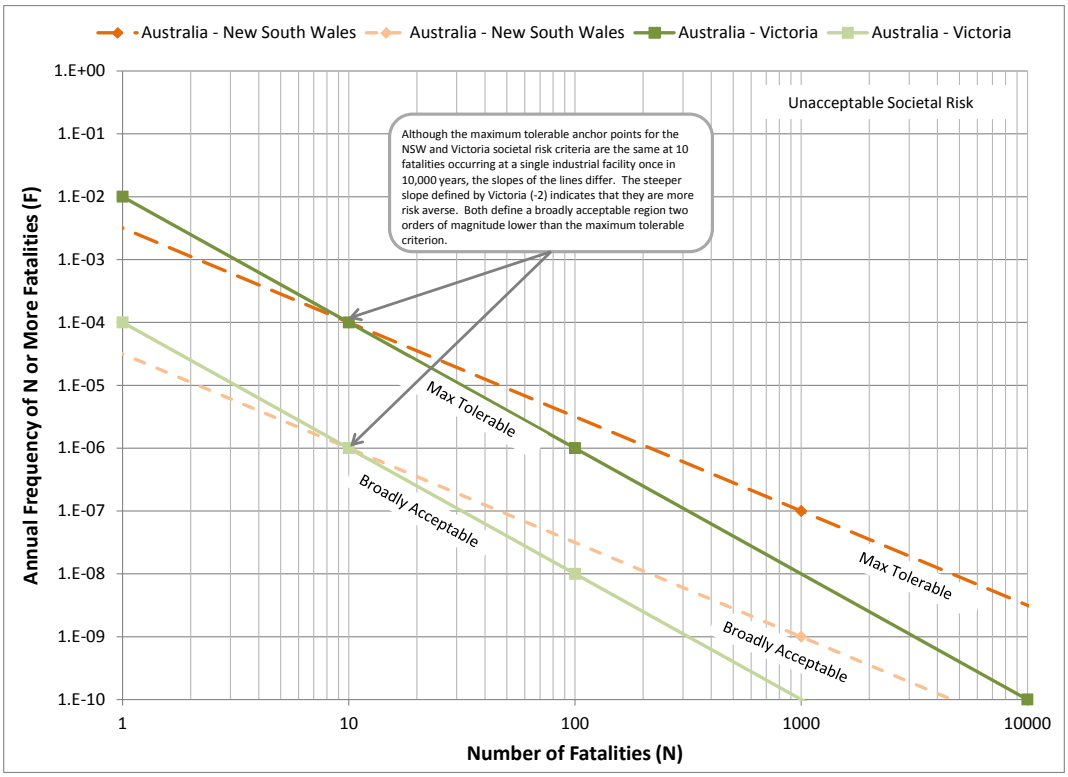



**Figure 11. Maximum Tolerable and Broadly Acceptable Societal Risk Criteria in the NSW and Victoria, Australia (derived from CCPS, 2009[107])**

[106] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 142-143.
[107] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009.

#### 6.1.3.5 Australian National Committee on Large Dams (ANCOLD)

The Australian National Committee on Large Dams (ANCOLD) prepares and issues guidelines which represent best practices and provide consistency for the safe design, management and operation of dams.[108]

##### 6.1.3.5.1 ANCOLD Individual Risk Criteria Development

As presented by McDonald, IR criteria were first proposed by ANCOLD in 1994 and updated in 2003. Specifically, for new dams, and upgrading of existing dams, the maximum tolerable IR should not exceed $1 \times 10^{-5}$ fatality/year, except in exceptional circumstances. Additionally, for existing dams an IR up to 10 times that for new dams is tolerable ($1 \times 10^{-4}$ fatality/year) and is subject to ALARP principles.[109] The basis of the ANCOLD IR criteria is that "a dam or other facility should not impose on any individual an increment of risk that is more than a small fraction of their background risk."[109] This philosophy is depicted in Figure 12 with a summary of the ANCOLD IR criteria for dams are provided in Table 15.

ANCOLD did not propose worker life safety guidelines.

[108] http://www.ancold.org.au/?page_id=3469
[109] McDonald, L. Tolerable Risk Criteria: - The ANCOLD Guidance. Working Group on Risk Assessment.

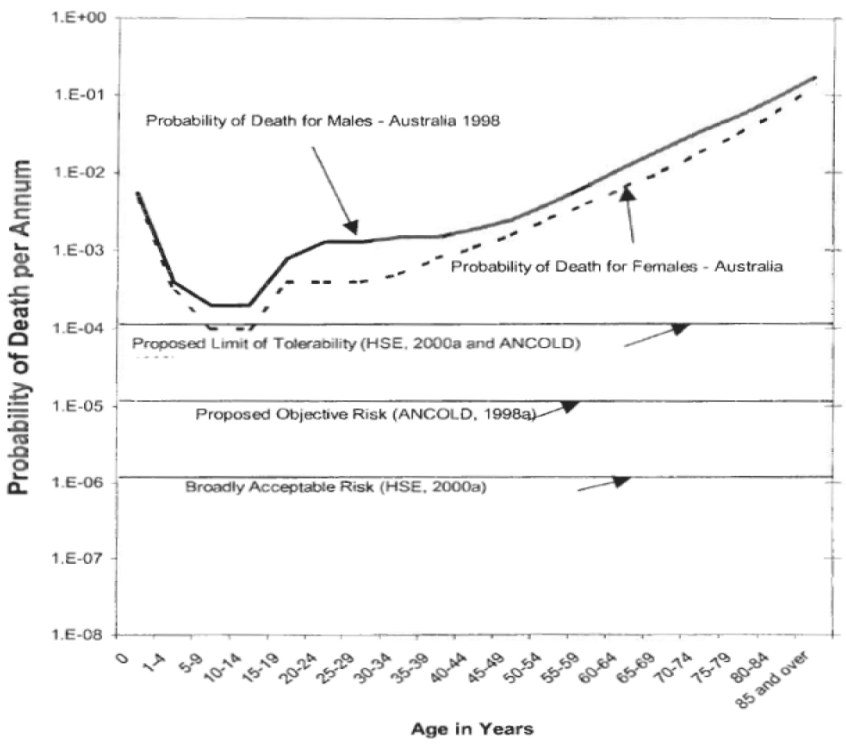



**Figure 12. Background Risk and ANCOLD IR Criteria[109]**

**Table 15. Summary of ANCOLD IR Criteria for Dams**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Public IR<br>(new dams or upgrading existing dams) | Maximum Tolerable: $1 \times 10^{-5}$ |
| Public IR<br>(existing dams) | Maximum Tolerable: $1 \times 10^{-4}$ |

6.1.3.5.2 ANCOLD Societal Risk Criteria Development

The ANCOLD SR criteria sets a maximum tolerable SR criterion for existing dams according to Figure 13 where 10 fatalities occurring from a single dam failure at 1 in 10,000 years at a slope of (-1) sets the maximum tolerable limit. The SR criteria are based on similar criteria defined by the UK, Netherlands, and Hong Kong. ANCOLD also defines a broadly acceptable region two orders of magnitude below the maximum tolerable criteria. In between these two regions they apply ALARP principles.[110] For new dams or major modifications, the SR maximum tolerable criterion is set an order of magnitude lower.

[110] McDonald, L. Tolerable Risk Criteria: - The ANCOLD Guidance. Working Group on Risk Assessment.

The horizontal line in Figure 13 is the intersection of the maximum tolerable SR risk criterion and the 1 x $10^{-5}$ IR criterion. Essentially, for any 'N' greater than 100 fatalities and 'F' greater than 1 x $10^{-5}$ fatality/year, the risk from a dam failure is considered unacceptable. The horizontal line bears some resemblance to the Venezuelan SR risk criteria (see Section 0) which has two step-wise changes in its maximum tolerable SR criterion.

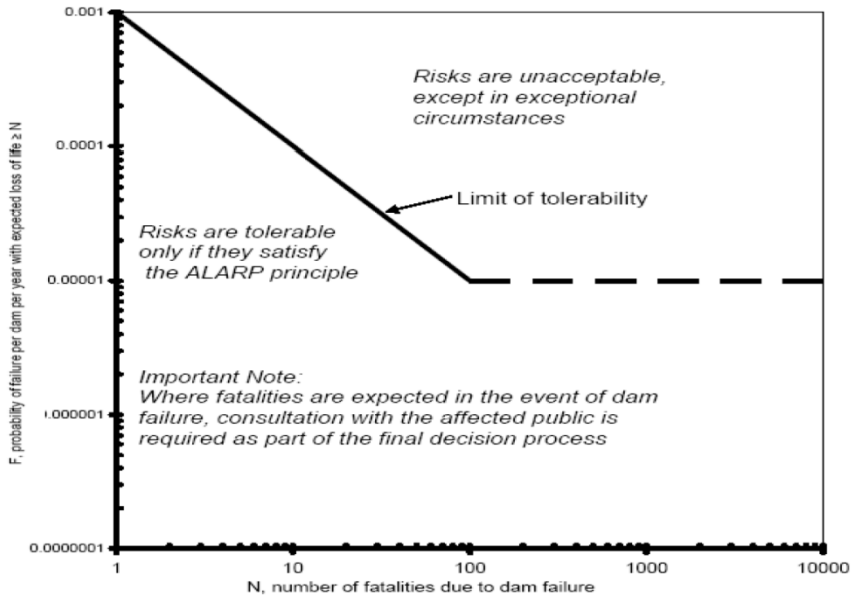



**Figure 13. ANCOLD Maximum Tolerable Risk Criteria for Dams[110]**

### 6.1.4 Brazil

As in Australia, Brazil defines risk criteria by state and includes São Paulo, Rio De Janeiro, and Rio Grande Do Sul. Each State has developed similar IR and SR criteria for both fixed facilities and pipelines to be used when preparing risk assessments as part of Environmental Impact Assessments (EIAs) for licensing of new and modified installations. A full QRA is required if specific consequence impacts can reach off-site receptors. The levels of consequence impact differ by State.

#### 6.1.4.1 São Paulo

At the time São Paulo adopted their risk tolerability criteria, there was little to no experience in developing such criteria. Therefore, the criteria are slightly less restrictive so that they might be

easier to meet. The state environmental agency (CETESB[111]) used an average of several international standards to establish their risk criteria.[112]

#### 6.1.4.1.1 São Paulo Individual Risk Criteria Development

In São Paulo, the CETESB has defined IR criteria to evaluate risk assessment studies performed for licensing of new (or significantly modified) fixed facilities and pipelines. Specifically, the maximum tolerable IR for any new facility should not exceed 1 x $10^{-5}$ fatality/year. Additionally, the broadly acceptable IR is defined as 1 x $10^{-6}$ fatality/year, one order of magnitude lower than the maximum tolerable risk level. If the risk lies between these values, ALARP principles apply.[113]

The IR criteria for new pipelines are set an order of magnitude higher at 1 x $10^{-4}$ fatality/year for the maximum tolerable risk and 1 x $10^{-5}$ fatality/year for the broadly acceptable level.[113] If additional pipelines are to be installed along an existing route, the accumulated risk of the affected land area must be assessed and if it exceeds the IR criteria, new construction is prohibited where risk levels are exceeded.[114]

As discussed in the CCPS guidelines, the IR of 1 x $10^{-5}$ fatality/year for fixed facilities can be exceeded so long as the SR criteria for the facility are met. In addition, the criteria were originally intended for new or significantly modified facilities and are now being extended to routine renewal of operating licenses for existing facilities.[115] A summary of the São Paulo IR criteria are provided in Table 16.

**Table 16. Summary of São Paulo IR Criteria**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR (new facilities) | Maximum Tolerable: 1 x $10^{-5}$<br>Broadly Acceptable: 1 x $10^{-6}$ |
| Offsite Public IR (pipelines) | Maximum Tolerable: 1 x $10^{-4}$<br>Broadly Acceptable: 1 x $10^{-5}$ |

#### 6.1.4.1.2 São Paulo Societal Risk Criteria Development

The societal risk criteria for all three Brazilian states are provided in Figure 14. São Paulo defined a maximum tolerable SR criterion of 10 fatalities occurring once in 10,000 years at a

[111] Companhia de Tecnologia de Saneamento Ambiental
[112] Kirchhoff, D. and Doberstein, B. Pipeline risk assessment and risk acceptance criteria in the state of São Paulo, Brazil. Impact Assessment and Project Appraisal. September 2006.
[113] Kirchhoff, D. and Doberstein, B. Pipeline risk assessment and risk acceptance criteria in the state of São Paulo, Brazil. Impact Assessment and Project Appraisal. September 2006.
[114] Rodrigues, R. Pipeline Risk Management. 2010.
[115] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 132.

slope of (-1) which is the same as the initial SR criteria defined by the UK ACMH. São Paulo also defines a broadly acceptable region two orders of magnitude below the maximum tolerable criteria. In between these two regions ALARP principles are applied.

#### 6.1.4.2 Rio de Janeiro

##### 6.1.4.2.1 Rio de Janeiro Individual Risk Criteria Development

Rio de Janeiro establishes IR criteria for new and existing facilities as well as pipelines. The maximum tolerable IR for any new facility or pipeline should not exceed 1 x $10^{-6}$ fatality/year whereas this level is an order of magnitude higher for existing facilities and pipelines (1 x $10^{-5}$ fatality/year).[116] The greater tolerance for risk at existing facilities highlights the technological difficulties in retrofitting an existing facility to meet the more stringent standards set for new facilities. Rio de Janeiro does not define a broadly acceptable IR. A summary of the Rio de Janeiro IR criteria are provided in Table 17.

**Table 17. Summary of Rio de Janeiro IR Criteria**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR (new facilities and pipelines) | Maximum Tolerable: 1 x $10^{-6}$ |
| Offsite Public IR (existing facilities and pipelines) | Maximum Tolerable: 1 x $10^{-5}$ |

##### 6.1.4.2.2 Rio de Janeiro Societal Risk Criteria Development

The societal risk criteria for all three Brazilian States are provided in Figure 14. Rio de Janeiro defined a maximum tolerable SR criterion of 100 fatalities occurring once in 100,000 years at a slope of (-1.5) which is the same as Rio Grande do Sul (see Section 0). The broadly acceptable region is set one order of magnitude below the maximum tolerable limit. In between these two regions ALARP principles are applied. Rio de Janeiro is the only State that requires evaluation of SR for pipelines – the criteria are the same as that defined for fixed facilities.[117]

#### 6.1.4.3 Rio Grande Do Sul

##### 6.1.4.3.1 Rio Grande Do Sul Individual Risk Criteria Development

Rio Grande Do Sul established the same IR criteria as that set for São Paulo where the maximum tolerable IR for any new facility should not exceed 1 x $10^{-5}$ fatality/year. Additionally,

[116] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 132.
[117] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 131.

the broadly acceptable IR is defined as 1 x $10^{-6}$ fatality/year, one order of magnitude lower than the maximum tolerable risk level. ALARP principles apply between these two levels.

The IR criteria for new pipelines are set an order of magnitude higher at 1 x $10^{-4}$ fatality/year for the maximum tolerable risk and 1 x $10^{-5}$ fatality/year for the broadly acceptable level.[113] A summary of the Rio Grande do Sul IR criteria are provided in Table 18.

**Table 18. Summary of Rio Grande do Sul IR Criteria for New Facilities**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR (new facilities) | Maximum Tolerable: 1 x $10^{-5}$<br>Broadly Acceptable: 1 x $10^{-6}$ |
| Offsite Public IR (pipelines) | Maximum Tolerable: 1 x $10^{-4}$<br>Broadly Acceptable: 1 x $10^{-5}$ |

6.1.4.3.2 Rio Grande Do Sul Societal Risk Criteria Development

The societal risk criteria for Rio Grande Do Sul are the same as Rio de Janeiro (see Figure 14). Rio Grande Do Sul defined a maximum tolerable SR criterion of 100 fatalities occurring once in 100,000 years at a slope of (-1.5). The broadly acceptable region is set one order of magnitude below the maximum tolerable limit. In between these two regions ALARP principles are applied.

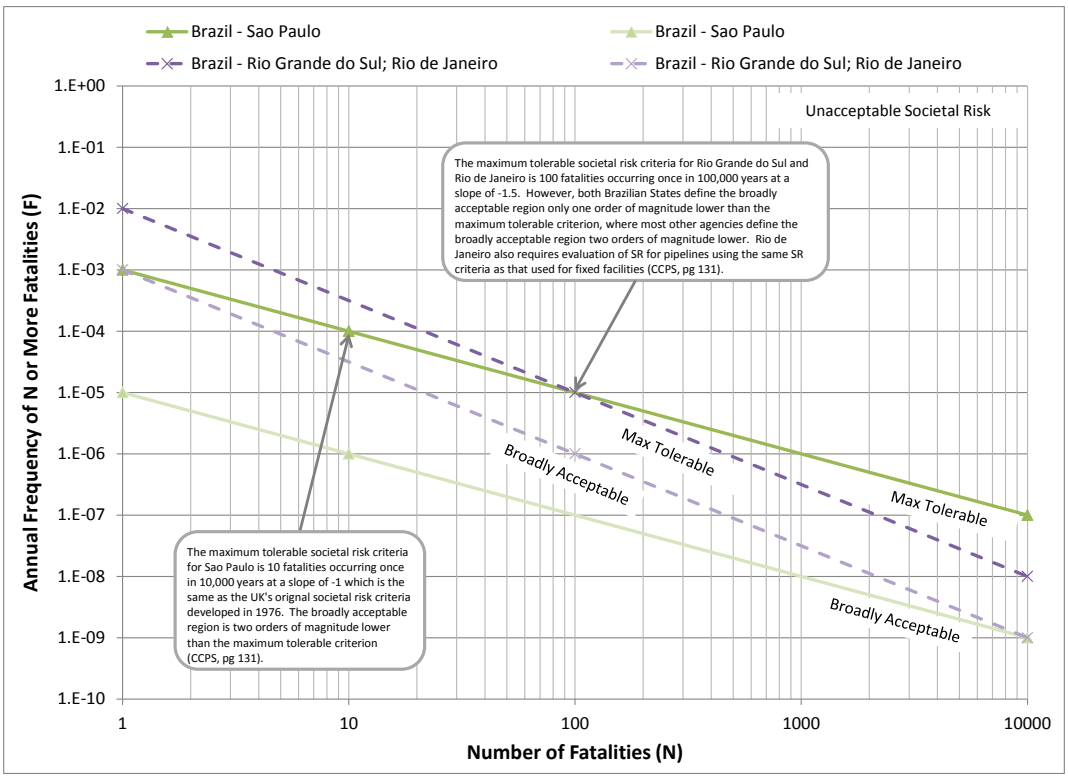



**Figure 14. Maximum Tolerable and Broadly Acceptable Societal Risk Criteria for Three States in Brazil (derived from CCPS, 2009[118])**

## 6.1.5 Hong Kong

Risk criteria development in Hong Kong was largely driven by the high population densities living and working near hazardous facilities, specifically LPG storage facilities, and landslide risks. Being a former British colony, there is a noticeable influence from the UK on the Hong Kong risk criteria. The Hong Kong risk criteria are used primarily for land use planning and licensing of hazardous facilities decisions. There are currently no specific risk criteria for transportation risks.[119]

### 6.1.5.1 Hong Kong Societal Risk Criteria Development

As shown in Figure 15, the Hong Kong just tolerable criteria of 10 equivalent fatalities occurring once in 10,000 years[120] is the same as in the 1970s era UK SR criteria (see Section 0) except for the fact that any scenario with greater than 1,000 fatalities (N) is unacceptable regardless of

[118] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009.
[119] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 127.
[120] Hong Kong Government Risk Guidelines. Annex 4 of Technical Memorandum for Environmental Impact Assessment Ordinance (EIAO-TM). http://www.epd.gov.hk/eia/english/legis/memorandum/annex4.html

the annual frequency (F). The switch to a consequence-based approach at N greater than 1,000 fatalities is the same as the earlier Dutch criteria.

The broadly acceptable region is defined two orders of magnitude lower than the maximum tolerable curve with an ALARP region in between the two curves, which is also the same as the UK SR criteria.

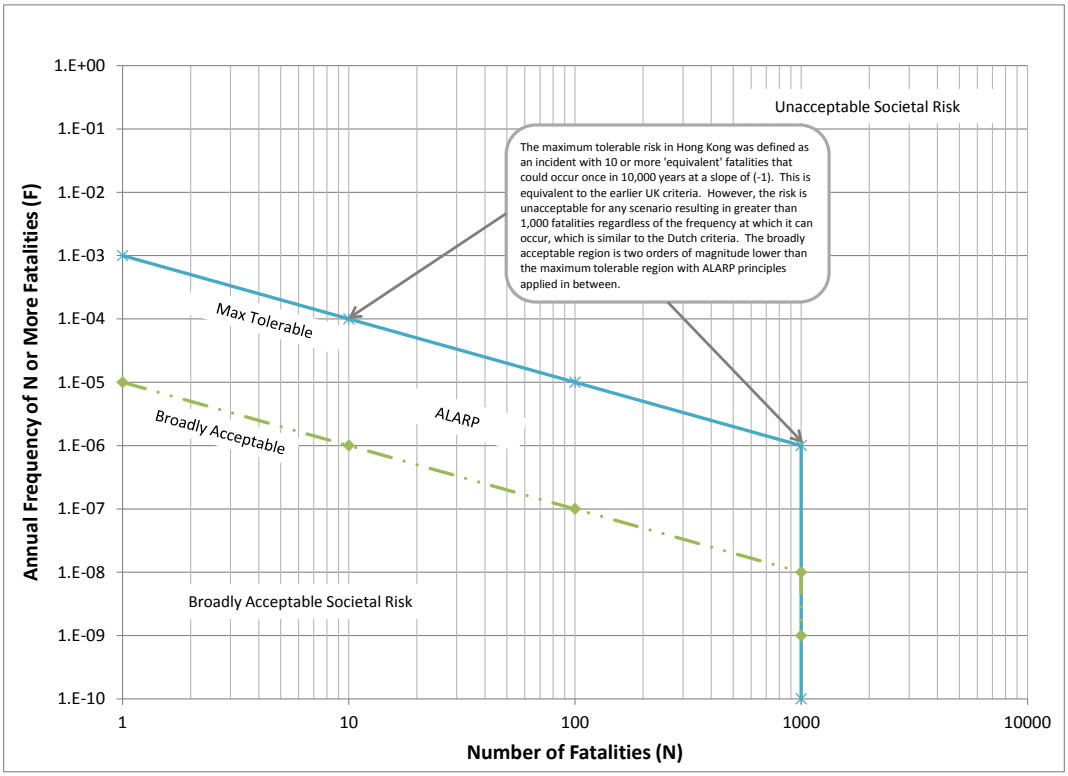



**Figure 15. Hong Kong Societal Risk Criteria (derived from CCPS, 2009[121])**

### 6.1.5.2 Hong Kong Individual Risk Criteria Development

The IR criteria for Hong Kong allow the consideration of exposure duration to the hazard(s) when calculating IR, also called 'personal IR'. The maximum tolerable IR criterion is set at 1 x $10^{-5}$ fatality/year for both new and existing hazardous facilities. Although, no distinction is made between new and existing facilities, the Hong Kong government allows for more flexibility in application of the IR criteria in existing situations. Hong Kong also does not define a broadly acceptable region for IR criteria, nor does it specify the application of ALARP principles to IR.[122] A summary of the Hong Kong IR criteria are provided in Table 19.

[121] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009.
[122] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 127.

**Table 19. Summary of Hong Kong IR Criteria for New and Existing Facilities**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR (new facilities) | Maximum Tolerable: $1 \times 10^{-5}$ |
| Offsite Public IR (existing facilities) | Maximum Tolerable: $1 \times 10^{-5}$ (can use risk reduction if exceeded) |

## 6.1.6 France

As discussed in the CCPS Guidelines, risk criteria in France traditionally have been consequence-based. However, in response to a large explosion at a chemical facility in Toulouse in 2001, France enacted legislation to address general risk assessment principles, land use planning, risk communication, and compensations from damages.[123] A brief discussion of this approach is provided below; however for further details please refer to the CCPS Guidelines for Developing Quantitative Safety Risk Criteria[124].

### 6.1.6.1 France Societal Risk Criteria Development

Rather than defining quantitative SR criteria, France uses a semi-quantitative approach. In the semi-quantitative approach, categories of consequence and frequency are defined in a series of tables. Based on estimates of the consequence and frequency levels, a decision matrix is then used to define acceptability for permitting a new facility or for modifying an existing facility. As defined in Table 20, some combinations of consequence and frequency result in unacceptable risks while other risks are only acceptable if risk reduction measures are implemented. For lower frequency medium and moderate consequences, the risks are broadly acceptable.

[123] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 144.
[124] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 144-147.

**Table 20. French Decision Matrix for Permitting New or Modified Facilities[125]**

| | Frequency Range | | | | |
|---|---|---|---|---|---|
| **Consequence Severity** | **E $<10^{-5}$** | **D $10^{-5}$ to $10^{-4}$** | **C $10^{-4}$ to $10^{-3}$** | **B $10^{-3}$ to $10^{-2}$** | **A $>10^{-2}$** |
| Extreme | Unacceptable (new plant)<br><br>Stringent risk reduction required (existing plant) | Unacceptable | Unacceptable | Unacceptable | Unacceptable |
| Catastrophic | Risk reduction required | Stringent risk reduction required | Unacceptable | Unacceptable | Unacceptable |
| Significant | Risk reduction required | Risk reduction required | Stringent risk reduction required | Unacceptable | Unacceptable |
| Medium | Acceptable | Acceptable | Risk reduction required | Stringent risk reduction required | Unacceptable |
| Moderate | Acceptable | Acceptable | Acceptable | Acceptable | Risk reduction required |

#### 6.1.6.2 France Individual Risk Criteria Development

France uses a similar approach to IR criteria as discussed previously for SR. Again hazard level matrices are provided for new and existing facilities which provide guidance to land use decision-makers. In particular, new construction is prohibited if the IR is estimated to be 'very high' or 'high' and relocation of residences residing in a 'very high' IR zone is mandated for existing installations. Decisions for lower IR facilities are left up to the planning authorities based on input from local citizen advisory groups.

### 6.1.7 Switzerland

#### 6.1.7.1 Switzerland Societal Risk Criteria Development

As discussed in the CCPS Guidelines[126], Switzerland is the only country that attempts to create an equivalency between number of fatalities (N) in a traditional F-N curve and injuries, environmental impacts, and property damage. The equivalent value is called a 'Disaster Value' as defined in Figure 16.

There are three regions to the Swiss SR curve: 1) an acceptable region, 2) a transition region (similar to ALARP) and 3) an unacceptable region (see Figure 16). Much like other SR criteria, if the cumulative risk falls in the unacceptable region, the risk must be reduced below the maximum tolerable limit or the enforcement authority can impose operational restrictions or shutdown a facility. In the transition region, the cumulative risks have to be reduced to a level

[125] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 146.
[126] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 148.

defined by the authority based on public needs and environmental protection. If the cumulative risk is in the acceptable region, the risk assessment is complete but it does not relieve the operator from taking appropriate risk reduction measures.[127]

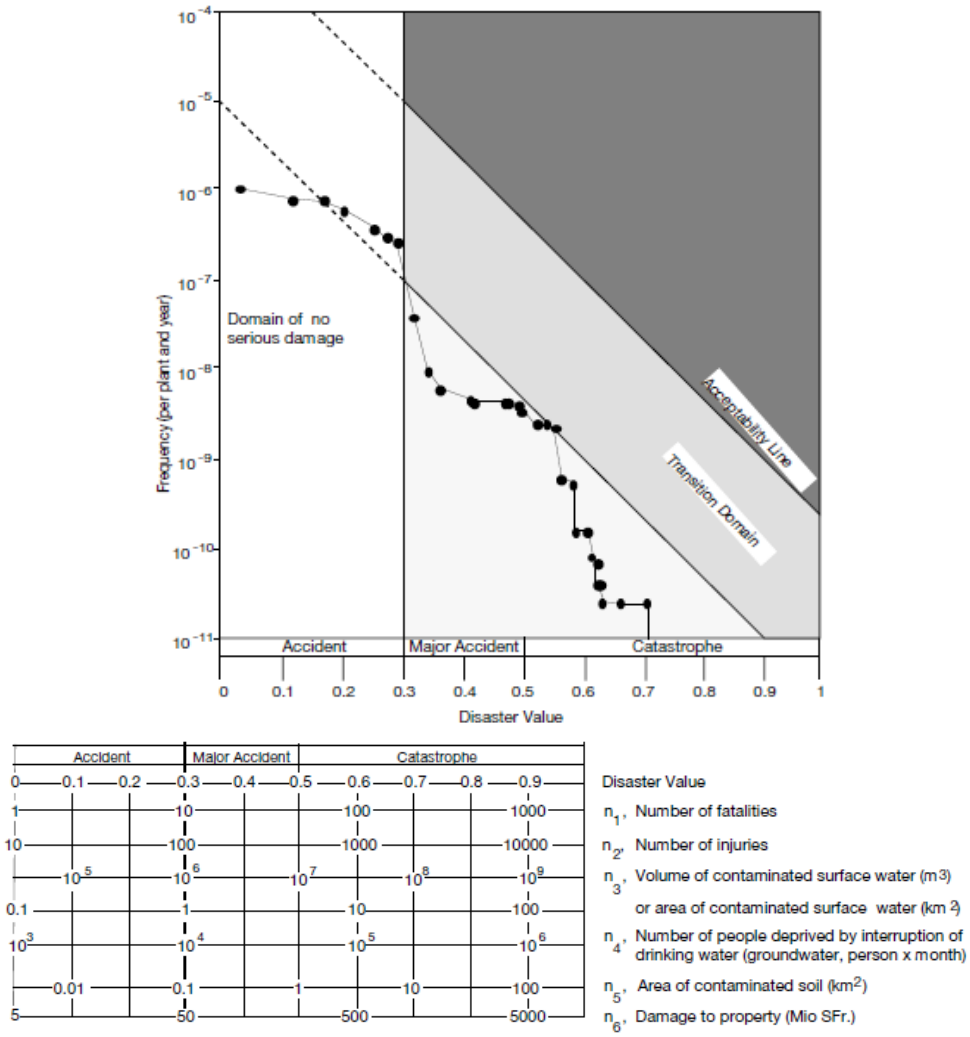



**Figure 16. Switzerland Societal Risk Criteria[128]**

### 6.1.7.2 Switzerland Individual Risk Criteria Development

Switzerland has not defined any individual risk criteria.[129]

[127] Gmunder, F.K., Meyer, P., and Schiess, M. The Control of Major Chemical Hazards in Switzerland in the Framework of Sustainable Development – Liquefied Petroleum, Ammonia, and Chlorine as Examples.
[128] Gmunder, F.K., Meyer, P., and Schiess, M. The Control of Major Chemical Hazards in Switzerland in the Framework of Sustainable Development – Liquefied Petroleum, Ammonia, and Chlorine as Examples.
[129] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 148.

## 6.1.8 Canada

In 2004, the Canadian Society for Chemical Engineering (CSChE) published a Risk Assessment - Recommended Practice for Municipalities and Industry. Within this document, the CSChE provide recommendations for risk assessment that are applicable to a broader class of hazards and risk sources than a previous MiniGuide compiled by the Major Industrial Accidents Council of Canada (MIACC). The focus of the recommended practice is on land-use planning and siting decisions but the document also mentions that many of the techniques can be used for other applications such as design of hazardous installations and emergency response planning.[130]

### 6.1.8.1 Canada Individual Risk Criteria Development

The CSChE recommended practice focuses on IR criteria. However, similar to several Australian States, societal risk concerns are built into the individual risk criteria through the definition of different acceptable land uses based on varying population densities and vulnerabilities. The IR is location-based which assumes an individual is present 100% of the time. Additionally, the IR criteria are applicable to both fixed facility and hazardous goods transport, which includes pipelines.

According to the MIACC, no other land use (outside of the risk generator) should be allowed where the IR is greater than $1 \times 10^{-4}$ fatality/year. This implies that higher risks are tolerable for on-site personnel; however, the MIACC did not provide specific values for worker IR. An IR for non-industrial (manufacturing facilities, warehouses) or active open spaces where there is continuous access and limited numbers of people is permitted between $1 \times 10^{-4}$ and $1 \times 10^{-5}$ fatality/year. For commercial spaces where there is continuous access and easy evacuation, the acceptable IR is between $1 \times 10^{-5}$ and $1 \times 10^{-6}$ fatality/year. If the IR is below $1 \times 10^{-6}$ fatality/year, development is not restricted.[130] A summary of the Canadian IR criteria are provided in Table 21.

**Table 21. Summary of Canadian IR Criteria**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR<br>Industrial Facilities | Maximum Tolerable: $1 \times 10^{-4}$<br>Broadly Acceptable: $1 \times 10^{-6}$ |
| Offsite Public IR<br>Non-Industrial or Active Open Spaces | Maximum Tolerable: $1 \times 10^{-5}$ to $1 \times 10^{-4}$<br>Broadly Acceptable: $1 \times 10^{-6}$ |
| Offsite Public IR<br>Commercial Facilities | Maximum Tolerable: $1 \times 10^{-6}$ to $1 \times 10^{-5}$<br>Broadly Acceptable: $1 \times 10^{-6}$ |

[130] Canadian Society for Chemical Engineering. Risk Assessment – Recommended Practices for Municipalities and Industry. 2004. http://www.cheminst.ca/sites/default/files/pdfs/Connect/PMS/Risk%20Assessment%20%E2%80%93%20Recommended%20Practices%20for%20Municipalities%20and%20Industry.pdf

### 6.1.8.2 Canada Semi-Quantitative Risk Criteria Development

The CSChE recommended practice provides a semi-quantitative decision framework based on a risk matrix. The CSChE provide some examples of frequency and consequence categories[131] and discuss that how an operating company selects the definitions for the different frequency and consequence categories can make the criteria for risk acceptability more (or less) stringent. By making the criteria more stringent, the operating company can use the risk matrix as a tool for continuous improvement of its safety culture and performance. However, the CSChE discourage its use in situations with public safety and land use implications at stake. Instead, they recommend use of QRA and comparison against public risk acceptability guidelines when making decisions. [132] The example risk matrix provided in the CSChE recommended practice is presented in Figure 17.

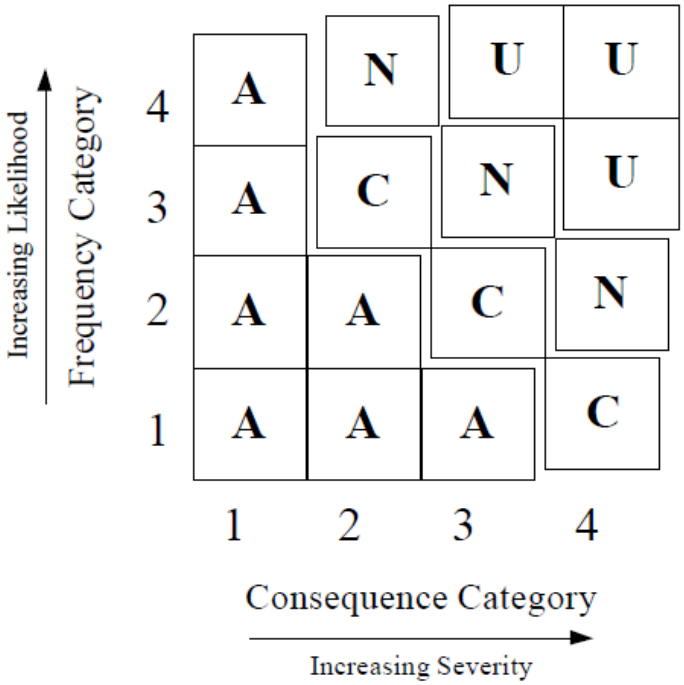



**Figure 17. Example Semi-Quantitative Risk Criteria (Risk Matrix) [133]**

[131] Suggestions for the risk matrix frequency categories were provided from a number of sources including CCPS, Alp, and CCPA. The consequence categories were defined by four categories with the most severe rated as a '4' (death or severe health effects) and the least severe rated as a '1' (no injury or health effects). The decision risk matrix was adapted from CCPS and included frequency-consequence categories falling into an unacceptable, not desirable, conditionally acceptable with controls, and acceptable as is categories.

[132] Canadian Society for Chemical Engineering. Risk Assessment – Recommended Practices for Municipalities and Industry. 2004. http://www.cheminst.ca/sites/default/files/pdfs/Connect/PMS/Risk%20Assessment%20%E2%80%93%20Recommended%20Practices%20for%20Municipalities%20and%20Industry.pdf

[133] Canadian Society for Chemical Engineering. Risk Assessment – Recommended Practices for Municipalities and Industry. 2004. http://www.cheminst.ca/sites/default/files/pdfs/Connect/PMS/Risk%20Assessment%20%E2%80%93%20Recommended%20Practices%20for%20Municipalities%20and%20Industry.pdf

## 6.1.9 Malaysia

### 6.1.9.1 Malaysia Individual Risk Criteria Development

According to CCPS, Malaysia requires a risk assessment of major hazardous installations to fulfil requirements of their Environmental Quality Act. Major hazardous installations are defined as facilities storing or processing large quantities of toxic or flammable materials that can harm the surrounding populations, property and environment.[134]

The Malaysian IR criterion defines a maximum tolerable level of 1 x $10^{-5}$ fatality/year for industrial developments and 1 x $10^{-6}$ fatality/year for sensitive populations like schools, hospitals, etc. Additionally, Malaysian authorities require a buffer zone between major hazardous installations and any other development. The buffer zone must be a minimum of 500 meters or the distance to an IR of 1 x $10^{-6}$ fatality/year, whichever is greater.[134] A summary of the Malaysian IR criteria are provided in Table 22.

**Table 22. Summary of Malaysian IR Criteria**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR<br>Industrial Facilities | Maximum Tolerable: 1 x 10-5 |
| Offsite Public IR<br>Sensitive and Other Developments | Maximum Tolerable: 1 x 10-6 |

### 6.1.9.2 Malaysia Societal Risk Criteria Development

No documentation was found indicating that Malaysia has defined any SR criteria.

## 6.1.10 Singapore

### 6.1.10.1 Singapore Individual Risk Criteria Development

Under Singapore's Environmental Protection and Management Act, the Pollution Control Department (PCD) can require QRA for installations that store, transport, or use hazardous substances.[135] Similar to the IR criteria developed by Australia and Canada, the Singapore's PCD accounts for varying population densities and vulnerabilities in the definition of their IR criteria. The PCD also uses a combination of IR levels and hazard zones to define maximum tolerable risk limits:

[134] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 135.
[135] Pollution Control Department (PCD) Guidelines for Quantitative Risk Assessment (QRA) Study (For Installations Which Store, Transport Or Use Hazardous Substances). Rev: November 2014. http://www.nea.gov.sg/docs/default-source/anti-pollution-radiation-protection/central-building-planning/qra-guidelines_nov-2014.pdf?sfvrsn=0

- The following hazard zones and IR level must be contained within the plant boundary:
  - $5 \times 10^{-5}$ fatality/year IR
  - 37.5 kW/m$^2$ heat radiation zone
  - 5 psi explosion overpressure hazard zone
- An IR of $5 \times 10^{-6}$ fatality/year can only extend into industrial developments
- An IR of $1 \times 10^{-6}$ fatality /year can only extend into commercial and industrial developments
- Hazard zones for the worst credible scenarios[136] cannot extend into residential areas and no high-rise developments can be located within the fireball zone.

The Singapore risk criteria are a combination of IR and aspects of SR through the definition of consequence-based criteria (thermal radiation zones, overpressure zones, toxic zones). The PCD document does not indicate if the IR risk is location-based (present 100% of the time) or personal-based (account for exposure duration). A summary of the Singapore's IR criteria are provided in Table 23.

**Table 23. Summary of Singapore's IR Criteria**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR<br>Industrial Facilities | Maximum Tolerable: $5 \times 10^{-5}$<br>(with 1 km buffer zone) |
| Offsite Public IR<br>Areas Between Industrial and Commercial | Maximum Tolerable: $5 \times 10^{-6}$ |
| Offsite Public IR<br>Commercial Developments | Maximum Tolerable: $1 \times 10^{-6}$ |

#### 6.1.10.2 Singapore Societal Risk Criteria Development

No documentation was found indicating that Singapore has defined any SR criteria. However, the PCD criteria discussed in Section 0 contain some elements of societal risk through the definition of consequence-based hazard zones in which certain types of land use is prohibited.

### 6.1.11 Norway

Norway, rather than prescribing risk tolerance criteria, allows those conducting the risk assessment for the offshore industry to establish their own basis for decision-making. In developing risk criteria, the NORSOK standard for 'Risk and Emergency Preparedness Assessment' emphasizes that identification of risk reducing measures as input to ALARP

[136] The worst credible scenario is defined as toxic effect zones out to IDLH or corresponding to 3% probability of fatality; a thermal radiation zone to 4 kW/m2 or 3% probability of fatality; an overpressure zone of 0.5 psi; and fireball zone which can be out to the lower flammability limit (LFL) or ½ the LFL.

evaluations must be performed throughout the risk assessment process.[137] In addition, QRA risk acceptance criteria should, at a minimum, include casualties, environmental damage, and property damage. The NORSOK standard mentions that risk criteria related to other types of risk like health effects and financial impacts are needed but were not included in the scope. "The RAC[138] should be at a level where there is a reasonable balance between ambitions as to continuous improvement, defined safety objectives and technology improvements on one hand and what is realistic to achieve on the other."[137]

#### 6.1.11.1 Norway Individual Risk Criteria Development

The NORSOK standard provides some parameters that can be used when developing IR criteria including:[137]

- Fatal Accident Rate (FAR) which is the number of fatalities per 100 million exposed hours.
- Individual risk (IR) or Individual Risk Per Annum (IRPA) which is the annual probability of fatality for an individual.
- Group Individual Risk (GIR) or Average Individual Risk (AIR) which are equivalent to the average IR for defined groups.

The NORSOK standard also indicates that the IR should be personal-based, accounting for an individual's exposure time each year (rather than location-based which assumes an individual is exposed to the risk 100% of the time).

The NORSOK standard also gives guidance for IR and SR criterion for pipelines. They indicate that the criteria should be established for any 10 km section of the pipeline route and that the IR and SR criteria should not be scaled according to the actual pipeline length.

#### 6.1.11.2 Norway Societal Risk Criteria Development

The NORSOK standard focuses on the use of F-N curves for defining SR criteria. However, they also suggest the use of Potential Loss of Life (PLL) as an intermediate result to give a picture of the fatality risk to which the facility or workforce is exposed and possibly as a criterion for normally unmanned installations or for groups with irregular exposures.[137]

As indicated in Section 0, SR criteria should be established for any 10 km section of the pipeline route and not be scaled according to the actual pipeline length.

---

[137] NORSOK Standard Z-013, Edition 3, October 2010. Risk and Emergency preparedness assessment. Norwegian Oil Industry Association (OLF) and the Federation of Norwegian Industry, Lysaker, Norway. 2010.
[138] Risk Assessment Criteria

#### 6.1.11.3 Norway Environmental Risk Criteria Development

The NORSOK standard provides guidance on development of both qualitative and quantitative environmental risk criteria. For quantitative criteria they suggest categories based on recovery time for sensitive environmental resources at an upper acceptable limit for frequency. The acceptable frequency limits are not defined in the documents. The recovery time categories are defined below:[139]

- Insignificant damage: recovery time less than 1 month
- Minor damage: recovery time 1 month to 1 year
- Moderate damage: recovery time 1 year to 3 years
- Considerable damage: recovery time 3 years to 10 years
- Serious damage: recovery time more than 10 years

For qualitative/semi-quantitative criteria, the NORSOK standard also provides guidance for developing a risk matrix with three acceptability regions: 1) high risk (unacceptable) where risk reduction, management attention, and detailed assessments are required; 2) medium risk (ALARP) where risk reduction is implemented using ALARP principles; 3) low risk (broadly acceptable) where risk reduction measures are not necessary.

### 6.1.12 Venezuela

#### 6.1.12.1 Venezuela Individual Risk Criteria Development

As described in a paper by Cornwell[140], Petroleos de Venezuela, S.A. (PDVSA) published a document requiring companies to evaluate IR levels posed by a project and compare them with the following criteria:

- Maximum Tolerable IR: $1 \times 10^{-3}$ [141]
- Broadly Acceptable IR: $1 \times 10^{-6}$

#### 6.1.12.2 Venezuela Societal Risk Criteria Development

The PDVSA take a different approach to SR criteria than all other country organizations reviewed for this study. Instead of a continuous line at a specific slope, the PDVSA define step-

[139] NORSOK Standard Z-013, Edition 3, October 2010. Risk and Emergency preparedness assessment. Norwegian Oil Industry Association (OLF) and the Federation of Norwegian Industry, Lysaker, Norway. 2010.
[140] Cornwell, J.B. and Meyer, M.M. Risk Acceptance Criteria or "How Safe is Safe Enough?". II Risk Control Seminar, October 13, 1997.
[141] There is a discrepancy in this value between the article by Cornwell and Meyer (1 x 10-3) and article by Kirchhoff and Doberstein (1 x 10-6). Since Kirchhoff and Doberstein quoted Cornwell and Meyer, the IR values reported herein are from the Cornwell and Meyer article.

wise curves for the maximum tolerable and broadly acceptable regions. The criteria are summarized below and presented in Figure 18.[142]

- Maximum Tolerable Societal Risk Levels:
  - 1 to 10 fatalities, the societal risk is considered unacceptable at an annual frequency greater than $1 \times 10^{-2}$.
  - 10 to 50 fatalities, the societal risk is considered unacceptable at an annual frequency greater than $1 \times 10^{-4}$.
  - 50 to 1,000 fatalities, the societal risk is considered unacceptable at an annual frequency greater than $1 \times 10^{-6}$.
- Broadly Acceptable Societal Risk Levels:
  - 1 to 10 fatalities, the societal risk is considered unacceptable at an annual frequency greater than $1 \times 10^{-6}$.
  - 10 to 50 fatalities, the societal risk is considered unacceptable at an annual frequency greater than $1 \times 10^{-8}$ (presumed).
  - 50 to 1,000 fatalities, the societal risk is considered unacceptable at an annual frequency greater than $1 \times 10^{-10}$ (presumed).

As is evident in Figure 18, the maximum tolerable line does not extend beyond 1,000 fatalities and the broadly acceptable line does not extend beyond 10 fatalities. We have presumed, similar to the Hong Kong and earlier Dutch criteria, that for fatalities (N) greater than 1,000 the risk is unacceptable regardless of frequency (F). Moreover, we have presumed that the broadly acceptable curve mimics the maximum tolerable curve, except that the values are four orders of magnitude lower.

[142] Cornwell, J.B. and Meyer, M.M. Risk Acceptance Criteria or "How Safe is Safe Enough?". II Risk Control Seminar, October 13, 1997.

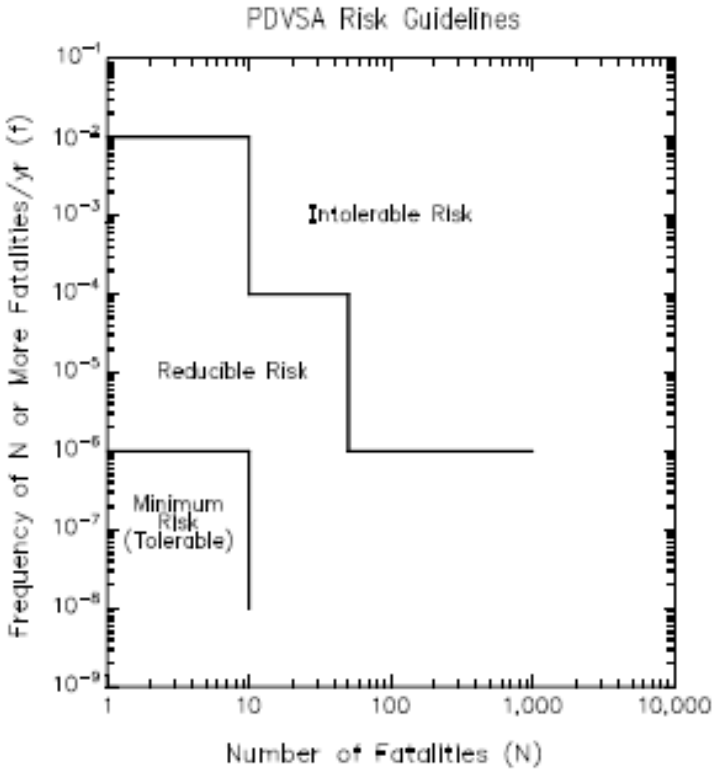



**Figure 18. Venezuelan Societal Risk Criteria[143]**

## 6.1.13 Czech Republic

### 6.1.13.1 Czech Republic Individual Risk Criteria Development

Very little information was found regarding risk criteria used in the Czech Republic. In a paper written by Trbojevic, he presented a maximum tolerable IR criterion for existing installations of 1 x $10^{-5}$ fatality/year and a maximum tolerable IR criterion for new installations of 1 x $10^{-6}$ fatality/year in the Czech Republic[144]. For existing installations, risk reduction must be carried out. A summary of the Czech Republic IR criteria are provided in Table 24.

[143] Cornwell, J.B. and Meyer, M.M. Risk Acceptance Criteria or "How Safe is Safe Enough?". II Risk Control Seminar, October 13, 1997.
[144] Trbojevic, V.M., Risk Criteria in EU. Risk Support Limited, London, U.K.

**Table 24. Summary of the Czech Republic IR Criteria**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker IR | None |
| Offsite Public IR (new facilities) | Maximum Tolerable: 1 x $10^{-6}$ |
| Offsite Public IR (existing facilities) | Maximum Tolerable: 1 x $10^{-5}$ |

### 6.1.13.2 Czech Republic Societal Risk Criteria Development

As shown in Figure 19, the Czech Republic just tolerable SR criteria for new installations of 10 equivalent fatalities occurring once in a million years[145] at a slope of (-2) is the most risk averse SR criteria of any presented thus far. It is likely that this criterion is difficult to meet for many new hazardous installations. The information reviewed does not indicate if this criterion is mandated by a regulatory authority.

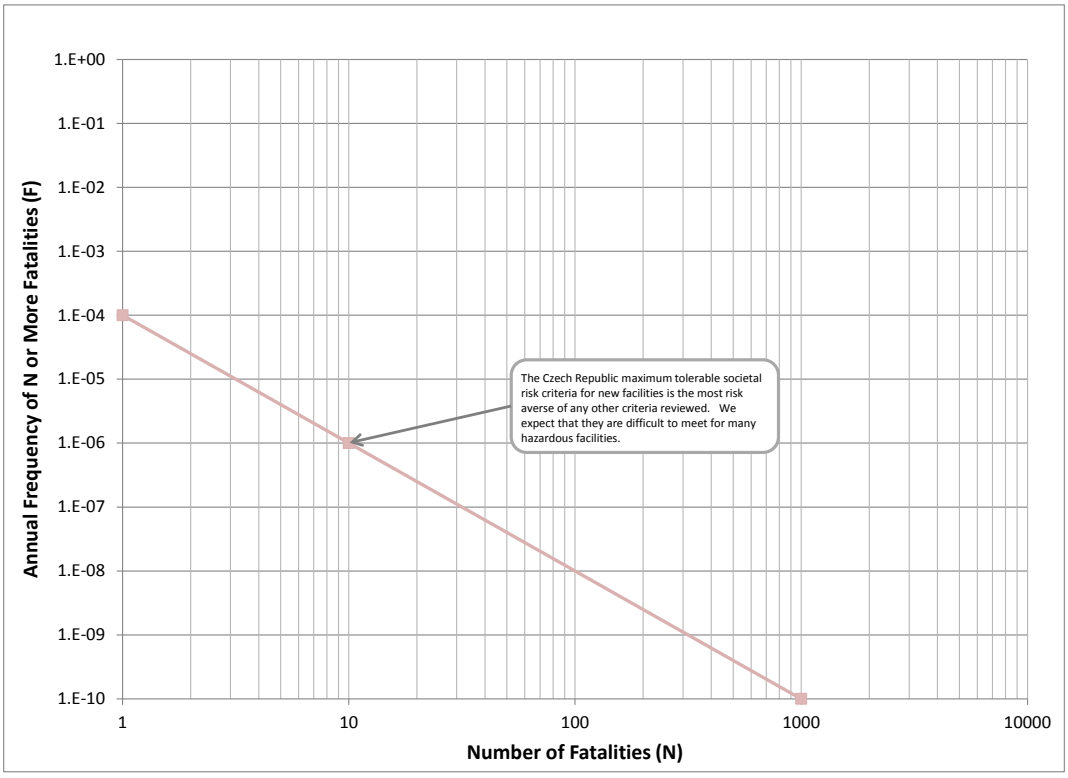



**Figure 19. Czech Republic Maximum Tolerable Societal Risk Criteria[146]**

[145] Trbojevic, V.M., Risk Criteria in EU. Risk Support Limited, London, U.K.
[146] Trbojevic, V.M., Risk Criteria in EU. Risk Support Limited, London, U.K.

### 6.1.14 Hungary

Very little information was found regarding risk criteria used in Hungary. Trbojevic presented a maximum tolerable IR criterion of 1 x $10^{-5}$ fatality/year and a broadly acceptable IR criterion of 1 x $10^{-6}$ fatality/year for Hungary[147].

### 6.1.15 Germany

#### 6.1.15.1 Germany Impact-Based Risk Criteria Development

As discussed in the paper by Trbojevic[148], Germany uses an impact-based (consequence-based) approach to defining risk acceptability. In particular, Germany does not allow for any level of risk from thermal radiation, overpressure, and toxic dose to be imposed on people or the environment. It is unclear as to what consequence endpoints they consider when assessing risk.

### 6.1.16 International Maritime Organization (IMO)

As described by Skjong and Eknes, the IMO approach to risk-based safety and environmental regulations is the development of a Formal Safety Assessment (FSA) which identifies hazards, conducts a risk assessment, identifies risk control options, performs cost benefit analysis, and recommendations for decision making related to maritime safety.[149] The IMO has proposed both SR and IR criteria; however no additional information was found during this review indicating that these criteria were subsequently adopted.

#### 6.1.16.1 IMO Individual Risk Criteria Development

As discussed by Skjong and CCPS[150], the proposed IR criteria presented had not yet been formally adopted by the IMO as of 2006 timeframe. The proposed IMO individual risk criteria are presented in Table 25. The IMO based their individual risk levels for existing ships on the UK IR criteria (see Section 0) and also adopted ALARP principles for risks falling between the maximum tolerable and broadly acceptable levels. The IMO chose to reduce the maximum tolerable IR criterion for new ships by an order of magnitude to reflect the potential for implementing new technology.[151]

---

[147] Trbojevic, V.M., Risk Criteria in EU. Risk Support Limited, London, U.K.
[148] Trbojevic, V.M., Risk Criteria in EU. Risk Support Limited, London, U.K.
[149] Skjong, R. and Eknes, M. Economic Activity and Societal Risk Acceptance. DNV.
[150] Skong, R. Risk Acceptance Criteria: Current proposals and IMO position. Surface Transport Technologies for Sustainable Development. June 2002.
[151] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 159-160.

**Table 25. Summary of the IMO IR Criteria**

| Risk Receptor | Individual Risk (fatality/year) |
|---|---|
| Worker (crew members) IR (existing ships) | Maximum Tolerable: $1 \times 10^{-3}$<br>Broadly Acceptable: $1 \times 10^{-6}$ |
| Worker (crew members) IR (new ships) | Maximum Tolerable: $1 \times 10^{-4}$<br>Broadly Acceptable: $1 \times 10^{-6}$ |
| IR for Passengers and Public Ashore (existing ships) | Maximum Tolerable: $1 \times 10^{-4}$<br>Broadly Acceptable: $1 \times 10^{-6}$ |
| IR for Passengers and Public Ashore (new ships) | Maximum Tolerable: $1 \times 10^{-5}$<br>Broadly Acceptable: $1 \times 10^{-6}$ |

#### 6.1.16.2 IMO Societal Risk Criteria Development

Figure 20 presents the IMO just tolerable SR criteria for three different ship types. The maximum tolerable SR criterion proposed by the IMO for bulk & ore carriers is an incident with 10 or more fatalities that could occur once in 1,000 years at a slope of (-1). This criterion is equivalent to the UK criteria for a single hazardous facility but was developed by estimating the economic importance of the shipping activity to society against the average fatality rate per unit of economic production.[150] The maximum tolerable societal risk for passenger roll-on/roll-off ferries is an order of magnitude higher than the criteria set for bulk & ore carriers reflecting its greater economic importance. The SR criterion for passenger roll-on/roll-off ferries is also equivalent to the UK maximum tolerable risk criterion for multiple hazardous facilities. The broadly acceptable region for each ship type is two orders of magnitude lower than the maximum tolerable region with ALARP principles applied in between.

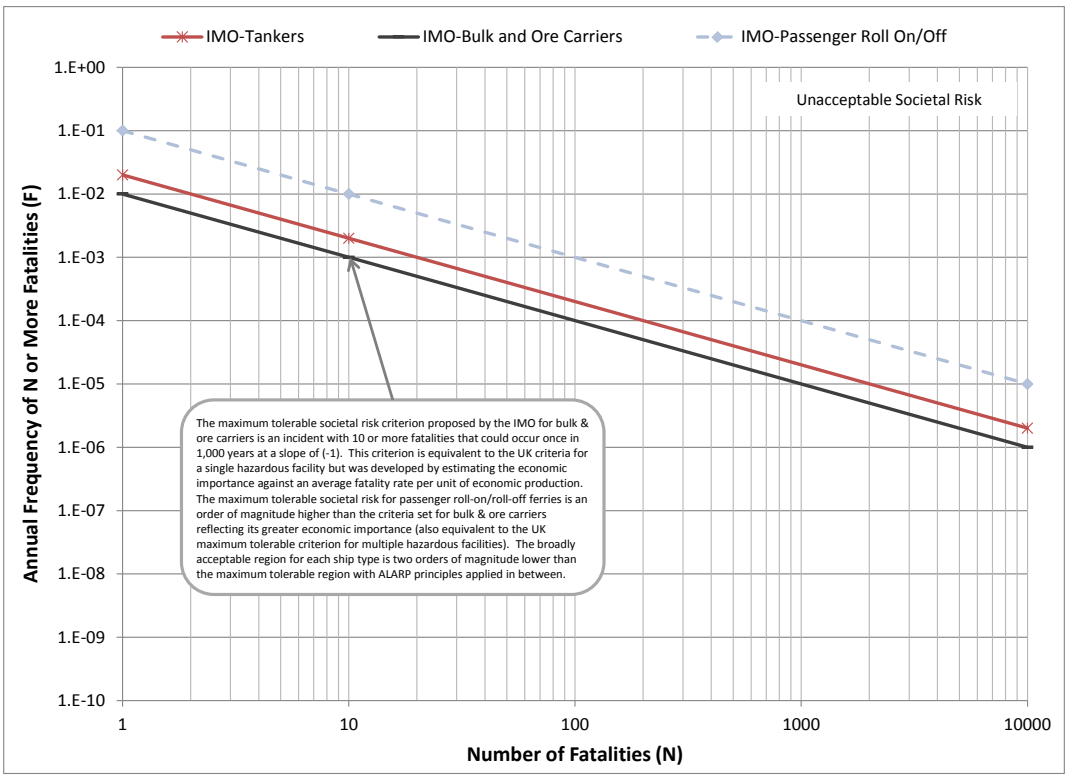



**Figure 20. IMO Maximum Tolerable Societal Risk Criteria[152]**

## 6.2 U.S. Government Agencies

We performed a cursory review of risk tolerability practices implemented by some U.S. Government Departments and Agencies. Given the time frame and resources this survey is extensive but not exhaustive. Several agencies focus on semi-quantitative risk assessments or impact-based assessments to determine risk tolerability and/or the level of regulatory burden. In addition, several other agencies, particularly under the EPA, FDA, NRC, and OSHA, evaluate the individual cancer risk from exposure to chemicals (wastes, contaminants, additives, pollutants, etc.) over the lifetime of an individual to determine tolerable exposures.

### 6.2.1 Department of Defense (DOD)

DOD has developed risk criteria for at least two applications.

#### 6.2.1.1 Missile Test Ranges

Individual and societal risk criteria have been developed addressing hazardous activities associated with the operation of DOD missile test ranges.[153] As shown in Table 26 and Figure

[152] Trbojevic, V.M., Risk Criteria in EU. Risk Support Limited, London, U.K.
[153] Common Risk Criteria Standards for National Test Ranges, Standard 321-07, U.S. Department of Defense, June 2007.

21, the criteria address both the risks to the general public and to mission essential personnel and critical operations personnel.

**Table 26. Individual and Societal Risk Criteria for DOD Test Range Operations[154]**

| Basis | Undesired Event | Maximum Acceptable Value | |
|---|---|---|---|
| | | Mission Essential and Critical Operations Personnel (IR) | General Public (SR) |
| Per Mission | Individual probability of casualty | 1x10-5 | 1x10-6 |
| | Expected casualties, casualty/event | 1x10-4 | 1x10-4 |
| | Individual probability of fatality | 1x10-6 | 1x10-7 |
| | Expected fatalities, fatality/event | 1x10-4 | 1x10-5 |
| Annual | Expected casualties, casualty/year | 1x10-2 | 1x10-3 |
| | Expected fatalities, fatality/event | 1x10-2 | 1x10-3 |

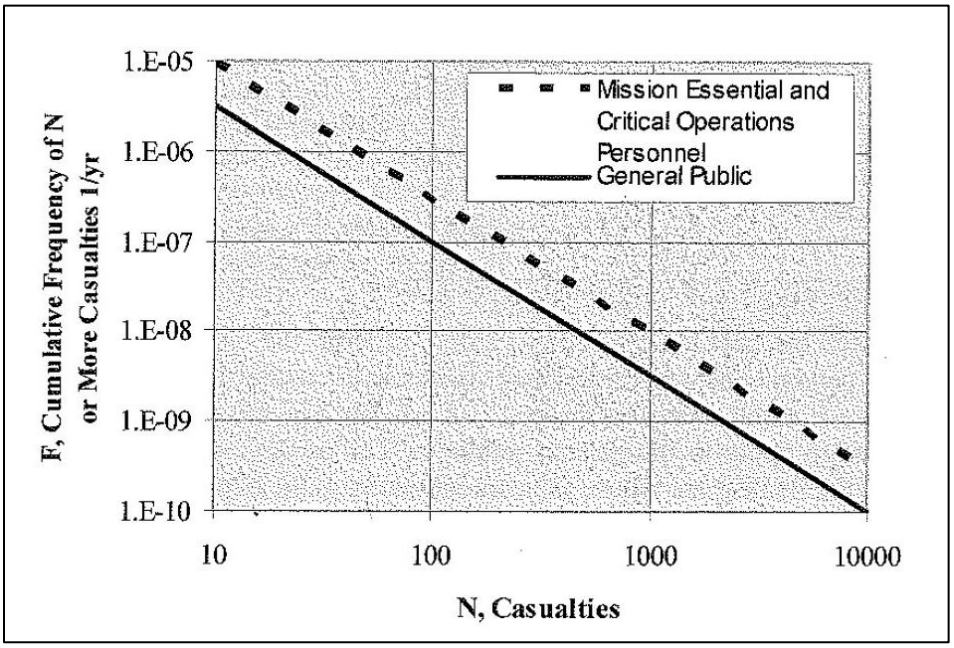



**Figure 21. DOD Test Range Societal Risk Criteria[155]**

[154] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 157.
[155] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 157.

#### 6.2.1.2 Explosives Handling Operations

As discussed in the CCPS Guideline, DOD risk criteria for explosives handling operations have been developed by the Risk-Based Explosives Safety Criteria Team of the DOD Explosives Safety Board. The criteria are summarized in Table 27.

**Table 27. Individual and Societal Risk Criteria for DOD Explosives Handling Operations[156]**

| Risk To: | Acceptance Criteria |
|---|---|
| **Workers** | |
| Any one worker (annual probability of fatality), fatality/year | Limit maximum risk to $1x10^{-4}$ |
| All workers (annual expected fatalities), fatality/year | Attempt to lower risk if above $1x10^{-3}$ Accept above $1x10^{-2}$ only with significant national need |
| **Public** | |
| Any one person (annual probability of fatality), fatality/year | Limit maximum risk to $1x10^{-6}$ |
| All public (annual expected fatalities), fatality/year | Attempt to lower risk if above $1x10^{-5}$ Accept above $1x10^{-3}$ only with significant national need |

The criteria for any one worker or person represent the IR criteria, while the criteria for all workers or all public represent SR criteria. The criteria for the public are intended to apply to the general public as well as government employees working at the facility but whose jobs are unrelated to the explosives activity.

#### 6.2.1.3 Defense Systems

DOD's Mil-Std-882E outlines the DOD approach for identifying hazards and assessing and mitigating associated risks encountered in the development, test, production, use, and disposal of defense systems. The Standard covers hazards as they apply to systems / products / equipment / infrastructure (including both hardware and software) throughout design, development, test, production, use, and disposal.

Severity and probability levels are assessed using the definition in Mil-Std-882E. Risks are expressed as a Risk Assessment Code (RAC). The associated risk matrix (Figure 22) is to be used unless tailored alternative definitions and/or a tailored matrix are formally approved. When a hazard cannot be eliminated, the associated risk should be reduced to the lowest acceptable level within the constraints of cost, schedule, and performance by applying the system safety design order of precedence. The system safety design order of precedence identifies alternative mitigation approaches and lists them in order of decreasing effectiveness.

[156] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 158.

| RISK ASSESSMENT MATRIX | | | | |
|---|---|---|---|---|
| SEVERITY / PROBABILITY | Catastrophic (1) | Critical (2) | Marginal (3) | Negligible (4) |
| Frequent (A) | High | High | Serious | Medium |
| Probable (B) | High | High | Serious | Medium |
| Occasional (C) | High | Serious | Medium | Low |
| Remote (D) | Serious | Medium | Medium | Low |
| Improbable (E) | Medium | Medium | Medium | Low |
| Eliminated (F) | Eliminated | | | |

**Figure 22. DOD Risk Assessment Matrix[157]**

## 6.2.2 Department of the Interior (DOI)

### 6.2.2.1 Bureau of Reclamation

The Bureau of Reclamation uses two guidelines to assess dam safety risk: 1) Annualized Failure Probability (similar to IR criteria); and 2) Annualized Life Loss (similar to SR criteria).

#### 6.2.2.1.1 Bureau of Reclamation Annualized Failure Probability Criteria Development

The Bureau of Reclamation uses an annualized failure probability (similar to IR criteria) to ensure a minimum level of safety even when the consequences are not high. This guideline is used to maintain public trust by assuring a low likelihood of dam failure.[158] The following guideline is used by the Bureau and is represented by the horizontal line at 1 x $10^{-4}$ dam failures/year in Figure 23:[158]

> *...a guideline of 1 in 10,000 per year for the accumulation of failure likelihoods from all potential failure modes that would result in life-threatening unintentional release of the reservoir. When the mean estimate is above this threshold level there is generally increasing justification to take action to reduce or better understand the risks. Below this threshold level there is generally decreasing justification to reduce or better understand the risks.*

***Dam Safety Public Protection Guidelines – A Risk Framework to Support Safety Decision-Making (p 10)***

[157] MIL-STD-882E. Department of Defense Standard Practice – System Safety. May 11, 2012.
[158] U.S. Department of the Interior – Bureau of Reclamation Dam Safety Office. Reclamation Managing Water in the West. Interim Dam Safety Public Protection Guidelines. A Risk Framework to Support Dam Safety Decision-Making.

#### 6.2.2.1.2 Bureau of Reclamation Annualized Life Loss Criteria Development

The Bureau of Reclamation also defines an annualized life loss criterion (similar to SR criteria) to recognize society's risk aversion to low probability, high consequence events. The Bureau defines this risk as:[159]

> *...Annualized Life Loss, and uses a guideline of 0.001 fatalities per year to address this measure of risk. When the mean estimate is above the guideline of 0.001 fatalities per year, there is generally increasing justification to take action to reduce or better understand the risks. There is generally decreasing justification to reduce or better understand the risks when they are below this guideline.*

***Dam Safety Public Protection Guidelines – A Risk Framework to Support Safety Decision-Making (p 10)***

This criterion is represented by the line with a (-1) slope in Figure 23. ALARP principles are also used but in a manner that differs from most other SR criteria discussed thus far. Instead of ALARP being the region below a maximum tolerable criterion or in between maximum tolerable and broadly acceptable criteria, it is represented by a region below $1 \times 10^{-6}$ annualized failure probability and greater than 1,000 fatalities. The guidance document suggests that ALARP principles be considered in this region and encourages additional interaction between decision-makers and risk estimators to understand the uncertainty in the calculations and basis for the risks that fall into this region.[159]

In addition, the Bureau did not want to define prescriptive risk criteria but rather broad advisory guidance:[159]

> *Due to the approximate nature of the risk estimates, risks just below the lines are essentially the same as risks just above the lines. Therefore, risk estimates plotting just below the line have almost as strong justification for action as those plotting just above. When risks are near the guideline values and confidence in the risk estimates is not high, a prudent course of action may be to gather additional data or conduct additional analyses to better define the risks.*

***Dam Safety Public Protection Guidelines – A Risk Framework to Support Safety Decision-Making (p 13)***

With this philosophy in mind, the Bureau provides a framework for decision making based on the annualized life loss or annualized failure probability combined with confidence in the risk results. Decision outcomes may be to do nothing (risks are low and confidence is high), identify risk reduction measures (risks are high and confidence is high), or take action to increase confidence in risk results so that a more clear decision can be made. This decision matrix is provided in Figure 24.

---

[159] U.S. Department of the Interior – Bureau of Reclamation Dam Safety Office. Reclamation Managing Water in the West. Interim Dam Safety Public Protection Guidelines. A Risk Framework to Support Dam Safety Decision-Making.

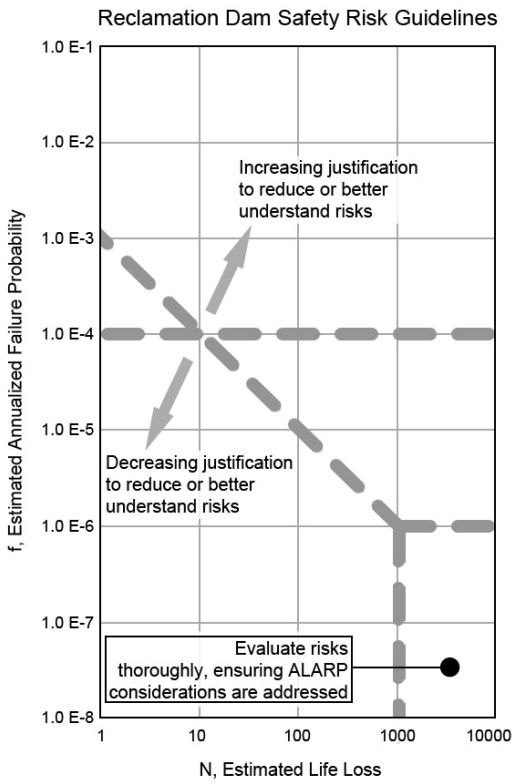



**Figure 23. Bureau of Reclamation Risk Tolerability Guidelines[160]**

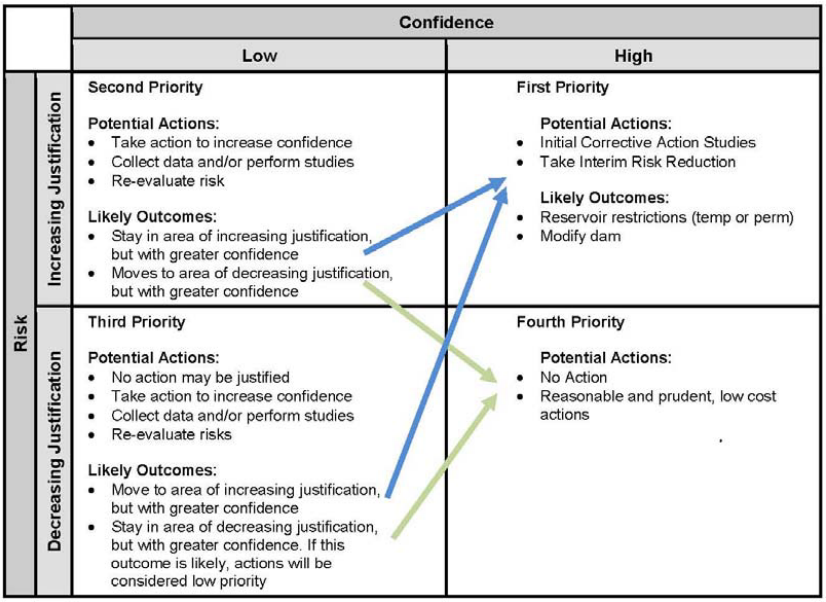



**Figure 24. Bureau of Reclamation Decision Matrix[160]**

[160] U.S. Department of the Interior – Bureau of Reclamation Dam Safety Office. Reclamation Managing Water in the West. Interim Dam Safety Public Protection Guidelines. A Risk Framework to Support Dam Safety Decision-Making.

## 6.2.3 Department of Transportation (DOT)

### 6.2.3.1 Federal Railroad Administration (FRA)

#### 6.2.3.1.1 Safety-Critical Train Control Systems

The FRA's Office of Research and Development has developed a methodology for a quantitative risk analysis of proposed safety-critical train control systems.[161] They've developed a software tool to help automate the process of data preparation and risk comparison between the current system operation (base case) and the proposed case. The comparison enables the calculation of tolerable hazard rates that the proposed system must be designed not to exceed. That is, the proposed safety-critical train control system will be at least as safe as the system it replaces, in accordance with DOT FRA Regulations.

The Practical Risk Assessment Methodology (PRAM) is a Cause-Consequence Analysis supported by event tree analyses, and by statistical analysis of available historical data from FRA's Railroad Accident/Incident Reporting System (RAIRS). The accident probabilities and consequences are calculated for each hazard, and then the collective risks are calculated in the form of total cost of accidents per train-mile for the base case and proposed system. The proposed case risk is compared to the existing system to arrive at the quantitative hazard rates that the proposed system is intended to replace. These hazard rates, called tolerable hazard rates, form a key part of the safety requirements specification for the proposed system. The risk is expressed in terms of $/train mile, based on number of accidents that could occur, the accident severity in terms of dollars, and traffic volume.

The FRA indicates that other industry standards can be used to define the tolerable risk level or acceptable safety performance limit, such as the GAMAB (which means, globally at least as good) principle, ALARP (as low as reasonably possible) principle, and the MEM (minimum endogenous mortality) principle. The GAMAB principle requires the risk of the new system to be no higher than that associated with the system being replaced. An upper and a lower bound on tolerable individual fatality rate in fatalities per year can be derived from the ALARP principle. And a single value for ASPL can be derived from the MEM principle.[162]

[161] U.S. DOT, FRA. A Practical Risk Assessment Methodology for Safety-Critical Train Control Systems. DOT/FRA/ORD-09/15. July 2009.
[162] Different Approaches For Determination of Tolerable Hazard Rates, by Dr. Hendrik Schäbe, Institute for Software, Electronics, Railroad Technology, TÜV InterTraffic GmbH, 51105 Köln (2001).

## 6.2.4 Environmental Protection Agency (EPA)

### 6.2.4.1 EPA Individual Cancer Risk Criteria Development

As reported by CCPS, "the EPA uses QRA to support decision-making in the implementation of a number of regulations for which the Agency is responsible."[164] In a predominance of cases, the risk criteria pertain to an individual's risk of dying from cancer over a lifetime exposure to a chemical. This type of criteria is based on a chronic exposure rather than an acute exposure as most of the other risk criteria discussed in this report address (immediate or prompt fatality). Therefore, to compare on a common basis, an assumption of lifetime[163] for the chronic exposure must be assumed to determine the IR as fatality/year.

**Table 28. Summary Various Individual Risk Criteria Used by the EPA (as of 1996)[164]**

| Regulation | Typical Acceptable Residual Risk Fatality/Lifetime | Broadly Acceptable IR Fatality/Year | Comments |
|---|---|---|---|
| TSCA (Toxic Substances Control Act) | Occupational: $10^{-4}$ to $10^{-5}$<br>Non-Occupational: $10^{-5}$ to $10^{-6}$ | $2.5 \times 10^{-6}$ to $1.4 \times 10^{-7}$<br>$2.5 \times 10^{-7}$ to $1.4 \times 10^{-8}$ | Unstated, but values are typical |
| FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act) | Occupational: $10^{-4}$ to $10^{-5}$<br>Non-Occupational: $10^{-5}$ to $10^{-6}$ | $2.5 \times 10^{-6}$ to $1.4 \times 10^{-7}$<br>$2.5 \times 10^{-7}$ to $1.4 \times 10^{-8}$ | Unstated, but values are typical |
| FFDCA (Federal Food, Drug, and Cosmetic Act) | Zero for additives<br>Average diet: $10^{-6}$<br>Non-dietary: $10^{-6}$ | 0<br>$1.4 \times 10^{-8}$<br>$1.4 \times 10^{-8}$ | |
| SDWA (Safe Drinking Water Act) | $1 \times 10^{-4}$ to $1 \times 10^{-6}$ | $1.4 \times 10^{-6}$ to $1.4 \times 10^{-8}$ | |
| CWA (Clean Water Act) | $1 \times 10^{-5}$ to $1 \times 10^{-7}$ | $1.4 \times 10^{-7}$ to $1.4 \times 10^{-9}$ | |
| RCRA (Resource Conservation and Recovery Act) | For listing of a site: $10^{-5}$<br>Corrective action: $10^{-4}$ to $10^{-6}$<br>Incinerators: $10^{-5}$ | $1.4 \times 10^{-7}$<br>$1.4 \times 10^{-6}$ to $1.4 \times 10^{-8}$<br>$1.4 \times 10^{-7}$ | |
| CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) | $1 \times 10^{-4}$ to $1 \times 10^{-6}$ | $1.4 \times 10^{-6}$ to $1.4 \times 10^{-8}$ | Depending in part on intended future use of site |
| CAA (Clean Air Act) | $1 \times 10^{-6}$ | $1.4 \times 10^{-8}$ | Legislative trigger in the CAA Amendments for enhancement of Maximum Available Control Technology requirements |

### 6.2.4.2 EPA 'Effective Dose Equivalent' Individual Risk Criteria Development

The responsibilities in assessing risk for Yucca Mountain have been mandated by law in the Energy Policy Act of 1992.[165] The U.S. Environmental Protection Agency (EPA) is required to

[163] The EPA assumes a lifetime of 70 years for public exposures and 40 years for occupational exposures.
[164] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 154.
[165] Energy Policy Act of 1992. (1992). Public Law 102-486.

promulgate public health and safety standard for radioactive material stored or disposed of in the Yucca Mountain repository. The U.S. Nuclear Regulatory Commission (NRC) is required to incorporate the EPA standards into licensing standards for the Yucca Mountain repository, while the Department of Energy (DOE) is required to show compliance with the NRC standard. These regulatory requirements come from two primary sources, with 40 CFR Part 197 being the one that has been promulgated by the EPA.

40 CFR §197.2 define the risk metrics of interest:

> *The DOE must ensure that no member of the public in the general environment receives more than an annual committed effective dose equivalent of 150 microsieverts (15 millirems) from the combination of …*

***40 CFR §197.4***

This paragraph defines the type of risk under consideration. It is an individual risk (as stated by "no member of the public") in the vicinity of Yucca Mountain ("in the general environment"). The individual is defined also by the regulation as "reasonably maximized exposed individual" (RMEI). It is therefore a different approach than for the WIPP (see Section 0), where the risk was based on release of radionuclide and not impact on individual.

Radioactivity poisoning leading to cancer is the primary concern in the case of radioactive waste management (prompt fatality due to exposure to radionuclide is negligible in this case). Therefore considering the risk of fatality would not have been appropriate. As such, the choice was to regulate on an additional exposure to radiation that could be attributed to the repository. The initial requirement was defined for a period of 104 years. However, it was not following the guidance from the National Academy of science[166] as mandated by Congress in the Energy Policy Act of 1992. As a result, 40 CFR §197 was published by the EPA with a revision of the standards and extension of the period from 104 years to geological stability (106 years).

The limit for the period between 104 years and 106 years is set to 1 millisievert (100 millirems).

The risk is measured by a metric called "annual committed effective dose" which is defined in 40 CFR §197.2.

The choice of word is important as it indicates the form of output required by EPA to regulate. An annual dose had to be estimated for a period of time. Which means the metric was a time dependent quantity that should be no more than the regulatory thresholds.

[166] National Research Council. (1995). Technical Bases for Yucca Mountain Standards. Washington D.C.: National Academies Press.

10 CFR §63.303 goes beyond the definition with the indication that it has to be an arithmetic mean (implying there is some uncertainty in the process that needs to be captured and that the regulation will be applied to the mean).

> *Compliance is based upon the arithmetic mean of the projected doses from DOE's performance assessments for the period within 1 million years after disposal…*

***10 C.F.R. §63.303***

DOE therefore developed an expected dose (i.e. averaged over aleatory uncertainty) including all scenario classes under consideration. The mean (over epistemic uncertainty) was selected as the regulatory metric.

Figure 25 represents graphically the regulation thresholds (15 mrem/year up to 10,000 years; 100 mrem/year from 10,000 years to 106 years) considered for the Yucca Mountain project.

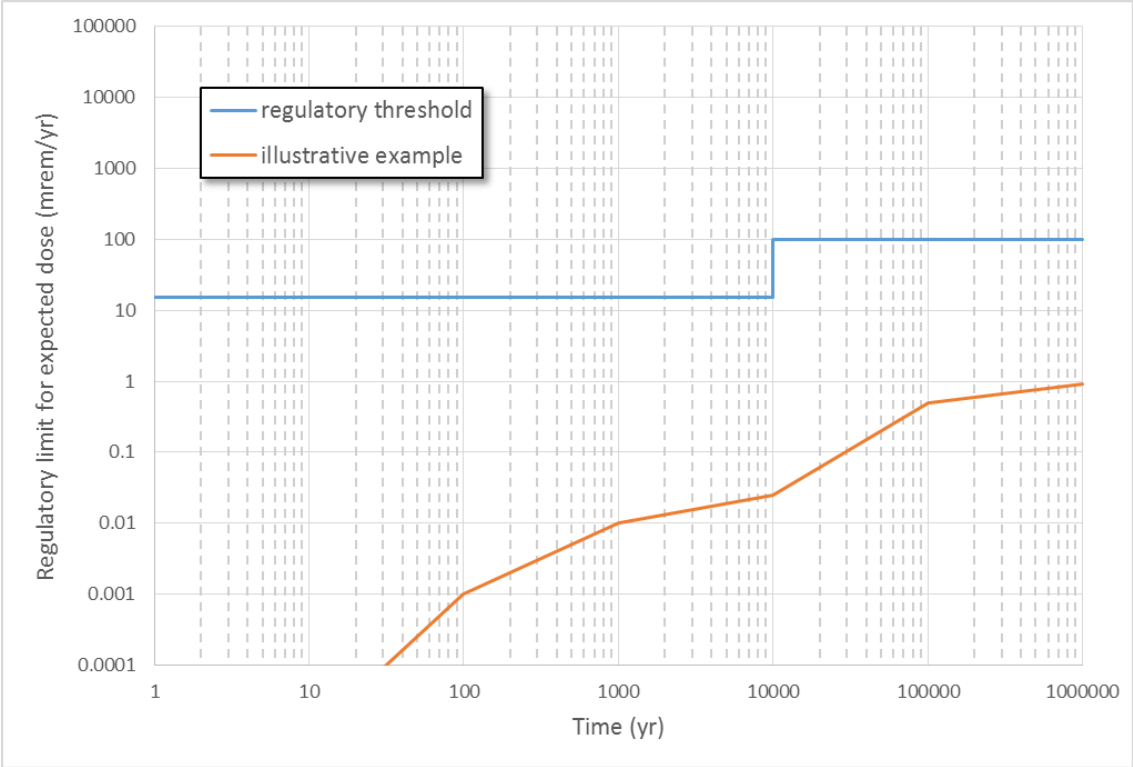



**Figure 25. Representation of Threshold used for Yucca Mountain with an Illustrative Example of Mean Annual Dose**

#### 6.2.4.3 Environmental Risk Criteria Development

The Waste Isolation Pilot Plant (WIPP) Land Withdrawal Act (LWA) passed by Congress in 1992 and amended in 1996 assigns the responsibility of the regulatory oversight to the EPA.[167,168] The resulting regulation requirement can be found in 40 C.F.R. §191.13:

> *Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (appendix A); and (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1(appendix A).*

***40 C.F.R. §191.13***

The type of risk is therefore not defined as a direct measure applied to human health, but rather an intermediate value represented by the cumulative amount of selected radionuclides released in the environment.

Another important aspect of this metric is that it is cumulative over time, so it does not have the temporal component. This metric is estimated directly at 10,000 years.

As a risk, however, it is not represented as a convolution of both likelihood and magnitude, but as a composed representation, in which a certain magnitude should be below a certain probability of occurrence. The regulation threshold is less than 0.1 probability of reaching the regulatory amount and less than a 0.001 probability to reach 10 times this amount. See Figure 26 for an example of the WIPP regulatory threshold limit.

[167] WIPP Land Withdrawal Act. (1992). Public Law 102-579.
[168] WIPP Land Withdrawal Act as Amended. (1996). Law 104-201.

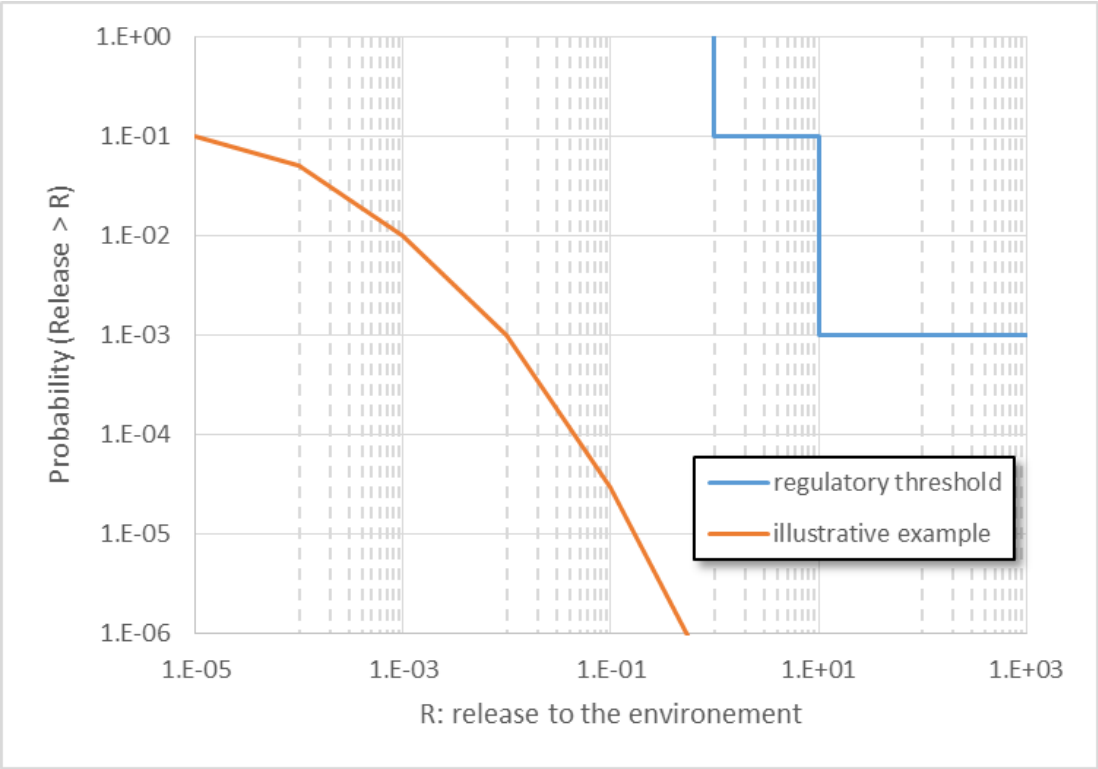



**Figure 26. Representation of Regulatory Threshold for WIPP with an Illustrative CCDF[169]**

#### 6.2.4.4 EPA Impact Risk Criteria Development

The EPA Risk Management Plan (RMP) rule was promulgated under 40 CFR Part 68 for chemical accident prevention and mitigation at facilities that use large quantities of specific regulated hazardous substances. Requirements of the RMP rule include hazard assessments, prevention programs, and emergency response plans. For facilities subject to the rule, they must complete an offsite consequence analyses to provide information to state, local and federal government agencies and the public about the consequences of an accidental release on the surrounding public and environment.[170] There are two elements to the analysis: 1) worst-case release scenario (release of the largest quantity from a single vessel or process line failure) and 2) alternative release scenario (more likely but still can reach offsite receptors). Depending on the results of the analysis, a facility may be required to follow more (or less) stringent regulatory requirements.

[169] Complementary Cumulative Distribution Function (CCDF)
[170] U.S. EPA. Risk Management Program Guidance for Offsite Consequence Analysis. EPA 550-B-99-009. March 2009. http://www.epa.gov/sites/production/files/2013-11/documents/oca-chps.pdf

The consequence endpoints that are specified in 40 CFR Part 68.22 are as follows:

- Toxics: Endpoint (mg/L) depends on the hazardous substance
- Flammables – Explosion: 1 psi overpressure
- Flammables – Radiant heat/exposure time: 5 kW/m2 for 40 seconds
- Flammables – Flash fire: Lower Flammability Limit (LFL)

For fewer regulatory requirements, the distances to these endpoints must not reach any offsite receptors, the facility must not have had an accidental release of a regulated substance in the past five years that led to an offsite death, injury, or environmental response or restoration, and emergency response procedures have been coordinated with local responders.

Although the consequence-based criteria used by EPA are not used for specific land use planning decisions, they are used for determination of the required regulatory oversight.

## 6.2.5 Food and Drug Administration (FDA)

### 6.2.5.1 FDA Individual Cancer Risk Criteria Development

Very little information was found beyond what was reported by CCPS. Similar to the EPA, the FDA uses criterion for lifetime cancer risk from exposure to cosmetics and food additives, colors, and contaminants. The criterion reported is a risk of $1 \times 10^{-6}$ fatality/lifetime which is equivalent to $1.4 \times 10^{-8}$ fatality/year, assuming a 70 year lifetime.[171]

## 6.2.6 Occupational Safety and Health Administration (OSHA)

### 6.2.6.1 OSHA Individual Cancer Risk Criteria Development

Again, very little information was found on the use of risk tolerability criteria within OSHA, aside from what was reported by the CCPS regarding risk acceptability for workplace exposure to benzene. In this publication, the criterion presented is a risk of $1 \times 10^{-3}$ fatality/lifetime which is equivalent to $2.2 \times 10^{-5}$ fatality/year, assuming a 45-year lifetime.[171]

### 6.2.6.2 OSHA Process Safety Management

The OSHA Process Safety Management (PSM) rule was promulgated under 29 CFR Part 1910 for preventing or minimizing the consequence of catastrophic releases of toxic, reactive, flammable, or explosive chemicals.[172] There are several requirements mandated by the PSM rule including process hazard analysis, operating procedures, training, mechanical integrity, etc.

[171] CCPS Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009, page 155.
[172] OSHA. Process Safety Management of Highly Hazardous Chemicals. https://osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760

Although, specific risk tolerability criteria are not provided to help comply with portions of this regulation, the authors have worked with several oil & gas companies that include a risk evaluation when performing their process hazard analyses (PHAs), specifically during hazard and operability studies (HAZOPs). Some of these operators used risk tolerance criteria based on cost-benefit assumptions to determine what HAZOP recommendations to implement.

## 6.2.7 Santa Barbara County, California

A few local authorities, like the Santa Barbara County Planning and Development Department, require the use of risk assessment for land use planning and siting of hazardous facilities. The risk tolerability criteria provided by the Planning and Development Department focus on acute risks from threshold quantities of hazardous materials to which the public may be involuntarily exposed. However, the Planning and Development Department may still approve projects that present an unacceptably high risk, even after risk reduction, so long as there is substantial evidence supporting the project. As discussed in the Environmental Thresholds and Guidelines Manual "these thresholds should not function as the sole determinants of significance for public safety impacts. Rather, they must be used in concert with applicable County policy, regulation, and guidelines to address other qualitative factors specific to the project which also help determine the significance of risk."[173]

Facilities that are required to conduct a QRA are determined through a screening process which evaluates the reasonable worst-case distance to the threshold level for hazardous materials. If the hazard zone encompasses off-site receptors and the calculated personal-based individual risk (accounts for exposure time) is greater than $1 \times 10^{-6}$ fatality/year, then it is subject to detailed QRA. Certain facilities, like major sour gas pipelines and gas processing facilities are automatically subject to QRA and risk thresholds.[174]

### 6.2.7.1 Santa Barbara Individual Risk Criteria Development

As discussed above, IR calculations are only used to determine if a facility is required to conduct a QRA and not used to determine risk tolerability. The IR value that triggers the QRA requirement is an IR greater than one fatality in a million years ($1 \times 10^{-6}$ fatality/year).

### 6.2.7.2 Santa Barbara Societal Risk Criteria Development

Figure 27 provides the Santa Barbara SR criteria. The maximum tolerable SR criterion is an incident with 10 or more fatalities that could occur once in 100,000 years at a slope of (-2). This criterion is equivalent to the Dutch criteria for a single hazardous facility. The broadly

[173] County of Santa Barbara Planning and Development. Environmental Thresholds and Guidelines Manual. October 2008
[174] County of Santa Barbara Planning and Development. Environmental Thresholds and Guidelines Manual. October 2008

acceptable region (green zone) is two orders of magnitude lower than the maximum tolerable region.

New developments with risk profiles (including risk reduction measures) that enter the red zone in Figure 27 are deemed unacceptable and as such will not be approved for development. More stringent criterion is applied for new developments with highly sensitive land use (schools, hospitals, etc.) which deems the mitigated risk to be unacceptable if it enters the amber zone. For non-sensitive land use, ALARP principles are applied in the amber zone. Any risk profile that falls solely in the green zone is deemed to have an insignificant impact on public safety and requires no risk reduction measures. The same criteria apply where modifications to existing facilities might increase the risk into the red zone (or amber zone for sensitive land use).

The Santa Barbara societal risk criteria are more conservative than most of the other countries reviewed, especially with regards to sensitive land use in which it is the most conservative of all SR criteria reviewed.

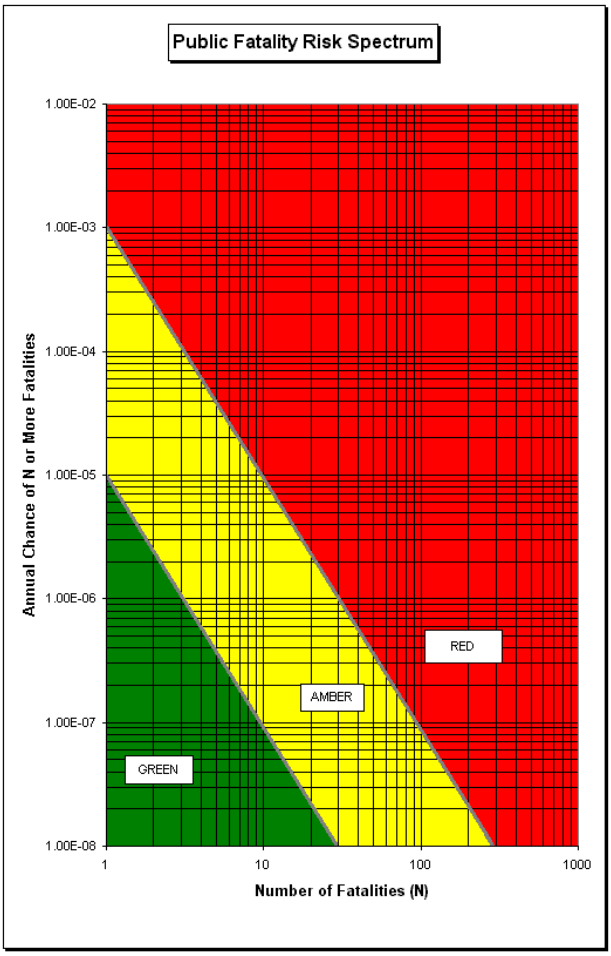



**Figure 27. Santa Barbara Societal Risk Criteria[174]**

## 6.2.8 Nuclear, Aeronautical, and Aerospace Industries

Many of the risk methods used in the nuclear, aeronautical, and aerospace industries are the same, or very similar, to those used in the oil and gas industry. However, there are specific risk assessment methods that do not appear in typical risk analyses used by other industries. Because of the general unfamiliarity with specific terms used as part of these analyses, definitions are provided in the glossary that are unique to the nuclear, aeronautical, and aerospace industries. For example, damage tolerant analyses, and epistemic and aleatory analyses may be methods that are unfamiliar even to a seasoned practitioner of risk in the oil and gas field but are common in nuclear and aeronautical risk analyses. Additionally, there is extensive use of event tree and fault tree analysis in the aerospace and nuclear industry that is rarely seen for pipeline risk analyses.

This section will consider the rationale and approach used in the Nuclear, Aeronautical and Aerospace industries to set up thresholds that could be used to assess what was acceptable or not in term of risk.

### 6.2.8.1 Department of Energy (DOE)

### 6.2.8.2 General Guidance

DOE has two quantitative safety objectives that are established as “aiming points” (not requirements) that guide the development of DOE’s nuclear safety requirements and standards:[175]

- The risk to an average individual in the vicinity of a DOE nuclear facility for prompt fatalities that might result from accidents should not exceed one-tenth of one percent (0.1%) of the sum of prompt fatality risks resulting from other accidents to which members of the population are generally exposed. For evaluation purposes, individuals are assumed to be located within one mile of the site boundary.
- The risk to the population in the area of a DOE nuclear facility for cancer fatalities that might result from operations should not exceed one-tenth of one percent (0.1%) of the sum of all cancer fatality risks resulting from all other causes. For evaluation purposes, individuals are assumed to be located within 10 miles of the site boundary.

### 6.2.8.3 Nuclear Regulatory Commission (NRC)

The present regulations for obtaining an operating license for a nuclear power plant are based on deterministic and prescriptive requirements that cannot be quickly replaced. Therefore, the

[175] Technical Basis for U.S. Department of Energy Nuclear Safety Policy, DOE Policy 420.1, U.S. Department of Energy, July 2011.

current requirements are maintained, while risk-informed and/or performance-based regulations are being developed and implemented.

The NRC developed the Probabilistic Risk Assessment (PRA) Implementation Plan in 1994 to focus the agency's efforts on PRA-related activities. This plan was superseded in 2000 by the Risk-Informed Regulation Implementation Plan (RIRIP). Then, in April 2007, the NRC replaced the RIRIP with the Risk-Informed, Performance-Based Plan (RPP). The NRC interpretation of the commission statement on risk informed regulation is summarized below:[176]

The NRC established its regulatory requirements for reactor, materials, and waste applications to ensure that "no undue risk to public health and safety" results from licensed uses of facilities and materials covered by the Atomic Energy Act. In other words, the NRC's requirements ensure that there is a low probability of accidents that could adversely affect the health and safety of the public.

The white paper stated that:

“The Commission is advocating certain changes to the development and implementation of its regulations through the use of risk-informed, and ultimately performance-based, approaches. The Probabilistic Risk Assessment (PRA) Policy Statement (60 FR 42622, August 16, 1995) formalized the Commission's commitment to risk-informed regulation through the expanded use of PRA.”

Explicitly, the Commission’s PRA policy statement states that:

1 The use of PRA technology should be increased in all regulatory matters to the extent supported by the state-of-the-art in PRA methods and data and in a manner that complements the NRC’s deterministic approach and support the NRC’s traditional defense-in-depth philosophy.

2 PRA and associated analyses should be used in regulatory matters, where practical within the bounds of the state-of-the art, to reduce unnecessary conservatism associated with current regulatory requirements, regulatory guides, license commitments, and staff practices. Where appropriate, PRA should be used to support the proposal for additional regulatory requirements in accordance with 10 CFR 50.109. Appropriate procedures for including PRA in the process for changing regulatory requirements should be developed and followed.

3 PRA evaluations in support of regulatory decisions should be as realistic as practicable and appropriate supporting data should be publicly available for review.

[176] Nuclear Regulatory Commission. (2007). UPDATE ON THE IMPROVEMENTS TO THE RISK-INFORMED REGULATION IMPLEMENTATION PLAN. NRC.

4 The Commission's safety goals for nuclear power plants and subsidiary numerical objectives are to be used with appropriate consideration of uncertainties in making regulatory judgments on the need for proposing and back fitting new generic requirements on nuclear power plant licenses.

The Commission, in the white paper, noted that "to understand and apply the commitment expressed in the PRA Policy Statement, it is important that the NRC, the regulated community, and the public at large have a common understanding of the terms and concepts involved."

The following provides the Commission's definitions of the terms and the Commission expectations regarding risk-informed and performance-based regulation.

- Risk-informed regulation – "A risk-informed approach to regulatory decision-making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to public health and safety."

- Performance-based regulation – "A performance-based regulatory approach is one that establishes performance and results as the primary bases for regulatory decision making, and incorporates the following attributes: (1) measurable (or calculable) parameters (i.e., direct measurement of the physical parameter of interest or of related parameters that can be used to calculate the parameter of interest) exist to monitor system, including facility and licensee, performance, (2) objective criteria to assess performance are established based on risk insights, deterministic analyses and/or performance history, (3) licensees have flexibility to determine how to meet the established performance criteria in ways that will encourage and reward improved outcomes, and (4) a framework exists in which the failure to meet a performance criterion, while undesirable, will not in and of itself constitute or result in an immediate safety concern."

- Risk-informed and performance-based regulation – "A risk-informed and performance-based approach to regulatory decision-making combines the risk-informed and performance-based elements discussed … above, and applies these concepts to NRC rulemaking, licensing, inspection, assessment, enforcement, and other decision making."

There are two additional supporting reports, all of which provide many words that state the NRC will continue to use deterministic methods for licensing plants but that risk should be considered to insure public safety. For operating licensing many risk analyses are recommended, e.g. PRA, but there are no deterministic values given.

After plant operating licenses have been granted there have been new risks that were identified. These are either aging risks or emergent risks and there is a specific case where risk does provide the basis for action. Nuclear power plants were designed with pipe whip restraints to guard against the occurrence of a "double ended guillotine" break of the pipe and subsequent large pipe movement that damages other systems particularly the emergency core cooling system. Because these restraints must be placed very closely to the pipe the vibration and thermal expansion loads were causing initiation damage to the pipe. The Nuclear Regulatory Commission (NRC) Standard Review Plan (SRP) 3.6.3 describes Leak-Before-Break (LBB) assessment procedures that can be used to demonstrate compliance with the 10 CFR 50 Appendix A, GDC-4 requirement that primary system pressure piping exhibit an extremely low probability of rupture. SRP 3.6.3 does not allow for assessment of piping systems with active degradation mechanisms, such as Primary Water Stress Corrosion Cracking (PWSCC) which is currently occurring in systems that have been granted LBB exemptions. Along with the existing qualitative steps to assuring safety in LBB lines with PWSCC, the NRC staff, working cooperatively with the nuclear industry through a memorandum of understanding, is developing a new, modular based, comprehensive piping system assessment methodology to directly demonstrate compliance with the regulations. This tool, called xLPR (eXtremely Low Probability of Rupture), would properly model the effects and uncertainties of both active degradation mechanisms and the associated mitigation activities. This program will be released in May 2016. However, the definition of extremely low has never been defined so changes may become necessary depending on the commission's final deliberation.

#### 6.2.8.4 Federal Aviation Administration (FAA)

The use of risk assessment is identified and defined by the Federal Aviation Administration (FAA) and detailed in Federal Aviation Administration Risk Management Handbook.[177] However, these risks are identified and associated only with those activities that the FAA regulates. For example, pilot response or air traffic control. The FAA uses many of the similar methods and tools described in the previous sections as illustrated by Figure 28.

[177] Federal Aviation Administration. (2009). Risk Management Handbook. Washington DC: Federal Aviation Administration. Retrieved from http://www.faa.gov/library/manuals/aviation/

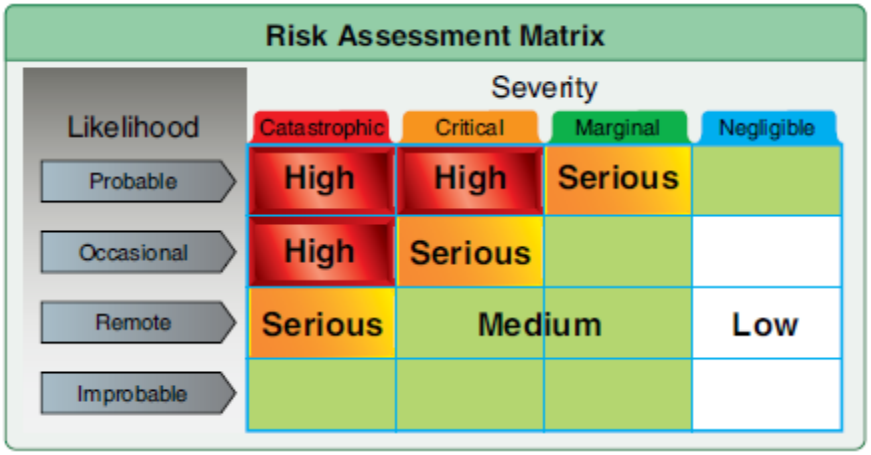



**Figure 28. FAA Semi-Quantitative Risk Criteria Example[178]**

The FAA regulates air traffic and commercial space transportation. However, there is no actual risk regulation performed by the FAA. For example if the regulations for fatigue[179] are examined,[180] the FAA requires the carriers to assess the risk of fatigue and to have a program and procedures in place that mitigate the risk without specifying any level of risk below which the carrier must reduce the risk. Quoting from the FAA Fatigue Risk Management Systems for Aviation Safety[180]:

> *An FRMS[181] consists of organizational processes and procedures to control fatigue risk in aviation operations. An FRMS is a data-driven and scientifically based process that allows for continuous monitoring and management of safety risks associated with fatigue-related error. It is part of a repeating performance improvement process. This process leads to continuous safety enhancements, by identifying and addressing fatigue factors across time and changing physiological and operational circumstances. Structurally, an FRMS is composed of processes and procedures for measuring, modeling, managing, mitigating, and reassessing fatigue risk in a specific operational setting. An FRMS is an effective fatigue mitigation strategy when the organization bases it on valid scientific principles. An FRMS combines schedule assessment, operational data collection, continuous and systematic analysis, and both proactive and reactive fatigue mitigations, guided by information provided by scientific studies of fatigue. Overall, an FRMS offers a way to more safely conduct flights by offering flexibility not available within regulatory limits. An FRMS complements prescriptive flight time, duty time, and rest period requirements.*

[178] Trbojevic, V.M., Risk Criteria in EU. Risk Support Limited, London, U.K.
[179] Fatigue in this case refers to human fatigue not metal fatigue
[180] Federal Aviation Administration. Fatigue Risk Management Systems for Aviation Safety. FAA Advisory Circular No: 120-103A. 2013.
[181] Fatigue Risk Management System

The document goes on to provide suggestions, which become less restrictive for smaller carriers, on what should be done to insure that the flight crew is well rested. None is mandated for risk. There are limits on the time for which a crew member can be on duty, see Table 29, however, none of these limits are related to any risk definition.

**Table 29. Comparison of Flight Crew Limits for the Proposed New FAA FAR Part 117 to the Current Rule**

| Item | "New" FAR Part 117 | Current Rule FAR Part 121 |
|---|---|---|
| Applicability | Applicable to all types of passenger operations - scheduled and non-scheduled, domestic and international. | Different rules for scheduled, non-scheduled, domestic, supplemental and international Part 121 operations. |
| Flight Duty Periods (FDP) | Limits the length of the FDP based on the time of day the pilot starts the FDP and number of landings the crew is to perform. See table below. | Currently there are no limits in the regulations. The 16-hour limit was obtained through a legal interpretation and does not take into account the time of report and is not adjusted for the number of flights scheduled in the FDP. |
| Minimum Rest | Minimum rest is 10 hours, which begins when the crew is released from duty. This is designed to ensure an 8-hour sleep opportunity. The crew will be required to notify the company if the rest break needs to be extended to achieve the 8-hour sleep opportunity. | 9 hours reducible to 8 hours that starts when the crew is released from duty and ends when the crew reports for duty. Does not factor in a sleep opportunity. |
| Reduced Rest | Not applicable. | Reducible to 8 hours rest. |
| Maximum Flight Time Limits, Un-augmented | Hard limit, not extendable. See Table below. | 8 hours scheduled that can be extended due to "unforeseen circumstances." |
| Cumulative Limitations | Cumulative fatigue protections are measured in terms of flight hours...<br>• 100 block hours in any 672 consecutive hours (28 days)<br>• 1,000 block hours in any 365-day period ... and duty hours:<br>• 60 flight duty period hours in any 168 consecutive hours<br>• 190 flight duty period hours in any 672 consecutive hours. | Limits flight hours on the basis of weekly, monthly and yearly basis dependent on type of operations flown and type of equipment operated (e.g. domestic, international or supplemental). |
| Flight Duty Period - Split Duty | Applied to night operations between the hours of 2200 and 0500 and requires a 3-hour rest in a suitable accommodation during the FDP. | No current limits. |
| Reserve | -Defines short-call and long-call reserve.<br>-Airport/standby reserve (as defined in Part 117) is part of the pilot's FDP.<br>-Maximum short-call reserve availability | Reserve not defined in current FAR. |

| Item | "New" FAR Part 117 | Current Rule FAR Part 121 |
|---|---|---|
| | period is 14 hours.<br>-Maximum amount of time spent on reserve and FDP is the value in the Table B FDP table plus 4 hours or 16 hours, whichever is less, as measured by the start of the reserve availability period.<br>- May be shifted from long-call to short-call only if pilot receives a legal rest period (10 hours). | |
| FDP Extensions | FDP may be extended by 2 hours with concurrence of PIC. Extension beyond 30 minutes can only occur once before receiving a 30-hour rest period. Any extension cannot violate the cumulative duty limit. Strict reporting requirements on all extensions beyond 30 minutes. | No current rule for extensions or reporting. Everything is based on scheduled operations and flight time. |
| Fitness for Duty | Joint responsibility between the pilot and the airline for ensuring the pilot is fit for duty. The pilot must sign that he or she is fit for duty to take the flight. If a pilot reports fatigue, he or she must be removed from the flight. | Current FAR is vague in regards to fitness for duty. |
| Fatigue Risk Management Systems | Provides an option to develop an FAA-approved FRMS. | No current option. |

For commercial aircraft there is an assumption that the aircraft is both fail safe[182] and damage tolerant. These concepts do not fit into any risk definition since they assume, by definition, that the aircraft is damaged but that this damage is controlled by design and inspections. We continue with an overview for methods that are in line with the classic risk definitions where consequences are measured by loss, e.g. property, life.

[182] Airbus does not use fail safe as a criterion in their design. This makes them a higher risk aircraft although this difference could be negligible compared to other uncertainties

For commercial space launches the FAA has a dual (and conflicting) role:

> *The FAA's authority to issue rules on commercial space transportation safety is found in Title 49 of the United States Codes, section 322(a), which authorizes the Secretary of Transportation to carry out the Commercial Space Launch Act of 1984, as amended and re-codified at 51 United States Code (U.S.C.) Subtitle V—Commercial Space Transportation, ch. 509, Commercial Space Launch Activities, 51 U.S.C. 50901-50923 (the Act). The Act authorizes the Secretary of Transportation and thus the FAA, through delegations, to oversee, license, and regulate commercial launch and reentry, and the operation of launch and reentry sites as carried out by U.S. citizens or within the United States. 51 U.S.C. 50904, 50905. The Act directs the FAA to exercise this responsibility consistent with public health and safety, safety of property, and the national security and foreign policy interests of the United States. 51 U.S.C. 50905. Section 50901(a)(7) directs the FAA to regulate only to the extent necessary, in relevant part, to protect the public health and safety and safety of property. The FAA is also responsible for encouraging, facilitating, and promoting commercial space launches and reentries by the private sector. 51 U.S.C. 50903.*

Thus, the FAA must oversee and license commercial space travel consistent with public health and safety but must also promote commercial space flight. In the FAA rule making for commercial space flight:

> *The FAA also recognizes that the federal launch ranges may perform separate $E_C$[183] analyses for three different hazard categories, including debris, toxic releases and blast overpressure. When the FAA relies on a federal launch range's $E_C$ analysis to determine whether the FAA $E_C$ requirement is met, the FAA is interested only in the debris analysis performed by a range, and this provision makes that clear. For toxic releases and blast overpressure, the federal launch ranges implement specific safety requirements designed to keep toxic releases and the effects of blast from reaching the public. For example, if more than a given number of parts per million of a toxic release would reach people, a launch will be delayed until conditions improve. Likewise, if atmospheric effects threaten to carry overpressure impact to persons outside the federal launch site, a launch will be delayed.*

Thus, for the commercial space launch a limit is defined. But there are three defined consequences: (1) debris, (2) toxic release, and (3) over pressurization. Each has an expected casualty ($E_C$) limit of 30 x $10^{-6}$ per launch. Ultimately, this means that the collective risk of casualty for a population of 50,000 people in the launch range could proceed if no more than two casualties are expected. No uncertainty in this prediction is included.

[183] $E_C$ is defined as the expected casualties for the population is the defined launch range per launch event.

As discussed by Skjong, the aircraft industry never presents societal risk diagrams like F-N curves because in the case of plane accidents, the outcome is mostly survivors or mostly casualties.[184]

#### 6.2.8.5 National Aeronautics and Space Administration (NASA)

Volume 1 of the NASA System Safety Handbook[185] presents the overall framework for system safety and the general concepts to implement the framework.

Traditionally, system safety assessment at NASA has focused on the application of a set of safety analysis tools to identify safety risks and formulate effective controls. Tools used for this purpose include various forms of hazard analyses, failure modes and effects analyses, and probabilistic safety assessment (commonly also referred to as probabilistic risk assessment (PRA)). In the past, it was assumed that to show that a system is safe, it is sufficient to provide assurance that the process for identifying the hazards has been as comprehensive as possible and that each identified hazard has one or more associated controls.

While historically this approach has been used reasonably effectively to ensure that known risks are controlled, NASA is moving to a more holistic, performance-based approach as systems become more complex and the cost of designing, building, and operating them become more of an issue.

The NASA System Safety Handbook states that an adequately safe system adheres to the fundamental principles of:

- Meeting or exceeding the minimum tolerable level of safety established by the stakeholders[186]
- Being as safe as reasonably practicable (ASARP)

Both of these principles apply throughout the entire system life cycle, from concept studies to closeout. The fundamental nature of these principles is illustrated in Figure 29, which shows a high level objectives hierarchy that comprise the overall fundamental objective “Achieve an adequately safe system” into its fundamental components, throughout the system life cycle. The resulting six objectives at the bottom of the figure set the stage for the further development of safety objectives on a system-by-system basis, as negotiated by the organizational unit performing the task and the unit overseeing the task.

---

[184] Skjong, R. Risk Acceptance Criteria: current proposals and IMO position. Surface transport technologies for sustainable development. June 2002.
[185] NASA System Safety Handbook. Volume 1, System Safety Framework and Concepts for Implementation, NASA/SP-2010-580, Version 1.0, November 2011.
[186] The minimum tolerable level of safety need not be fixed over the life cycle of the system.

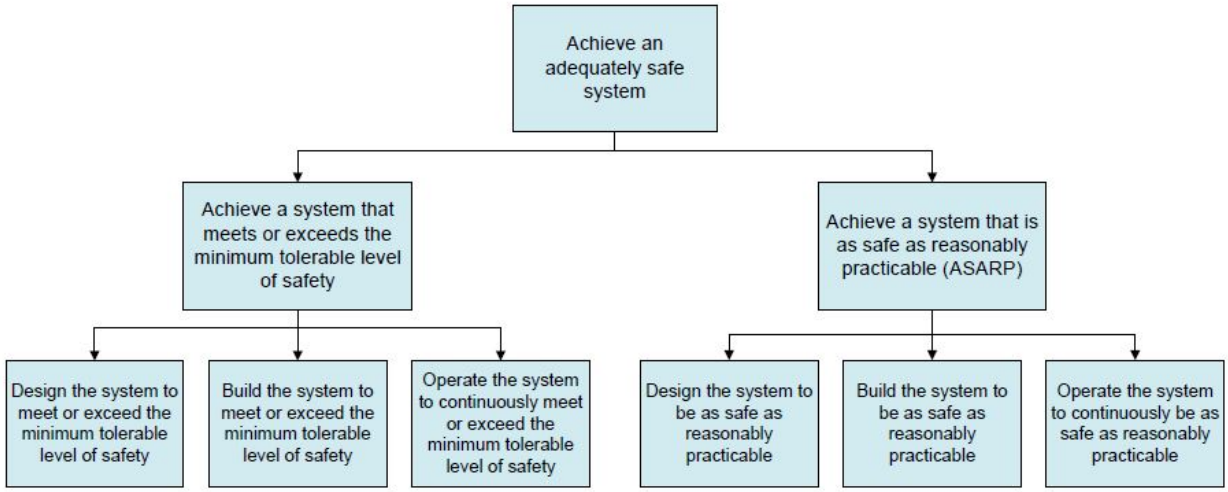



**Figure 29. Fundamental Principles of Adequate Safety**

The Handbook states that minimum tolerable levels of safety can be either explicit or implicit. NASA's safety goals and thresholds are explicit minimum tolerable levels of safety for transporting astronauts to the International Space Station (ISS). In other cases, such as robotic missions where loss of mission is the dominant concern, a minimum tolerable level of safety might not be explicitly defined. Instead, estimates (whether qualitative or quantitative) of the probability of loss of mission are considered in decision making, with minimum tolerable levels implicit in the decisions.

The NASA safety goals and thresholds reflect a tolerance for an initial safety performance that is below long-term expectations for safety, as expressed in terms of a design threshold, a requirement for life cycle continuous safety improvement, and a statement of verification protocol:

- **"Design Threshold:** At a minimum, the spaceflight system designed for transport of the crew to the ISS shall be at least as safe for the combined ascent and entry phases as the Space Shuttle was at the end of its operational life, and in the aggregate, for a 210-day mission to ISS, the system shall be at least as safe as the Space Shuttle was at the end of its operational life on a 12-day mission to the ISS.
- **Life Cycle Continuous Safety Improvement:** For the long term, any acquisition of crew transportation capabilities or services to the ISS shall include a continuous safety upgrade and improvement program throughout the acquisition life cycle. The ultimate goal of the upgrade and improvement program shall be a system that will be an order of magnitude safer for the combined ascent and entry phases than was the Space Shuttle at the end of its operational life, and that in the aggregate, will be substantially safer for

a 210-day mission to the ISS than was the Space Shuttle at the end of its operational life.

- **Verification:** Numeric criteria shall be used to verify compliance with the design thresholds and long term goals. The criteria are mean values and shall be determined via probabilistic safety analyses using NASA-accepted methods similar to those applied by the Space Shuttle, ISS, and Constellation programs. These evaluations must be an integral part of NASA's overall program of insight and oversight in order to understand, address, and, where necessary, accept the risks associated with the spaceflight system."

## 6.3 C-FER IR and SR Criteria

In the document Guidelines for Reliability Based Design and Assessment (RBDA) of Onshore Natural Gas Pipelines[187], C-FER Technologies provides SR and IR safety criteria to define maximum tolerable risk levels for ultimate limit states (ULS) reliability targets – which imply pipeline ruptures or large leaks as the limit state. These criteria are discussed in detail below.

### 6.3.1 C-FER Technologies RBDA Societal Risk Criteria

C-FER Technologies[188] describes two approaches for quantification of maximum tolerable societal risk criteria: 1) societal risk with fixed expectation; and 2) societal risk with aversion function. The first measure, societal risk with fixed expectation, uses the expected number of fatalities from a natural gas pipeline release as a direct measure of risk implying that the risk associated with a low probability incident causing a large number of fatalities is equivalent to a high probability incident causing a small number of fatalities. However, much like other organizations discussed in this report, there is a greater aversion for low probability, high consequence events. Therefore, C-FER Technologies offers a second measure of societal risk which includes an aversion factor. This criterion uses the expected number of fatalities from a natural gas pipeline release raised to a power greater than one as a measure of risk. The societal risk with aversion function criterion implies that risk increases exponentially with the number of fatalities – low probability, high consequence events are a greater risk than high probability, low consequence event. As shown in Figure 30, the aversion function maximum tolerable criterion has a significantly steeper slope than the fixed expectation criterion at the higher number of fatalities (N).

[187] C-FER Technologies, Guidelines for Reliability Based Design and Assessment of Onshore Natural Gas Pipelines, Submitted to Pipeline Research Council, International, Inc. October 2011.

[188] The information in the C-FER Technologies, Guidelines for Reliability Based Design and Assessment of Onshore Natural Gas Pipelines is based on the following papers: 1) Nessim, M.A., Zhou, W., Zhou, J., Rothwell, B., and McLamb, M. Target Reliability Levels for Design and Assessment of Onshore Natural Gas Pipelines (Paper IPC04-0321), Proceedings, International Pipeline Conference, Calgary, Alberta, 2004; and 2) Nessim, M.A. and Zhou, W. Target Reliability Levels for the Design and Assessment of Onshore Natural Gas Pipelines. Gas Research Institute Report 04/0230, 2005. This methodology is also laid out in CSA Z662, Appendix O.

The maximum tolerable societal risk criteria proposed by C-FER Technologies for reliability targets (not absolute risk targets) were generated by calibration to existing codes and regulations, including ASME B31.8, ASME B31.8S, and 49 CFR 192.327. New pipelines designed and operated to the requirements of these codes are widely accepted as safe, which implies the societal risk for the existing pipeline network can be considered tolerable. Therefore, the maximum tolerable SR criteria is "equal to the calculated average societal risk for a network of new pipelines that are designed, operated and maintained according to the above-mentioned codes and regulations."[189] In most cases, the total risk is calculated over an evaluation length of 1.6 km.

The SR criteria proposed by C-FER Technologies were developed as targets "to control risk to the public based on generally accepted safety benchmarks for involuntary risk. Risk to workers was not explicitly combined with risk to the public because the former is a voluntary risk that is typically assigned different tolerance benchmarks than involuntary risk."

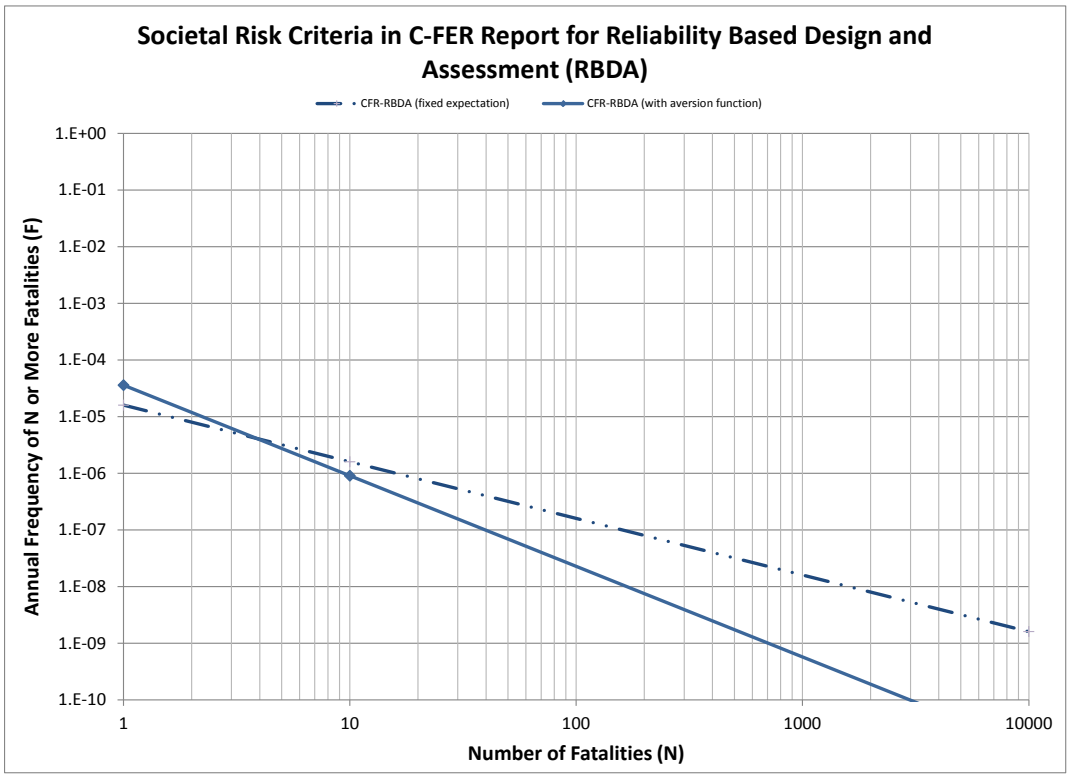



**Figure 30. C-FER RBDA Societal Risk Criteria**

[189] According to CSA Z662, Appendix O, a total of 240 design cases were analyzed in the calibration, covering combinations of all Class locations (1, 2, 3, and 4), three design pressures (4.1, 6.9, and 9.7 MPa), four grades (241, 359, 414, and 483), and five outside diameters (219.1, 406.4, 610, 762, and 1067 mm).

##### 6.3.1.1.1 C-FER Technologies RBDA Individual Risk Criteria

C-FER Technologies takes a slightly different approach to IR criteria than other organizations that have established IR criteria for pipelines. Instead of defining criteria for new and existing pipelines or for sensitive populations, they use the regulatory Class definitions to define the degree of tolerable IR. These criteria are presented as follows.

- Class 1: $1 \times 10^{-4}$ fatalities/year
- Class 2: $1 \times 10^{-5}$ fatalities/year
- Class 3 and 4: $1 \times 10^{-6}$ fatalities/year

The IR criteria selected were based on information published by HSE and MIACC and then applied by Class Location, where Class 1 locations have the highest maximum tolerable risk level at $1 \times 10^{-4}$ fatalities/year and Class 3 and Class 4 locations have the lowest maximum tolerable risk level at $1 \times 10^{-6}$ fatalities/year. Much like what was done for the SR criteria, the decrease in tolerable IR as a function of class location reflects a requirement to decrease the risk as the number of people exposed to the risk increases (aversion to high consequence incidents).

##### 6.3.1.1.2 C-FER Technologies RBDA Use of Criteria for Reliability Targets Based on Population Density

Figure 31 shows reliability targets as a function of population density, operating pressure, and pipeline diameter for all SR and IR criteria. Pipelines falling into the upper-left portion of Figure 31 represent tolerable reliability targets while pipelines falling into the lower-right portion of Figure 31 represent unacceptable reliability targets. The proposed target (thicker black line) is defined as the upper envelope (or most conservative) for all criteria.

C-FER Technologies warns that when calculating the population density, that the number of occupants within an assessment area centered on that point, divided by the size of the assessment area should not take into account fractional time a building or facility is in use. The fraction of time a building or facility is in use is already built into the SR reliability targets.

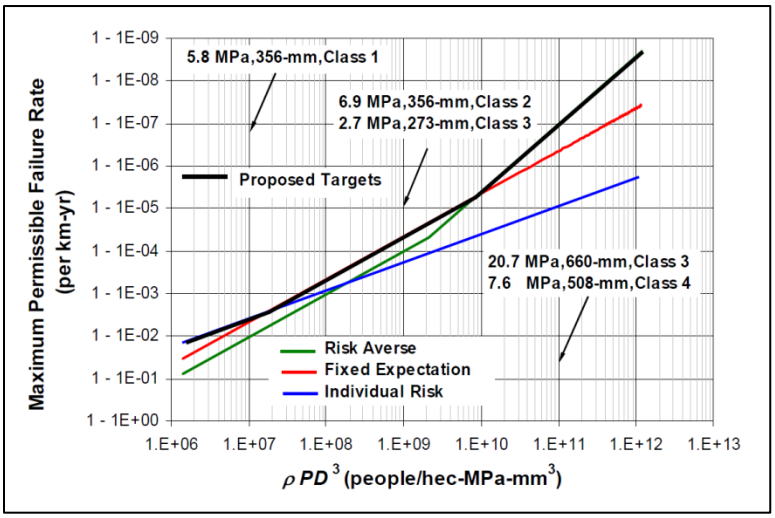



**Figure 31. Reliability Targets Based on Population Density**

### Based on Location Class

Figure 32 shows reliability targets as a function of average population density for each class location, operating pressure, and pipeline diameter for all SR and IR criteria. Pipelines falling into the upper-left portion of Figure 32 represent tolerable reliability targets while pipelines falling into the lower-right portion of Figure 32 represent unacceptable reliability targets. The proposed target (thicker black line) is defined as the upper envelope (or most conservative) for all criteria.

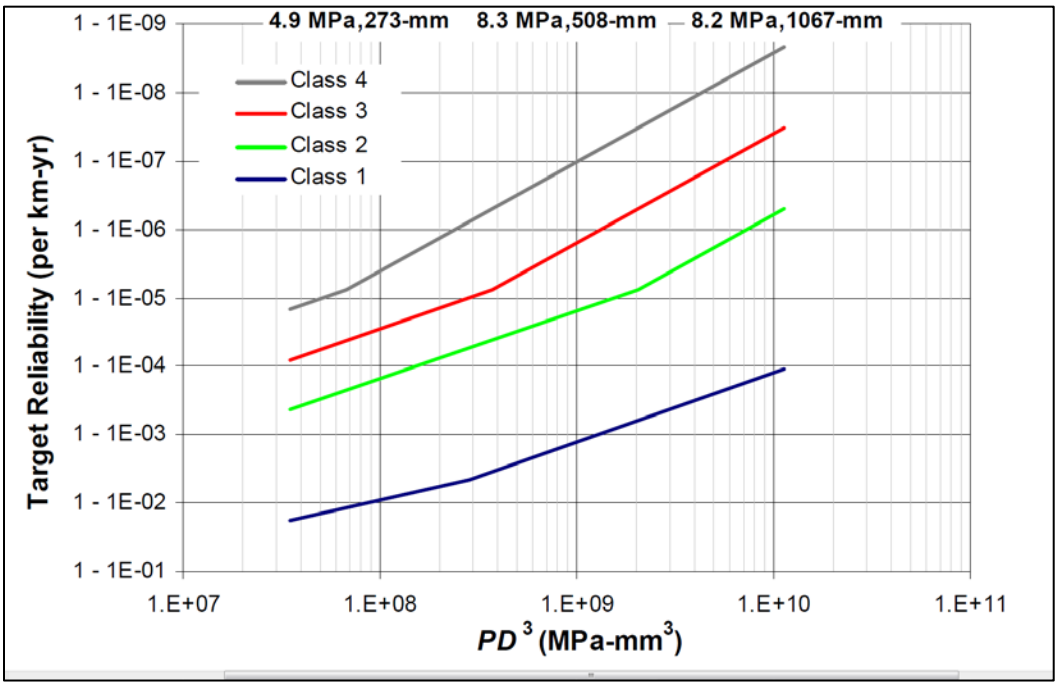



**Figure 32. Reliability Targets Based on Location Class**

## 6.4 Pipeline Companies

### 6.4.1 Industry Survey Questions

The industry survey was structured around three main topics:

- Basic pipeline information: Commodities transported; mileage of transmission, distribution and gathering lines; and mileage within HCAs.
- Basic risk model information: Scope and use of risk assessments; type of risk assessment (qualitative, semi-quantitative, or quantitative); use of software; and types of consequences evaluated.
- Risk tolerability criteria: Risk tolerance levels; how risk tolerance levels are determined; methods used to communicate risk tolerance; scope of risk criteria; and barriers to implementation of risk criteria.

The individual survey questions are provided in Appendix A. The actual survey was sent out as an online web link that respondents could access to complete and submit the survey to a central database. The companies that responded to the survey are kept confidential.

### 6.4.2 Summary of Responses

The survey was sent to approximately 100 pipeline operators with a total of 24 survey responses received. The responses cover a representative cross section of liquid and natural gas (transmission, distribution, and gathering) with some respondents having assets in more than one category. The survey responses were compiled into categories and discussed in greater detail in the subsequent report sections. The actual survey responses are provided in Appendix B.

#### 6.4.2.1 Basic Pipeline Information from Survey Respondents

Eighteen of the companies who responded to our survey transport natural gas, with a total of 268,462 miles of pipeline, of which 2 percent are located within an HCA. Ten respondents transport hazardous liquids, totaling 40,191 miles, with 59 percent located within HCAs (see Figure 6). The majority of the represented pipeline miles consists of distribution, followed by transmission, with a small percentage of gathering lines (see Figure 34).

Figure 35 shows the number of participating operators transporting different types of hazardous liquids which includes crude oil followed by refined product, highly volatile liquids (HVL), ammonia (NH3), carbon dioxide (CO2), and various chemicals.

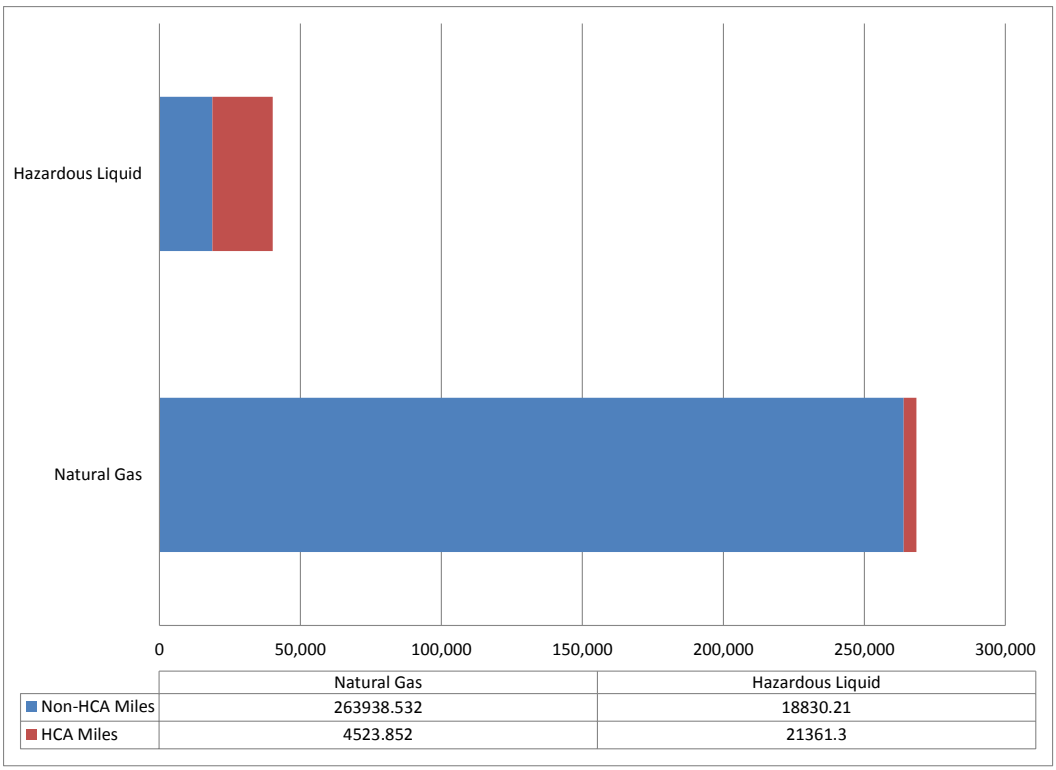



**Figure 33. Pipeline Mileage by Product Represented in Survey Responses**

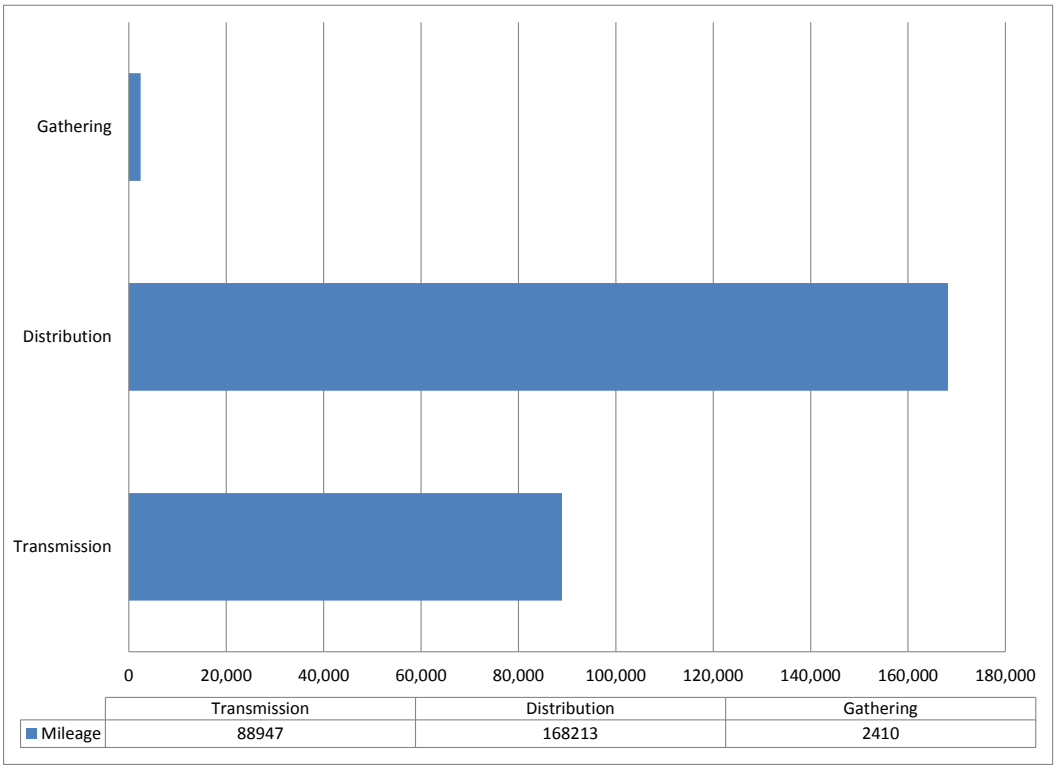



**Figure 34. Pipeline Mileage by Pipeline Type Represented in Survey Responses**

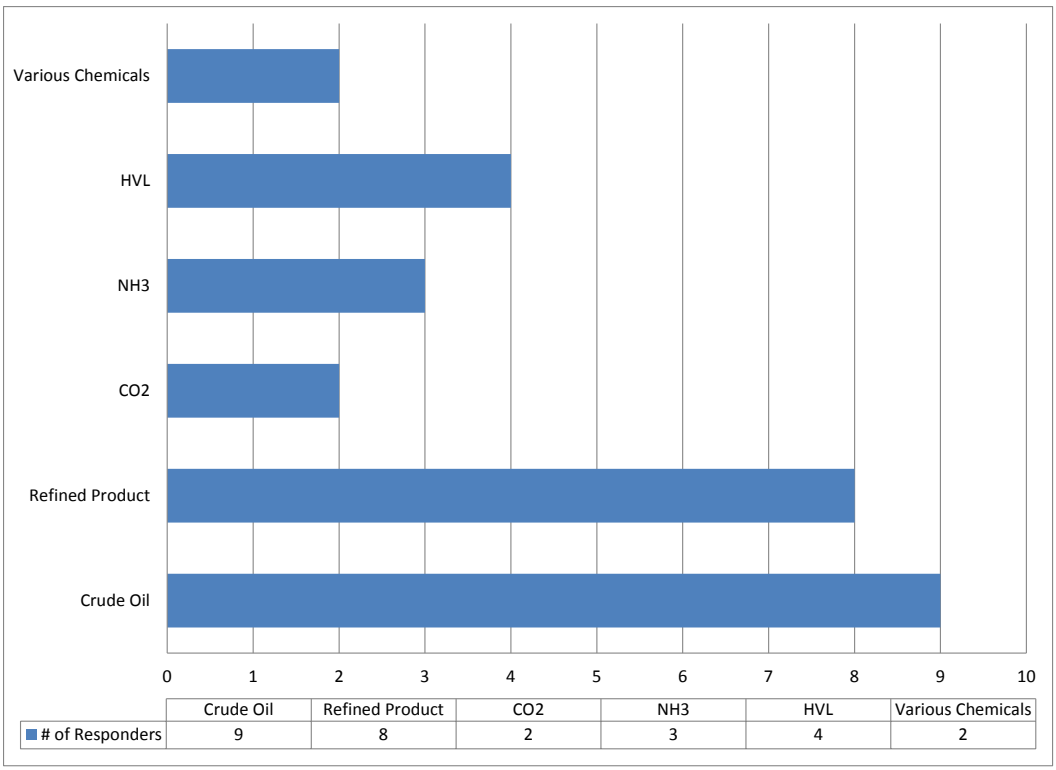


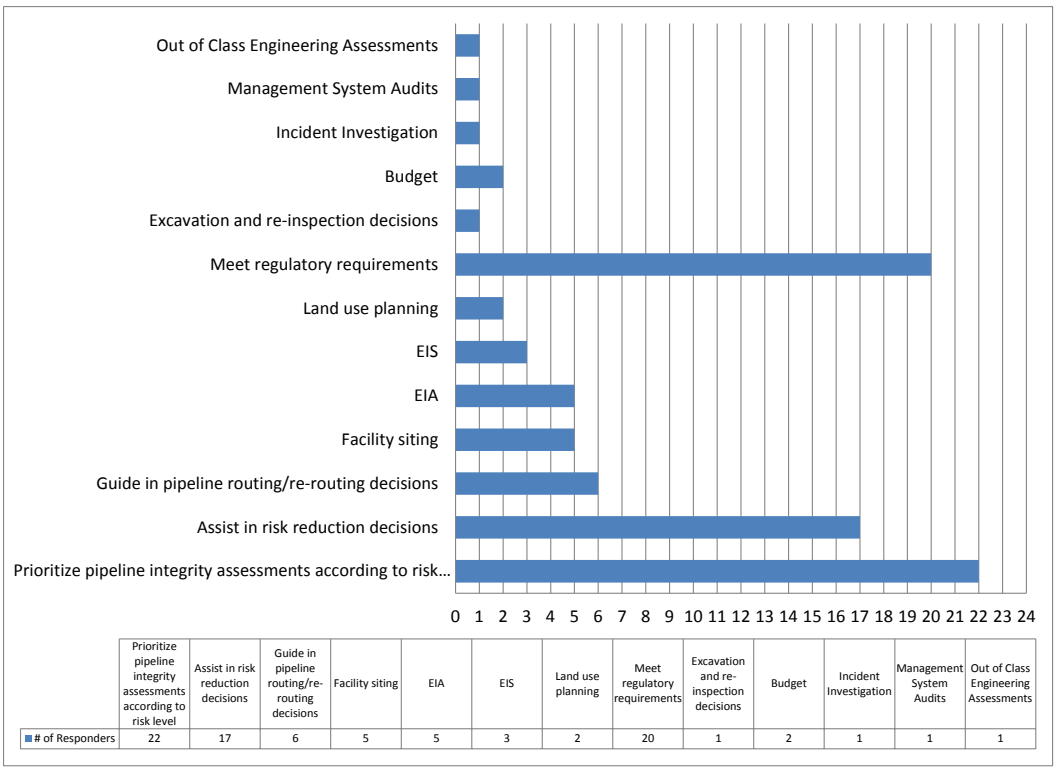

**Figure 35. Hazardous Liquid Products Represented in Survey Responses**

#### 6.4.2.2 Basic Risk Model Information from Survey Respondents

Survey participants were asked what best describes their use of risk assessments. The leading drivers (as shown in Figure 36) were to prioritize pipeline segments for integrity assessments, meet regulatory requirements, and assist in risk reduction decisions.

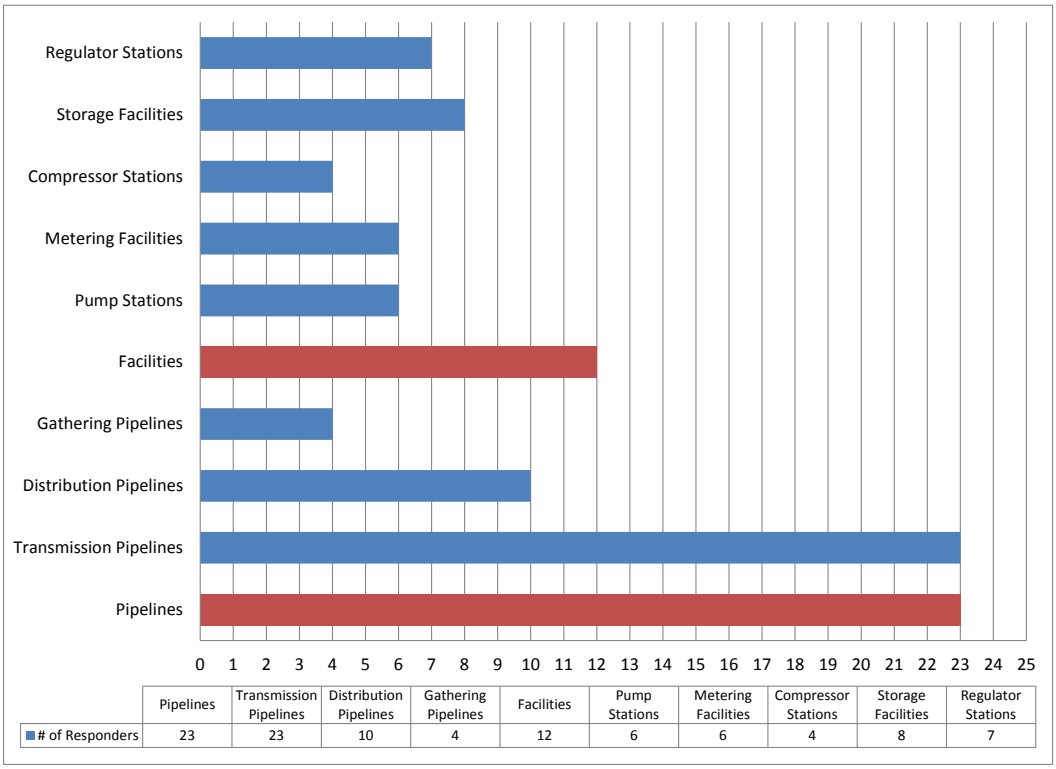
Most respondents used more than one risk model depending on the pipeline type (transmission, distribution, gathering), product type, and asset type (pipeline, facility).

The primary scope of the risk assessments includes transmission pipelines with less than half of the companies including distribution lines and a few gathering lines. About half of the companies include facilities, such as pumping and compressor stations, metering facilities and storage and regulator facilities (See Figure 37).




| | Prioritize pipeline integrity assessments according to risk level | Assist in risk reduction decisions | Guide in pipeline routing/re-routing decisions | Facility siting | EIA | EIS | Land use planning | Meet regulatory requirements | Excavation and re-inspection decisions | Budget | Incident Investigation | Management System Audits | Out of Class Engineering Assessments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # of Responders | 22 | 17 | 6 | 5 | 5 | 3 | 2 | 20 | 1 | 2 | 1 | 1 | 1 |

**Figure 36. Uses of Risk Assessment Represented in Survey Responses**




| | Pipelines | Transmission Pipelines | Distribution Pipelines | Gathering Pipelines | Facilities | Pump Stations | Metering Facilities | Compressor Stations | Storage Facilities | Regulator Stations |
|---|---|---|---|---|---|---|---|---|---|---|
| # of Responders | 23 | 23 | 10 | 4 | 12 | 6 | 6 | 4 | 8 | 7 |

**Figure 37. Scope of Risk Assessments Represented in Survey Responses**

The primary approach used to section a pipeline for a risk assessment is dynamic segmentation, which involves dividing a pipeline based on risk variables so that the segments have constant risk characteristics. Other methods include dividing a pipeline based on changes in pipe property or on a per-mile or kilometer basis (see Figure 38).

Thirteen of the risk assessments are performed using purchased software models, often tailored to suit the individual company. Eight companies use non-software models such as risk matrices or process hazards analysis (PHA) techniques such as what-if analyses, checklists, and/or Hazard and Operability Studies (HAZOPs) (see Figure 39).

There are ranges of risk modeling approaches being used with half using semi-quantitative techniques (i.e. risk matrices with numerical ranges for likelihood and/or consequences) to evaluate risk. Companies are also using relative risk/index models where likelihood and consequence variables are assigned to each pipeline segment resulting in relative risk scores. The variables are typically weighted to reflect their relative impact. The variables are typically based on the pipeline integrity threats identified in ASME B31.8S standard and by PHMSA. Three companies are implementing quantitative/probabilistic risk assessment approaches.

The three primary consequence categories include public health and safety, environment, and worker health and safety. Other categories included equipment damage, business interruption, product loss, reputation damage and litigation issues (see Figure 41).

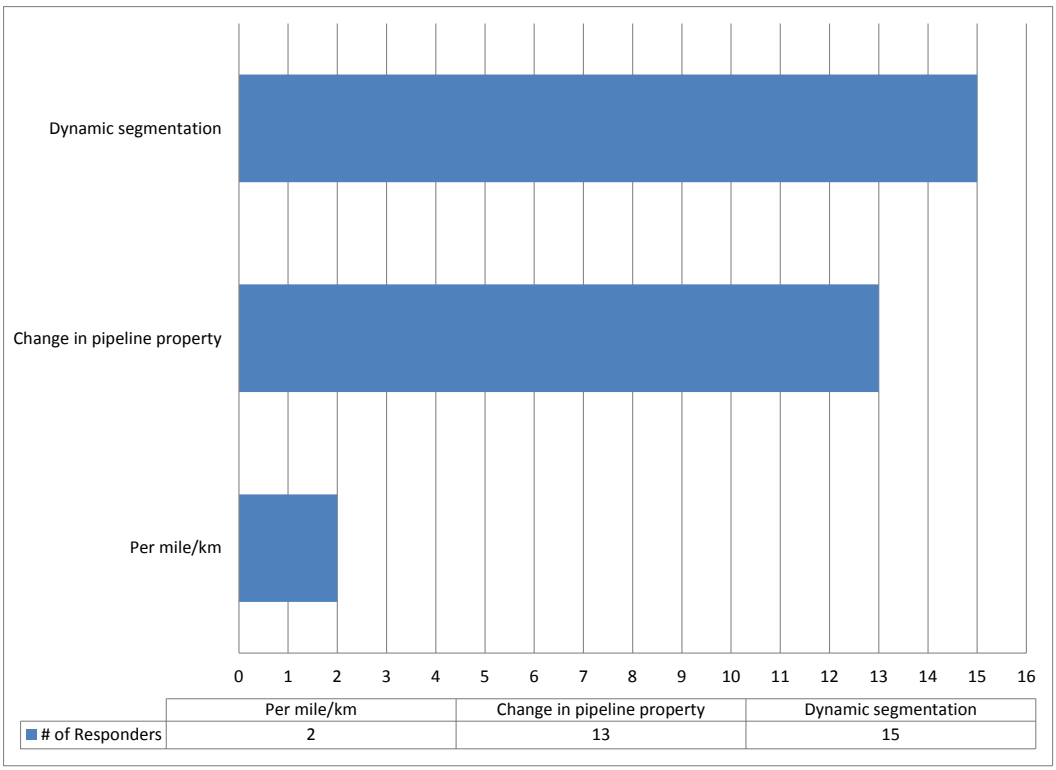



**Figure 38. Segmentation for Pipeline Risk Assessments Represented in Survey Responses**

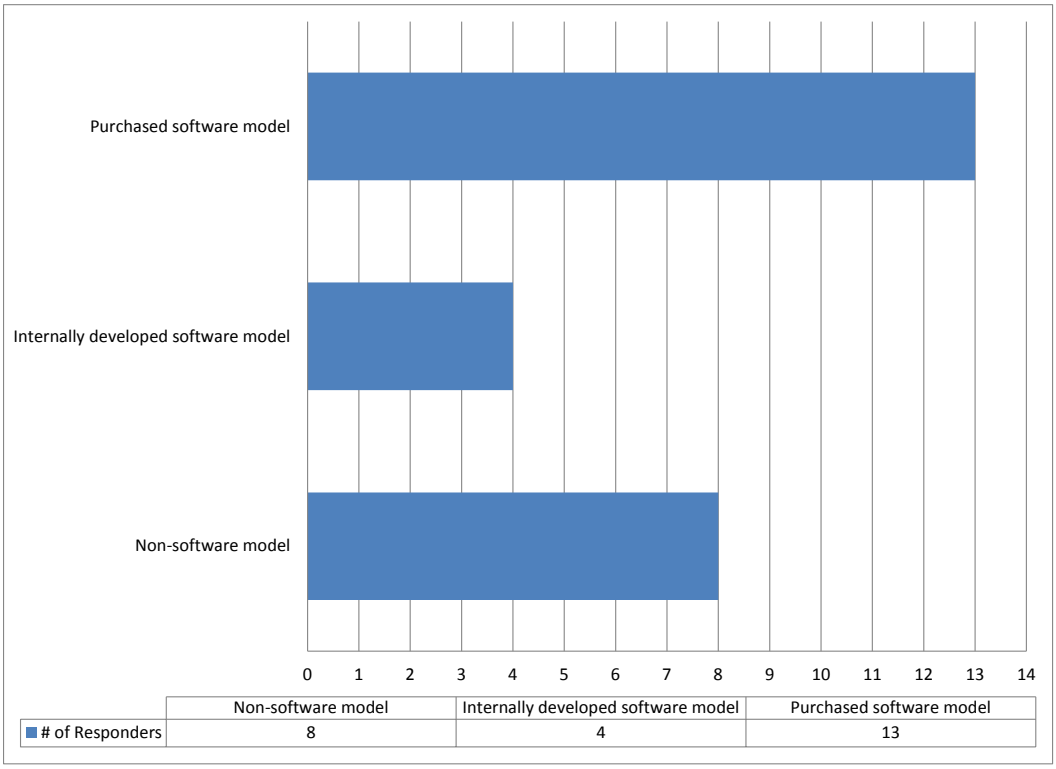



**Figure 39. Risk Assessment Types Represented in Survey Responses**

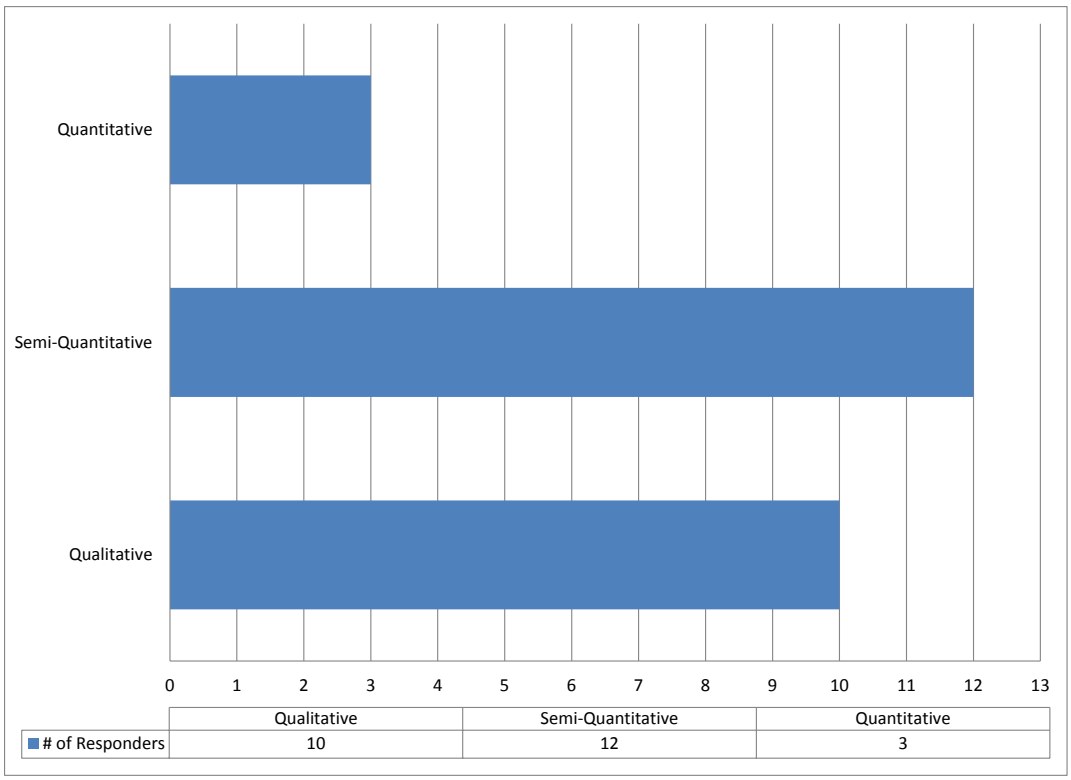



**Figure 40. Risk Assessment Models Represented in Survey Responses**

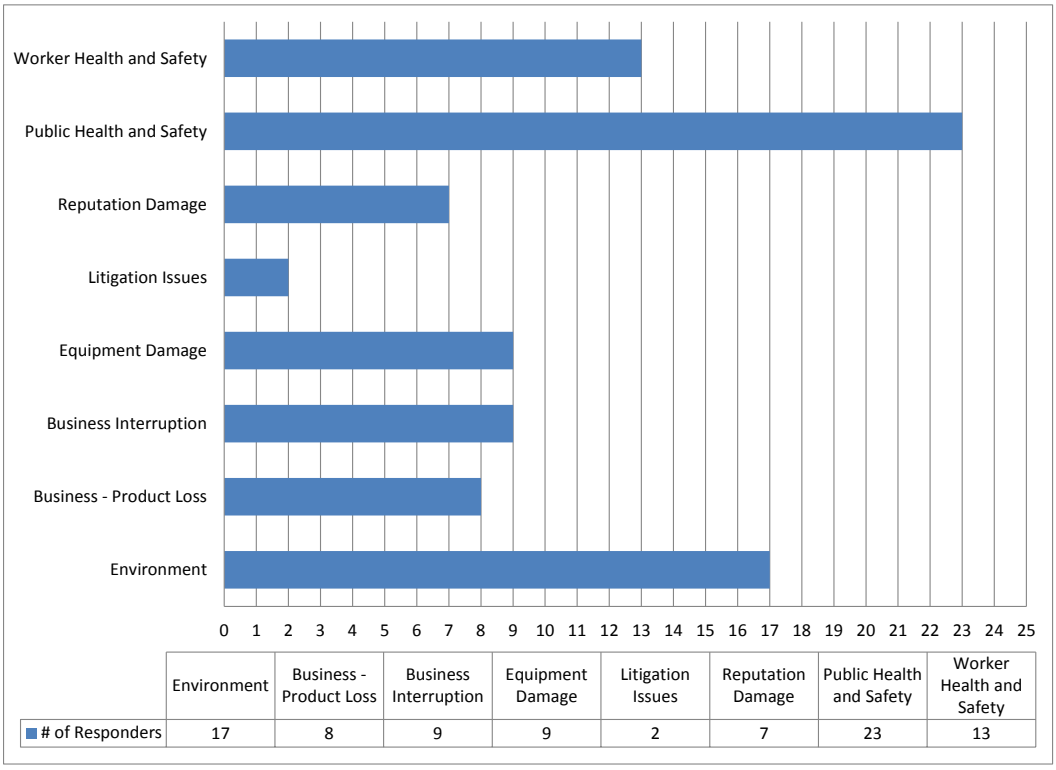



**Figure 41. Risk Assessment Consequence Categories Represented in Survey Responses**

#### 6.4.2.3 Risk Tolerability Criteria from Survey Respondents

Many of the respondents (9 of 24) have defined some form of risk tolerability criteria; however, much like risk models, there is a wide range of techniques being used. For respondents that use index-based risk models or risk matrices, risk criteria are generally defined by the index score or category. A score above a certain number or within a specified risk range is intolerable, a score below a certain number is broadly acceptable, and in between is a 'gray area' (also termed by many as 'Low As Reasonably Practical'; ALARP), where risk reduction measures are desirable, but may not be implemented if the cost is grossly disproportionate to the benefit received. These risk tolerable levels have been both qualitative and semi-quantitative.

Several operators surveyed have not established risk criteria levels, but instead use relative risk ranking to prioritize ILI assessments, identify facilities for risk assessments, and as a basis to continually work toward reducing risk. A few of the companies indicated that they are in the process of establishing risk criteria. Barriers to establishing risk criteria have included a lack of historical data, legal concerns, and lack of expertise and/or resources to mention a few (see Section 4.2.4).

As shown in Figure 42, relative risk/index models and risk matrices are the most common methods of presenting risk tolerance levels, followed by comparison criteria and individual risk. Five responses indicated that they present their risk in terms of societal and environmental risk. Although none of the survey results indicated that they express risk thresholds in monetary terms ($/year/mile), where the risk level represents the amount that the company is willing to invest to avoid a specific event, responses indicated that cost/benefit analyses are a critical component in the risk management process.

Defining risk tolerability levels for qualitative, relative risk index models and risk matrices is typically based on input from SMEs and integrity specialists. It is a relatively simple approach used to rank risks; however, it cannot be used to compare the risk of dissimilar systems – pipelines versus highway transportation, for example. Relative risk scores can also be difficult to apply when trying to evaluate risk reduction measures.

Using quantitative risk levels provides a clearer basis for the relationship between frequency and consequence estimates. It helps to identify the major contributors to risk in order to more effectively target risk reduction activities and resources.

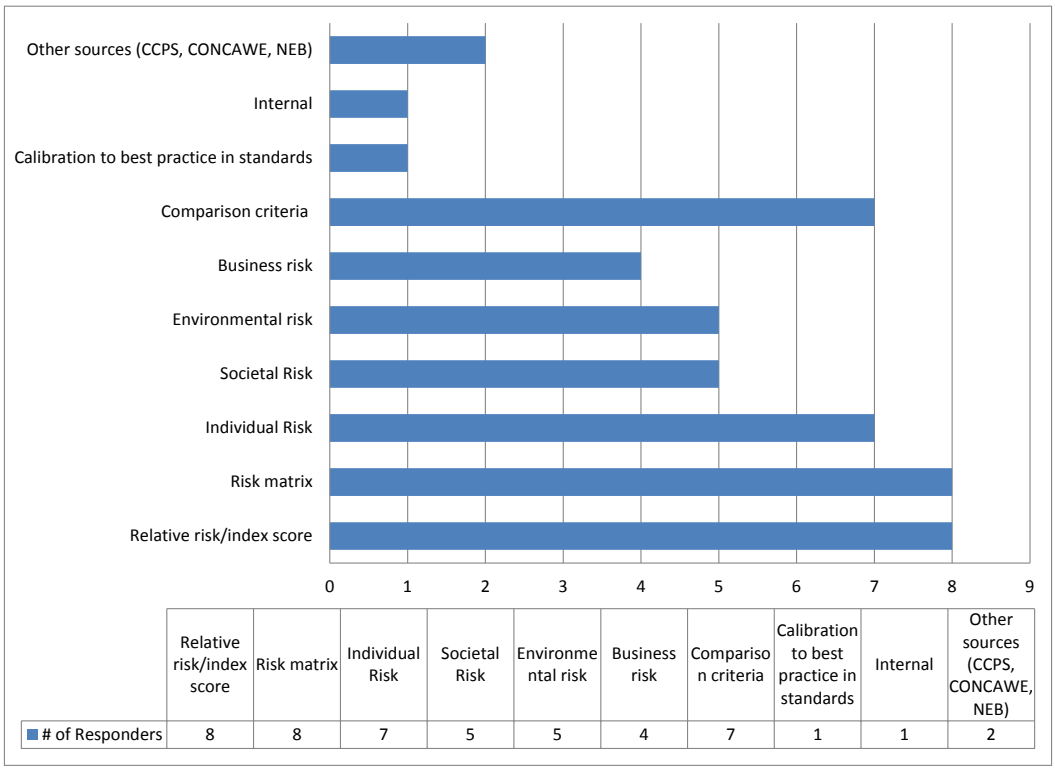
As indicated by one respondent, quantitative data driven approaches allow for the use of all evidence of threats (historical incidents, assessments, mechanistic understanding of threats); better representation of different threats; direct comparison between threats (without arbitrary assumptions about the percentage of total risk); ability to explicitly account for threat

interaction; accurately represent growth and accurate consequence representation; ability to compare against consciously established risk tolerances; and defendable rationale for good decision making.

Multiple risk criteria have been established by some companies, differentiating between product type (liquid versus gas) and asset type (pipeline or facility). Risk criteria have been established on a system-wide level, on a unit-length basis, as well as facility level. Safety levels equivalent to code compliance are also used for ILI-based decisions and engineering assessments.

One respondent uses individual risk and societal risk criteria for natural gas pipelines and environmental risk for liquid pipelines.

As shown in Figure 43, nine of those surveyed have defined an unacceptable / intolerable level. Fewer companies have defined the ALARP level and the Broadly Acceptable Level. In some cases historical data has been used, in other cases the limits are subjective. One example of quantified tolerability levels from our survey (for natural gas pipelines) is shown below in Table 30 where risk criteria levels are presented in terms of both individual and societal risk.




| | Relative risk/index score | Risk matrix | Individual Risk | Societal Risk | Environmental risk | Business risk | Comparison criteria | Calibration to best practice in standards | Internal | Other sources (CCPS, CONCAWE, NEB) |
|---|---|---|---|---|---|---|---|---|---|---|
| # of Responders | 8 | 8 | 7 | 5 | 5 | 4 | 7 | 1 | 1 | 2 |

**Figure 42. Methods Used to Communicate Risk Tolerance Levels Represented in Survey Responses**

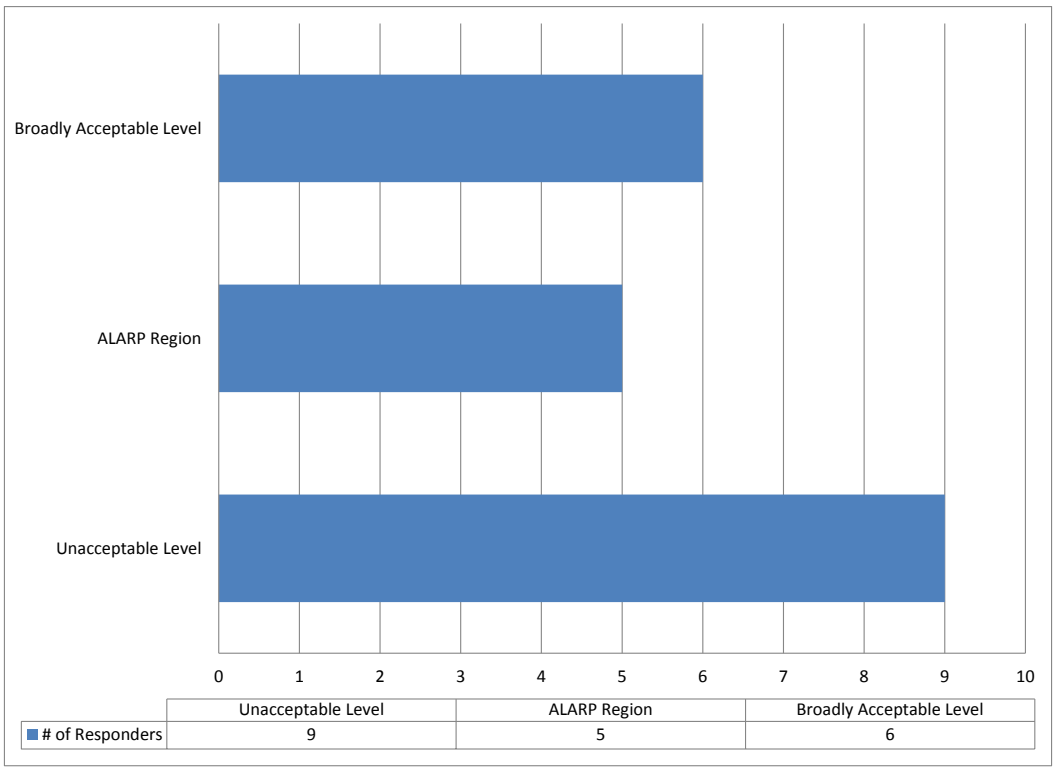



**Figure 43. Risk Tolerance Levels Represented in Survey Responses**

As presented in Task 1, individual risk provides a perspective on facility/pipeline risk from an individual's point of view, whether a worker or a member of the public. Societal risk provides a perspective on the risk to the surrounding public and environment, especially from potentially catastrophic events.

**Table 30. Example of Quantified Risk Tolerability Levels for Natural Gas Pipelines**

| Risk Range | Societal Risk | | | Individual |
|---|---|---|---|---|
| | Frequency (F) | Number of Fatalities (N) | Slope of F-N Curve | Fatality/year |
| Unacceptable | $1 \times 10^{-3}$ | 1 | -1 | $1 \times 10^{-4}$ |
| ALARP | $1 \times 10^{-3}$ | 1 | -1 | $1 \times 10^{-4}$ to $1 \times 10^{-6}$ |
| Broadly Acceptable | $1 \times 10^{-5}$ | 1 | -1 | $< 1 \times 10^{-6}$ |

The survey results show that risk criteria levels were most often established by company senior management, SMEs, and risk analysts, with a number of companies using risk consultants (see Figure 44). Risk criteria levels have also been applied on a case-by-case basis, with one

respondent noting that they adapt the criteria based on heightened public perception. Approaches for establishing risk tolerance levels include:

- Leadership engagement
- Internal comparative studies
- Regulatory benchmarks
- Benchmarking with other companies
- Literature searches
- Meeting with stakeholders
- Risk surveys

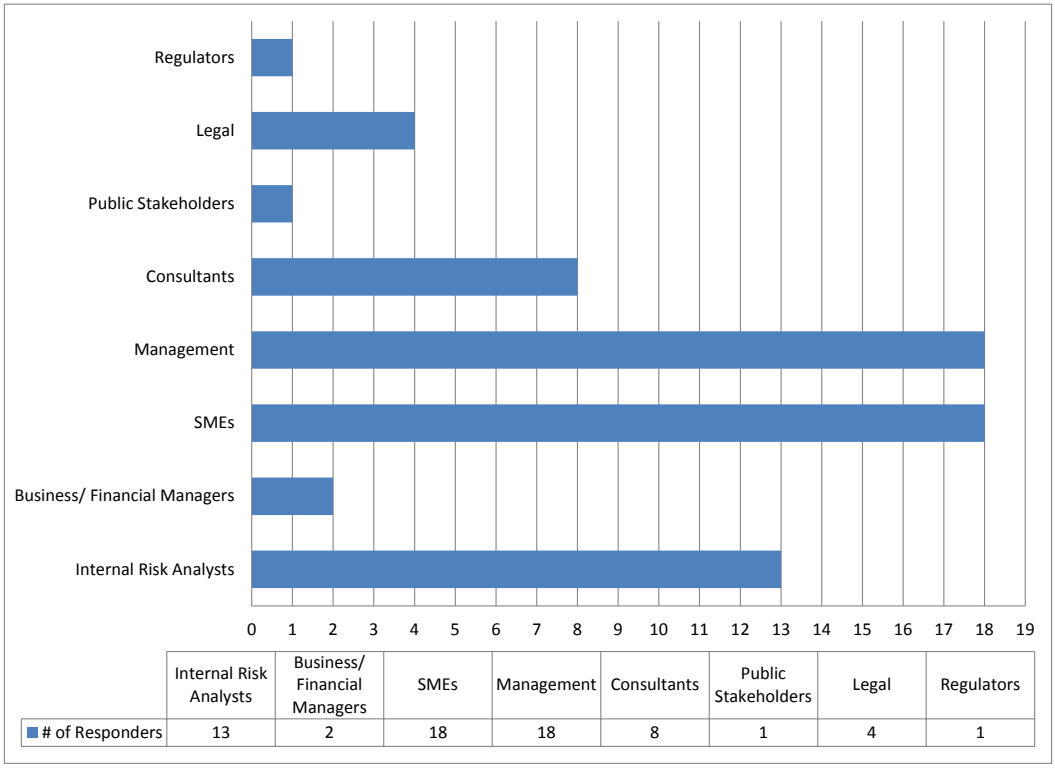



**Figure 44. Individuals Involved in Defining Risk Tolerance Levels Represented in Survey Responses**

### 6.4.2.4 Barriers for Establishing Risk Tolerability Levels

Setting risk tolerability levels is not a simple task. The respondents identified the following barriers to establishing risk tolerability levels.

- Public perception (of tolerable risk)
- Communicating risk levels in terms of fatalities
- Legal sensitivities (the litigious atmosphere in the USA)
- Misconceptions regarding risk
- Management having the technical expertise to help make such determination

- Levels not been defined to allow SMEs flexibility
- Company risk tolerance belongs on a continuum with the public and the regulator
- Understanding the risk tolerance of the public and the regulatory is largely a guessing game today.
- Unclear direction of regulators
- Appropriated resources required by regulation to be redirected to lower risk activities
- Differences between public perception and actual risk
- Difficult to explain F-N curves or IRPA to not only employees, contractors and management but also the public
- Sensitivity to monetized risk
- Understanding risk and their consequences
- Public perception is likely the biggest barrier, as there appears to be no level of risk that is tolerable to the public other than "zero"
- Difficult to define what is an acceptable risk tolerable level from company and industry perspective
- Lack of consistency in the risk models used in industry
- Understanding the risk based on threats present at the facilities
- Public perception of reasonable risks versus worst case scenario
- Cost of gathering necessary data and acting on results
- Absolute Risk Tolerance levels cannot be defined. The method of utilizing relative risk to prioritize preventive and mitigative measures is much more practical and realistic.
- Tools and techniques to better use the vast amount of data available to run probabilistic risk models.

#### 6.4.2.5 Needed Improvements in Risk Assessment Methodologies

Survey participants were asked what improvements in risk assessment methodologies, available information, or data collection would be most helpful. Survey respondents identified the following suggestions for improvements in the overall risk assessment process.

- Example risk tolerance levels and how they are used to better understand the process
- Better guidelines for quantitative risk criteria by North American Regulatory Agencies; better acceptance of risk assessments to drive improved integrity decisions (risk-based decisions as opposed to prescriptive decisions lead to a more optimized program.
- Consistency in the risk methodologies used by industry
- Industry accepted risk tolerance ranges per threat specific
- A capability to integrate available data
- A database (ex. geo-spatial) that is automatically normalized, kept current, accurate, reliable, easily accessible, and has the “significant” variables that affect risk (both

likelihood and consequence) to help “actively” manage the risk, and not to the nth-degree of variables, in which if required to have risk as a number, can be standardized across industry for risk, likelihood and consequence modeling. Has a “true” gap analysis been done to “validate” real issues based on this database; for example, LFERW, water crossings, etc.?

- A robust database of previous events, including causal factors and outcomes, would be incredibly helpful for calibrating both probabilities of events occurring and the outcomes of those events. Right now we use what we feel is the best data and methodologies available, but have little to benchmark against.
- Data integration with an easy to use application/customization, updates in knowledge/materials/trends/risks. Simply applicability for various types of systems, distribution, transmission, plant/facilities, etc.
- Accuracy of data collection, geo-spatial information, standardization of data collection metrics, traceability of steel materials, phased array development (plastic and steel)
- More data pertaining to quantitative risk modeling including monetized examples. Quantitative risk assessment methodologies presented have required a large amount of additional work for marginal gains in risk scoring and have not shown a monetized value for additional work.
- Standard risk model templates. Risk assessment model agreed to and approved by state regulators and other stakeholders.
- Centralized data repository. Data collection methodologies white paper.
- Further development of consequence factors.
- Improved pigging methods for pipe material and attribute discernment; increased accuracy of affordable GPS devices; increased use of mobile data collection devices; availability of standardized data sets.
- An industry risk standard would be ideal. A summary of industry's best practices as related to risk analysis would be helpful.
- Going after the big data (in good quality). Integrate most of the available data in all attributes of all 9 threats and consequences.
- Publicly available failure rates for specific equipment components
- Fragility curves for pipeline and pipeline features exposed to external stresses
- How the value of life (or Statistical Value of Life) is used to establish safety tolerance levels

# 7 REFERENCES

Australian National Committee on Large Dams, Inc. website: http://www.ancold.org.au/?page_id=3469

Canadian Society for Chemical Engineering. Risk Assessment – Recommended Practices for Municipalities and Industry. 2004. Found at: http://www.cheminst.ca/sites/default/files/pdfs/Connect/PMS/Risk%20Assessment%20%E2%80%93%20Recommended%20Practices%20for%20Municipalities%20and%20Industry.pdf

Center for Chemical Process Safety (CCPS) Guidelines for Developing Quantitative Safety Risk Criteria. Wiley Publication. 2009.

Common Risk Criteria Standards for National Test Ranges, Standard 321-07, U.S. Department of Defense, June 2007.

Cornwell, J.B. and Meyer, M.M. Risk Acceptance Criteria or "How Safe is Safe Enough?". II Risk Control Seminar, October 13, 1997.

County of Santa Barbara Planning and Development. Environmental Thresholds and Guidelines Manual. October 2008.

Criteria for the assessment of risk from industry – expanded discussion, 1992. Found at 691_B627.pdf

Curtis, P. and Carey, M. Committee of Sponsoring Organizations of the Treadway Commission (COSO). Risk Assessment in Practice. Found at: http://www.coso.org/documents/COSOAnncsOnlineSurvy2GainInpt4Updt2IntrnlCntrlIntgratdFrmwrk%20-%20for%20merge_files/COSO-ERM%20Risk%20Assessment%20inPractice%20Thought%20Paper%20OCtober%202012.pdf

Docket No. PHMSA-2010-0229, 80 FR 61610

Energy Policy Act of 1992. (1992). Public Law 102-486.

Federal Aviation Administration (FAA). (2009). Risk Management Handbook. Washington DC: Federal Aviation Administration. Retrieved from http://www.faa.gov/library/manuals/aviation/

Federal Aviation Administration. Fatigue Risk Management Systems for Aviation Safety. FAA Advisory Circular No: 120-103A. 2013.

General Motors Research Laboratories. (1979). Societal Risk Assessment - How Safe is Safe Enough? In R. C. Schwing (Ed.), International symposium on Societal Risk Assessments. Warren (MI): Springer Science.

Gmunder, F.K., Meyer, P., and Schiess, M. The Control of Major Chemical Hazards in Switzerland in the Framework of Sustainable Development – Liquefied Petroleum, Ammonia, and Chlorine as Examples.

Goodfellow, G. and Haswell, J. A Comparison of Inherent Risk Levels in ASME B31.,8 and UK Gas Pipeline Design Codes. IPC2006-10507. September 25-26, 2006. http://www.penspen.com/wp-content/uploads/2014/09/comparison-of-risk-levels.pdf

Haswell, J. V., Goodfellow, G.D., Jackson, N.W., and McConnell, R. New UK Pipeline Risk Assessment Codes – IGEM TD/2 and PD 8010 Part 3. IChemE, 2009, pg. 308-317.

Hazardous Industry Planning Advisory Paper (HIPAP) No 4, Risk Criteria for Land Use Safety Planning, New South Wales (NSW) Government, January 2011.

Hazardous Industry Planning Advisory Paper (HIPAP) No 10: Land Use Safety Planning, January 2011. http://d.planning.nsw.gov.au/Portals/0/HIPAP%2010%20Final%202011.pdf

Hazardous Materials Cooperative Research Program (HMCRP). Report 12, Hazardous Materials Transportation Risk Assessment: State of the Practice. Transportation Research Board. Sponsored by Pipeline and Hazardous Materials Safety Administration. 2013.

Health and Safety Commission Advisory Committee on Major Hazards. First Report. 1976

Health and Safety Executive. Flixborough (Nypro UK) Explosion 1st June 1974 – Accident Summary. http://www.hse.gov.uk/comah/sragtech/caseflixboroug74.htm

Health and Safety Executive (HSE), Reducing risks, protecting people. HSE's decision-making process, 2001 http://www.hse.gov.uk/risk/theory/r2p2.pdf

Health and Safety Executive (HSE). Societal Risk: Initial briefing to Societal Risk Technical Advisory Group. Prepared by the Health and Safety Laboratory and the Health and Safety Executive. 2009.

Hill, R. T. (1992). Pipeline Risk Analysis. Major Hazards Onshore and Offshore, (pp. 657-670).

Hong Kong Government Risk Guidelines. Annex 4 of Technical Memorandum for Environmental Impact Assessment Ordinance (EIAO-TM). http://www.epd.gov.hk/eia/english/legis/memorandum/annex4.html

IGEM/TD/1. Application of pipeline risk assessment to proposed developments in the vicinity of high pressure Natural Gas pipelines. The Institute of Gas Engineers and Managers.

IGEM/TD/1 Edition 5. Steel pipelines and associated installations for high pressure gas transmission. The Institute of Gas Engineers and Managers.

Institution of Chemical Engineers. (1985). Nomenclature for hazard and risk assessment in the process industries. Warrington, UK: The Institution.

Kirchhoff, D. and Doberstein, B. Pipeline risk assessment and risk acceptance criteria in the state of São Paulo, Brazil. Impact Assessment and Project Appraisal. September 2006.

Kurth, R. E. (1994). Probabilistic Damage Tolerant Analysis to Improve Aging Aircraft Maintenance and Inspection Schedules. 1994 ASME International Mechanical Engineering Congress and Exposition. Chicago, IL: ASME.

McDonald, L. Tolerable Risk Criteria: - The ANCOLD Guidance. Working Group on Risk Assessment.

MIL-STD-882E. Department of Defense Standard Practice – System Safety. May 11, 2012.

Nanney, S. and Lee, K. Presentation on Current Regulatory Requirements for Evaluation of Risk. PHMSA Pipeline Risk Modeling Methodologies Public Workshop. September 9, 2015.

NASA System Safety Handbook. Volume 1, System Safety Framework and Concepts for Implementation, NASA/SP-2010-580, Version 1.0, November 2011.

National Research Council. (2009). Science and Decisions - Advancing Risk Assessment. Washington D.C.: National Academy Press

National Research Council. (1995). Technical Bases for Yucca Mountain Standards. Washington D.C.: National Academies Press.

National Research Council. (1994). Science and Judgment in Risk Assessment. Washington D.C.: National Academy Press.

National Transportation Safety Board (NTSB). Safety Study – Integrity Management of Gas Transmission Pipelines in High Consequence Areas. NTSB/SS-15/01. January 27, 2015.

NORSOK Standard Z-013, Edition 3, October 2010. Risk and Emergency preparedness assessment. Norwegian Oil Industry Association (OLF) and the Federation of Norwegian Industry, Lysaker, Norway. 2010.

Nuclear Regulatory Commission (NRD). (2007). UPDATE ON THE IMPROVEMENTS TO THE RISK-INFORMED REGULATION IMPLEMENTATION PLAN. NRC.

Pollution Control Department (PCD) Guidelines for Quantitative Risk Assessment (QRA) Study (For Installations Which Store, Transport Or Use Hazardous Substances). Rev: November 2014. Found at: http://www.nea.gov.sg/docs/default-source/anti-pollution-radiation-protection/central-building-planning/qra-guidelines_nov-2014.pdf?sfvrsn=0

The Presidential/Congressional Commission on Risk Assessment and Risk Management. Framework for Environmental Health Risk Management. Final Report Volume 1. 1997

Rodrigues, R. Pipeline Risk Management. 2010.

Schork, J. M. and Lutostansky, E. M., Societal Risk Criteria and Pipelines, Global Congress on Process Safety, 2012.

Sedwick, 2002. The Impact of Catastrophes on Shareholder Value, A Research Report Sponsored by Sedgwick Group, Rory F. Knight & Deborah J. Pretty, The Oxford Executive Research Briefings, 2002.

Skjong, R. Risk Acceptance Criteria: current proposals and IMO position. Surface transport technologies for sustainable development. June 2002.

Skjong, R. and Eknes, M. Economic Activity and Societal Risk Acceptance. DNV.

Technical Basis for U.S. Department of Energy Nuclear Safety Policy, DOE Policy 420.1, U.S. Department of Energy, July 2011.

Trbojevic, V.M., Risk criteria in EU, Risk Support Limited, London, U.K.

U.S. Department of the Interior – Bureau of Reclamation Dam Safety Office. Reclamation Managing Water in the West. Interim Dam Safety Public Protection Guidelines. A Risk Framework to Support Dam Safety Decision-Making.

U.S. Department of Labor, Occupational Safety & Health Administration (OSHA). Process Safety Management of Highly Hazardous Chemicals. Found at: https://osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760

U.S. Environmental Protection Agency (EPA). Risk Management Program Guidance for Offsite Consequence Analysis. EPA 550-B-99-009. March 2009. Found at: http://www.epa.gov/sites/production/files/2013-11/documents/oca-chps.pdf

U.S. Government Accountability Office. Gas Pipeline Safety – Guidance and More Information Needed before Using Risk-Based Reassessment Intervals. June 2013.

Walker, T. Reducing Risks, Protecting People – Decision-Making on the Basis of Risk. University of Bath, School of Management. Center for the Study of Regulated Industries. January 2003.

WIPP Land Withdrawal Act. (1992). Public Law 102-579.

WIPP Land Withdrawal Act as Amended. (1996). Law 104-201.

# APPENDIX A – INDUSTRY SURVEY QUESTIONS

# Industry Survey for Pipeline Companies

Kiefner & Associates and EMC2 are working on a project for the U.S. DOT Pipeline and Hazardous Materials Safety Administration (PHMSA) to learn the extent that pipeline companies (as well as other relevant industries, and government agencies) are using risk tolerability criteria to support risk management decisions. In other words, have you defined a level of risk above which is intolerable and likewise a level below which would be considered acceptable? The intent of this project is not to propose or suggest specific risk criteria, but to provide a summary of current practices.

This survey is addressing one of three PHMSA studies on pipeline risk assessments.

1. DTPH5615T00001, Approaches for Preventing Catastrophic Events
2. **DTPH5615T00002, White Paper on Risk Tolerance**
3. DTPH5615T00003, Critical Review of Candidate Pipeline Risk Models

A brief overview of the project is available on the PHMSA website at:
https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=639

We would very much appreciate your feedback. We realize this is sensitive information; therefore, company names will be kept confidential. Forwarding to other colleagues is welcomed. We appreciate your contribution to our research!

| 1 | > | 2 | > | 3 | > | 4 |
|---|---|---|---|---|---|---|
| **Pipeline Information** | | Risk Models/Assessments | | Risk Tolerance | | Personal Information |

What best describes the type(s) of pipeline you operate and the respective mileage?

- ☐ Natural gas
- ☐ Hazardous liquid
- ☐ Other (please describe)

_____

Mileage of natural gas pipeline

_____

Mileage of natural gas pipeline in High Consequence Area (HCA)

_____

Mileage of hazardous liquid pipeline

_____

Mileage of hazardous liquid pipeline in High Consequence Area (HCA)

_____

For the lines you operate, what percentage are transmission: *(Must be a number less than or equal to **100**.)*

_____

For the lines you operate, what percentage are distribution: *(Must be a number less than or equal to **100**.)*

_____

For the lines you operate, what percentage are gathering: *(Must be a number less than or equal to **100**.)*

_____

If you operate hazardous liquid lines, please check all that apply:

- ☐ Crude oil
- ☐ Refined product
- ☐ Liquefied natural gas (LNG)
- ☐ Carbon dioxide (CO2)
- ☐ Anhydrous ammonia (NH3)
- ☐ Other (please describe)

_____

1 Pipeline Information > **2 Risk Models/Assessments** > 3 Risk Tolerance > 4 Personal Information

What best describes your use of risk assessments? (Check all that apply.)

- ☐ Prioritize pipeline integrity assessments according to risk level
- ☐ Facility siting
- ☐ Environmental Impact Statements
- ☐ Meet regulatory requirements (Only for HCAs)
- ☐ Assist in risk reduction decisions
- ☐ Guide in pipeline routing/re-routing decisions
- ☐ Environment Impact Analysis Land use planning
- ☐ Other (please describe)

---

What is the scope of your risk assessment program?

- ☐ Prioritize pipeline integrity assessments according to risk level
- ☐ Pipelines - Distribution
- ☐ Facilities
- ☐ Facilities - Metering Facility
- ☐ Facilities - Storage facilities
- ☐ Pipelines - Transmission
- ☐ Pipelines - Gathering
- ☐ Facilities - Pump Stations
- ☐ Facilities - Compressor Stations
- ☐ Facilities - Regulator stations

For pipeline risk assessments, how do you segment your pipeline?

- ☐ Per mile / kilometer
- ☐ Change in pipeline property (coating type, wall thickness, seam type, etc.)
- ☐ Dynamic segmentation

Do you use a risk model(s) to perform your risk assessments?

- ☐ Yes
- ☐ No

If you do not use a risk model, what process do you use to perform your risk assessments? (Subject Matter Expert (SME) input, HAZOPs, What-if Analyses, Checklist, Risk Matrices, etc.). Please describe the process.

_____

_____

_____

_____

_____

Why did you choose this risk modeling approach? (Data-driven, ease of use, available off-the-shelf, etc.) Please describe

_____

_____

_____

_____

_____

If yes, how many?

_____

Please provide the name and/or names of the risk model(s) used, indicate if developed internally or purchased (also state if it's proprietary), and briefly describe the risk model(s) - (e.g. quantitative or qualitative; assets evaluated; how results are evaluated)

_____

_____

_____

_____

_____

Do you use specific software for your risk model?

- ☐ Yes
- ☐ No

If yes, was it developed...

- ☐ Internally
- ☐ Purchased

If purchased, was it off-the-shelf or customized for your particular system?

_____

_____

_____

_____

_____

Would you primarily describe your pipeline risk assessment methodology as qualitative, semi-qualitative, or quantitative?

- ☐ Qualitative: (Relative risk score / index model; Low, medium, high (risk matrix); SME)
- ☐ Semi-quantitative: (Risk matrix with numerical ranges for likelihood and/or consequences)
- ☐ Quantitative: (Historical data, probabilistic models, monetized)

What types of consequence categories do you address?

- ☐ Environment
- ☐ Business
- ☐ Business - Product loss
- ☐ Business - Business interruption
- ☐ Business - Equipment damage
- ☐ Other (please describe)
- ☐ Business - Litigation issues
- ☐ Business - Reputation damage
- ☐ Population (Health & Safety)
- ☐ Population - Public
- ☐ Population - Worker

_____

How do you currently make your risk management decisions?*(Highest risk segments are mitigated first; specific criteria is used to decide where and where not to act; SME input only; is there a level where no action is required; cost-benefit analyses, etc.)*

_____

_____

_____

_____

_____

Have you established risk tolerance levels? (Have you defined boundaries for what is intolerable versus tolerable in terms of risk?)

- ☐ Yes
- ☐ No

If not, why not?

_____

_____

_____

_____

_____

If you have defined risk tolerance levels (boundaries), how were they determined? (Group consensus, historical data, other regulatory bodies, etc.)

_____

_____

_____

_____

_____

Do you think the risk tolerance levels defined by your company differ from public perceptions of tolerable?

- ☐ Yes
- ☐ No

If yes, do you have programs in place to address these discrepancies or do you work with public stakeholders to develop criteria that are acceptable for both?

_____

_____

_____

_____

_____

What methods are you using to communicate your risk tolerance levels? Please check all that apply.

- ☐ Relative risk/index score
- ☐ Risk matrix
- ☐ Individual risk
- ☐ Societal risk
- ☐ Environmental risk
- ☐ Business risk
- ☐ Comparison criteria (benchmarks based on previous experience, PHMSA incident data)
- ☐ Other (please describe)

_____

Do you use a common basis for defining your risk tolerance levels (e.g. costs; fatalities only) or do you have multiple risk tolerance criteria? (Individual risk concerns, societal risk concerns, environmental risk concerns, business risk concerns, other). Please describe

_____
_____
_____
_____
_____

Do you define risk tolerability criteria on a system-wide basis or by individual unit-lengths (or segments) along the pipeline system? Please Describe

_____
_____
_____
_____
_____

Have you determined an "unacceptable" risk level? (Intolerable risk except in extraordinary circumstances and risk reduction measures are essential.)

- ☐ Yes
- ☐ No

If yes, please specify:

_____

Have you determined a "tolerable" or "ALARP" (as low as reasonably practicable) range? (Risk reduction measures desirable, but may not be implemented if the cost is grossly disproportionate to the benefit received.)

- ☐ Yes
- ☐ No

If yes, please specify:

_____

Have you determined a "broadly acceptable" level? (Risks are deemed tolerable or negligible; no further risk reduction measures are required)

- ☐ Yes
- ☐ No

If yes, please specify:

_____

What approach did you use to establish the tolerance levels? (Meeting with stakeholders,benchmarks defined by other regulatory agencies, risk sensitivity surveys, internal corporate benchmarks, other.)

_____

_____

_____

_____

_____

Who is involved in defining your risk criteria and/or your tolerance levels? Please check all that apply.

- ☐ Internal risk analysts
- ☐ Business/financial managers
- ☐ Subject Matter Experts (SMEs)
- ☐ Management
- ☐ Consultant
- ☐ Public Stakeholders
- ☐ Legal
- ☐ Other (please describe)

_____

Do you review your risk tolerability criteria as part of management of change?

- ☐ Yes
- ☐ No

Do you regularly review your risk tolerability criteria for applicability to current operations?

- ☐ Yes
- ☐ No

What barriers do you believe exist in defining risk tolerable levels? (Public perception, management / legal sensitivities, other issues)

_____

_____

_____

_____

_____

What improvements in risk assessment methodologies, available information, or data collection would be most helpful to your organization?

_____

_____

_____

_____

_____

**NAME**

First

Last

**TITLE / POSITION**

**ADDRESS**

Street Address

Address Line 2

City

State

Postal / Zip Code

Country

Would it be acceptable for Kiefner engineers to follow-up with you regarding clarification on specific responses provided for this survey, if necessary?

- ☐ Yes
- ☐ No

# APPENDIX B – INDUSTRY SURVEY RESPONSES

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| **Pipelines and Mileage** | | | | | | | | |
| Natural Gas | 500 | | | | 400 | 61951 | | 503.5 |
| NG-HCA miles | 200 | | | | 358 | 1288 | | 63.8 |
| NG-US miles | | | | | | | | |
| Hazardous Liquid | | 39.5 | 5697 | 4000 | 3000 | | 11600 | 3592.2 |
| HL-HCA miles | | 39.5 | 3506 | 2700 | 1500 | | 4800 | 1243.4 |
| HL-US miles | | | | | | | | |
| Total Miles | 500 | 39.5 | 5697 | 4000 | 3400 | 61951 | 11600 | 4095.7 |
| Total HCA miles | 200 | 39.5 | 3506 | 2700 | 1858 | 1288 | 4800 | 1307.2 |
| Total US miles | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Transmission | 40% | 100% | 85% | 99% | 100% | 6% | 100% | 74% |
| Distribution | 23% | 0% | 0% | 0% | 0% | 94% | 0% | 0% |
| Gathering | 37% | 0% | 15% | 1% | 0% | 0% | 0% | 26% |
| Crude Oil | x | | x | x | | | x | x |
| Refined Product | | x | | x | x | | x | x |
| LNG | | | | | | | | |
| CO2 | | | x | | | | | x |
| NH3 | x | | | x | | | x | |
| Other | | | | | | | | |
| HVL | | | x | | | | | x |
| Various Chemicals | | | | x | | | | |
| **Use of Risk Assessment** | x | x | x | x | x | x | x | x |
| Prioritize pipeline integrity assessments according to risk level | | x | x | | x | x | | x |
| Assist in risk reduction decisions | | x | | | x | | | x |
| Guide in pipeline routing/re-routing decisions | | x | x | | x | x | | x |
| Facility siting | | x | x | | x | x | | x |
| EIA | | x | | | x | | | x |
| EIS | | x | | | x | | | x |
| Land use planning | x | x | x | x | x | x | x | x |
| Meet regulatory requirements | | | | | | | | |
| Other | | | | | | | | |
| Excavation and re-inspection decisions | | | | | | | | |
| Budget | | | | | | | | |
| Incident Investigation | | | | | | | | |
| Management System Audits | | | | | | | | |
| Out of Class Engineering Assessments | | | | | | | | |
| Distribution Integrity | | | | | | | | |
| Pipeline Replacement/Modernization Planning | x | x | x | x | x | x | x | x |
| **Scope of Risk Assessment Program** | | | | | | | | |
| Transmission Pipelines | | x | x | x | x | x | x | x |
| Distribution Pipelines | | | | | | x | | |
| Gathering Pipelines | | | | x | | | | x |
| Pipelines | | x | x | x | x | x | x | x |
| Facilities | x | | | x | x | | x | x |
| Pump Stations | | | x | x | | | x | x |
| Metering Facilities | | | x | | | | x | x |
| Compressor Stations | | | | | | | | |
| Storage Facilities | | x | x | | | | x | x |
| Regulator Stations | | | | | | | x | x |
| **Pipeline Segmentation for Risk** | | | | | | | | |
| Per mile/km | x | | | | | | | |
| Change in pipeline property | | | | x | | x | x | x |
| Dynamic segmentation | | x | x | x | | x | x | |
| **Types and Use of Risk Models** | | | | | | | | |
| Non-software model | x | x | | x | x | | | x |
| Internally developed software model | | | | | | | | |
| Purchased software model | | | x | x | | x | x | |
| Proprietary? | | x | | x | | | | x |
| # of Risk Models | | 1 | 2 | 5 | 1 | 2 | 2 | |
| Qualitative | | | | x | | x | x | x |
| Semi-Quantitative | | x | x | | x | | | |
| Quantitative | | | | | | | | x |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Description: | | It does not have a name, it is a proprietary program developed by RCP Consultants. Risk matrix with numerical ranges for likelihood and/or consequences. | Mainline Risk Model (off-the-shelf): the software to run the model was purchased but the model (risk algorithms) are developed and maintained jointly by Risk professionals and SMEs. The level of sophistication varies by threat. Some algorithms are essentially flow charts, some are simply weighting relevant conditions, and others are more sophisticated fault trees or equations. Consequence comes from spill modeling. The end result is a risk score from 1-10. Each pipeline system is periodically reviewed and scores ranging in the top 5% are scrutinized to identify risks that are later developed into scenarios to be evaluated using our risk matrix.<br><br>Facility Risk Model - the software to run the model was purchased but the model (risk algorithms) are developed and maintained by Risk professionals. The algorithm is fairly simple in that it takes the probability of failure for each component and multiplies that by the number of components at the facility. The feet of pipe in the facility is also considered. All equipment and pipe within the facility is aggregated to determine an overall likelihood of failure. Consequence comes from spill modeling. The end result is a risk score from 1-10. Facilities with the highest risk scores are scheduled for an onsite risk assessment. The onsite assessment relies heavily on "what-if" analysis to identify risks that are later developed into scenarios to be evaluated using our risk matrix. | Pipeline Ranking Index Model - Internal; proprietary; semi-quantitative; line pipe<br>Water Crossing Prioritization Model - Internal; proprietary; qualitative; water crossings<br>Exposed Pipe Prioritization Model - Internal; proprietary; qualitative; line pipe at exposures<br>Long Seam Prioritization Model - Third party; proprietary; semi-quantitative; ERW line pipe<br>Station Piping Prioritization Model - Internal; proprietary; qualitative; station line pipe | A formal risk assessment and Hazard & Effect Management Process (HEMP) process is used in which meeting participants include Engineering, OPS, and HSSE staff. All available data is integrated and discussed to determine the effectiveness of barriers and recovery measures are discussed. Although there is no formal computer model used, action items are documented and followed though using the MOC process when changes result.<br><br>Each asset is analyzed no less that every three years. | 1 relative model for transmission pipelines using RiskFrame Modeler<br>1 relative model for distribution pipelines using Uptime DNV GL<br><br>for both applications , RiskFrame Modeler and Uptime DNV GL, applications are pretty much off the shelf but run customized internally developed algorithms to evaluate data. | Qualitative - developed by American Innovations (used for the majority of assets operated)<br>Quantitative (Probabilistic) - developed by American Innovations (for specific assets) | What-if analysis, checklists, and HAZOP - technique used is determined by the complexity of facility or pipeline being evaluated. Individual scenarios are risk ranked per corporate matrix. |
| Reason for use of model | | | | | | | | |
| **Consequence Categories Addressed** | | | | | | | | |
| Environment | | x | x | x | x | | x | x |
| Business - Product Loss | | | | x | | | | x |
| Business Interruption | | | x | | | | | x |
| Equipment Damage | | | x | x | | | | x |
| Litigation Issues | | | | | | | | |
| Reputation Damage | | | x | | x | | | x |
| Public Health and Safety | | x | x | x | x | x | x | x |
| Worker Health and Safety | | | x | x | x | | | |
| Other | | | | | | | | |
| Response Time | | | Our actual consequence types are Safety, Environment, Regulatory, Reliability, Financial, Corporate reputation | | | | | |
| **Risk Tolerance Criteria** | | | | | | | | |
| Have you established risk tolerance levels? | N | Y | Y | N | Y | N | N | Y |
| If not, why not? | | | | Adequacy and accuracy of establishing risk tolerance levels | | Overall, risk tolerance level is not established. However, for ILI remediation we use POE and established acceptable criteria. | To allow for SME input and the flexibility of resources to be applied to the highest risk. | |
| How were they determined? | | Each segment of pipeline is analyzed and given a relative risk factor between 1 and 5. It's based on PHMSA's 9 identified threat factors and 3 consequence factors, | Risk tolerance was established by engaging the entire leadership team in setting up the risk matrices. Final approval resided with the company President and VP | | RAM matrix and Goal Zero dictate acceptable risk tolerance levels. | | | Group of SMEs developed risk matrix and another group determined the F-N curve and IRPA. Lawyers involved in Risk Matrix, F-N Curve, and IRPA. |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| | | in addition to specific properties of our pipeline and products. | of Operations. | | | | | Risk Matrix<br>Corporate F-N curve<br>IRPA |
| How do you make your risk management decisions? | | Highest risk segments are mitigated first | Relative risk scores feed into the calculation of assessment intervals.<br><br>When evaluating other preventative and mitigative measures, the risk matrix is used to evaluate risk in more absolute terms. The results are compared against risk criteria and risks that are intolerable are scheduled for risk treatment within defined timeframes. Approval authority for the risk treatment is defined as well as variance authority for accepting a risk that is outside of tolerance. | SME Input<br>Highest risk mitigated first | A Goal Zero approach independent of regulatory requirements is employed. | | Highest risk segments with SME input | Where the cause-consequence scenario lands on the risk matrix drives whether or not further action is required to lower risk. Also, pending the type of risk analysis, cost-benefit-analysis is don as well. |
| Do you think risk tolerance levels defined by your company differ from public perceptions of tolerable risk? | | N | Y | N | N | | N | |
| Do you work with public stakeholders to develop criteria acceptable to both? | | | I am unsure whether we are aligned with public perceptions of acceptable risk. We do engage public stakeholders for feedback on our company's performance; however, no formal public review of risk tolerance has occurred. | | | | | We do not publish our F-N curve and IRPA. |
| **Methods used to communicate risk tolerance levels** | | | | | | | | |
| Relative risk/index score | | x | | x | | | x | |
| Risk matrix | | | x | | x | | x | x |
| Individual risk | | | | | | | x | x |
| Societal risk | | | | | | | x | |
| Environmental risk | | | | | | | x | x |
| Business risk | | | | x | | | | x |
| Comparison criteria | | | | x | | | x | x |
| Other | | | | | | | | |
| Calibration to best practice in standards | | | | | | | | |
| Internal | | | | | | | | |
| Other sources (CCPS, CONCAWE, NEB) | | | | | | | | x |
| **Specific Risk Tolerance Criteria** | | | | | | | | |
| Common Basis for risk criteria | | x | x | | x | | | |
| Multiple risk criteria | | | | | | | x | x |
| Describe | | We use multiple factors to create a common basis. We combine threats (9 categories with multiple sub-categories), consequences (3 categories with multiple sub-categories). The threat score is multiplied by the consequence score to give the relative risk level. | All risks are evaluated against a common set of risk matrices that generates an A, B, C, or D ranking and a 1-100 risk score. The risk rank determines whether a risk is tolerable and specific risk treatment criteria have been established for each ranking. | | Risk defined in RAM considers harm to people, environment, economics, and reputation.<br>All pipeline and facility assets must be at ALARP. | | | We have multiple risk tolerance criteria as it depends on the situation; we have a corporate process with pre-defined tools and the complexity/consequence being analyzed, then choose the appropriate analysis, i.e. Risk Matrix, Consequence Modeling, LDCE, EFRD. |
| System-wide risk criteria | | | | | x | | x | x |
| Individual unit length criteria | | x | | | | | x | |
| Describe | | The criteria is the same for each segment | | | | | | System-wide basis (the target F-N curve and IRPA value is all the same for pipelines, facilities, and throughout the corporate). |
| Unacceptable Level | | | x | | x | | | x |
| Describe | | | A and B risks are intolerable | | Via RAM matrix | | | Depending where on the risk matrix the ranking falls. We use a 6x6 matrix and if the risk is in the red zone (risk rankings 1-5) actions must be taken to lower the risk. There are published time frames associated with lowering the risk. Unacceptable risk is anything |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | above the F-N curve or greater than the targeted IRPA. |
| ALARP Region | | | x | | x | | | x |
| Describe | | | We strive to reduce risks to a C or lower. We use a "risk merit" calculation to weight the benefits of risk reduction against the implementation risk (cost). | | ALARP | | | Depending where on the risk matrix the ranking falls. We use a 6x6 matrix and if the risk is in the yellow zone (risks rankings 6) actions to lower risk can be implemented if the benefit is there. Of course, anything below the targeted F-N curve and IRPA as well. |
| Broadly Acceptable Level | | | x | | x | | | x |
| Describe | | | D risks are tolerable | | ALARP | | | Depending where on the risk matrix the ranking falls. We use a 6x6 matrix and if the risk is in the green zone (risks rankings 7-10) no further action is necessary to lower risk. |
| Approach used to establish tolerance levels: | | | Leadership engagement, benchmarking with other companies, literature search on societal risk | Meet with stakeholders | ALARP | | Meeting with stakeholders, risk surveys, internal corporate benchmarks | Corporate criteria |
| **Who is involved in establishing criteria?** | | | | | | | | |
| Internal risk analysts | | | x | | | x | x | |
| Business/financial managers | | | | | | | | |
| SMEs | | | | x | x | x | x | x |
| Management | | x | x | x | | | x | x |
| Consultants | | x | | | | | | |
| Public stakeholders | | | | | | | | |
| Legal | | | x | | | | x | x |
| Other | | | | | | | | |
| Regulators | | | | | | | | |
| Criteria is regularly reviewed | | x | x | x | x | | x | x |
| Criteria reviewed as part of MOC | | | | x | x | | x | Depends on what is changing |
| What barriers exist for defining risk tolerability levels? | | Management having the technical expertise to help make such determination. | Company risk tolerance belongs on a continuum with the public and the regulator. Understanding the risk tolerance of the public and the regulatory is largely a guessing game today. | Legal sensitivities | Public tolerability and the resultant reputational risk. | All those items listed (public perception, management/legal sensitivities) are barriers we are facing. Also unclear directions of regulators. | Appropriated resources required by regulation to be redirected to lower risk activities | The litigious atmosphere in the USA. Differences between public perception and actual risk. Trying to explain things like F-N curves or IRPA to not only employees, contractors and management but also the public. |
| What improvements in risk assessment methodologies, available information, or data collection would be most helpful? | | | | Defining an industry accepted methodology | | Capability to integrate available data. | Improved data integration | A database (ex. geo-spatial) that is automatically normalize, kept current, accurate, reliable, easily accessible, and has the "significant" variables that affect risk (both likelihood and consequence) to help "actively" manage the risk, and not to the nth-degree of variables, in which if required to have risk as a number, can be standardize across industry for risk, likelihood and consequence modeling. Has a "true" gap analysis been done to "validate" real issues based on this database; for example, LFERW, water crossings, etc. |

| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| **Pipelines and Mileage** | | | | | | | | |
| Natural Gas | 653.4 | 4240 | | | 3600 | 23198 | 22985 | 11245.45 |
| NG-HCA miles | 186.6 | 120 | | | 36 | 45.113 | 86.4 | 25.8 |
| NG-US miles | | | | | | | | |
| Hazardous Liquid | | | 8600 | 1453.81 | | | | |
| HL-HCA miles | | | 7000 | 212.4 | | | | |
| HL-US miles | | | | | | | | |
| Total Miles | 653.4 | 4240 | 8600 | 1453.81 | 3600 | 23198 | 22985 | 11245.45 |
| Total HCA miles | 186.6 | 120 | 7000 | 212.4 | 36 | 45.113 | 86.4 | 25.8 |
| Total US miles | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Transmission | 1% | 5% | 98% | 100% | 11% | 3% | 4% | 2% |
| Distribution | 99% | 95% | 0% | 0% | 89% | 97% | 96% | 98% |
| Gathering | 0% | 0% | 2% | 0% | 0% | 0% | 0% | 0% |
| Crude Oil | | | x | x | | | | |
| Refined Product | | | x | x | | | | |
| LNG | | | | | | | | |
| CO2 | | | | | | | | |
| NH3 | | | | | | | | |
| Other | | | | | | | | |
| HVL | | | x | | | | | |
| Various Chemicals | | | | | | | | |
| **Use of Risk Assessment** | | | | | | | | |
| Prioritize pipeline integrity assessments according to risk level | x | x | x | x | x | x | x | x |
| Assist in risk reduction decisions | x | x | x | x | x | x | x | x |
| Guide in pipeline routing/re-routing decisions | | x | | | x | | | x |
| Facility siting | | | | | | | | |
| EIA | | | | | | | | |
| EIS | | | | | | | | |
| Land use planning | | | | | | | | |
| Meet regulatory requirements | x | x | x | x | x | x | x | x |
| Other | | | | | | | | |
| Excavation and re-inspection decisions | | | | | | | | |
| Budget | | | | | | | | |
| Incident Investigation | | | | | | | | |
| Management System Audits | | | | | | | | |
| Out of Class Engineering Assessments | | | | | | | | |
| Distribution Integrity | | | x | | | x | | |
| Pipeline Replacement/Modernization Planning | | | | | | | | |
| **Scope of Risk Assessment Program** | | | | | | | | |
| Transmission Pipelines | x | x | x | x | x | x | x | x |
| Distribution Pipelines | x | | | | | x | x | x |
| Gathering Pipelines | | | x | | | | | |
| Pipelines | x | x | x | x | x | x | x | x |
| Facilities | | | | x | x | x | x | |
| Pump Stations | | | | x | | | | |
| Metering Facilities | | | | | x | | | |
| Compressor Stations | | | | | x | | | |
| Storage Facilities | | | | | x | | x | |
| Regulator Stations | | | | | x | x | x | |
| **Pipeline Segmentation for Risk** | | | | | | | | |
| Per mile/km | | | x | | | | | |
| Change in pipeline property | | x | x | | | x | | |
| Dynamic segmentation | | | | x | x | x | x | x |
| **Types and Use of Risk Models** | | | | | | | | |
| Non-software model | | | x | | | | | |
| Internally developed software model | x | | | | x | x | | |
| Purchased software model | x | x | | x | | x | x | x |
| Proprietary? | | | | | x | | | |
| # of Risk Models | 2 | 1 | 1 | 2 | | 3 | 2 | 2 |
| Qualitative | x | x | | | x | | | |
| Semi-Quantitative | | | x | x | | x | x | x |
| Quantitative | | | | | | | | |

| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| Description: | Transmission (653.4 miles): UpTime software and the algorithms from the Keifner model. Distribution mains (13,498 miles) ESRI Model Builder with algorithms developed internally. Qualitative models | Kiefner risk model, purchased. | Scenario-based process using a risk matrix. | Third Party Pipeline Risk Assessment Model - Quantitative/Semi-quantitative Internally Developed Risk Model Facility - Qualitative<br><br>Customized in working with a third party consultant. | Internally developed (proprietary) - Relative Risk Model (Qualitative) broken down by covered segment. Probability used eight threats, consequences used six categories, the product of the two scores resulting in total relative risk. Cyclic Fatigue not included as a threat currently, interactivity of threats not taken into additional consideration due to relative nature of the model (essentially already included). | Transmission - Uptime v3.4. Purchased from vendor DNV GL. Qualitative analysis utilizing dynamic segmentation.<br><br>Distribution - An application was developed in-house to facilitate overall risk ranking for the distribution system. The system is semi-qualitative in that we use partial hard data from systems and partial likelihood scores from subject matter experts. Distribution also uses the MRP v3.4 purchased from DNV GL to rank pipeline replacement projects, which uses a quantitative analysis. | Purchased Software (Geofields-Risk Frame Modeler) with internally developed algorithms. Semi-quantitative analysis of all pipeline and appurtenances. Results are evaluated graphically and tabularly.<br><br>Off the shelf but customized using available data and a internally developed algorithm. | DNVGL Uptime - Purchased program that is data driven with SME input, GIS based, can be quantitative or qualitative, assesses pipe, results are supplied by risk score and graphical representation<br><br>Mulbauer Risk Matrix (Transmission HCA) - Risk score matrix based on SME input, qualitative, assesses pipe, results are supplied by risk score<br><br>Customized version of off-the-shelf product |
| Reason for use of model | | | It is our established process for risk assessment companywide. | | | | | |
| **Consequence Categories Addressed** | | | | | | | | |
| Environment | | | x | x | x | x | x | x |
| Business - Product Loss | x | | | x | | x | x | |
| Business Interruption | | | | x | x | x | x | x |
| Equipment Damage | | | x | x | x | x | x | |
| Litigation Issues | | | | | | x | | |
| Reputation Damage | | | x | | | x | | |
| Public Health and Safety | x | x | x | x | x | x | x | x |
| Worker Health and Safety | x | | x | x | x | x | | x |
| Other | | | | | | | | |
| Response Time | | | | | x | | | |
| **Risk Tolerance Criteria** | | | | | | | | |
| Have you established risk tolerance levels? | N | N | Y | N | N | N | N | Y |
| If not, why not? | Difficult to quantify. | Haven't had the need since any flaws found are remediated. | | Working toward defining an acceptable risk tolerance level. | The model reflects the relative risk score of covered segments. The scores are expected to change over time as the pipelines age, assessments are performed, repairs/replacements are completed, and risks/consequences change over time. | Risk is relative, so there is not a specific "number" that is "bad". | Risk score is semi-quantitative and we do not yet have the necessary information to establish a full quantitative model necessary to assign absolute risk where a tolerance level could be specified. | |
| How were they determined? | | | Risk tolerance levels based upon group consensus (industry) of acceptable individual and societal risks, which includes input from regulatory bodies. | | | | | We use the historical data to define tolerance levels. |
| How do you make your risk management decisions? | Highest risks mitigated first. SME input or taking accelerated actions on facilities that are demonstrating failures/leaks. | Highest risk, any flaws found are remediated | Risks evaluated against company's risk acceptability criteria. Higher overall risk (probability + consequence) as well as higher consequence segments (considering degrees of public impact) given priority. No action required for segments where risk is determined as ALARP. | Combination of results from the risk assessment and SME input. | Decisions are made by reviewing Risk Model results, SME input, operator experience and prudence (including risk assessments of pipelines not covered by IMP), assessment results/confirmatory information, and re-assessment requirements. | Transmission - Highest risk segments, SME input, what-if scenarios, cost benefit analyses, annual risk review meetings with SMEs, etc. | Segment mitigation is based on risk score, cost-benefit analysis, SME input, and available budget. | System is sub-divided and methods for mitigation/awareness are developed either globally or by specific area. Mitigative efforts are a result of SME input and company goals to reduce risk. |
| Do you think risk tolerance levels defined by your company differ from public perceptions of tolerable risk? | N | | Y | N | N | | | N |
| Do you work with public stakeholders to develop criteria acceptable to both? | The public is risk averse and so is the Company. | | No formal programs in place, although we continue to work to ensure our acceptable risk criteria is properly calibrated for impacts to members of the public. | Still working toward defining a company risk thresholds. | | | | |
| **Methods used to communicate risk tolerance levels** | | | | | | | | |
| Relative risk/index score | x | | | x | | | | |
| Risk matrix | | x | x | x | | | | x |
| Individual risk | | | x | x | | | | |
| Societal risk | | | x | x | | | | |
| Environmental risk | | | x | x | | | | |
| Business risk | | | | x | | | | |

| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| Comparison criteria | | x | x | | | | | x |
| Other | | | | | | | | |
| Calibration to best practice in standards | | | | | | | | |
| Internal | | | | | | | | |
| Other sources (CCPS, CONCAWE, NEB) | | | | | | | | x |
| **Specific Risk Tolerance Criteria** | | | | | | | | |
| Common Basis for risk criteria | | | | | | | | |
| Multiple risk criteria | | | x | | | | | x |
| Describe | | | We have multiple risk tolerance criteria, including degrees of harm to individuals (members of the public and company employees), the environment, company reputation and assets. | Still working on defining company risk thresholds. | | | | We evaluate threats individually and the overall risk through the use of historical data. |
| System-wide risk criteria | x | | x | | | | | x |
| Individual unit length criteria | | x | x | | | | | |
| Describe | System wide all our transmission lines are ranked relative to one another. Risk score is assigned by pipeline. | Individual segments using Kiefner model. | Primary criteria is on a segment basis, consistent with our scenario-based risk process. Secondarily, we consider the aggregated risk on a system-wide basis. | We would like to establish risk tolerability criteria on both a system-wide basis and by individual unit-lengths. | | | | We will use system-wide criteria to develop risk tolerability thresholds. |
| Unacceptable Level | | x | x | | x | | | x |
| Describe | | follow 192 and Rstreng | Per company criteria for combination of probability + consequence | | Burst Pressure Ratio of less than 1.1, wall loss greater than 70%, dents with metal loss, reassessment interval of less than ~3 years, etc. | | | Historical data is used to develop deviation boundaries from a normal average. |
| ALARP Region | | | x | | | | | |
| Describe | | | ALARP range consistent with industry criteria of gross disproportionate cost to risk reduction | | | | | |
| Broadly Acceptable Level | | | x | x | | | | |
| Describe | | | Per company criteria for combination of probability + consequence | Utilizing industry baseline failure frequency per each threat | | | | |
| Approach used to establish tolerance levels: | | | Tolerance levels have been defined company wide based upon industry and regulatory benchmarks for societal risk as well as internal corporate benchmarks | In working progress | | | | |
| **Who is involved in establishing criteria?** | | | | | | | | |
| Internal risk analysts | x | | x | x | x | x | x | x |
| Business/financial managers | | | | | | | x | |
| SMEs | x | x | x | x | x | x | x | x |
| Management | x | x | x | x | x | x | x | x |
| Consultants | x | | | x | | x | x | |
| Public stakeholders | | | | | | | | |
| Legal | | | x | | | | | |
| Other | | | | | | | | |
| Regulators | | | | | | | | |
| Criteria is regularly reviewed | | | x | x | x | x | | x |
| Criteria reviewed as part of MOC | | | | x | x | x | | |
| What barriers exist for defining risk tolerability levels? | Public perception, sensitivity to associating risk with dollars. | Understanding risk and their consequences. | Public perception is likely the biggest barrier, as there appears to be no level of risk that is tolerable to the public besides "zero". Legal sensitivities of a company deciding what is "tolerable risk" to which members of the public may be subjected is also a challenge. | It's hard to define what is an acceptable risk tolerable level from company and industry perspective - that would deem as acceptable. Lack of consistency in the risk models used in industry. | | We focus on relative risk rather than absolute value. We prioritize the highest ranked segments first. Because we don't use a "tolerable level" but focus on highest ranked there are few (if any) barriers. | Our understanding of the risk based on threats present on the facilities. Public perception of reasonable risks vs. worst case scenario. Cost of gathering necessary data and acting on results. | Public perception of tolerable risk |
| What improvements in risk assessment methodologies, available information, or data collection would be most helpful? | We are primarily a LDC with some transmission pipelines our risk levels have changed very little since formal risk models have been in use. | Validation of the current model we are using (Kiefner). | A robust database of previous events, including causal factors and outcomes, would be incredibly helpful for calibrating both probabilities of events occurring and the outcomes of those events. Right now we use what we feel is the best data and methodologies available, but have little to | Consistency in the risk methodologies used by industry. Industry accepted risk tolerance ranges per threat specific. | Data integration with an easy to use application/customization, updates in knowledge/materials/trends/risks. Simply applicability for various types of systems, distribution, transmission, plant/facilities, etc. | Accuracy of data collection, geo-spatial information, standardization of data collection metrics, traceability of steel materials, phased array development (plastic and steel) | More data pertaining to quantitative risk modeling including monetized examples. Quantitative risk assessment methodologies presented have required a large amount of additional work for marginal gains in risk scoring | Further development of consequence factors |

| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| | | | benchmark against. | | | | and have not shown a monetized value for additional work. Standard Risk Model Templates, centralized Data repository Data collection methodologies white paper. | |

| | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| **Pipelines and Mileage** | | | | | | | | |
| Natural Gas | 16640 | 13664 | 8560.141 | 8819.893 | 1415 | 104 | 40900 | 49083 |
| NG-HCA miles | 208 | 79 | 6 | 133.139 | 16 | 2 | 492 | 1178 |
| NG-US miles | | | | | | | 15238 | |
| Hazardous Liquid | | | | 39 | | | 2170 | |
| HL-HCA miles | | | | 39 | | | 321 | |
| HL-US miles | | | | | | | 1391 | |
| Total Miles | 16640 | 13664 | 8560.141 | 8858.893 | 1415 | 104 | 43070 | 49083 |
| Total HCA miles | 208 | 79 | 6 | 172.139 | 16 | 2 | 813 | 1178 |
| Total US miles | 0 | 0 | 0 | 0 | 0 | 0 | 16629 | 0 |
| Transmission | 12% | 1% | 1% | 3% | 12% | 90% | 100% | 13% |
| Distribution | 88% | 99% | 99% | 97% | 88% | 0% | 0% | 87% |
| Gathering | 1% | 0% | 0% | 0% | 0% | 10% | 0% | 0% |
| Crude Oil | | | | | | x | x | |
| Refined Product | | | | | | x | | |
| LNG | | | | | | | | |
| CO2 | | | | | | | | |
| NH3 | | | | | | | | |
| Other | | | | | | | | |
| HVL | | | | x | | | | |
| Various Chemicals | | | | | | x | | |
| **Use of Risk Assessment** | | | | | | | | |
| Prioritize pipeline integrity assessments according to risk level | x | x | x | x | | x | x | |
| Assist in risk reduction decisions | x | x | | | x | x | x | |
| Guide in pipeline routing/re-routing decisions | x | | | | | | x | |
| Facility siting | x | | | | | | | x |
| EIA | x | | | | | | x | |
| EIS | x | | | | | | | |
| Land use planning | x | | | | | | | |
| Meet regulatory requirements | x | x | x | x | | x | x | |
| Other | | | | | | | | x |
| Excavation and re-inspection decisions | | | | | | | x | |
| Budget | | | | | | | | x |
| Incident Investigation | | | | | | | | |
| Management System Audits | | | | | | | | |
| Out of Class Engineering Assessments | | | | | | | x | |
| Distribution Integrity | | | | | | | | |
| Pipeline Replacement/Modernization Planning | x | | | | | | | |
| **Scope of Risk Assessment Program** | | | | | | | | |
| Transmission Pipelines | x | x | x | x | x | x | x | x |
| Distribution Pipelines | x | | x | x | x | | | x |
| Gathering Pipelines | | | | | | x | | |
| Pipelines | x | x | x | x | x | x | x | x |
| Facilities | x | | | | | | x | x |
| Pump Stations | x | | | | | | | |
| Metering Facilities | x | | | | | | | x |
| Compressor Stations | x | | | | | | x | x |
| Storage Facilities | x | | | | | | | x |
| Regulator Stations | x | | | | | | | x |
| **Pipeline Segmentation for Risk** | | | | | | | | |
| Per mile/km | | | | | | | | |
| Change in pipeline property | | x | x | x | x | | x | x |
| Dynamic segmentation | x | x | | | | x | x | x |
| **Types and Use of Risk Models** | | | | | | | | |
| Non-software model | | | | | | x | | x |
| Internally developed software model | | | | | | | x | |
| Purchased software model | x | x | | | x | | | |
| Proprietary? | x | | | | | | x | |
| # of Risk Models | 1 | 2 | 0 | 0 | 3 | 1 | 3 | |
| Qualitative | x | | x | | | x | | |
| Semi-Quantitative | | x | | x | x | | | x |
| Quantitative | | | | | | | x | |

| | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| Description: | It is the Kiefner Northeast Gas Association Risk Model). It is a qualitative (relative) Risk Model which segments the pipe based on a change in pipe attributes. It is proprietary to members of the Northeast Gas Association. Results are evaluated through various reports output from the database, as well as through GIS mapping analysis.<br><br>It is the Kiefner Northeast Gas Association Risk Model. It has been implemented within ESRI ArcGIS using dynamic segmentation. It was custom developed for an Industry Association Group by Kiefner and Associates, implemented in Microsoft Access. The database schema was then modeled into a GIS environment and the algorithm was automated utilizing ESRI model builder. | 1) Model developed by James Sewall Company. We chose this risk model in 2004 to prioritize high risk segments. This model is relative risk model.<br>2) Dynamic Risk: are currently working with Dynamic Risk in developing a new risk model for our TRMN lines. This model will use a semi-quantitative approach; will have dynamic segmentation, can measure interactive threats and run what-if scenarios.<br><br>Both models are off the shelf-however a certain degree of customization is needed for any product. | SME Input | SME input to develop a relative risk matrix | For Transmission we use a relative risk ranking software.<br>For Distribution we use software calibrated to our system for micro level (segment) risk ranking.<br>Also for Distribution we use SME input to a risk matrix for macro level risk ranking.<br><br>Off-the-shelf | Qualitative risk model developed internally.<br><br>The purpose of the Pipeline Risk Analysis process is to provide a comprehensive and systematic risk analysis methodology to be applied across company pipeline assets in order to: 1) uniformly evaluate and compare the relative potential for the occurrence and severity of pipeline integrity threats along each pipeline; 2) uniformly evaluate and compare the relative potential for impact on the public and the environment in the event of a release at any location along a pipeline; 3) evaluate the effectiveness of risk prevention, detection, and mitigation programs currently in place along the pipelines; 4) identify areas where additional prevention, detection, and mitigation activities may reduce the probability and/or the consequence of a perceived risk; and, 5) facilitate knowledge-based, risk-informed decision-making with regard to effective allocation of company resources to mitigate pipeline integrity risk. | Three different approaches: QRA (reports using 2 measures, IR and SR, Environmental impact), Reliability Based (probabilistic) ILI decision making models, and engineering assessments (alternatives to code compliance) | An enterprise risk framework along with a Risk Evaluation Tool (RET) is utilized to identify and assess risks. This framework uses the tool to calculate a relative risk score for each risk. The relative risk score is assessed from SME input, HAZOPs, and risk matrices. Actual consequence or probability data is used, where applicable. Currently, the company is piloting risk models to quantify risk assessments for the enterprise risk process.<br><br>Semi-quantitative: (Risk matrix with numerical ranges for likelihood and/or consequences) |
| Reason for use of model | | | Minimum amount of mileage in HCA | Ease of use, best fit for our system characteristics | | | Quantitative data driven approaches allow: use of all evidence of threat (historical incidents, assessments, mechanistic understanding of threats); better representation of different threats; direct comparison between threats (without arbitrary assumptions about the percentage of total); ability to explicitly account for threat interaction; accurately represent growth and accurate consequence representation; ability to compare against consciously established risk tolerances; and defendable rationale for good decision making. | The enterprise risk framework (AKA Integrated Planning Process) is used to provide a consistent and transparent method to assess risk across the entire company (gas, electric, and generation). |
| **Consequence Categories Addressed** | | | | | | | | |
| Environment | x | x | | | | x | x | x |
| Business - Product Loss | x | | | | | | | x |
| Business Interruption | x | | | | | | | x |
| Equipment Damage | | | | | | | | x |
| Litigation Issues | | | | | | | | x |
| Reputation Damage | | | | | x | | | x |
| Public Health and Safety | x | x | x | x | x | x | x | x |
| Worker Health and Safety | x | | | | x | | x | x |
| Other | | | | | | | | |
| Response Time | | | | | | | | Interruption of public services, Reliability, Compliance, Financial |
| **Risk Tolerance Criteria** | | | | | | | | |
| Have you established risk tolerance levels? | N | N | N | N | Y | N | Y | N |
| If not, why not? | The pipeline system is maintained at a level where the entire system is designed and maintained to at least the minimum DOT code requirements. As such, the entire system is safe and reliable to operate. When analyzing the system for Risk Reduction, it is a proactive process used for long term planning purposes that will | We will be working to establish tolerance levels in our new model. | Minimum amount of transmission mileage in HCA | No need, low risk facilities | | We perform a qualitative risk model (relative index model) not a probabilistic risk model. | | We have not yet quantified risk to be able to consistently compare to a threshold of "acceptable risk". Additionally, we expect that it would be appropriate for our regulator and the public to provide input into an acceptable risk tolerance. |

| | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| | maintain that safe and reliable system on a long term basis. It is also used to analyze the system in terms of changes that are happening to the system, so that the system design and operation can provide service for the continually changing requirements. | | | | | | | |
| How were they determined? | The common basis for defining risk tolerance is meeting or exceeding the various state and federal code requirements for designing and operating the pipeline system as well as prevention of incidents by undertaking assessments, replacements and Preventive and Mitigative measures on the higher risk segments. | Case by case approach. Currently, SME input, as well as historic data and PHMSA guidelines are main tools for this. | | Have not defined risk tolerance levels | Based upon remaining within code compliance. | N/A | Other regulatory bodies and an internal comparative study to find most appropriate for the decision | Other regulatory bodies and an internal comparative study to find most appropriate for the decision |
| How do you make your risk management decisions? | All available data sources are reviewed including risk scores, GIS Data, assessment data, leak data, maintenance data, SME input, historical data, corrosion data, Gas Control data, Incident data, etc., in order to best maintain a safe and reliable system. Cost benefit analysis is also performed in order to determine the most cost effective way to implement risk reduction measures. The Risk model scores are relative rankings and not representative of absolute Risk. | Currently, we rely mostly on SME input.<br><br>With the new model, we expect that risk analysis results will provide additional help us in our decision making process. | SME input only | Highest risk segments are assessed first | Transmission P&M measures are SME input based. Distribution P&M measures are based on SME review of both system-wide (macro) threats and segment level (micro) risk ranking. | The driving principal behind the Company Pipeline Risk Model is to systematically and comprehensively identify, capture, and integrate specific integrity-related data to answer the following three questions about the pipeline integrity threats and consequences along each company pipeline:<br>1. Where does the threat (or consequence) apply, and to what extent?<br>2. What are we doing about it?<br>3. Is what we're doing working?<br>Knowing the answers to these three questions for each threat and consequence along each pipeline significantly facilitates the identification and analysis of integrity-related risks, the effectiveness of current risk management programs, and the identification of areas where additional risk management (additional P&M measures) may be needed. | If specific risk criteria (IR, SR, environmental, etc.) is exceeded, the segment that causes the exceedance has to be mitigated. Furthermore, segments with highest probability of failure are also mitigated.<br><br>For ILI based decisions both FPR (failure pressure ratio) and reliability thresholds (based on calibration to code specified risk levels) are used to mitigate defects.<br><br>In engineering assessment similar code calibrated risk/reliability levels are used for recommending mitigative and preventative measures. | At the enterprise level, the risks are ranked based on their relative risk score. The company uses a risk-informed budgeting allocation (RIBA) process to determine which mitigation activities are to occur in the operating year. This process uses a similar relative risk ranking while considering operational constraints to create an executable portfolio of mitigation activities. The RIBA and RET tools both evaluate risk and use the same criteria to score risks. The RET is used to score risks while the RIBA is used to score mitigation programs/projects. The methodology to produce a risk score is different for RIBA and RET.<br><br>In engineering assessment similar code calibrated risk/reliability levels are used for recommending mitigative and preventative measures. |
| Do you think risk tolerance levels defined by your company differ from public perceptions of tolerable risk? | N | | | | N | | Generally No (however public perception is highly dynamic and situational and in some cases we do adapt according to perceptions. | |
| Do you work with public stakeholders to develop criteria acceptable to both? | The public expects a zero tolerance system. The pipeline system is maintained and operated with an expectation that it is safe and reliable to operate and that code requirements are met or exceeded. | | | | | N/A | We do adapt the criteria based on heightened public perception. In these cases perceived risk governs over actual risk. | |
| **Methods used to communicate risk tolerance levels** | | | | | | | | |
| Relative risk/index score | x | x | | | | x | | |
| Risk matrix | | | | | | | | |
| Individual risk | x | x | | | | | x | |
| Societal risk | x | | | | | | x | |
| Environmental risk | | | | | | | x | |
| Business risk | x | | | | | | | |
| Comparison criteria | x | | | | | | | |
| Other | | | | | | | | |
| Calibration to best practice in standards | | | | | | | x | |
| Internal | | | | | x | | | |
| Other sources (CCPS, CONCAWE, NEB) | | | | | | | | |
| **Specific Risk Tolerance Criteria** | | | | | | | | |
| Common Basis for risk criteria | x | | | | x | | | |
| Multiple risk criteria | | | | | | | x | |
| Describe | The common basis for defining risk | N/A | Have not defined risk tolerance | Have not defined risk tolerance | Code regulations | N/A | Multiple risk criteria. IR and SR for | |

| | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| | tolerance is meeting or exceeding the various state and federal code requirements for designing and operating the pipeline system as well as prevention of incidents by undertaking assessments, replacements and Preventive and Mitigative measures on the higher risk segments. | Currently, this is under development. | levels | levels | | | NG pipelines, environmental risk for liquid pipelines, and safety levels equivalent to code compliance for ILI based decisions and engineering assessment. | |
| System-wide risk criteria | x | | | | x | | x | |
| Individual unit length criteria | | | | | | | x | |
| Describe | Risk tolerance is on a system wide basis. The common basis for defining risk tolerance is meeting or exceeding the various state and federal code requirements for designing and operating the pipeline system as well as prevention of incidents by undertaking assessments, replacements and Preventive and Mitigative measures on the higher risk segments. | Currently, this is under development. | Have not defined risk tolerability criteria | Have not defined risk tolerability criteria | | N/A | Risk threshold is established based on the risk receptors tolerance levels to risk but the probability of failure limits correspond to the pipeline length that affects the risk receptor. | |
| Unacceptable Level | x | | | | | | x | |
| Describe | If a situation occurs in the field that arises to the level of an immediate condition, or a safety related condition as define in 49 CFR 191 and 192, then the pipeline system involved may require a reduction in pressure until the situation is corrected | | | | | | Risk reduction required for: SR (anything above a line with a slope of -1 and F of 10-3 at N = 1); IR (anything above 10-4 fatalities/yr) | |
| ALARP Region | | | | | | | x | |
| Describe | | | | | | | SR (anything between a line with a slope of -1 and F of 10-3 at N=1 and a line with a slope of -1 and F of 10-5 at N=1); IR (anything between 10-4 and 10-6 fatalities/yr) | |
| Broadly Acceptable Level | | | | | | | x | |
| Describe | | | | | | | SR (anything below a line with a slope of -1 and F of 10-5 at N=1); IR (anything below 10-6 fatalities/yr) | |
| Approach used to establish tolerance levels | Tolerance levels are reviewed on a case by case basis after detailed analysis by involved personnel. All applicable sources of data, code requirements and information are reviewed prior to making decisions. | Currently, this is under development. | No risk tolerance levels have been established | No risk tolerance levels have been established | Benchmarking internal corporate goals | the risk ranking of individual risk segments and the risk ranking of pipelines are reviewed by a SME team consisting of management, integrity engineers, risk engineers, corrosion engineers, and the integrity consulting SME to validate that the output reasonably represents the pipeline integrity risks of our assets. Should the team identify unrealistic or questionable results, the input attribute data and model settings are reviewed to identify possible errors in the data and/or in the model, and to identify risk factors and/or attributes not adequately incorporated into the model. The risk engineer incorporates the suggested changes and corrections to the model and/or the data, re-runs the risk model, and re-generates the risk results. The review process is repeated until the team validates and accepts the model and the results. Ongoing review and validation occurs during Integrity Review Team meetings and during the risk engineer's pipeline-specific in- | Internal comparative studies to find most appropriate for the situations and benchmarks defined by other regulatory agencies | No establishment of tolerance has been complete. However, we are proactive in discussions with its regulator and other California utilities around risk tolerance. |

| | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|
| | | | | | | depth risk analyses. In both of these situations the risk data and results are analyzed at a greater level of detail. | | |
| **Who is involved in establishing criteria?** | | | | | | | | |
| Internal risk analysts | x | | | | | x | x | |
| Business/financial managers | x | | | | | | | |
| SMEs | x | x | | | x | x | x | |
| Management | x | x | | | x | x | x | |
| Consultants | x | x | | | | x | | |
| Public stakeholders | x | | | | | | | |
| Legal | | | | | | | | |
| Other | | | | | | | | |
| Regulators | x | | | | | | | |
| Criteria is regularly reviewed | x | | | | | | x | |
| Criteria reviewed as part of MOC | x | | | | | | x | |
| What barriers exist for defining risk tolerability levels? | Absolute Risk Tolerance levels cannot be defined. There are too many unknowns to factor in. It would also require a complete set of data for the pipeline system, which for systems that have been built over the last century, cannot be obtained except at great cost for investigation or replacement. The public will not accept any risk tolerance above zero. The method of utilizing relative risk to prioritize preventive and mitigative measures is much more practical and realistic. It allows the operators to maintain safe and reliable systems while responding to a continually changing environment. They are able to use all available data and knowledge to intelligently and cost effectively make decisions that enable them to maintain their systems into the future, without being forced to respond to an absolute risk value that may not be taking into account all relevant information. | Currently, this is under development. | Legal sensitivities, public perception | Legal sensitivities, public perception | public/regulatory perception, legal issues | Public perception, tools and techniques to better use the big quality data available to run Probabilistic risk model. | Public perception, communicating risk levels in terms of fatalities, legal sensitivities, misconceptions regarding risk. | Regulator consensus and public perception |
| What improvements in risk assessment methodologies, available information, or data collection would be most helpful? | Improved pigging methods for pipe material and attribute discernment; increased accuracy of affordable GPS devices; increased use of mobile data collection devices; availability of standardized data sets. | An industry risk standard would be ideal.<br>A summary of industry's best practices as related to risk analysis would be helpful. | | | | Going after the big data (in good quality)<br>Integrate most of the available data in all attributes of all 9 threats and consequences | Better guidelines for quantitative risk criteria by North Amercian Regulatory Agencies, better acceptance of risk assessments to drive improved integrity decisions (risk based decisions as opposed to prescriptive decisions lead to a more optimized program. | 1.Risk tolerances and how they are used would be helpful to further our understanding of risk tolerance.<br>2.Publicly available failure rates for specific equipment components may be helpful.<br>3.Fragility curves for pipeline and pipeline features exposed to external stresses.<br>4.How the value of life (or Statistical Value of Life) is used to establish safety tolerance levels.<br>5.Risk Assessment Model agreed to and approved by state regulators and other stakeholders |