PHMSA Pipeline Risk Model Working Group

Kiefner

General Knowledge – Paper Study on Risk Tolerance

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- October 5, 2016

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Purpose of this Project

- The purpose of this project was to study risk tolerability practices currently used by pipeline companies as well as other relevant industries, government agencies, and countries as a basis for comparison and guidance for use in the pipeline industry.

Approach

Task 1:	**Literature Survey**	Compile relevant approaches to defining risk tolerability criteria.
Task 2:	**Industry Survey**	Compile approaches used by pipeline companies.
Task 3:	**Final Report**	Prepare report summarizing the methodologies used for risk-based decision-making, specifically risk tolerability criteria.

Overview

- Background
- Risk Criteria Concepts
- Literature Search Results
- Industry Survey Results
- Ideas for Improvement
- Summary Points

Background

- During the 2015 Risk Workshop, PHMSA highlighted areas of improvement for risk modeling methodologies.
  - 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
    - connected to real life decision making.
  - Risk assessment approaches must tell us what can be done to reduce risk versus simply identifying which parts of the pipeline represent the highest risk.
  - Generating risk numbers is not the end goal. A more structured way to evaluate and reduce operations risk is the goal.

Background

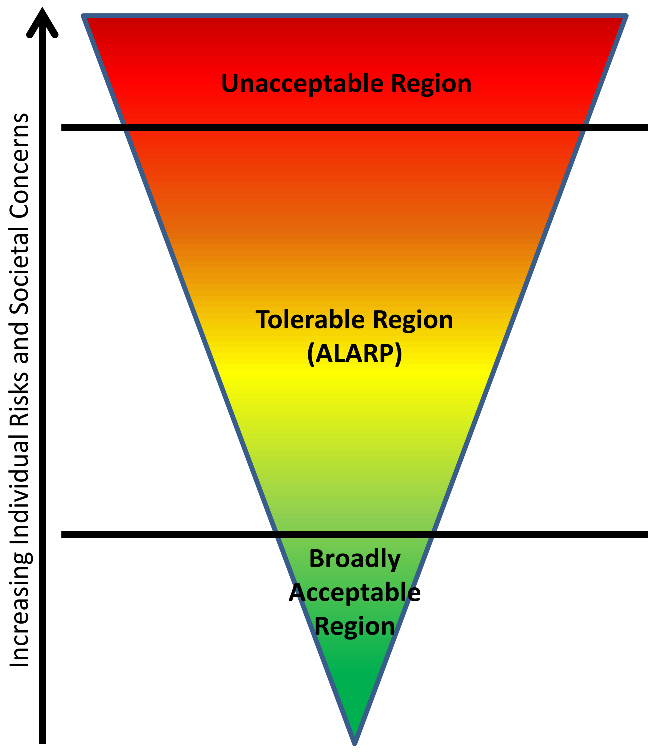
- It is important for pipeline operators to make risk-based decisions regarding the operation and maintenance of their pipelines.
- Many operators currently use some type of risk model or tool to help determine inspection intervals and prioritize maintenance schedules.
- Many use these models to provide a basis for decisions concerning additional preventive and mitigative measures.
- How many operators have set risk limits? How did they go about doing it?

Risk Tolerance Concepts

- **Risk** is defined as the combination of the probability that something adverse will happen and its consequence given it occurred.
- **Risk Management** involves an estimation of the risk, deciding whether or not it is tolerable and if not - implementing measures to reduce the risk to a tolerable level.
- **Risk Tolerability** refers to a willingness to assume a level of risk commensurate with the benefits received from accepting that risk.

Risk Tolerability Framework

- Establishing risk tolerance levels provides a basis to identify where action is required.
- These limits can be qualitative, semi-quantitative, or quantitative.
- Common Framework:
  - An **unacceptable level**, where risks are intolerable except in extraordinary circumstances and risk reduction measures are essential;
  - 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
  - A **broadly acceptable** region, where risks are deemed tolerable or negligible and no further risk reduction measures are required.



Considerations

- 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).
- The criteria must be unambiguous, clearly defined, and easily communicated to stakeholders.
- What types of factors are important to the stakeholders, such as human health and safety, environmental protection, legal/regulatory requirements, economic objectives, risk perception
- The criteria should be continuously reviewed to ensure it remains applicable to the risks being assessed.

Qualitative Risk Criteria

- Analysts use their collective knowledge to make judgments on frequency and consequence estimates.
- Subjective
- Risk Matrices are often used to present the levels.

Consequence Category	1	2	3	4
4	IV	II	I	I
3	IV	III	II	I
2	IV	IV	III	II
1	IV	IV	IV	III

Frequency Category

Frequency Categories

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

Consequence Categories

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

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

Semi-Quantitative Risk Criteria

- Example
- Frequency and Consequence Categories represented by numerical ranges
- Consequence categories are expressed in terms of dollars and frequency categories are expressed in terms of orders of magnitude.

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.

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.

Quantitative Risk Criteria

- **Individual Risk (IR)**
  - Annual chance that an individual will suffer a specified level of harm due to the hazards to which they are exposed (worker or off-site individual)
  - Typically expressed as the fatalities/year
  - 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.
  - Generally set by comparing risk associated with an industrial activity to risks posed by other activities that average individuals are exposed to on a daily and intermittent basis (driving a car, flying a plane, working…)
  - Calculation of IR assumes that the risk to an individual from all incident scenarios at their particular location are additive (fire, explosion, toxic release, etc.)
  - The probability of fatality is then used as guidance for setting maximum tolerable and broadly acceptable levels
  - Focus is solely on casualties and overlooks other impacts (e.g. environmental impacts, property damage, business interruption, reputation damage)

Quantitative Risk Criteria

- **Societal Risk (SR)**
  - Risk of multiple fatalities from one single event – used to evaluate the risk of fixed facilities to the general public
  - F-N curves are broadly used – expressed in terms of expected annual frequency (F) of the number (N or more) of fatalities
  - Societal risk provides a perspective on the risk to the surrounding public and environment, especially from potentially catastrophic events.
  - Many corporations have also adopted this method for internal evaluations of the relative risk of projects, plants and businesses, setting their own criteria.
  - Criteria must be adjusted based on the defined scale of the risk assessment (a single facility vs multiple facilities vs pipeline route)
  - Example: The UK recently proposed that the risk of an accident causing 50 fatalities or more from a single event should be regarded as intolerable if the frequency is estimated to be more than one in 5,000 per year.

Quantitative Risk Criteria

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Pipeline Specific

- Few regulatory bodies have addressed risk criteria for hazardous pipelines. In general, these agencies have defined either individual risk criteria or societal risk criteria for pipelines.
- Brazil, The Netherlands, UK: have defined individual risk criteria
- The Netherlands, UK: societal risk criteria
  - Both based on the F-N diagram for a given length of pipe (both use 1 km)
  - Dutch recommend evaluating the worst-case km within an urban area
  - British recommend summing F-N pairs over the entire length of pipeline through a community then normalizing the result to 1 km
- 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 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.

Quantitative Risk Criteria

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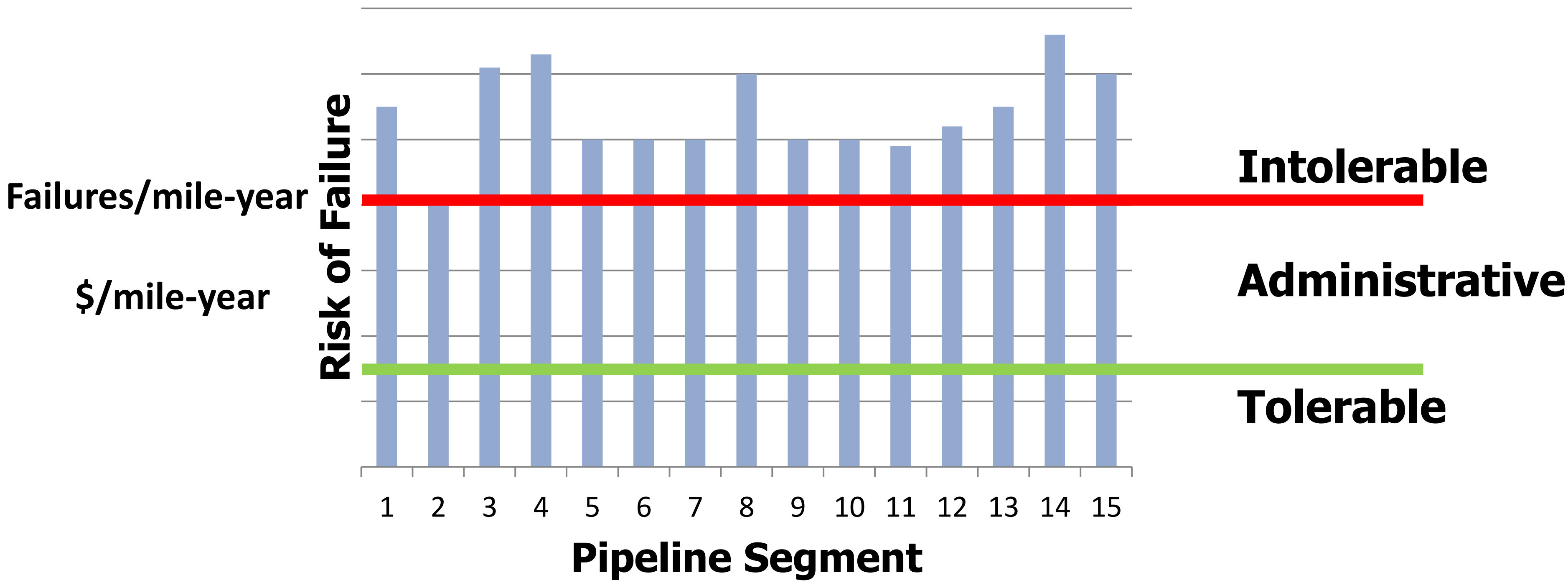
- **Pipeline Risk Profile**
  - By segment based on failure rates and consequences
  - Risk of failure = likelihood of failure x consequence of failure
  - Monetized: $/mile-year
  - Requires historical data, consequence modeling, and/or probabilistic analyses
  - Consequences: H&S (worker, public), Environment, Business (product loss, business interruption, equipment damage, litigation)



Quantitative Risk Criteria

Impact (Consequence Endpoint) Criteria

- Several regulatory bodies also use impact 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
- 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.

Quantitative Risk Criteria

Other Industry Criteria

- The aeronautical community, FAA, NASA, Air Force and Navy have incorporated risk in 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.

Advantages vs. Disadvantages

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

Advantages vs. Disadvantages

Technique	Advantages	Disadvantages
Quantitative Risk Criteria	• Provides the total risk and allows numerical aggregation which can account for risk interactions • Permits cost-benefit analysis to compare the effectiveness of risk reduction options • The greater level of detail required for analysis adds to the understanding of the process evaluated • Useful for addressing high consequence, low frequency events • If ALARP principles are used, encourages risk generators to drive risk downward	• Can be time-consuming and costly • Requires a greater level of expertise for effective decision-making • Must define units of measure (e.g. fatalities and/or dollar amounts) and annual frequency • Use of numbers may imply greater precision than the uncertainty of inputs warrants • Assumptions may not be apparent • Results can be difficult to understand • 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

Advantages vs. Disadvantages

Technique	Advantages	Disadvantages
Individual Risk Criteria	• Independent of the scale of the risk • 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 • Permits evaluation of risk reduction measures using a consistent basis • 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). • Can be overly restrictive if location-based criteria are used, not allowing for consideration of occupancy factors.

Advantages vs. Disadvantages

Technique	Advantages	Disadvantages
Societal Risk Criteria	• Provides a picture of the scale of an accident • Permits evaluation of risk reduction measures using a consistent basis • 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). • Criteria must be adjusted based on the defined scale of the risk assessment (a single facility vs multiple facilities vs pipeline route) • Societal risk is sensitive to data assumptions and confidence in the data which can lead to widely varying results • 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. • Too stringent criteria (such as in the Netherlands) can make compliance with the criteria difficult – especially for existing facilities. • 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).

Advantages vs. Disadvantages

Technique	Advantages	Disadvantages
Impact Risk Criteria	• Easier for public stakeholders to understand • Relatively easy to define and calculate impact levels	• Can be overly conservative because it does not consider the likelihood of large-scale incidents. • Results may be mis-leading in terms of actual risk to public receptors.

Task 1: Literature Search

- Australia: Western Australia, New South Wales, Queensland, Victoria
- Brazil: Sao Paulo, Rio Grande do Sul, Rio de Janeiro
- Canada
- Czech Republic
- France
- Germany
- Hong Kong
- Hungary
- Malaysia
- Netherlands
- Norway
- Singapore
- Switzerland
- United Kingdom
- United States: California, New Jersey
- United States: DOD, DOE, DOI, EPA, FDA, NRC, OSHA, FAA, NASA
- Venezuela
- International: International Maritime Organization (IMO)

Summary of results are provided in Tables 2 and 3 of the Report

Task 1: Literature Search

- 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.
- Most proactive: UK (HSE), Hong Kong, The Netherlands, various Australian States, and The United States through various government entities.
- The UK and the Netherlands pioneered the use of individual and societal risk criteria.
- 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.
- 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).
- 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.
- Generally 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.

UK – Individual Risk

The UK Health and Safety Executive (HSE):

- **Worker IR:** upper (1×10^{-3} fatality/year) and lower (1×10^{-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:** upper bound (1×10^{-4} fatality/year) which is an order of magnitude lower than that for workers but maintained the lower bound (1×10^{-6} fatality/year) as a risk that would not cause concern to the public or alter their behavior.

Risk Receptor	Individual Risk (fatality/year)
Worker IR	Maximum Tolerable: 1×10^{-3} Broadly Acceptable: 1×10^{-6}
Offsite Public IR	Maximum Tolerable: 1×10^{-4} Broadly Acceptable: 1×10^{-6}

UK – Individual Risk

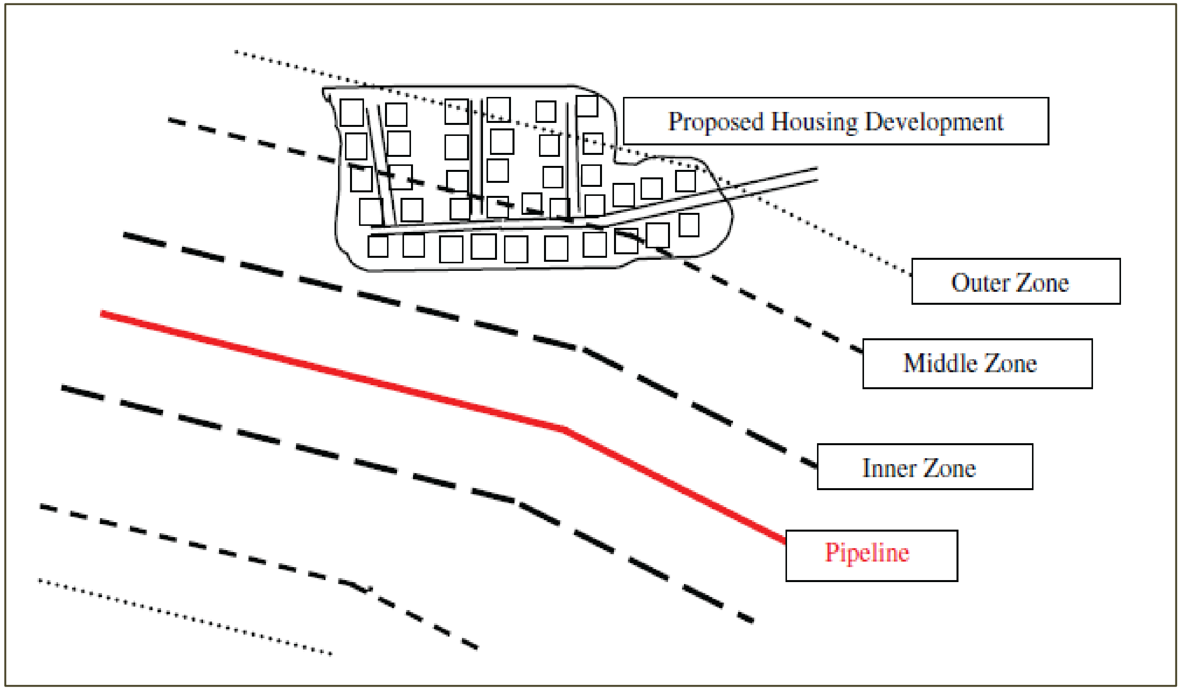
- HSE also set **risk-based zones around pipelines**, where the risks to people and developments must be assessed and considered by planning authorities for **new developments.**
- They've currently defined three levels for IR risk consideration:
  - An inner zone (IZ) adjacent to the pipeline and equivalent to an IR level of 1×10^{-5} fatality/year.
  - A middle zone (MZ) which applies to significant developments and is equivalent to an IR level of 1×10^{-6} fatality/year.
  - An outer zone (OZ) which applies to vulnerable or very large populations and is equivalent to an IR level of 3×10^{-7} fatality/year.

Risk Receptor	Individual Risk (fatality/year)
Public IR near IZ of Pipeline	Maximum Tolerable: 1×10^{-5}
Public IR (significant developments) near MZ of Pipeline	Maximum Tolerable: 1×10^{-6}
Public IR (vulnerable and very large populations) near OZ of Pipeline	Maximum Tolerable: 3×10^{-7}

UK – Individual Risk

Example site-specific gas pipeline risk-based zones

- 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 decide if the risk to the new developments (including risk reduction measures) is acceptable.

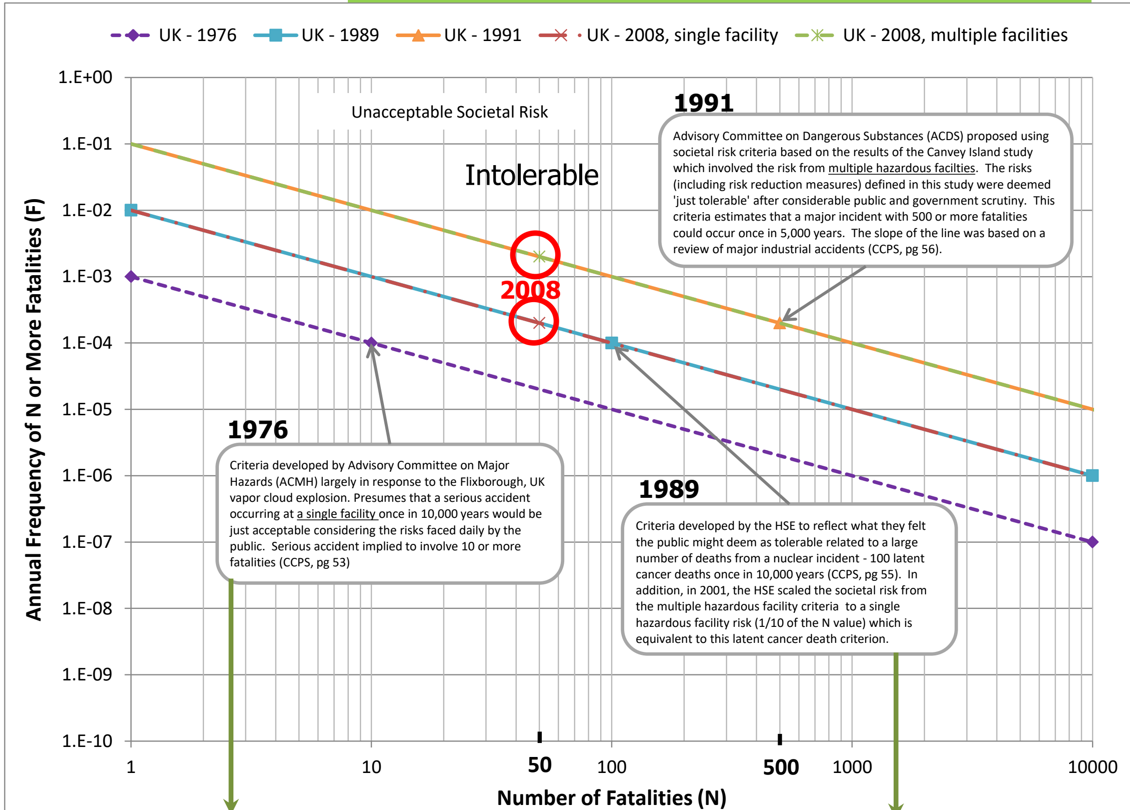


- Pipeline risk assessment codes (IGEM TD/2 and PD 8010), developed by the UK Onshore Pipeline Operators Association (UKOPA) provide pipeline operators with guidance on risk analysis for site specific pipeline properties.

UK – Societal Risk

1991: SR based on results of the Canvey Island study risk from multiple hazardous chemical/petrochemical processing complex. Major incident with >500 fatalities once in 5,000 yrs.

- In 2008, the HSE set two different SR criteria, one for single industrial facilities and another for multiple industrial facilities to account for the scale of the risk associated with multiple industrial facilities (set an order of magnitude higher than that for a single industrial facility).
- For <u>multiple facilities</u> the risk of an incident causing 50 fatalities or more is intolerable if the frequency is more than once in 500 years.
- For a <u>single facility</u>, the risk of an incident causing 50 fatalities or more is regarded as intolerable if the frequency is estimated to be more than once every 5,000 years.
- The broadly acceptable curve is 2 orders of magnitude below.



1976: Response to Flixborough vapor cloud explosion. Serious incident (10 or more fatalities) at a single facility once in 10,000 yrs. Acceptable considering the risks faced daily by the public.

Criteria developed by the HSE to reflect what the public might feel tolerable from a nuclear incident. 100 latent cancer deaths from nuclear incident once in 10,000 yrs.

The Netherlands - IR

- 1993 – 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.
- 1996 – The Ministry of Transport, Public Works, and Water Management set the IR criterion for dangerous goods transport to 1×10^{-6} fatality/year.
- 1999 – The Dutch Ministry for Housing, Spatial Planning, and the Environment introduced a distinction in IR criteria for vulnerable verses less vulnerable populations. The IR criterion for vulnerable populations was maintained at 1×10^{-6} fatality/year; however, the IR criterion for less vulnerable populations was increased by an order of magnitude to 1×10^{-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.
- 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.

The Netherlands - IR

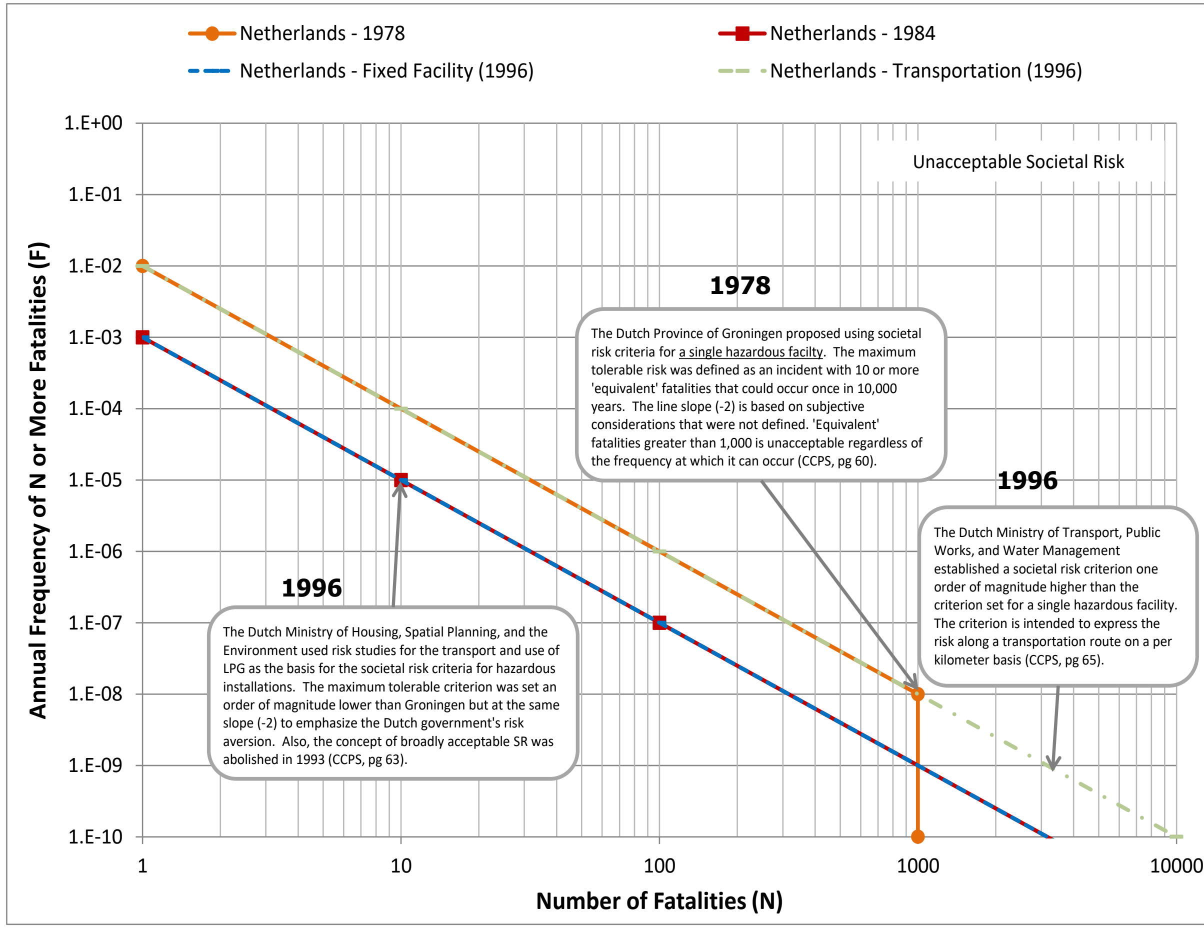
Summary of Dutch IR Criteria for New and Existing Facilities

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

- Vulnerable populations include houses, apartment buildings, other residential objects, hospitals, medical facilities, schools, and objects with high strategic value.
- Less vulnerable populations include shops, department stores, hotels, restaurants, cafes, commercial and industrial buildings, office buildings, and recreational facilities.

The Netherlands - SR

- 1978: Dutch Province of Groningen: risk of an incident resulting in 10 or more fatalities is intolerable if frequency is > once in 1,000 yrs. Slope (-2) was subjective.
  - Fatalities greater than 1,000 unacceptable regardless of frequency.
- 1996: Dutch Ministry of Housing used risk studies for transport and use of LPG as basis for an order of magnitude lower than Groningen (same slope). 10 or more fatalities, once in 10,000 yrs for hazardous installations.
- 1996: Ministry of Transport establish SR one order of magnitude higher than single hazardous facility for risk along a transportation route on a per km basis.



Brazil

- Brazil defines risk criteria by state and includes São Paulo, Rio De Janeiro, and Rio Grande Do Sul.
- These States have 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.

Brazil – IR Criteria

- States defined IR criteria to evaluate risk of licensing of new/existing fixed facilities.
- All three states have IR criteria for pipelines.
  - Sao Paulo and Rio Grande do Sul have set these criteria one order of magnitude higher than the IR for facilities
  - Rio de Janeiro has set its IR for pipelines equal to existing facilities.

São Paulo IR Criteria

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

Rio Grande do Sul IR Criteria for New Facilities

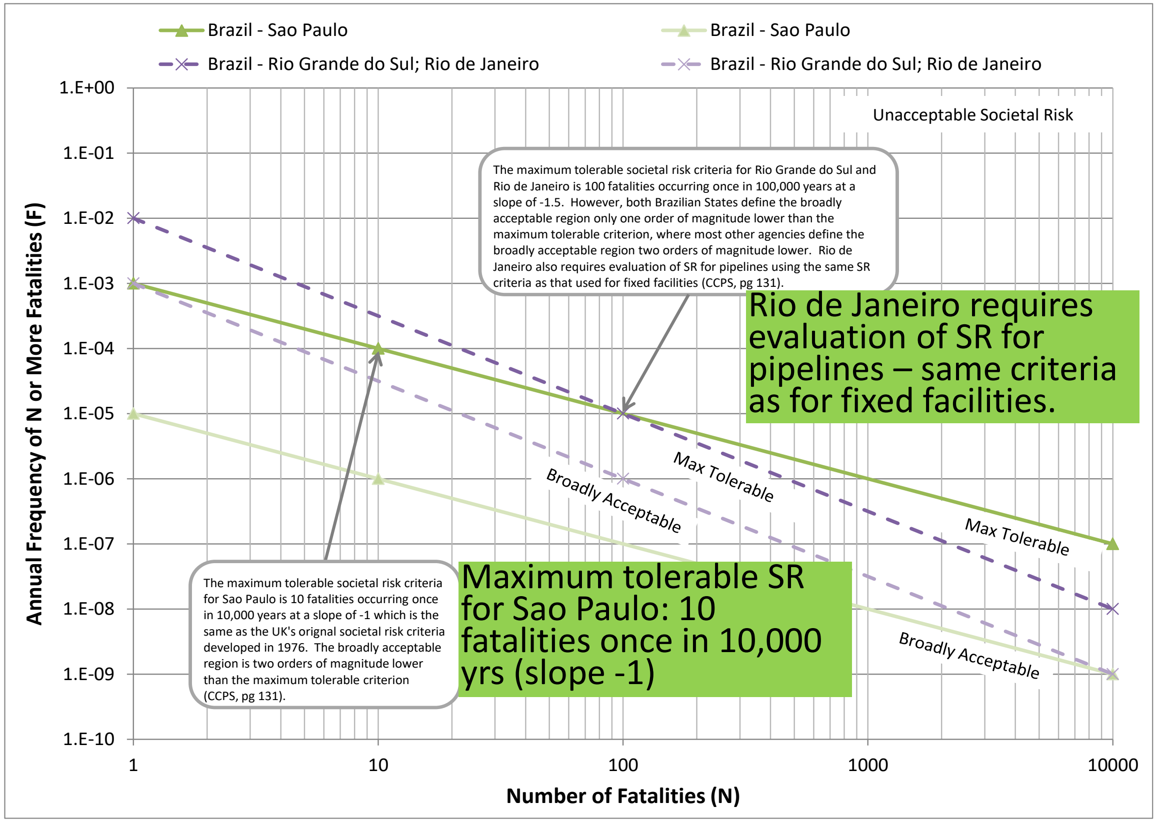
Risk Receptor	Individual Risk (fatality/year)
Worker IR	None
Offsite Public IR (new facilities)	Maximum Tolerable: 1×10^{-5} Broadly Acceptable: 1×10^{-6}
Offsite Public IR (pipelines)	Maximum Tolerable: 1×10^{-4} Broadly Acceptable: 1×10^{-5}

Rio de Janeiro IR Criteria

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

Brazil – SR

- The societal risk criteria for Rio Grande Do Sul are the same as Rio de Janeiro.
- All 3 set the maximum tolerable SR criterion of 100 fatalities occurring once in 100,000 years (different slopes).
- Rio de Janeiro is the only state that requires evaluation of SR for pipelines.



France

- Risk criteria 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, etc.
- Semi-quantitative approach
- French Decision Matrix for Permitting New or Modified Facilities

	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) 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

U.S. Government Agencies

- We performed a cursory review of risk tolerability practices implemented by some U.S. Government Departments and Agencies.
- Several agencies focus on semi-quantitative risk assessments or impact-based assessments to determine risk tolerability and/or the level of regulatory burden.
- 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.

U.S. DOT, PHMSA

- 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.
- 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.)
- 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.

DOE – Quantitative Objectives

- 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
  - 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.

DOD – Explosives Handling Operations

- 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 operations.

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

DOD – Defense Systems

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- 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.
- 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 (semi-quantitative).
- Risks are expressed as a Risk Assessment Code (RAC).
- The associated risk matrix 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.

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			

Consultant – C-FER - IR

- 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.
- 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.
  - Class 1: 1×10^{-4} fatalities/year
  - Class 2: 1×10^{-5} fatalities/year
  - Class 3 and 4: 1×10^{-6} fatalities/year

C-FER Technologies - SR

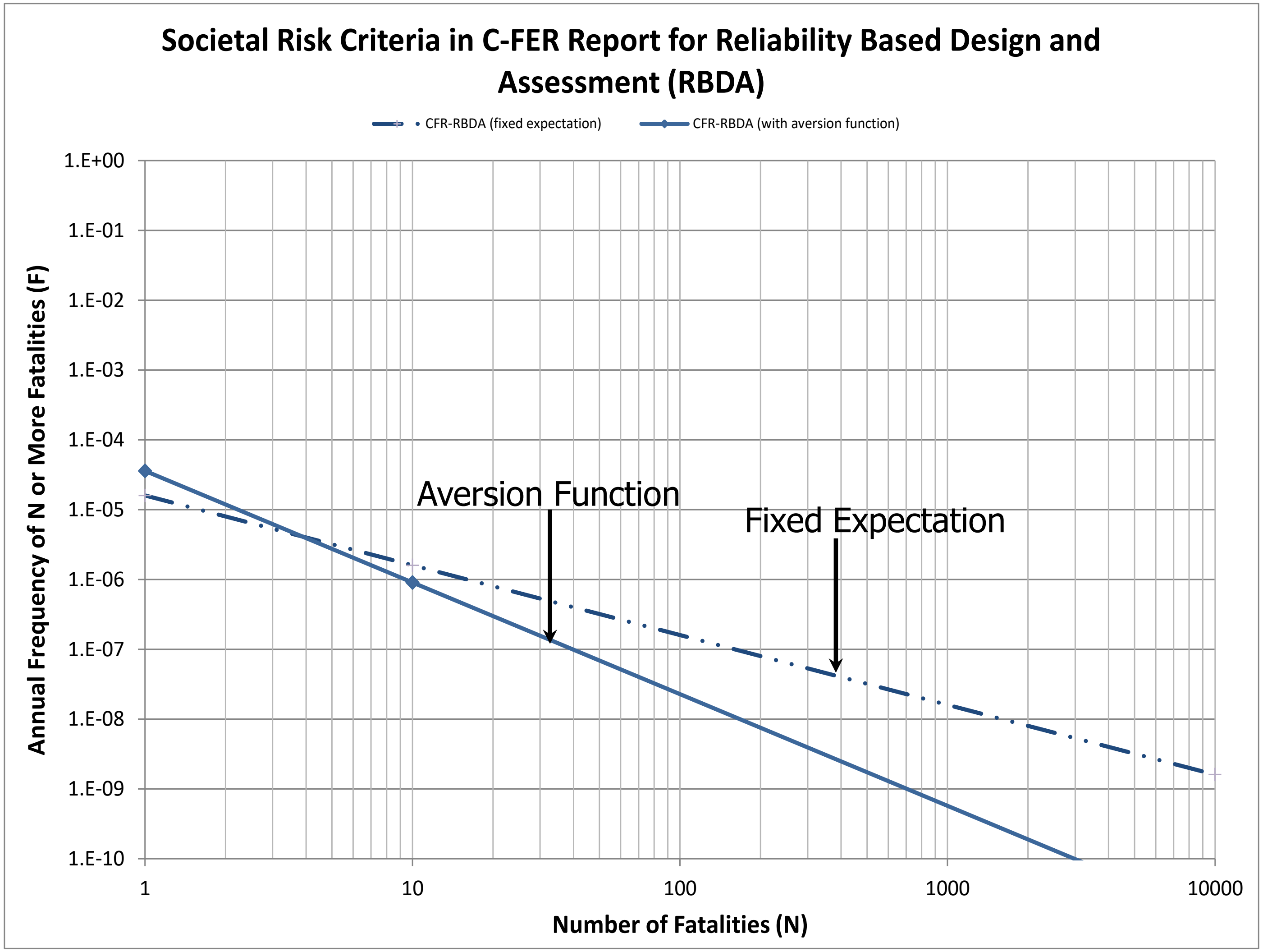
- C-FER Technologies developed two approaches for quantification of maximum tolerable SR criteria **related to pipelines**:
- Societal risk with **fixed expectation**
  - The first measure uses the expected number of fatalities from a natural gas pipeline release as a direct measure of risk implying 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.
- Societal risk with **aversion function**
  - The second measure of societal risk 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.

C-FER Technologies - SR

- The maximum tolerable SR criteria proposed 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.

- 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.” In most cases, the total risk is calculated over an evaluation length of 1.6 km.

C-FER - SR



Societal Risk Criteria in C-FER Report for Reliability Based Design and Assessment (RBDA)
CFR-RBDA (fixed expectation)
CFR-RBDA (with aversion function)
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
1.E-09
1.E-10
Annual Frequency of N or More Fatalities (F)
1
10
100
1000
10000
Number of Fatalities (N)
Aversion Function
Fixed Expectation

Task 2 – Industry Survey

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.

- Survey is included in Appendix A
- Responses included in Appendix B

Industry Survey

- Survey was sent to ~100 pipeline operators
- 24 responses (confidential)
- Representative cross section of liquid and natural gas (transmission, distribution, and gathering) – large and small operators
- 18 of the companies who responded to our survey transport natural gas, with a total of 268,462 miles of pipeline, of which 2% are located within an HCA.
- 10 respondents transport hazardous liquids, totaling 40,191 miles, with 59 percent located within HCAs.
- The majority of the represented pipeline miles consist of distribution, followed by transmission, with a small percentage of gathering lines.

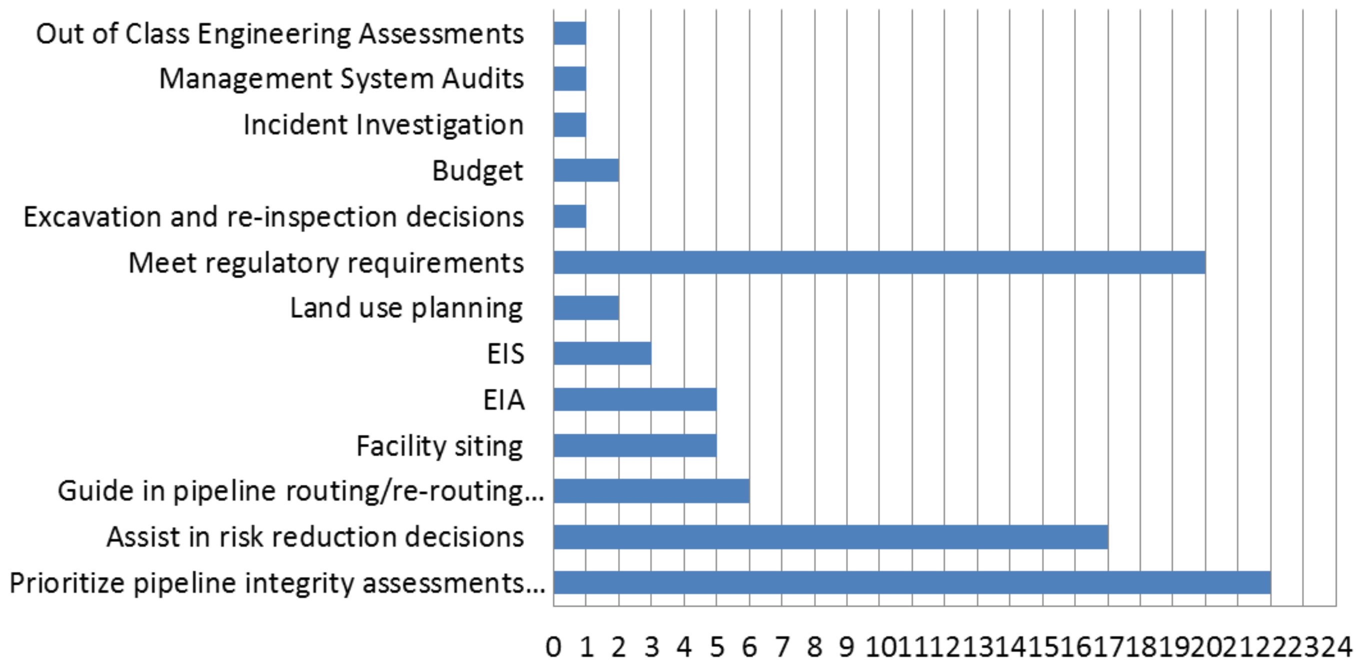
Industry Survey Results

Risk Models

- 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 and/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 <u>most using semi-quantitative techniques</u> (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.
  - Variables are typically weighted to reflect their relative impact.
  - 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.

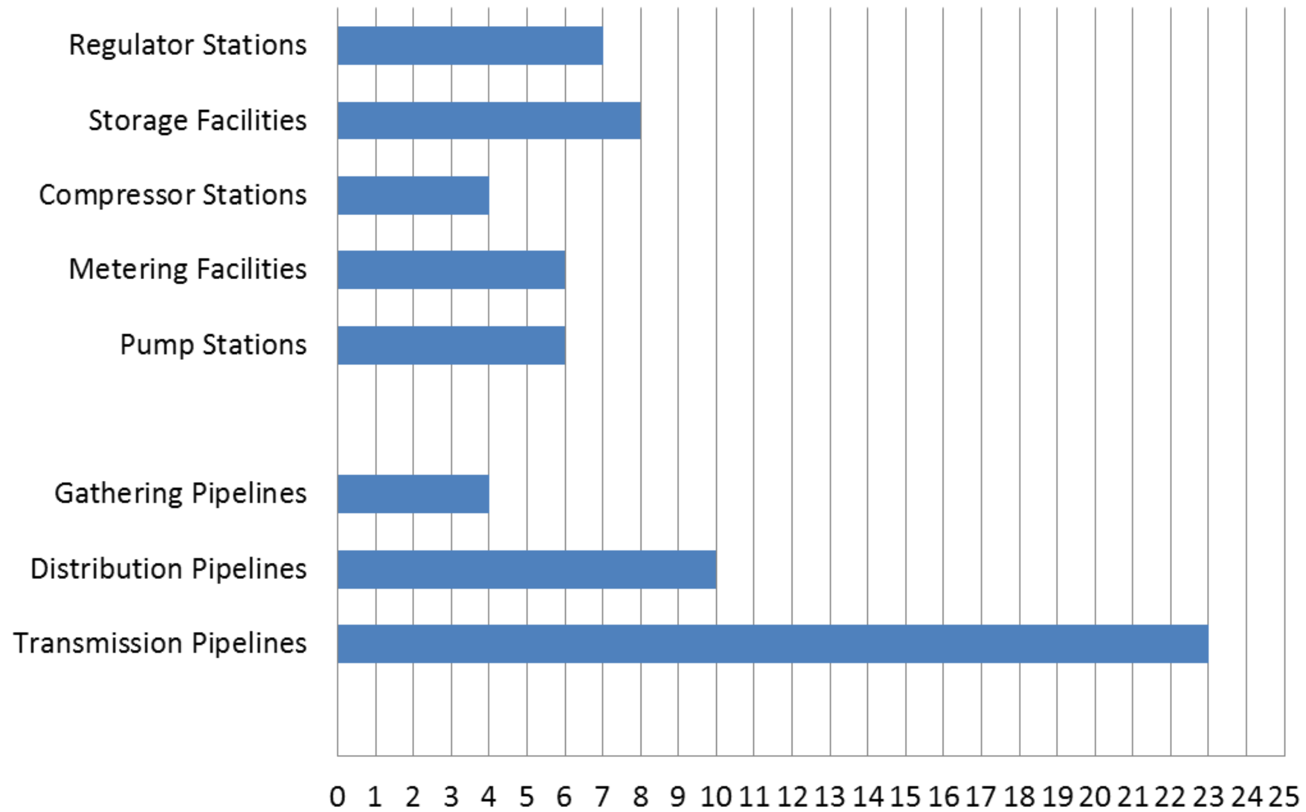
Use of Risk Assessment

- Prioritize for pipeline integrity assessments
- Regulatory requirements
- Risk-reduction decisions



	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

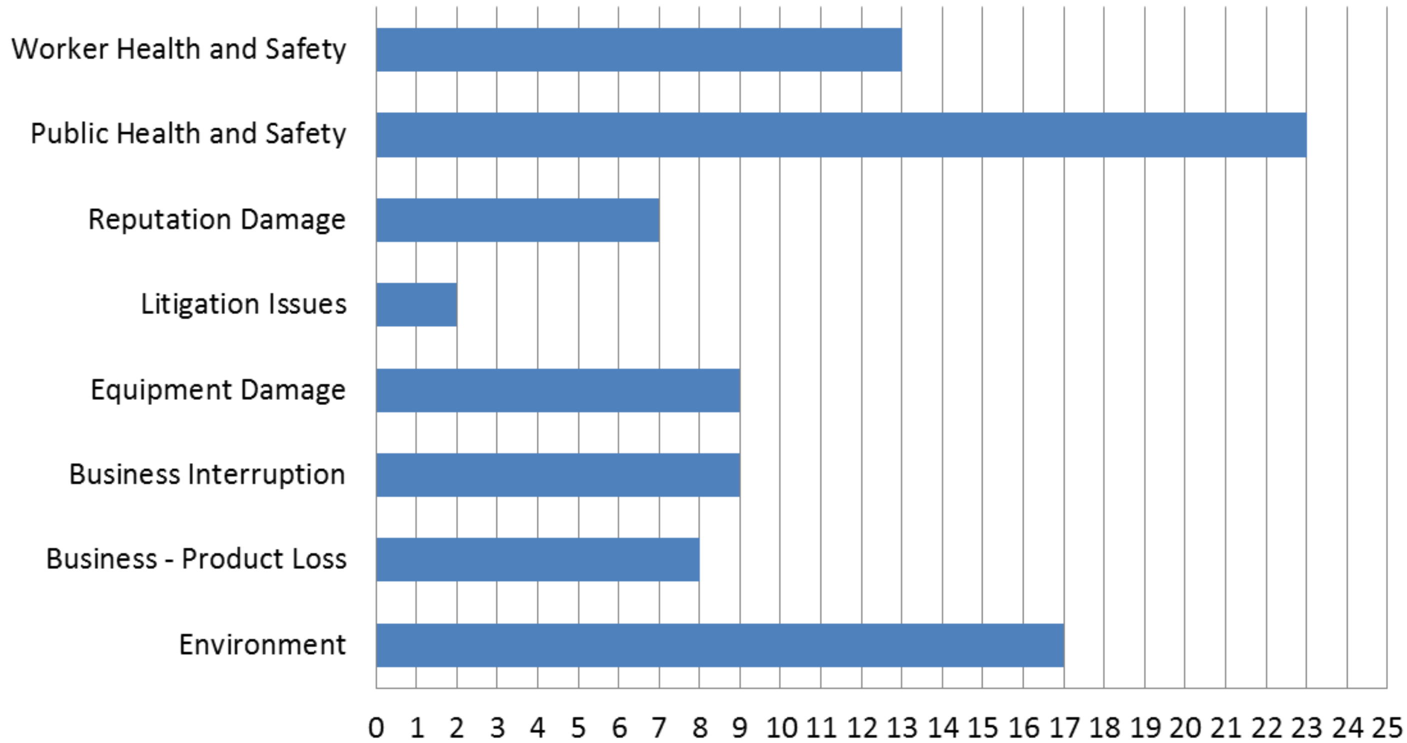
Scope of Risk Assessment



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

Consequence Categories

- Most focus on H&S and environmental impact



	Environment	Business - Product Loss	Business Interruption	Equipment Damage	Litigation Issues	Reputation Damage	Public Health and Safety	Worker Health and Safety
# of Responders	17	8	9	9	2	7	23	13

Risk Tolerability Criteria

- 9 of 24 respondents have defined an unacceptable / intolerable level of risk. Wide range of techniques used.
- 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.
- Example of multiple quantitative criteria approaches:
  - Natural gas pipeline – IR and SR
  - Liquid pipeline – Environmental Risk
  - Reliability-based (probabilistic) ILI decision-making models
  - Engineering assessments (performance-based compliance with codes)

Risk Tolerability Criteria

- 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.

Example Risk Criteria from Survey Response

- For natural gas pipelines
- Perform a QRA (consequence modeling, calculate IR and SR)
- Compare the calculated risk to the IR and SR criteria
- 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/year

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

Survey Results

Kiefner

- 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 – some on a case-by-case basis.
- Risk criteria levels were most often established by company senior management, SMEs, and risk analysts, with a number of companies using risk consultants.
- 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

Ideas for Improvement from Survey Responders

Kiefner

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.
- Standardization of data collection metrics, traceability of steel materials, phased array development (plastic and steel).
- A database of previous events, including root cause and causal factors.
- Failure rates for specific equipment components.
- Fragility curves for pipeline and pipeline features exposed to external stresses.
- How the value of life is used to establish tolerance levels.
- Data integration with an easy to use application/customization, updates in knowledge/materials/trends/risks. Approaches for various types of systems, distribution, transmission, plant/facilities, etc.
- Data pertaining to quantitative risk modeling including monetized examples.
- Data collection methodologies white paper.
- Integrate the available data in terms of the 9 threats and consequences.

Ideas for Improvement from Survey Responders

Guidance

- Example risk tolerance levels and how they are used to better understand the process.
- Consistency in the risk methodologies used by industry.
- Industry accepted risk tolerance ranges per threat specific.
- Standard risk model templates.
- Recommended risk assessment model(s).
- An industry risk standard with a summary of industry's best practices.
- 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).

Summary Points

- 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.

- 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?