Chapter 2

Risk Tolerance Criteria

Chapter Contents

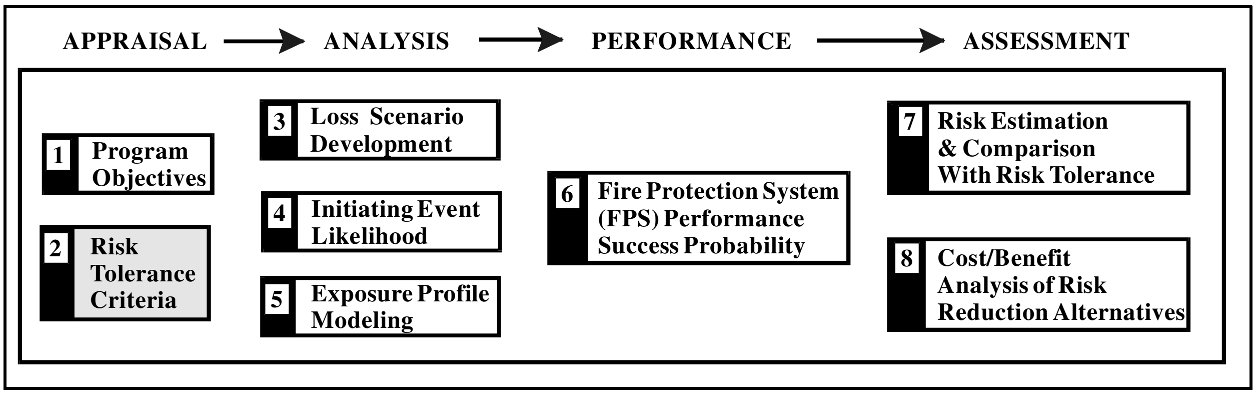
RISK TOLERANCE CRITERIA 2

2.1 INTRODUCTION

Risk tolerance criteria provides a quantitative basis against which risk analysis results and risk reduction efforts are measured. Establishing risk tolerance guidelines helps management make consistent, well-informed decisions based on risk (likelihood and consequences).

As presented in Fig. 2.1, risk tolerance criteria is Step 2 in the risk-informed, performance-based decision making process. Quantitative risk tolerance values must be established up front and agreed upon by the decision makers.

Fig. 2.1: Risk-Informed, Performance-Based Fire Protection Steps



In this book, the term “risk tolerance” is used instead of acceptable risk. Tolerance infers establishment of risk-based limits on fire or explosion incidents that will not adversely affect company stability, profitability, or life safety. Risk tolerance criteria should be integrated into business objectives and planning and include company image concerns. Risk tolerance criteria must fit the company’s business philosophy and culture and match the type of risk analysis methodology that will be performed by its engineering and loss control staff. The selection of appropriate risk tolerance criteria is a risk management responsibility and requires the involvement and support of senior management. Risk criteria establishes the levels and types of risks the company will tolerate for existing, new, and proposed facilities and operations.

The information in this chapter provides a methodology for establishing fire and explosion risk tolerance criteria “guide values” and graphical presentation.

The risk tolerance development process involves the following factors:

1. Must be specific to the defined risk assessment project
2. Must establish measurable quantitative values for risk comparison
3. Must provide input for evaluating acceptability of fire protection system performance success probability

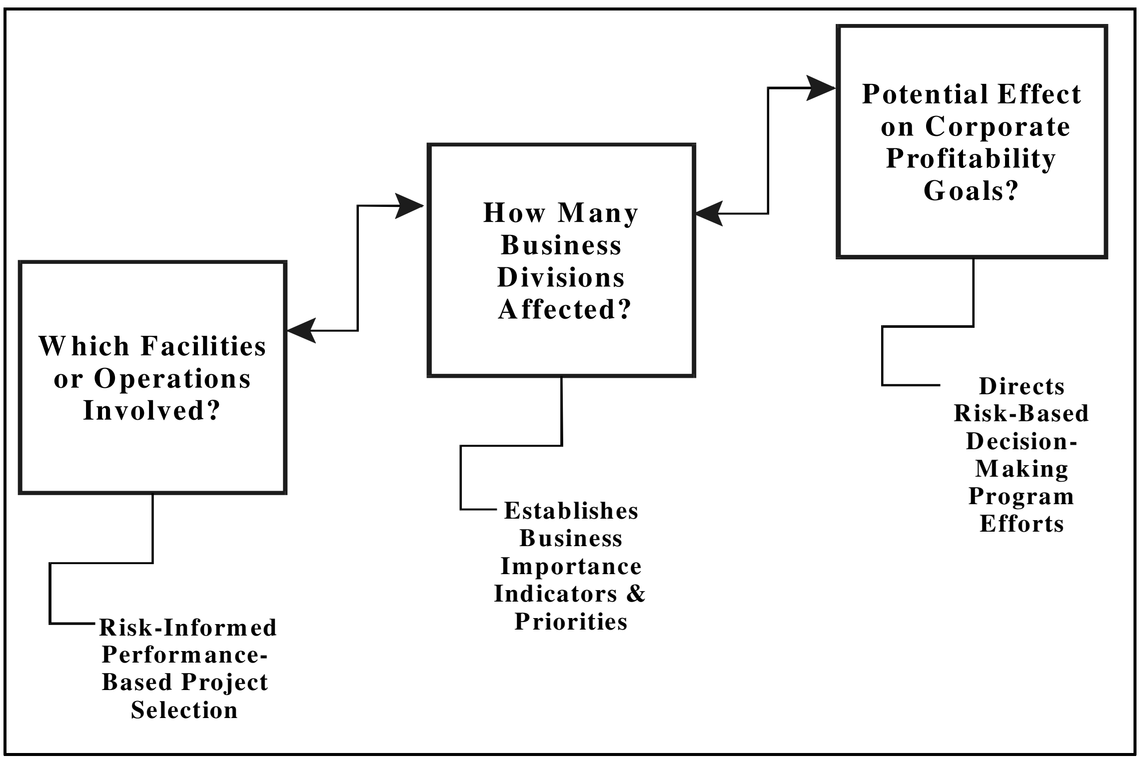
Risk tolerance criteria should not be thought of as fixed or static measures but rather as dynamic measures related to a company’s changing business objectives and focus.

2.1.1 Bottom-Up or Top-Down Approach

Fire and explosion (F&E) risk tolerance criteria involves the establishment of quantitative reference points or guide values for use in supporting the risk-based decision making process. There are two basic approaches for pursuing the development of risk tolerance guide values. Because we lack any standard definition, we will label these two approaches as either bottom-up or top-down, as shown in Fig. 2.2.

The bottom-up approach of F&E risk tolerance focuses on how specific facility risks can affect business divisions and corporate business operations. The top-down approach starts with defining and prioritizing the risk-based decision process at the corporate or business division level and then targeting specific facilities or operations for risk-based evaluation.

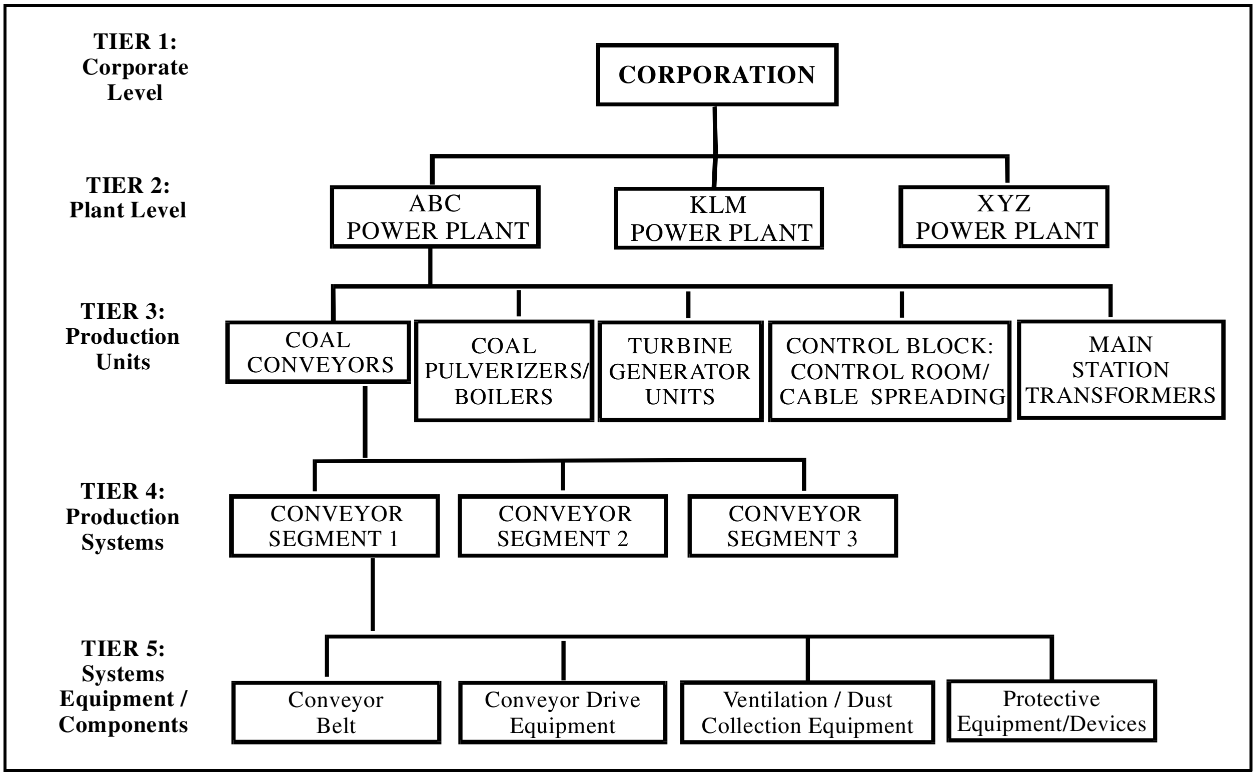
Fig. 2.2: F&E Risk Tolerance Criteria Information Flow



Most risk-based evaluations use a five-tier breakdown to identify F&E risk impacts on the corporation's strategic planning goals. As illustrated in Fig. 2.3, these tiers generally include:

Tier 1: Corporate level
Tier 2: Plant level
Tier 3: Production unit(s)
Tier 4: Production systems
Tier 5: Systems equipment/components

Fig. 2.3: General Example of a Five-Tier Breakdown for a Power Generation Company



At industrial facilities, risk-informed, performance-based fire protection projects generally focus on the Tier 4 level "Systems." The system boundaries in terms of equipment, components, and operations are defined, and the fire or explosion risk is quantified. If the risk exceeds the risk tolerance limits established by the management decision makers, then risk reduction is warranted. To evaluate risk reduction alternatives and benefits, risk tolerance criteria must be quantified.

2.1.2 Risk Tolerance Objectives

The development of risk tolerance criteria starts with the formulation of objectives. An objective is an expression of a decision maker's goal in terms of a guiding action. Presently, the majority of building codes that incorporate performance-based fire protection options provide qualitative objectives. Table 2.1 presents an example of some building code fire safety objectives.[1]

Table 2.1: Example of Some Building Code Objectives
Source: Hadjisophocleous etal. 1998.[1]

SOURCE	OBJECTIVES
CIB W14	• Limiting individual life and societal fire risks • Limiting fire spread to buildings Functional requirements for attaining the general objectives are: • Reducing the frequency of fire occurrence • Control of fire (smoke and flames) at an early stage • Ensuring a safe evacuation of people • Preventing fire spread (smoke and flames) to other building areas or buildings • Avoiding structural failure or limiting structural damage
Australia Building Code	• Safety to the occupants — safe egress from the building • Effective intervention of the fire brigade • Prevention of conflagration The above list should be adjusted for some buildings to account for objectives such as: • Prevention of structural damage in a building of strategic importance • Prevention of damage to the fabric of a historic building • Prevention of fire and/or water damage to contents of a museum, art gallery or computer room
New Zealand Building Code	Outbreak of fire: • To safeguard people from injury or illness caused by fire Means of escape: • To safeguard people from injury or illness from a fire while escaping to a safe place • To facilitate fire rescue operations Spread of fire: • To safeguard people from injury or illness when evacuating a building during a fire • To provide protection to fire service personnel during fire-fighting operations • To protect adjacent households and other property from the effects of fire • To safeguard the environment from the adverse effects of fire Structural stability: • To safeguard people from injury due to loss of structural stability during a fire • To protect household units and other property from damage due to structural instability during a fire
BSI Draft Code of Practice	• Limiting the probability of outbreak of fire: Minimized potential for ignition as far as reasonably practicable • Life safety objectives: The occupants of a building, fire-fighters and members of the public who are in the vicinity of a building should not be subjected to untenable conditions and building collapse • Loss prevention: Limit damage of fire on the continuing viability of a business • Environmental protection: Limit environmental impact from the release of quantities of hazardous materials

Table 2.2. presents another example listing of management goals, and loss control objectives. Presented in Table 2.1 and the first two columns of Table 2.2 are qualitative objectives. These are good things to state: “safeguard people from injury or illness caused by fire,” “minimize production downtime from equipment or building fires/explosions,” etc. However, as indicated in the last column of Table 2.2, labeled Risk Tolerance Criteria, the risk-informed approach will force management decision makers to establish likelihood and consequence limits for these objectives.

Table 2.2: Example Listing of Goals, Objectives, Risk Tolerance

MANAGEMENT GOALS (QUALITATIVE)	LOSS CONTROL OBJECTIVES (QUALITATIVE)	RISK TOLERANCE CRITERIA
1. Provide life safety for employees, contractors, public	• Minimize life safety exposures from a fire or explosion situation	Likelihood limit ? Consequence limit ?
2. Provide continuity of operations	• Minimize production downtime from equipment or building fires/ explosions	Likelihood limit ? Consequence limit ?
3. Provide property protection	• Minimize equipment and building damage from fire or explosion incidents	Likelihood limit ? Consequence limit ?
4. Minimize company image exposure	• Identify fire/explosion incidents that could adversely affect company image	Likelihood limit ? Consequence limit ?
5. Limit environmental impacts	• Minimize air, soil contamination from fire, extinguishing agents	Likelihood limit ? Consequence limit ?
6. Provide regulatory compliance	• Minimize regulatory fines via compliance with: – corporate policies – regulatory agencies – local codes	Likelihood limit ? Consequence limit ?
7. Provide cost-effective loss control features to limit the financial impact on company profitability	• Minimize the financial impact from the aggregate consequences associated with items 1 - 6	Financial impact assessment in terms of annualized risk ($)

Sections 2.2 and 2.3 address risk tolerance quantification approaches and development of graphical risk tolerance profiles.

2.2 FINANCIAL IMPACT RISK TOLERANCE

Fire and explosion (F&E) quantitative risk tolerance criteria can be expressed in a variety of ways. In this section, two methods will be addressed:

- annualized financial impact risk and
- likelihood of exceeding a defined exposure level.

2.2.1 Annualized Financial Impact Risk

In the application of risk-informed, performance-based projects, the end results are usually presented to business managers. The success of this approach lies in the ability to present to these business managers the F&E risk picture from a financial standpoint. In traditional quantitative risk assessments (QRAs), the results tend to be mathematical abstracts that may be difficult to explain to "nonrisk assessors."

Some of the many benefits of using an annualized financial impact risk approach are that it:[2]

- presents the total risk picture using the language of business — *financial* impacts
- directly combines the risks to people, environment, property, production, and the business on a common metric (i.e., equivalent monetary value)
- produces results that can be easily communicated to board-level executives
- provides essential information for executive or management decision making
- is invaluable in developing alternative strategic business options to achieve short-and-long term goals
- presents the total liability
- reveals the maximum potential loss for financial planning
- presents the expected annual losses which can then be incorporated in to business plans
- can be used to evaluate insurance needs, restructure insurance programs, assess the value for premiums paid, and optimize the insurance portfolio
- can be used to determine if certain risks prohibit a business segment or activity
- assists in evaluation of risk transfer
- can be invaluable in assessing alternative technologies

Fire and Explosion Viewed as a Financial Risk

In many cases, management is faced with competing business, technical, and loss control alternatives that may directly or indirectly affect company profitability.

The following provides an example of the primary factors included in the profitability equation:

⌶ Revenues − ⌶ Planned Cost − ⌶ Unplanned Cost = ⌶ Profits

The symbol ⌶ is used to acknowledge an uncertainty "bandwidth," which is associated with each factor. The uncertainties related to revenue projections are usually dealt with using "expected value" analysis (EVA). EVA is a widely used decision aid for business projections and decisions. In EVA, decision makers assign probabilities to best case, worst case, and other probable scenarios. The probabilities are mostly derived from subjective judgements based on marketing research and company, industry, and personal experience.

An example of an EVA-related revenue projection could look like this:

Scenario (Sn)	[A] Likelihood		[B] Revenue Projection (millions)		[A] × [B] Revenue EVA (millions)
1. Best Case	.10	×	$ 10	=	$ 1
2. Probable Case	.30	×	$ 7.5	=	$ 2.25
3. Worst Case	.60	×	$ 5	=	$ 3
					$ 6.25

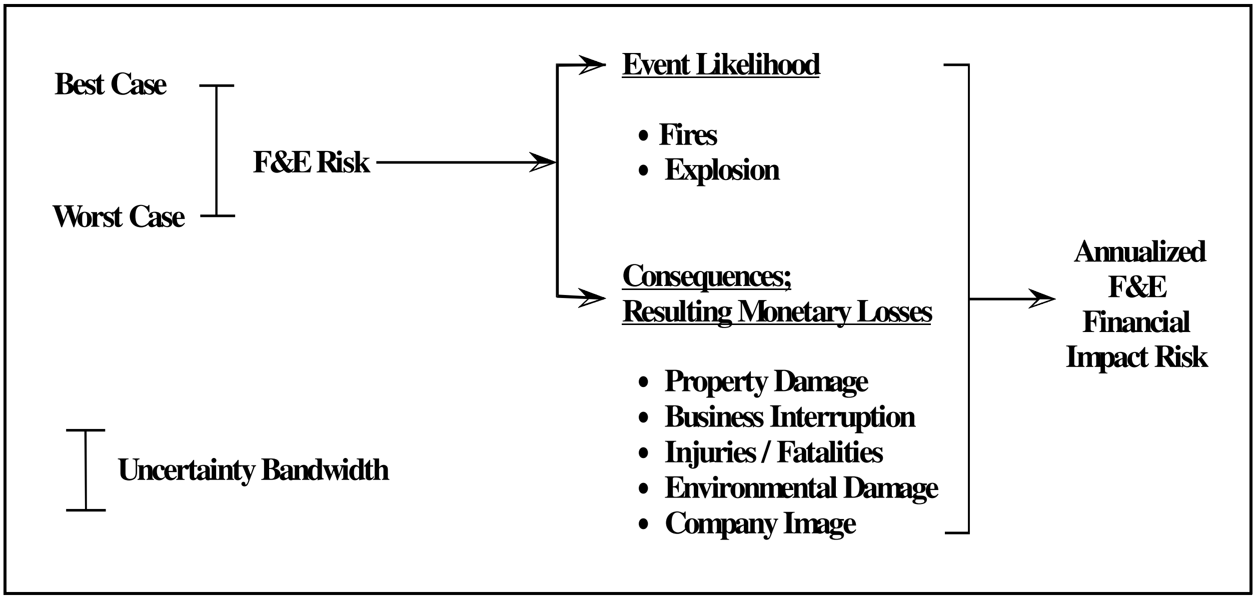
Planned costs (i.e., costs associated with production facilities, equipment, distribution, etc.) that are subtracted from revenue projections are usually dealt with in the same manner, that is relating the uncertainty in cost variables using EVA.

Unplanned costs, which we will define in this section as costs related to potential incidents such as fires or explosions, may or may not be included in the business profitability equation. If they are, the costs are usually estimated based on historical loss experience and therefore may not reflect realistic future loss potentials.

As depicted in Fig. 2.4, F&E likelihood and costs should be examined in terms of Total Annualized F&E Financial Impact Risk:

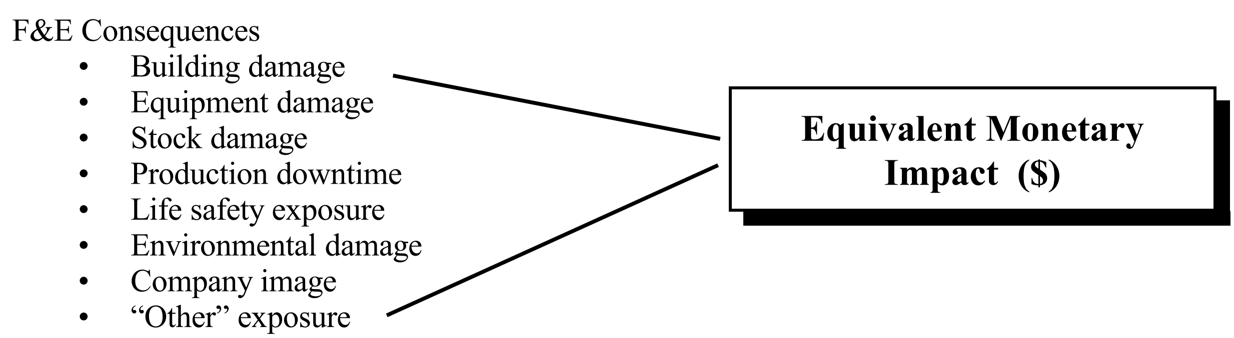
$$\text{Annualized F\&E Financial Impact Risk} = \text{Likelihood of Event Occurrence} \times \text{Consequences — Resulting Monetary Losses (\$)}$$

Fig. 2.4 F&E Financial Impact Risk



To evaluate the total monetary value that may be exposed to fire or explosion loss, the contribution of all the consequences must be recognized and estimated in terms of equivalent monetary values (EMVs) as illustrated in Fig. 2.5. This provides a framework for evaluating a business's financial impact and allows cost/benefit analysis of risk reduction opportunities.

Fig. 2.5 Equivalent Monetary Impact



NOTE: The approach for relating multiple consequences to an equivalent monetary value is addressed in Chap. 7, Risk Estimation and Comparison With Risk Tolerance.

Based on the preceding discussion, the profit equation can be rearranged as follows:

Profit = Revenues – Planned Costs – Annualized F&E Financial Impact Risk

For example purposes, let's assume that a risk assessment team, in meeting with the business managers of plant process ABC, develop the following information using expected value analysis EVA. The profit commitment for this project is assumed to be 30%.

Revenue projection	$ 6.25 million
Profit commitment (30%)	$ 1.875 million
Projected planned costs	$ 4.34 million

Profit	=	Revenues	–	Planned Costs	–	Annualized F & E Financial Impact Risk
$ 1,875,000.00	=	$ 6,250,000.00	–	$ 4,340,000.00	–	?

We can now estimate the F&E financial impact risk limit, which becomes our Risk Tolerance Limit:

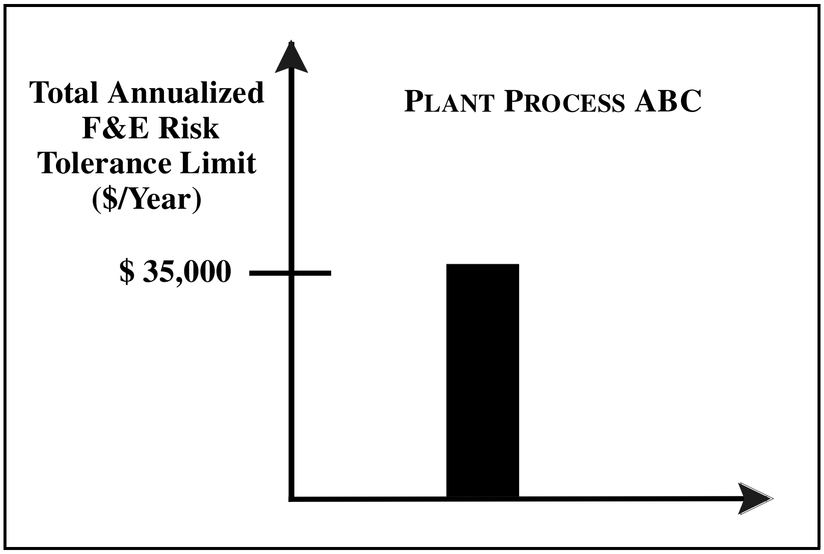
Total annualized F&E financial impact risk **tolerance limit**	=	$6,250,000	–	$ 4,340,000	–	$ 1,875,000	=	$ 35,000.00/year

The $35,000.00/year is the F&E risk tolerance limit. It is important to remember that this is a risk value and therefore consists of two components:

$ 35,000.00/year	=	Likelihood of Event Occurrence	×	Consequences — Resulting Monetary Losses from F&E

Figure 2.6 presents a graphical depiction of this.

Fig. 2.6: Example Risk Tolerance Limit



How Does This Relate To The Risk Model?

Remember this equation:

$$\begin{array}{c}\text{Total annualized}\\ \text{F\&E financial}\\ \text{impact risk}\\ \text{tolerance limit}\end{array} = \sum \begin{array}{c}\text{Likelihood of}\\ \text{event occurrence}\end{array} \times \begin{array}{c}\text{Consequences —}\\ \text{resulting monetary}\\ \text{losses from F\&E}\end{array}$$

Now into our Risk Tolerance equation, let's incorporate PERFORMANCE in terms of the conditional probability of Fire Protection System (FPS) Success:

$$\begin{array}{c}\text{\$ 35,000/year}\\ \text{F\&E risk}\\ \text{tolerance limit}\end{array} = \sum \begin{array}{c}\text{Likelihood of}\\ \text{event occurrence}\end{array} \times \begin{array}{c}\textbf{Probability of}\\ \textbf{FPS performance}\\ \textbf{success}\end{array} \times \begin{array}{c}\text{Consequences —}\\ \text{resulting monetary}\\ \text{losses from F\&E}\end{array}$$

The modeling method used for the analysis of F&E risk is the event tree, which is described in Chap. 3, Loss Event Scenario Development. Event tree analysis (ETA) provides a method for combining event likelihoods, FPS performance success probability, and consequences into a measure of RISK and RISK REDUCTION effects, as shown in Fig. 2.7.

Fig. 2.7: Event Tree Risk Model

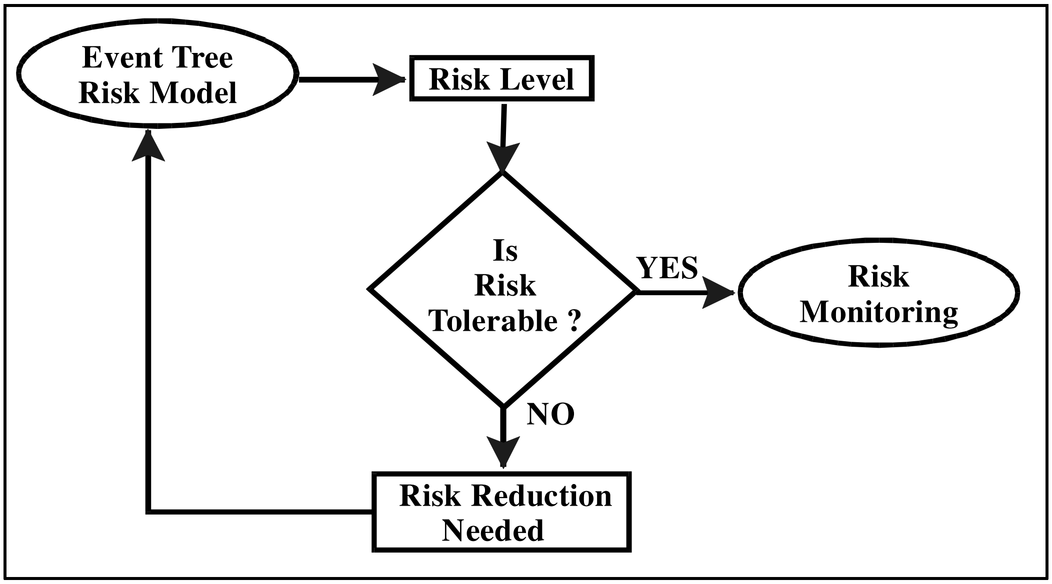
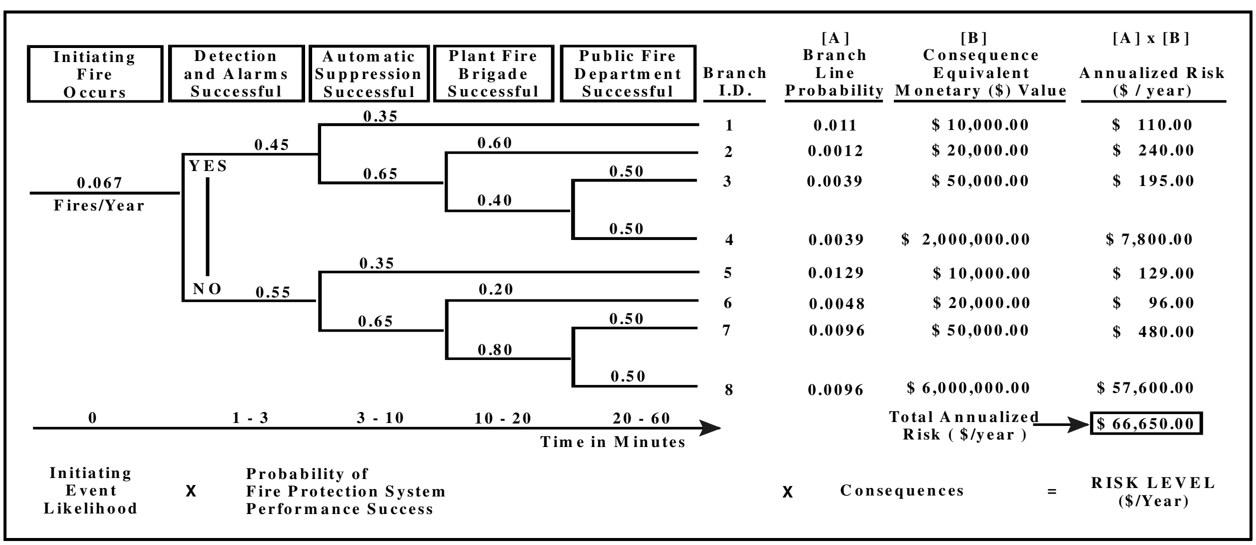


Figure 2.8 presents an event tree that estimates the "existing risk" for example plant process ABC. The risk equation is shown on the bottom of the event tree:

$$\sum \text{Initiating Event Likelihood} \times \text{Probability of FPS performance success} \times \text{Consequences (\$)} = \text{Risk level (\$/year)}$$

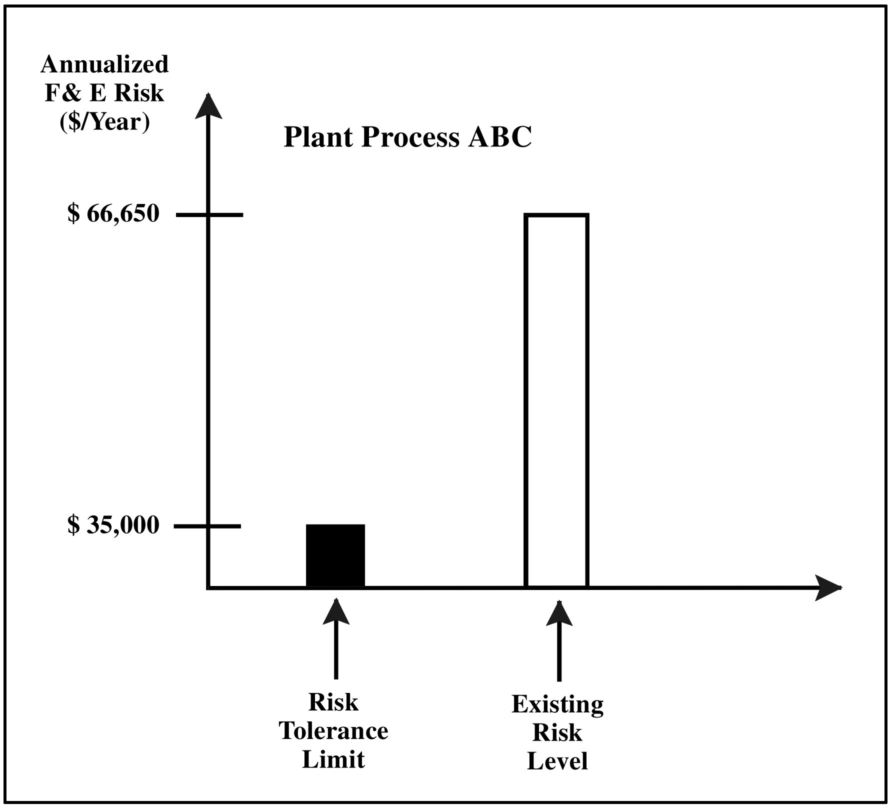
Fig. 2.8: Example Event Tree for Existing Risk of Process ABC



In Fig. 2.8, the last column calculates the existing annualized risk by multiplying the branch line probability [A] and consequences (in equivalent dollar value) [B]. The annualized risk for each branch line is added up for a total existing risk level of $66,650.00 ($/year).

Figure 2.9 provides a graphical profile of the Risk Tolerance Limit, $35,000 /year, in comparison to the estimated existing risk level in example Fig. 2.8. In this case, risk reduction is warranted.

Fig. 2.9: Example Profile-Risk Tolerance Limit versus Existing Risk Level



Please note that the focus of this example is on comparing existing risk to an established quantified Risk Tolerance Limit. Event tree construction, calculation, and analysis are described in Chaps. 3, 7, and 8.

2.3 EXPOSURE LEVEL RISK TOLERANCE

The methodology for developing event tree risk models in this book lends itself to not only financial impact risk analysis but also to analysis of specific exposures, which may be difficult to place into equivalent monetary terms. Life safety and business interruption exposure levels are discussed in this section.

2.3.1 Life Safety Risk Tolerance

Figure 2.10 presents an example event tree depicting life safety exposure levels in the last column. Table 2.3 presents a general example of life safety exposure levels that could be applied in an event tree analysis.

Fig. 2.10: Example Event Tree Presenting Life Safety Exposure Levels

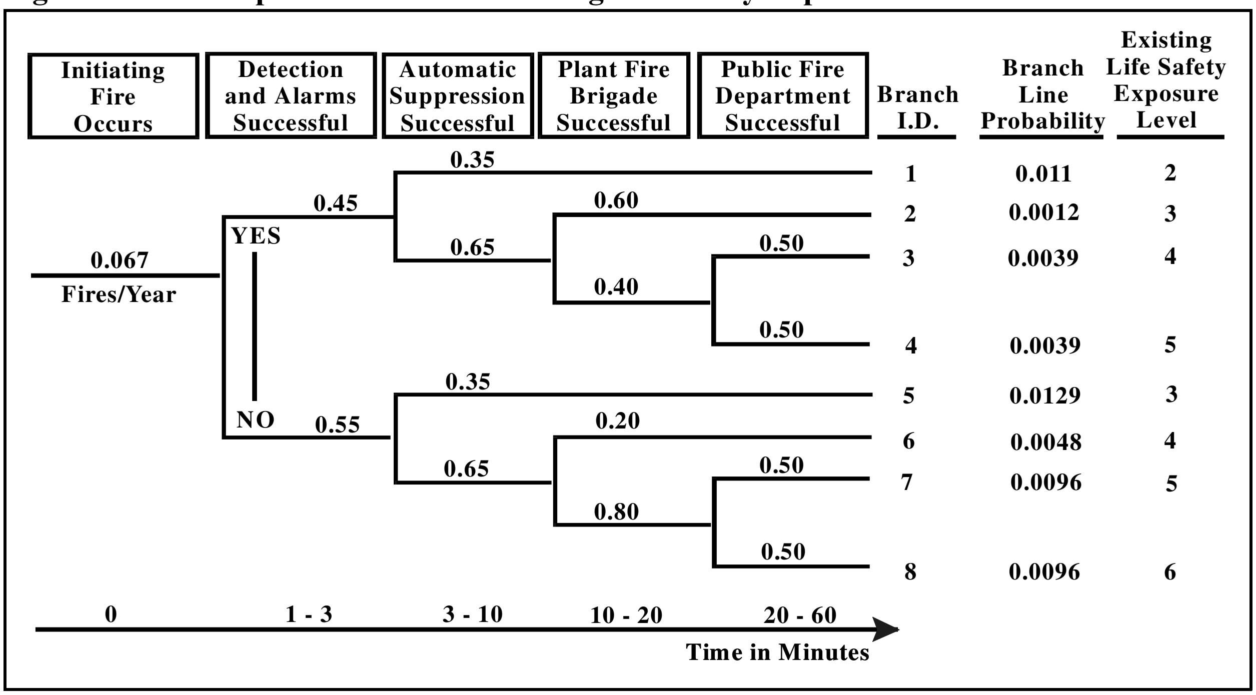


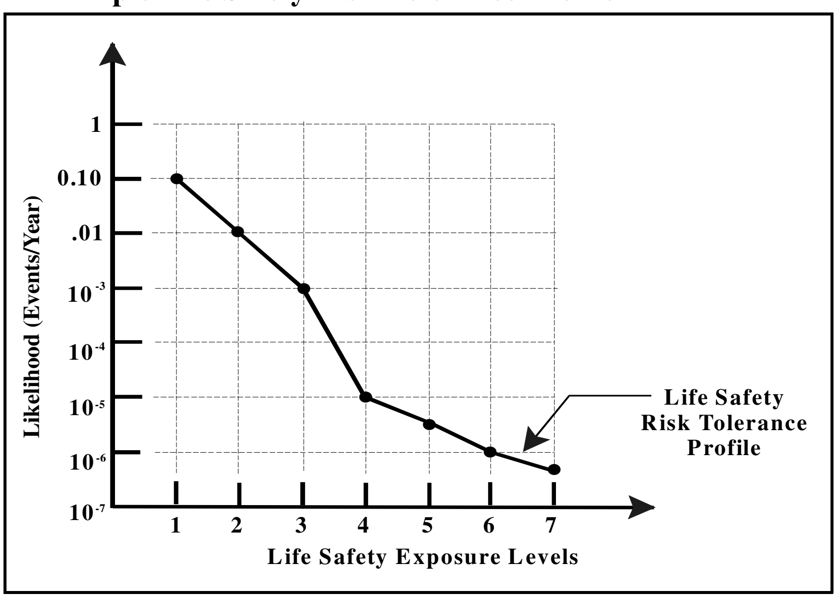
Table: 2.3: General Example of Life Safety Exposure Categories

LIFE SAFETY EXPOSURE	GENERAL DEFINITION	LIKELIHOOD TOLERANCE LIMITS (EVENTS/YEAR)
1 – LOW	FIRST AID – (ONE PERSON PRIMARILY SMOKE-RELATED EXPOSURE)	0.10
2 – MODERATE	MODERATE BURN INJURY POTENTIAL MAY REQUIRE HOSPITAL TREATMENT – (ONE PERSON)	0.01
3 – HEAVY	SEVERE BURN POTENTIAL REQUIRING HOSPITAL TREATMENT – (1-2 PEOPLE)	1×10^{-3}
4 – HIGH	POTENTIAL FOR MULTIPLE INJURIES, SINGLE PERSON DEATH ON-SITE	1×10^{-5}
5 – VERY HIGH	POTENTIAL FOR 1-3 FATALITIES ON-SITE	5×10^{-5}
6 – EXTREMELY HIGH	POTENTIAL FOR MULTIPLE INJURIES OR SINGLE PERSON DEATH – OFF-SITE	1×10^{-6}
7 – CATASTROPHIC	POTENTIAL FOR MULTIPLE FATALITIES – OFF-SITE	5×10^{-6}

LISTED IN THE LAST COLUMN OF TABLE 2.3 ARE LIKELIHOOD TOLERANCE LIMITS (EVENTS/YEAR) ASSOCIATED WITH EACH LIFE SAFETY EXPOSURE CATEGORY. LATER ON, WE WILL DISCUSS SOME BASIS FOR THESE LIKELIHOOD TOLERANCES. FOR NOW, HOWEVER, THE FOCUS IS ON DEVELOPING A LIFE SAFETY RISK TOLERANCE PROFILE.

FIGURE 2.11 PROVIDES AN EXAMPLE RISK TOLERANCE PROFILE, WHICH IS A GRAPHICAL PLOT OF LIFE SAFETY EXPOSURE LEVELS VERSUS LIKELIHOOD, BASED ON TABLE 2.3. POINTS ON THE RISK TOLERANCE PROFILE CURVE INDICATE POINTS OF LIKELIHOOD AND CONSEQUENCE LEVELS THAT ARE TOLERABLE TO THE DECISION MAKERS. THE AREA UNDER THE RISK PROFILE CURVE IS PROPORTIONAL TO THE TOTAL RISK, WHICH IS APPROXIMATED IN THE EVENT TREE RISK MODEL.

Fig. 2.11: Example Life Safety Risk Tolerance Profile



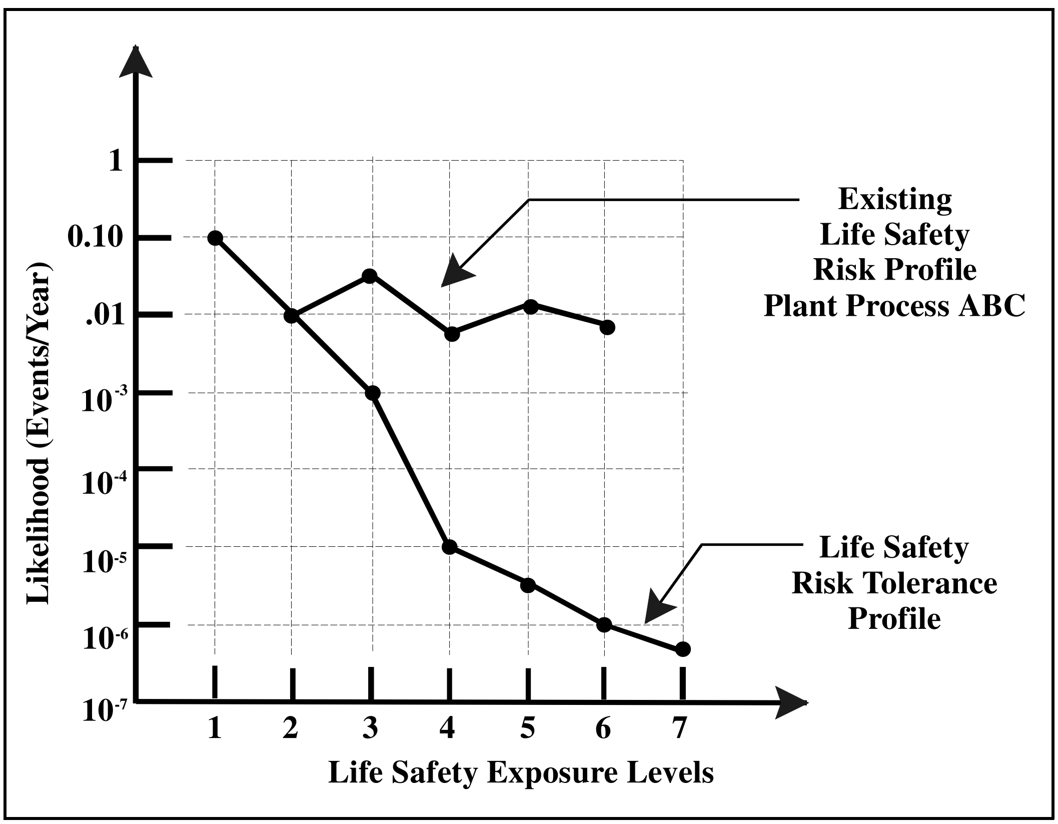
For the purpose of doing a quick comparison, Table 2.4 summarizes the life safety exposure levels and branch line likelihoods from the event tree in Fig. 2.10.

Table 2.4: Existing Likelihood of Reaching Life Safety Exposure Levels

BRANCH I.D.	LIFE SAFETY EXPOSURE LEVEL	LIKELIHOOD OF REACHING EXPOSURE LEVEL
1	2	0.011
2, 5	3	0.025
3, 6	4	0.0087
4, 7	5	0.0135
8	6	0.0096

The exposure level versus likelihood from Table 2.4, which we will assume is the existing life safety risk profile for Plant Process ABC, is plotted in Fig. 2.12. As seen in this figure, life safety risk reduction would be warranted.

Fig. 2.12 Example Profile of Existing Life Safety Risk versus Life Safety Risk Tolerance



Life safety risk tolerance is a subject of debate as it involves consideration of voluntary versus involuntary exposure. In general, people working on-site may be willing to accept a higher risk in contrast to people living beyond the plant site boundaries (i.e., the public).

For a first-order approximation of tolerable life safety risks to individuals, annualized F&E risks to an individual can be compared to:

- Accident statistic relating man-made and natural hazard risk.
- Industry specific and world wide accident rates
- Individual risk criteria used by other countries

Table 2.5 provides a breakdown of annual individual fatality rates based on U.S. National Safety Council statistics.[5,6,7]

Table 2.5: Annual Fatality Rate Data for Natural and Accidental Causes

CAUSE OF FATALITY	DEATHS PER 100,000 POPULATION	INDIVIDUAL CHANCE OF FATALITY PER YEAR (I.E., INDIVIDUAL RISK)
Diseases		
Heart disease	286	2.86×10^{-3}
Cancer	204	2.04×10^{-3}
Cerebrovascular disease	57	5.70×10^{-4}
Pneumonia	31	3.10×10^{-4}
Diabetes	19	1.90×10^{-4}
Accidents		
Motor vehicles	16.1	1.61×10^{-4}
Suicide	12.2	1.22×10^{-4}
HIV	11.7	1.17×10^{-4}
Homicide	10.5	1.05×10^{-4}
Falls	5.3	5.30×10^{-5}
Drowning	1.4	1.40×10^{-5}
Fires, Burns	1.4	1.40×10^{-5}
Natural Hazards & Environmental Factors		
Cataclysm (tornado, flood, earthquake, etc.)	0.09	9.00×10^{-7}
Excessive heat	0.09	9.00×10^{-7}
Excessive cold	0.40	4.00×10^{-6}
Lightning	0.04	4.00×10^{-7}

Source: *International Accident Facts*, Second Edition, 1999, National Safety Council, USA. *Accident Facts*, 1994 and 1988 Editions, National Safety Council, USA. The data are based on U.S. statistics.

Government authorities world-wide specifying numerical risk criteria include:[3]

- Ministry of Housing, Physical Planning and Environment (VROM) in the Netherlands
- Health and Safety Executive (HSE) in the United Kingdom
- Coordinating Committee for Potentially Hazardous Installations (CCPHI) in Hong Kong
- Department of Planning (DP) in the Australian State of New South Wales
- Environmental Protection Authority (EPA) in Western Australia
- Major Industrial Accidents Council of Canada (MIACC)
- County of Santa Barbara, California, USA

Individual risk is defined as the frequency at which an individual may be expected to sustain a given level of harm from the realization of specified hazards. It is usually taken to be the risk of death and usually expressed as a risk per year. Individual risk may be calculated in various ways, and although each is consistent with the above definition, the results may differ substantially.[3]

A summary of individual risk criteria for workers used by various companies and authorities around the world is given in Table 2.6. A summary of individual risk criteria for members of the public used by various authorities around the world is given in Table 2.7[3].

Table 2.6: Individual Risk Criteria for Workers
Source: Greenwood et al. 1997

AUTHORITY AND APPLICATION	MAXIMUM TOLERABLE RISK (PER YEAR)	NEGLIGIBLE RISK (PER YEAR)
Health & Safety Executive, UK (Existing hazardous industry)	10^{-3}	10^{-6}
Shell (onshore and offshore) (approx.)	10^{-3}	10^{-6}
BP (onshore and offshore)	10^{-3}	10^{-5}
Norsk Hydro (onshore plants)	10^{-3}	
ICI (onshore plants)	3.3×10^{-5}	
Statoil (onshore plants)	8.8×10^{-5}	

Table 2.7: Official Individual Risk Criteria for the Public
Source: Greenwood et al. 1997

AUTHORITY AND APPLICATION	MAXIMUM TOLERABLE RISK (PER YEAR)	NEGLIGIBLE RISK (PER YEAR)
VROM, The Netherlands (new plants)	10^{-6}	Not used
VROM, The Netherlands (existing plants or combined new plants)	10^{-5}	Not used
VROM, The Netherlands (transport)	10^{-6}	Not used
Health & Safety Executive, UK (existing hazardous industry)	10^{-4}	10^{-6}
Health & Safety Executive, UK (new nuclear power stations)	10^{-5}	10^{-6}
Advisory Committee on Dangerous Substance, UK (existing dangerous substances transport)	10^{-4}	10^{-6}
Health & Safety Executive, UK (new housing near existing plants)	10^{-5}	10^{-6}
Hong Kong Government (new plants)	10^{-5}	Not used
Department of Planning, New South Wales (new plants and housing)	10^{-6}	Not used
Environmental Protection Authority, Western Australia (new plants)	10^{-6}	Not used
Santa Barbara County, California, USA (new plants)	10^{-5}	10^{-7}

The most comprehensive and widely used criteria for individual risks are the ones proposed by the UK HSE as follows[3]:

Maximum tolerable risk for workers	10^{-3}
Maximum tolerable risk for members of the public	10^{-4}
Negligible risk	10^{-6}

These criteria were developed for application to existing activities. For new activities or for more safety-conscious companies, criteria are proposed that are more strict by an order-of-magnitude, as follows:

Maximum tolerable risk for workers	10^{-4} per year
Maximum tolerable risk for members of the public	10^{-5} per year
Negligible risk	10^{-7} per year

The Dutch risk policy has an upper limit in terms of both individual and societal risk, which defines an activity as intolerable regardless of the economic or societal benefits. A similar lower limit defines the level beyond which seeking of additional risk reduction cannot be justified. Between these limits is a gray area, termed ALARA (*as low as reasonably achievable.*) The current societal risk criterion is presented in Fig. 2.13. This is set with an upper limit of 10 fatalities in one incident at 10^{-5} per year (once in a 100,000 years) and a negligible lower limit of 10^{-7} per year (once in 10 million years).[3]

Fig. 2.13: Netherlands Societal Risk Criteria

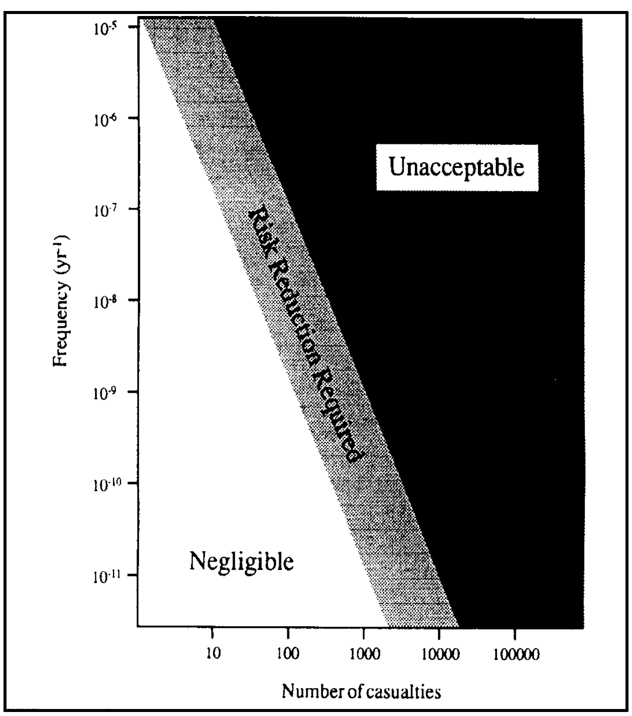


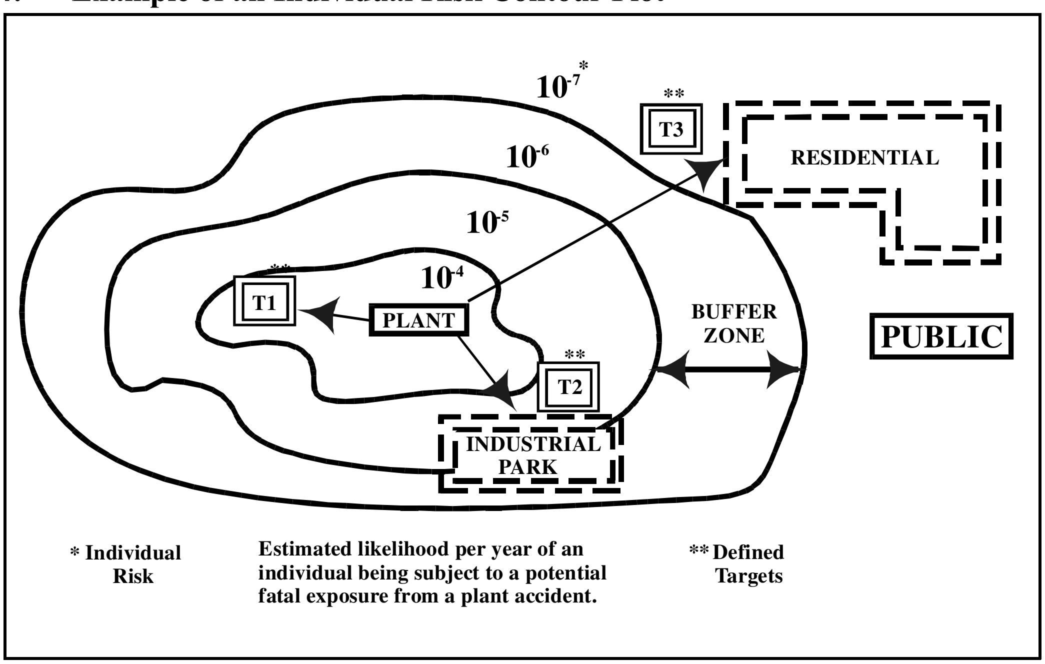
Table 2.8 presents an example of life safety risk tolerance criteria based on previous discussions.

Table 2.8: Example of Life Safety Risk Tolerance Criteria

LIFE SAFETY EXPOSURE LEVELS	LIKELIHOOD PER YEAR RANGES	FIRE & EXPLOSION LIFE SAFETY CONSEQUENCES
3 – 4	$10^{-3} – 10^{-4}$	Major injuries/fatality potential for plant personnel working at or near the facility or operation under risk evaluation
4	$10^{-4} – 10^{-5}$	Major injuries/fatality potential for plant personnel working on the plant site but beyond the direct boundaries of the facility or operation under risk evaluation
5 – 6	$10^{-5} – 10^{-6}$	Major injuries/fatality potential for people living beyond the plant site boundaries
7	$\leq 10^{-6}$	Major injuries/multiple fatality potential for residents in highly populated areas outside of plant site boundaries
Note: Refer to Table 2.3 for exposure level definitions		

In some cases, the risk evaluation team may want to plot a risk contour depicting individual risk levels at various target distances from the fire or explosion source. Figure 2.14 provides an example of this. In this figure, target [TI] is a selected target within the plant site boundaries. Target [T2] is a selected target at an adjacent industrial park. Target [T3] represents off-site risk to the public.

Fig. 2.14: Example of an Individual Risk Contour Plot



What is viewed as a tolerable risk will depend on a number of factors, including:

- *The nature of the risk.* Is it a voluntary risk, one that those who are at risk accept as part of a choice? Or is it involuntary?
- *Who or what is at risk.* Does it affect a single person or many people? What about the surrounding environment? Are areas such as schools or residential neighborhoods at risk?
- *The degree to which the risk can be controlled or reduced.* Making the case for a “tolerable” risk requires that the methods supporting risk reduction alternatives be technically sound.

Companies that have successfully established risk tolerance criteria have attained consistency in their decisions about risk. The selection of appropriate risk criteria is a corporate responsibility and requires the involvement and support of management decision makers as it establishes the levels and types of risks the company will tolerate.

2.3.2 Business Interruption Risk Tolerance

The minimization of production downtime and business interruption following a fire or explosion incident is a major concern of decision makers. Figure 2.15 presents an example event tree depicting business interruption (BI) exposure levels in the last column. Table 2.9 presents a general example of BI exposure levels that could be applied in an event tree analysis (ETA).

Fig. 2.15: Example Event Tree Focusing on Business Interruption (BI) Exposure Levels

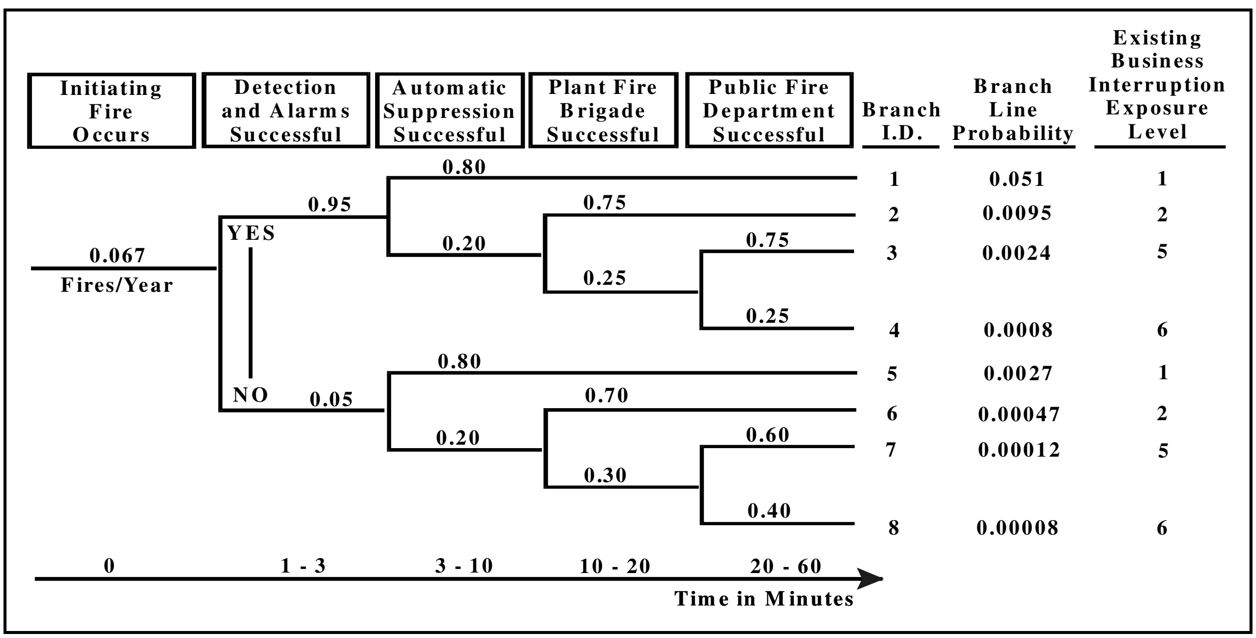


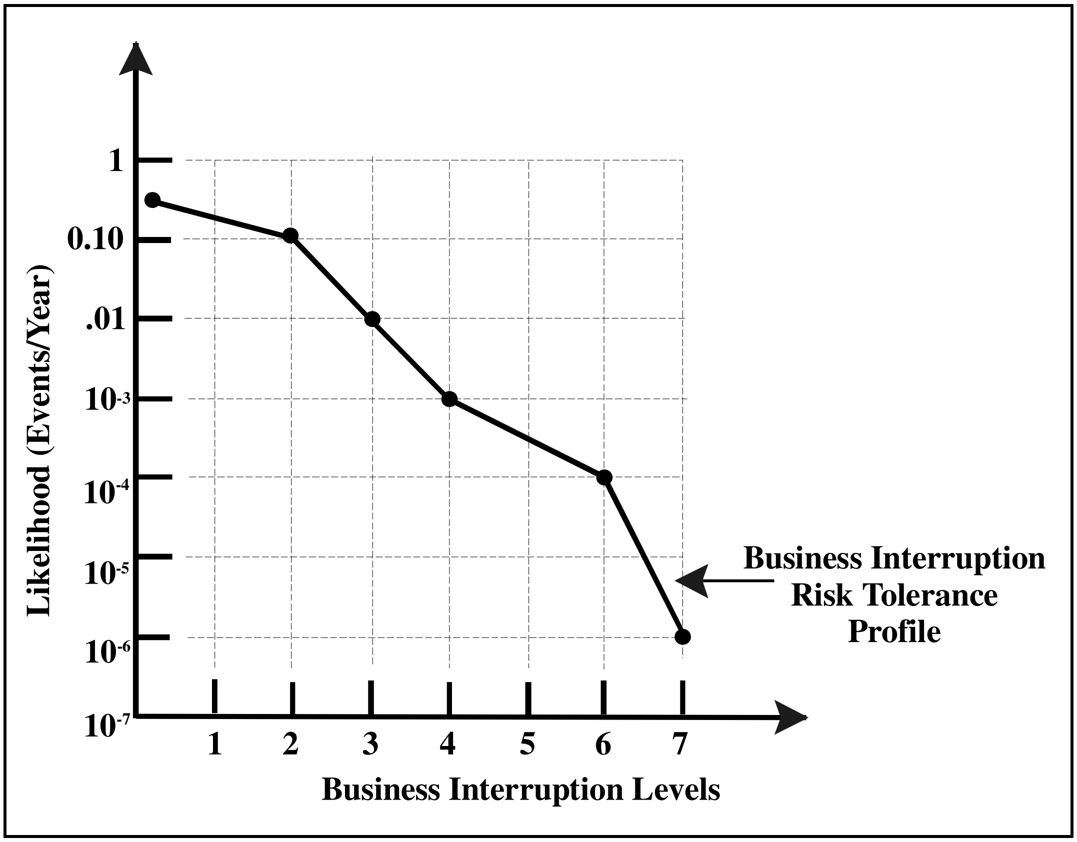
Table 2.9: Example of BI Levels and Risk Tolerance Criteria

BI Levels	Production Downtime Range	Average Production Downtime, Days	General Definition	Likelihood Tolerance Limits (Events/Yr)
1 – Slight	0 – 1 days	0.5	Limited localized minor equipment damage not requiring repair, but clean up and minimal downtime	0.33
2 – Light	1 – 10 days	5	Significant localized damage of some equipment components with minor production downtime	0.10
3 – Moderate	10 – 30 days	20	Significant localized damage of many equipment components with moderate production downtime	0.01
4 – Heavy	30 – 90 days	60	Heavy damage requiring major equipment repair and replacement and downtime	1×10^{-3}
5 – Major	90 – 270 days	180	Major widespread damage that may result in extensive repairs and equipment replacement with major downtime	5×10^{-3}
6 – Critical	270 – 365 days	318	Extensive downtime of the majority of the facility	1×10^{-4}
7 – Total or Maximum	1 – 2 years	—*	* Maximum downtime expected	1×10^{-6}

In Table 2.9 BI levels are categorized in terms of production downtime. In the last column of this table are likelihood tolerance limits (events/yr) associated with each BI level. These tolerance limits are usually selected by the consensus opinion of the decision making and risk assessment teams.

Figure 2.16 provides an example risk tolerance profile which is a graphical plot of BI exposure levels versus likelihood, based on Table 2.9.

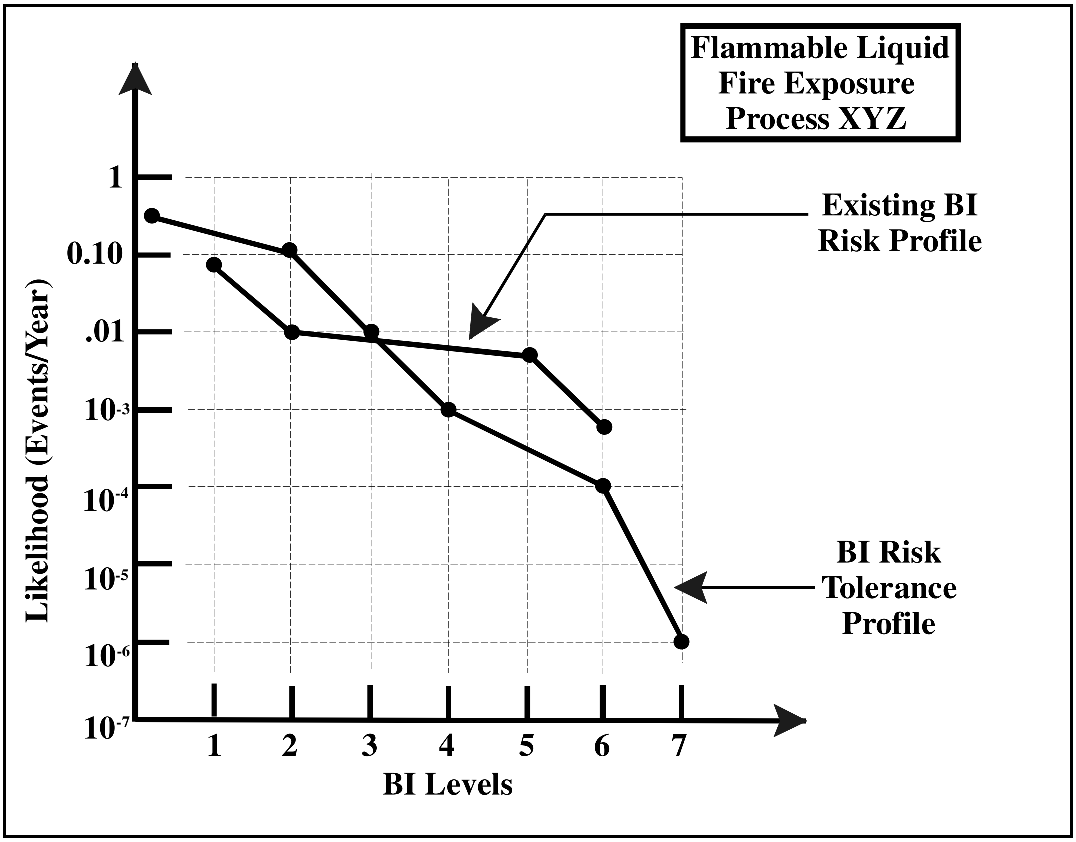
Fig. 2.16: Example BI Risk Tolerance Profile



For the purposes of a quick comparison, Fig. 2.17 provides a comparison plot of existing BI Risk (based on the ETA in Fig. 2.15) and the BI risk tolerance profile graph. As depicted in Fig. 2.17, BI risk reduction analysis would be warranted.

Please note that the focus of these examples is to illustrate development of risk tolerance profiles. Chapters 7 and 8 describe risk estimation and risk reduction analysis in detail using event trees and graphical risk profiles.

Fig. 2.17: Example of Existing BI Risk Versus the BI Risk Tolerance Profile



2.3.3 Establishing Consequence Categories

Each of the following consequences can be evaluated in terms of damage categories, which can be related to EMVs:

- Property damage (damage categories can be associated to percentages of equipment and/or building damage and directly related to monetary values)
- Loss of production/BI (categories can be associated with days downtime, % production loss, and directly related to monetary values)
- Life safety exposure (categories can be associated with potential human exposure levels and potential EMV ranges)
- Environmental damage (categories can be associated with toxic air emissions, soil, water contamination levels from fire combustion products and suppression agents, and selected monetary equivalents)
- Other (legal liabilities, regulatory fines, company image, loss of customers) can be defined in some cases and related to monetary values using relative scales.

Property Damage

Life safety exposure and BI have already been discussed. Table 2.10 provides an example of property damage exposure levels. The last column is available for selecting likelihood tolerance limits for each associated property damage level. Separate tables could be developed for building, equipment, and stock damage levels.

Table 2.10: Example of Property Damage Levels

PROPERTY DAMAGE LEVELS	DAMAGE FACTOR RANGE (%)	CENTRAL DAMAGE FACTOR (%)	GENERAL DEFINITION	LIKELIHOOD TOLERANCE LIMITS (EVENTS/YR) *
1 – Slight	0 – 1	0.5	Limited localized minor damage not requiring repair	
2 – Light	1 – 10	5	Significant localized damage of some components generally not requiring major repair	
3 – Moderate	1 – 30	20	Significant localized damage of many components warranting repair	
4 – Heavy	30 – 60	45	Extensive damage requiring major repairs	
5 – Major	60 – 100	80	Major widespread damage that may result in the facility being razed, demolished, or repaired	
6 – Destroyed	100	100	Total destruction of the majority of the facility	
* Would be selected by risk assessment and decision making team.				

Environmental Damage

Potential environmental impacts related to F&E incidents are difficult consequences to estimate in terms of an EMV as environmental impacts following a fire can take several forms. There may be clean-up costs associated with toxic material spills, contamination, or treatment and disposal of waste streams. This is a real potential cost, and although it should be considered in fire risk assessments, it often is not.

The costs for cleanup of environmental spills can be estimated along with potential regulatory fines that the company may incur. Other consequences, such as the effects of negative publicity surrounding F&E related environmental accidents, are more difficult to estimate.

Table 2.11 provides a general example of establishing some environmental exposure categories and associated average EMVs. The last column is available for selecting likelihood tolerance limits.

Table 2.11: Example of Environmental Damage Levels

ENVIRONMENTAL DAMAGE LEVELS		EMV * ($)	LIKELIHOOD TOLERANCE LIMITS (EVENTS/YR) **
Soil Contamination	**SC1** Negligible effect	1 K	
	SC2 Local – extensive effect	20 K	
	SC3 Major effect	250 K	
Water Contamination	**WC1** Negligible effect	1 K	
	WC2 Local – extensive effect	250 K	
	WC3 Major effect	2 M	
Air Contamination	**AC1** Negligible effect	1 K	
	AC2 Local – extensive effect	500 K	
	AC3 Major effect – extends offsite	5 M	

EMV = equivalent monetary value

* EMV estimates are facility, operation, and location specific. The $ values in this column are for example purposes only.

** Would be selected by risk assessment and decision making team.

2.3.4 Establishing Likelihoods

Likelihood ranges for events can be established using a format that lists expected time between occurrences and a qualitative description of these frequency ranges and categories or levels of likelihood.

When a team is assembled from the plant (e.g., engineering, operations, maintenance, environmental, safety, and fire protection) it is much easier to have a likelihood "range" to initially select risk tolerance likelihood criteria.

Table 2.12 provides an example of ranges of initiating event frequencies.[4] Table 2.13 provides an example of establishing qualitative descriptions of some potential likelihood levels. Relating qualitative descriptions to quantitative likelihood levels is important. If we rely on subjective estimates from the risk analysis team, what is a highly likely event to one team member may be an incident within the next 1 to 5 years, while to another, the same event may mean having an incident over the useful life of the operation.

Table 2.12: Example Ranges of Event Likelihoods [4]

EXPECTED TIME BETWEEN OCCURRENCES	FREQUENCY RANGE	PROBABILITY OF AT LEAST ONE OCCURRENCE IN 100 YEARS OF EXPERIENCE
<0.01 y (~4 days)	>100/y	~100%*
0.01 y (~4 days) to 0.1 y (~37 days)	100/y to 10/y	~100%*
0.1 y (~37 days) to 1 y	10/y to 1/y	~100%*
1 y to 10 y	1/y to 0.1/y	~100%*
10 y to 100 y	0.1/y to 0.01/y	~100% to ~60%
100 y to 1,000 y	1 x 10^{-2}/y to 1 × 10^{-3}/y	~60% to 10%
1,000 y to 10,000 y	1 x 10^{-3}/y to 1 × 10^{-4}/y	10% to1%
10,000 y to 100,000 y	1 x 10^{-4}/y to 1 × 10^{-5}/y	1% to 0.1%
100,000 y to 1,000,000 y	1 x 10^{-5}/y to 1 × 10^{-6}/y	0.1% to 0.01%
≥1,000,000 y	≤1 × 10^{-6}/y	≤0.01%

* Multiple occurrences expected.

Table 2.13: Example Qualitative Descriptions of Likelihood

LIKELIHOOD OF EVENT OCCURRENCE	QUALITATIVE DESCRIPTION
10/yr	Likely to occur repeatedly during the system life cycle
1/yr	Likely to occur several times during the system life cycle
1/10 yrs	Likely to occur sometime during the system life cycle
1/100 yrs	Not likely to occur during the system life cycle
1/1000 yrs	Very unlikely to occur during the system life cycle
1/10,000 yrs	Not expected to be possible

Table 2.14 provides another example of establishing event likelihood categories. This table provides loss event frequency ranges, which allows the risk assessment team to select a likelihood within a range.

Table 2.14: Examples of Some Likelihood Categories

LIKELIHOOD CATEGORY	DESCRIPTION	AVERAGE TIME BETWEEN OCCURRENCES (YEARS)	RANGE FREQUENCY (PER YEAR)
1	Not expected to occur	>300	<.003
2	Not likely to occur during plant lifetime	100-300	.003-.01
3	Likely to occur no more than once during plant lifetime	30-100	.01-.03
4	Likely to occur once or twice during plant lifetime	10-30	.03-.1
5	Likely to occur several times during plant lifetime	3-10	.1-.3
6	Likely to occur between once a year and once every three years	1-3	.3-1.0
7	Likely to occur more than once a year	<1	>1.0

2.3.5 Discussion on Loss Expectancy

On occasion, I am asked how the loss "expectancy" terminology used in the Property Insurance Industry, such as NLE, PML, or MFL, relates to risk estimation and risk tolerance. Loss expectancy estimates in the property insurance context are qualitative estimates of the severity and consequences of a defined fire scenario. They do not include the likelihood of occurrence or the use of any risk assessment tools such as ETA.

Table 2.15 presents the terminology applied in the breakdown of potential loss expectancy familiar in the insurance company and risk management fields:

- NLE – normal loss expectancy
- PML – probable maximum loss
- MFL – maximum foreseeable loss

Although there are slight variations to these terms, the general definitions are as follows:

- NLE – This is the expected loss level with detection and fire protection systems in service and performing there designed loss control function.
- PML – This is the expected loss level with the primary automatic fire protection system being out of service. Passive protection measures such as fire barrier walls and manual fire fighting capabilities are included in the evaluation of loss-limiting factors.
- MFL – This is the expected loss level considering the unavailability of automatic and manual protection measures. Passive protection measures such as hazard separation, barrier walls, etc., are the only factors considered as loss-limiting measures.

The NLE can be considered a best-case scenario. The performance of protection systems are assumed to provide detection, emergency control, suppression, and extinction capability for small fires associated with the facility and also for the design-basis fire for which the safety systems were designed for. The design-basis fire is a much used term in the fire protection industry for designing fire safety systems. Although the design-basis fire is mostly defined in qualitative terms, its intent is to define an ‘upper-bound’ (although not worst case) fire situation in terms of both severity and likelihood over the life-cycle of the facility or operation being protected.

The PML is based on the primary protection system being unavailable (i.e., out of service) at the time of fire incident. The PML, therefore, is related to the probability of protection system failure (being unavailable, unreliable, and/or ineffective) being 1.0.

The MFL is based on the failure of automatic and manual protection systems but would include the success of passive (separation, barriers, etc.) protection measures.

Table 2.15: Some General Loss Expectancy Terminology

SCENARIO LEVEL	GENERAL SCENARIO DESCRIPTION	GENERAL LOSS EXPECTANCY TERMINOLOGY
A	Design-Basis	NLE – Normal Loss Expectancy
B	High Challenge	PML – Probable Maximum Loss
C	Worst Case	MFL – Maximum Foreseeable Loss

The Move Towards Risk-Based Loss Expectancy Estimates

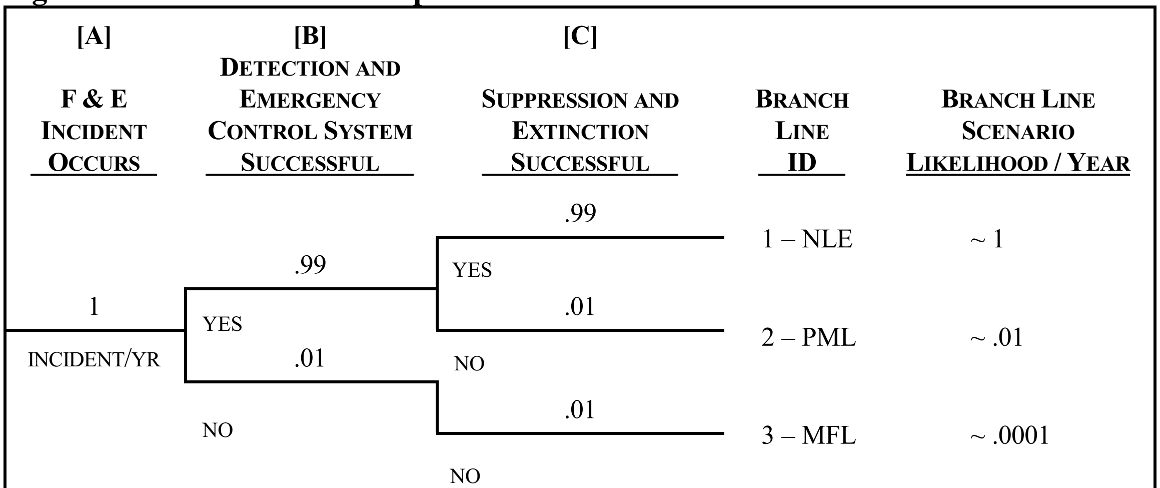
The modeling method used for fire risk analysis is the event tree, which is described in Chap. 3, Loss Event Scenario Development. Event tree analysis (ETA) provides a method for combining likelihoods and consequence levels.

ETA will be used here to illustrate the order-of-magnitude differences between loss-expectancy levels, which may be used by the decision making team in establishing F&E incident likelihood levels.

As presented in Fig. 2.18, the event tree is built on the following assumptions:

1. The frequency of fire is set at 1 fire/year
2. The failure probabilities for detection, emergency control, suppression and extinction are set at .01, which assumes a designed protection system’s performance success of 99%.

Fig. 2.18: Event Tree Example



Branch Line 1: (1) x (.99) x (.99) = approx .1
Branch Line 2: (1) x (.99) x (.01) = approx .01
Branch Line 3: (1) x (.01) x (.01) = approx .0001

As a first-order approximation, the difference between NLE, PML, and MFL loss-expectancy levels from a risk tolerance perspective could involve:

NLE → PML → 2 to 3 orders of magnitude
PML → MFL → 1 to 3 orders of magnitude

Table 2.1.6 presents an example of establishing first-order approximations of likelihood levels.

Table 2.16: Examples: First-Order Approximation of Likelihood Levels

Loss Expectancy Level	Guide Word	Likelihood Range Events/yr	General Definition
NLE	Likely	1 per 5 years (.2) 1 per 20 years (.05)	Nuisance Fire Design-Basis Fire
PML	Unlikely	10^{-2} 10^{-3}	Design-Basis Fire with Primary Protection System Failure; High Challenge Fire
MFL (on-site)	Very Unlikely	10^{-4} 10^{-5}	Worst Case-On-Site
MFL (off-site)	Extremely Unlikely	10^{-5} 10^{-6}	Worst Case-Off-Site

The grouping of event-tree-incident outcomes in terms of loss-expectancy groups (i.e., such as NLE, PML, MFL) and plotting risk profiles is addressed in Chap. 7, Risk Estimation and Comparison.

2.4 SOME KEY POINTS

Risk tolerance profiles must be developed prior to conducting detailed risk assessment. This establishes benchmark criteria upon which to judge the tolerability or needed reduction in fire or explosion risk levels.

Fire and explosion quantitative risk tolerance criteria can be addressed as an annualized financial impact risk or in terms of a likelihood tolerance limit related to exceeding defined exposure levels. In the financial impact risk approach, fire and explosion consequences such as property damage, business interruption (BI), life safety exposure, environmental damage, company image, etc. are combined into an equivalent monetary value (EMV) and are evaluated as a financial risk. In the likelihood tolerance limit approach, tolerable likelihood limits (events/year) are selected by the decision making team for various exposure levels. In both cases, risk tolerance criteria can be presented as a graphical profile that provides a quantitative tolerance benchmark for comparing existing risk levels and determining when risk reduction is needed.

The term “risk tolerance” infers establishment of risk-based limits on F&E incidents that will not adversely affect company stability, profitability and life safety. Risk tolerance criteria should be viewed as a dynamic measure related to a company’s changing business objectives and focus and should receive support from top management.

Quantitative F&E risk tolerance criteria must be established up front, and it is essential that all potentially affected parts of the organization be involved in the development of the guidelines. Companies that have successfully established risk tolerance criteria have attained consistency and cost-effectiveness in their risk management decisions.

2.5 REFERENCES

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