Chapter 3

Loss Scenario Development

Chapter Contents

LOSS SCENARIO DEVELOPMENT

3

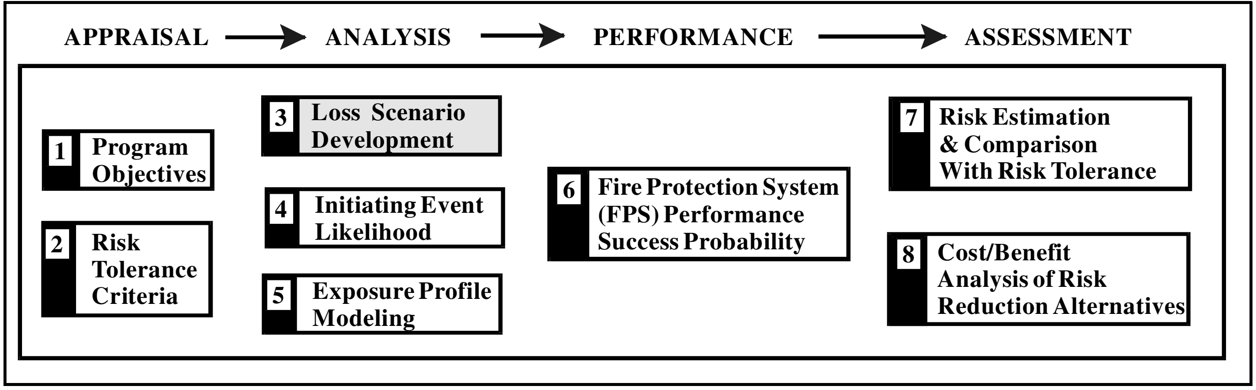
3.1 INTRODUCTION

A loss scenario represents the sequence of events that can result in undesirable fire or explosion incidents. The scenario development process must be:

- Sequentially structured in a time-related manner
- Credible in terms of realistic incident outcomes
- Contain sufficient information to allow the risk analysis team to quantify the scenario

As presented in Fig. 3.1, loss scenario development is step 3 in the risk-informed, performance-based decision making process. The input from steps 1 and 2 define the parameters for the types of fire scenarios and level of detail that will need to be developed.

Fig. 3.1: Risk-Informed, Performance-Based Fire Protection Steps



In this chapter, the term "loss scenario development" can best be defined as the reasoning methodology that describes the sequential relationships between time dependent fire loss events. In general, scenario modeling is an abstract representation of a real-world system or subsystem. Time limitations, complexity, and costs generally preclude the development of logic models, which represent every aspect and detail of fire loss exposure potential. Therefore, in most cases fire scenario logic models provide us with a simplified approach that attempts to include the significant aspects of fire events relevant to the risk-based decisions under evaluation.

Section 3.2 describes event sequencing using the concept of Source → Pathway → Target. This methodology provides systematic input for structuring event tree logic and focuses on the potential risk at a defined target or targets. Section 3.3 presents an overview of event tree structuring. Sections 3.4 and 3.5 discuss scenario data sources and an approach for screening initiating events.

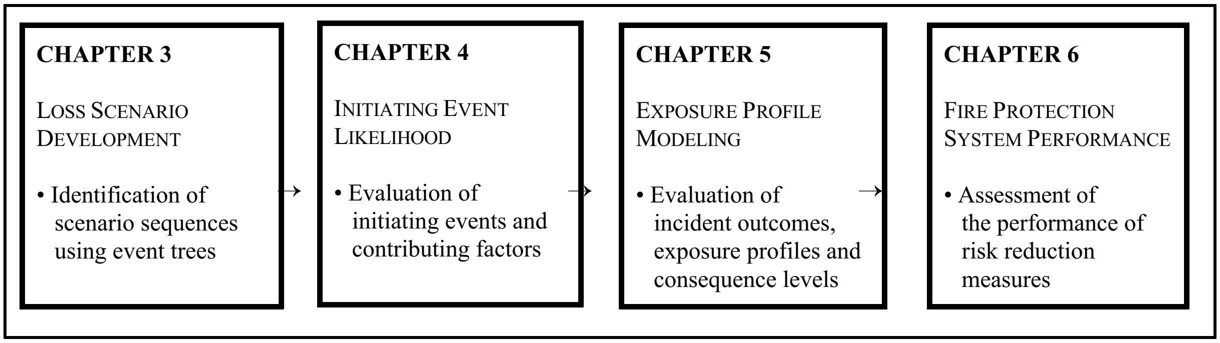
Scenario analysis is an important aspect of conducting credible risk-informed, performance-based projects. A comprehensive approach involves:

- Applying a consistent framework and systematic methodology

- Identifying contributing factors associated with fire and explosion (F&E) initiating events
- Evaluating the exposure-versus-time profile following the initiating event. Exposure elements include fire growth, propagation, incident outcomes, and potential consequence levels
- Assessing the performance of fire protection systems (detection systems, passive and active protection systems, life safety elements, etc.) in terms of modifying the outcome of the initiating event

It is important to point out that Chap. 3, Loss Scenario Development, introduces the development of a scenario-based "framework" focusing on event tree structuring. Chapters 4 through 6 provide the additional building blocks towards comprehensive scenario analysis, as illustrated in Fig. 3.2.

Fig. 3.2: Building Blocks Towards Comprehensive Scenario Analysis



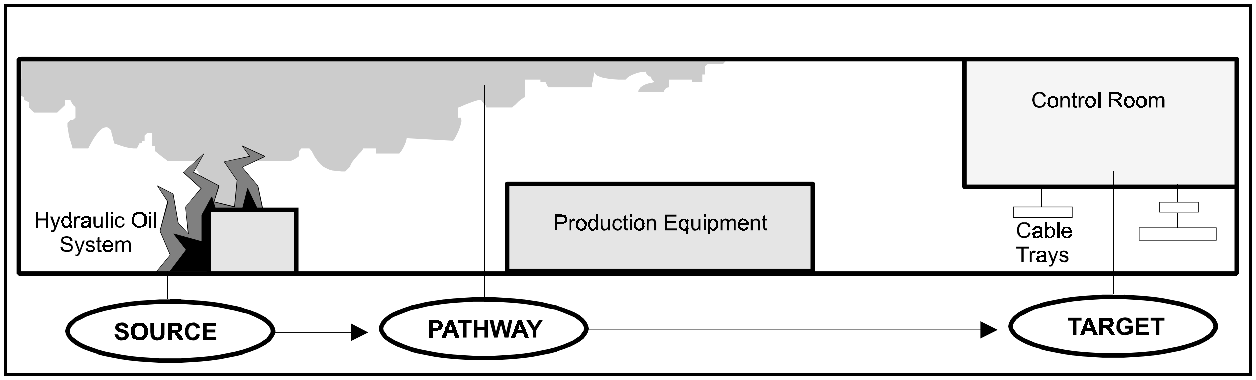
3.2 SEQUENCE OF EVENTS

A scenario represents a set of time-related events (transition states) that can lead to various fire or explosion outcomes. One systematic approach towards structuring fire scenarios is the Source (S) → Pathway (P) → Target (T) method:

- Target: The Target is the focus of the risk-based study and is the first thing to define. To be at risk, the target must be "vulnerable" to loss from the source fire exposure and have defined "value" to the owner.
- Source: After defining the target's vulnerability and value, the initiating source fire(s) that could expose the Target to loss must be identified and screened.
- Pathway: Pathway events include those factors that either "propagate" or "modify" the source fire(s). Pathway propagation factors can include fire growth, secondary fuel ignition, uncontrolled flame spread, etc. Pathway modification factors, which will reduce the exposure to the target, include FPSs such as detection, emergency control systems (ECSs), suppression systems, fire barriers, manual fire-fighting efforts.

Figure 3.3 presents an illustration of the S → P → T (Source → Pathway → Target) concept applied to an example production building. In this example, the scenario boundaries include the entire production building. The target or risk-study focus is the Control Room. The selected source fire for scenario evaluation is a hydraulic oil system fire.

Fig. 3.3: Example of Production Building S → P → T Concept



An example S → P → T scenario development worksheet is presented in Table 3.1 for the production building example . The table is set up as follows:

A. Evaluation Summary
  - What are the scenario boundaries?
  - What are the specific scenarios under evaluation? What is the risk focus?

B. Target
  - What is the target?
  - What is the fire exposure vulnerability to the target?
    - Temperature effects
    - Radiant heat effects
    - Smoke concentration effects
    - Toxic, corrosive gas effects
  - What is the value of the target?
    - Property replacement values
    - Production downtime/business interruption (BI) value
    - Trained operators – value

C. Source(s)
  - What are the potential initiating fire event occurrences?
  - What are the events that should be selected for further evaluation?

D. Pathway
  - What are the pathway propagators?
    - Fire progression potentials
    - Structural failures, domino effects
  - What are the pathway modifications (i.e., FPSs)?

    - Existing
    - Proposed

E. Assumptions/Actions
  - What are the limitations and assumptions of the scenario evaluation?
  - Actions — How many event trees will need to be structured (i.e., based on credible initiating bounding fire source inputs and FPSs options)

Note: Event tree structuring is described in Sect. 3.3.

There can be a wide variation in fire hazard evaluations conducted by different people concerning identification and selection of initiating fire event scenarios. For example, one person may speculate a small combustible fluid leak and ignition, while another may imagine a total release of all the combustible fluid inventory.

A credible initiating event is one that is both within the realm of possibility and is likely to be severe enough to cause significant damage (i.e., exceed risk tolerance limits).

Generally, at this stage in the risk analysis, what constitutes credibility, reasonable likelihood, and significance is mostly based on the experience and qualitative judgement of the risk assessment team. Having a team consensus approach and a consistent methodology to identify and screen scenarios for further risk review is a very important aspect of conducting a credible risk-informed study.

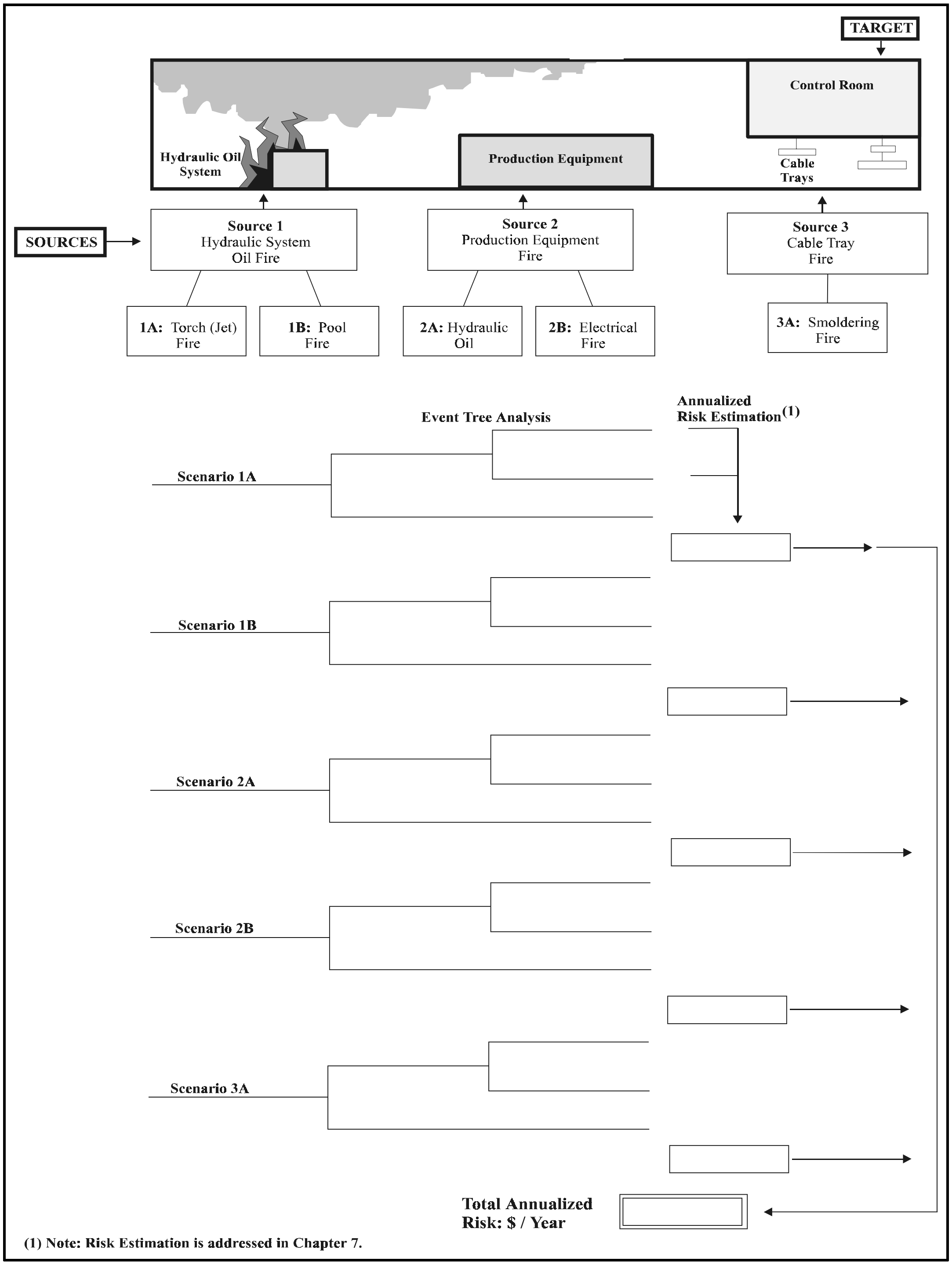
Table 3.1: Example Scenario Development Worksheet

<table>
<tr>
<td>A: Evaluation summary
Production Building ABC – an automated production facility. Scenario boundary includes entire production building.
Risk focus: fire exposure to critical control room operations</td>
<td>Evaluation team date: February 7, 2001
Team members:
Stan Smith – Safety
Tom Jones – Engineering
Jim Jones – Maintenance
Hank Edwards – Operations
Kevin Reed – Fire Risk Analyst</td>
</tr>
<tr>
<td>B: Target
Control Room Vulnerability (1)
<table>
<tr><th></th><th>Electronic Equipment</th><th>Operators</th></tr>
<tr><td>1. Connective heat from fire plume/ hot gas layer</td><td>Highly vulnerable</td><td>Highly vulnerable</td></tr>
<tr><td>2. Smoke, combustion gases (toxic, corrosive)</td><td>Highly vulnerable</td><td>Highly vulnerable</td></tr>
</table>
</td>
<td>Target value
• Control room equipment replacement values: $50M
• Replacement time: 6 months
100% business interruption for 6 months
• Highly trained operators staff control room</td>
</tr>
<tr>
<td>C: Sources(s)
(Initiating fire occurrences) (2)

Expanded list of potential initiating fire sources</td>
<td>Selected for further evaluation
1. Hydraulic system oil fire
1A. Torch (jet) fire
1B. Pool fire
2. Production equipment fire
2A. Hydraulic oil
2B. Electrical fire
3. Cable tray fire
3A. Smoldering fire</td>
</tr>
<tr>
<td>D: Pathway modification factors
(i.e., fire protection systems):
<u>Existing</u>
• Ceiling-level, ordinary hazard sprinkler system
Note: Existing sprinkler protection would not be effective against a hydraulic oil torch fire or a smoldering electrical fire</td>
<td>Pathway modification factors
(i.e., FPSs)
<u>Proposed options to evaluate</u>
• Detection system above hydraulic systems and cable trays
• Emergency control system for quick, reliable shutdown of hydraulic oil pumps and electrical power
• Installation of quick response heads on sprinkler system
• Reinforcement of control room walls</td>
</tr>
<tr>
<td>E: Assumption
List assumptions/limitations of scenario evaluation.</td>
<td>Actions (3)
Structure event trees to analyze source fires:
• 1A
• 1B
• 2A
• 2B
• 3A</td>
</tr>
<tr>
<td colspan="2">Remarks: (1) Quantification of vulnerability levels is addressed in Chap. 5, Exposure Profile Modeling
(2) Initiating source identification and screening is addressed in Sect. 3.5
(3) Event tree structuring is discussed in Sect. 3.3</td>
</tr>
</table>

Figure 3.4 presents an example of source fire potentials as listed in sections C and E of the scenario development worksheet, Table 3.1. Note that each selected initiating event source fire has a related event tree.

Fig. 3.4: Source Fire Exposures to Target and Related Event Trees



3.2.1 Some Examples

The S → P → T concept provides a method for systematic thinking and reasoning when attempting to develop scenarios. The concept has a wide range of application from outside chemical process structures to multi-compartmented industrial and commercial buildings.

Figure 3.5 presents an example of an exterior exposure to a critical control room operation. Applying the concept of S → P → T and using a scenario development worksheet (such as the in Table 3.1) provides a framework for developing event tree logic. The event tree logic, which will be addressed in Sect. 3.3, expands on pathway modification options.

Fig. 3.5: Example of Exterior Exposure

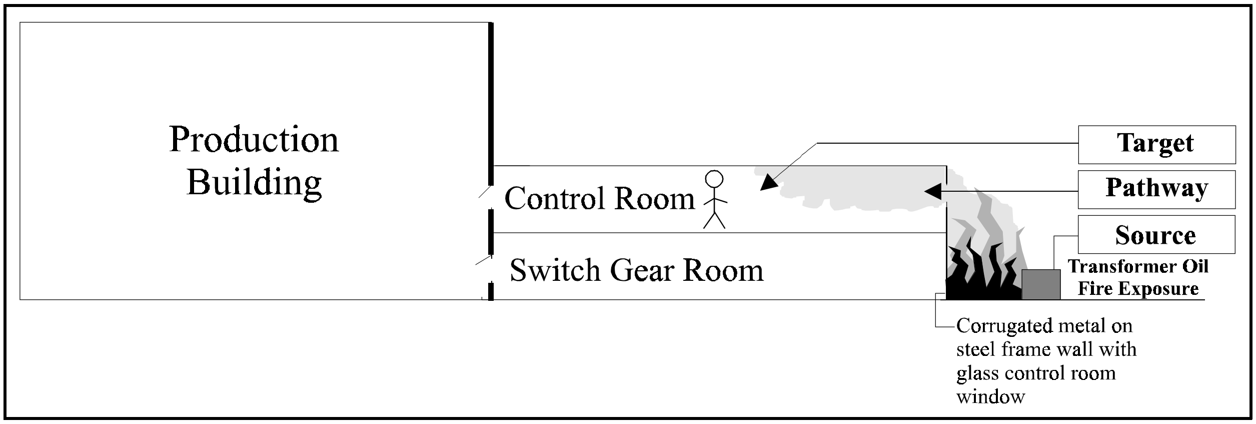


Figure 3.6 applies the concept of S → P → T to an example multi-floor compartmented building. Again the process is the same: start with qualitative definition of the target's value and vulnerability, identify and screen source fire potentials, identify pathway propagation factors, and identify possibly pathway modification options (i.e., FPSs).

Fig. 3.6: Example of Multi-Floor Building

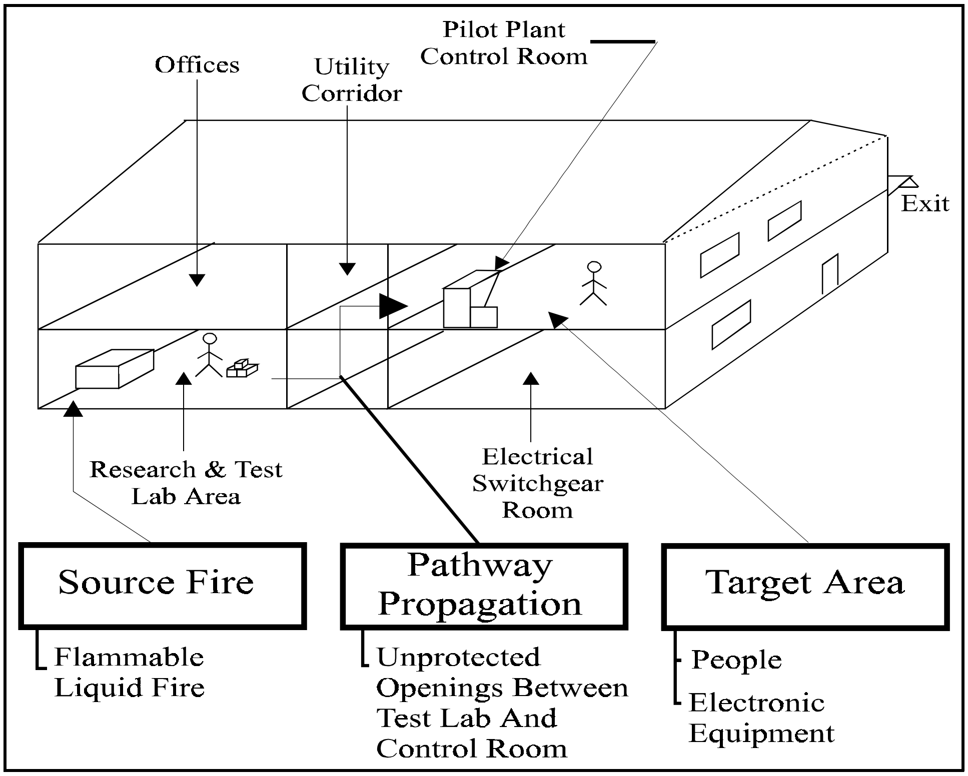


Figure 3.7 is an example of the S → P → T approach applied to off-site risk (i.e., fire or explosion risk beyond the plant site boundaries). For this example, Source 2 may represent the most severe off-site impact from a liquified flammable gas release, flash fire, BLEVE, or vapor cloud explosion. Pathway propagation factors may include topography, wind speed and direction, location of ignition sources, etc. Pathway modification options might include gas and flame detection, an emergency shutdown system (to reduce the release size), and a fixed FPS (e.g., fire proofing, water spray).

Fig. 3.7: Example of Off-Site Risk

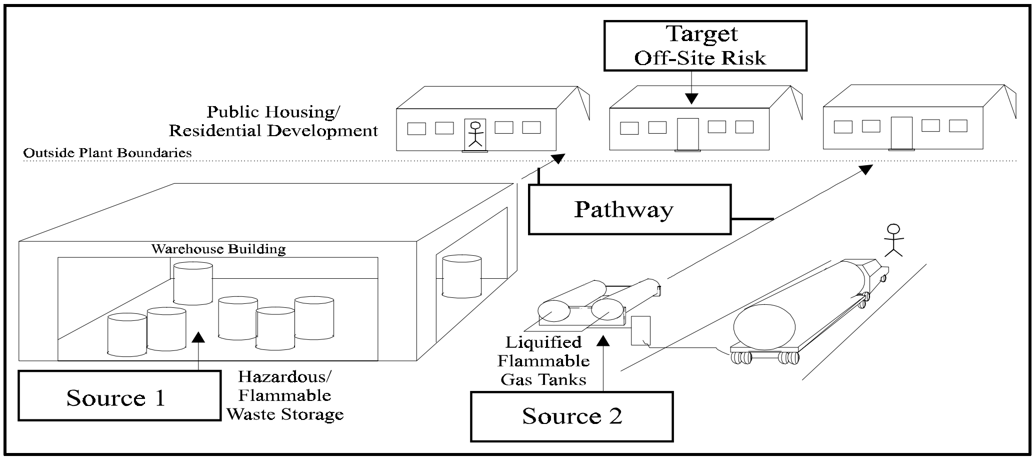
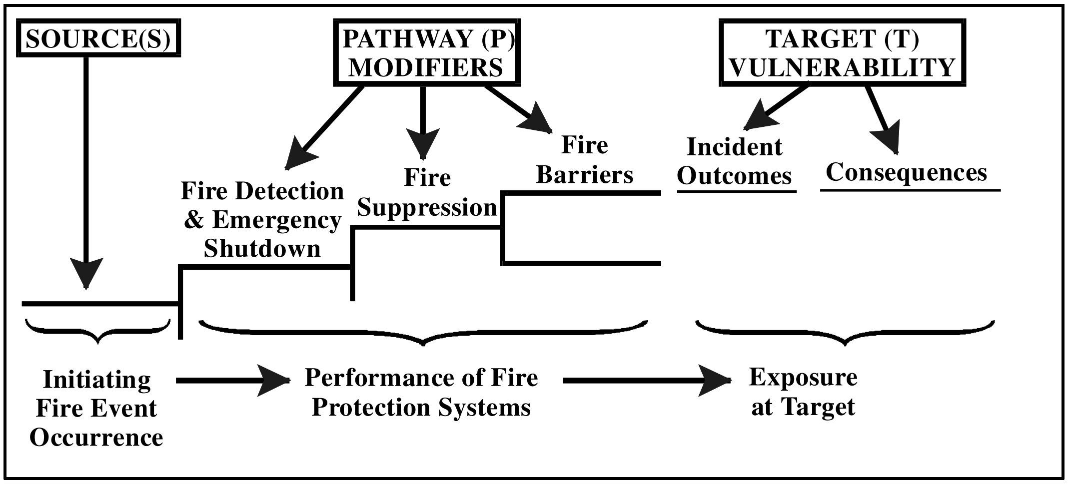


Figure 3.8 provides a general illustration of the relationship between the S → P → T scenario development concept and event tree structuring. Event tree structuring and analysis is discussed in the next section.

Fig. 3.8: Relationship Between S → P → T to Event Tree Structuring



3.3 EVENT TREE STRUCTURING

The most widely used risk assessment technique for structuring fire loss scenarios involves the use of event tree analysis (ETA). ETA conveys the initiating source fire event, FPS performance, incident outcomes, and consequences. Using ETA provides the major advantage of being able to incorporate time and conditional FPS performance probability into a scenario.

ETA is used to analyze both simple and complex processes in which several FPS levels may be in place to respond to specific initiating events. To complete an ETA, a risk analyst must identify initiating source fire events, evaluate the performance of existing or proposed fire protection options and evaluate incident outcomes and consequences.

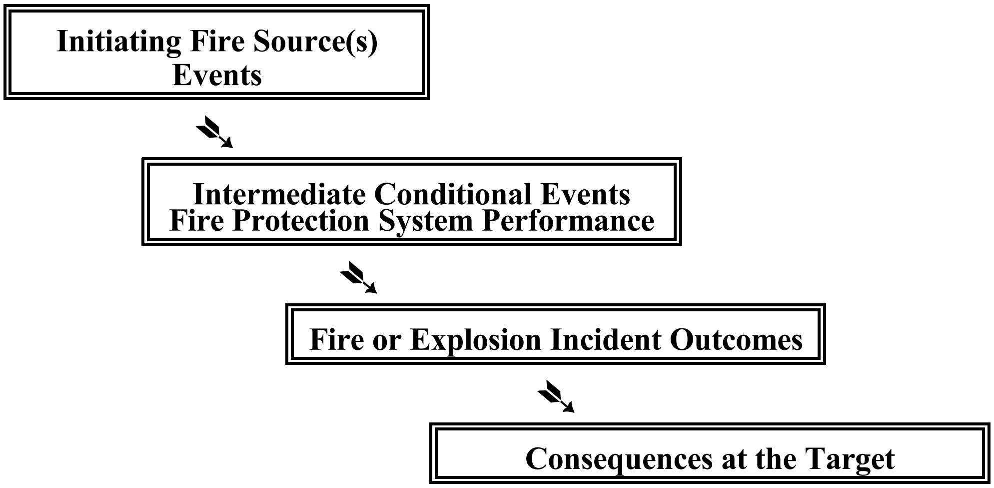
Event trees are similar to failure modes and effects analysis (FMEA) as they start with identifying a failure mode and then assess potential incident outcomes and consequences. However, methods such as FMEA or hazard and operability analysis (HAZOPS) don’t usually provide sufficient detail on FPS performance, nor do they provide a vehicle for estimating probabilities of fire protection performance success and quantifying risk.

ETA has several advantages in that it:

- Provides systematic organization of fire loss event stages
- Orders events in time-related sequences
- Identifies significant top fire loss events for subsequent FTA and probability modeling
- Allows evaluation of fire detection and protection system alternatives
- Demonstrates the relationship between the success of FPSs and the potential fire incident outcomes, consequences, and risk levels

To structure event tree modeling logic, the risk evaluation team must have knowledge of potential initiating events (i.e., equipment failures, human errors, external events, or system upsets that could lead to fire or explosions) and intermediate events such as FPE functions and emergency procedures. Event sequences must be individually evaluated to generate F&E loss scenarios. The general event tree modeling logic sequence stages are shown in Fig. 3.9.

Fig. 3.9: Event Tree Modeling Logic Sequence Stages



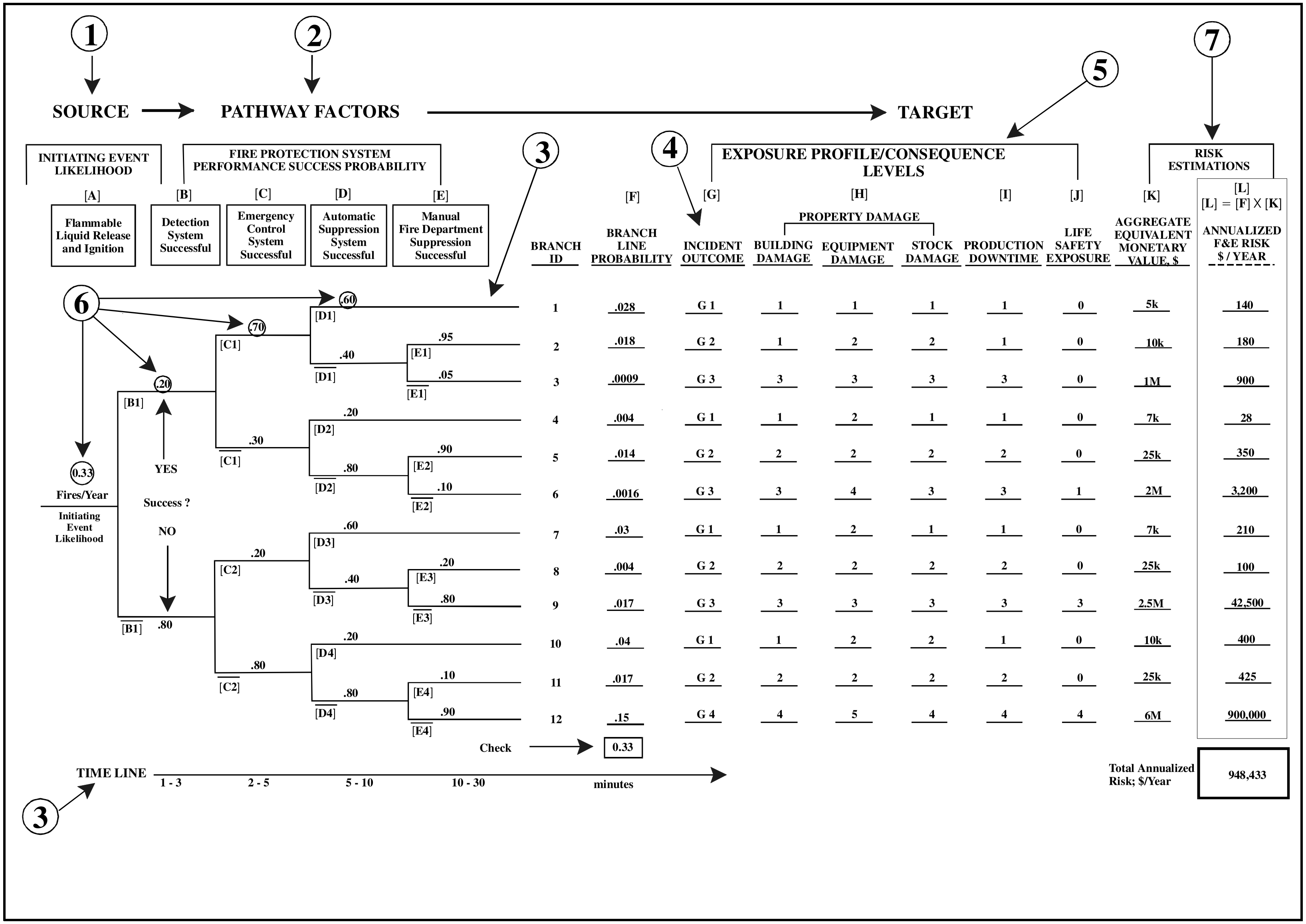
This section introduces event tree structuring and provides an overview of ETA steps. Quantification of initiating event likelihoods, FPS performance success probabilities, and exposure profile modeling at the target are covered in other chapters.

3.3.1 ETA Steps

Figure 3.10 present an example fire risk event tree framework. Event tree development steps include:

① Identifying the initiating fire source event.
② Identifying the pathway factors to be evaluated within the event tree analysis. For example, FPSs, existing or proposed, which will modify the propagation of the initiating fire source event.
③ Structuring the event tree branch logic and time line.
④ Assessing the incident outcomes.
⑤ Identifying and quantifying exposure and consequences of concern at the target.
⑥ Quantifying branch line probabilities. This involves quantifying the initiating event likelihood and conditional probabilities of pathway factors (i.e., FPS performance success).
⑦ Quantifying the risk.

Fig. 3.10: Example Fire Risk Event Tree Framework



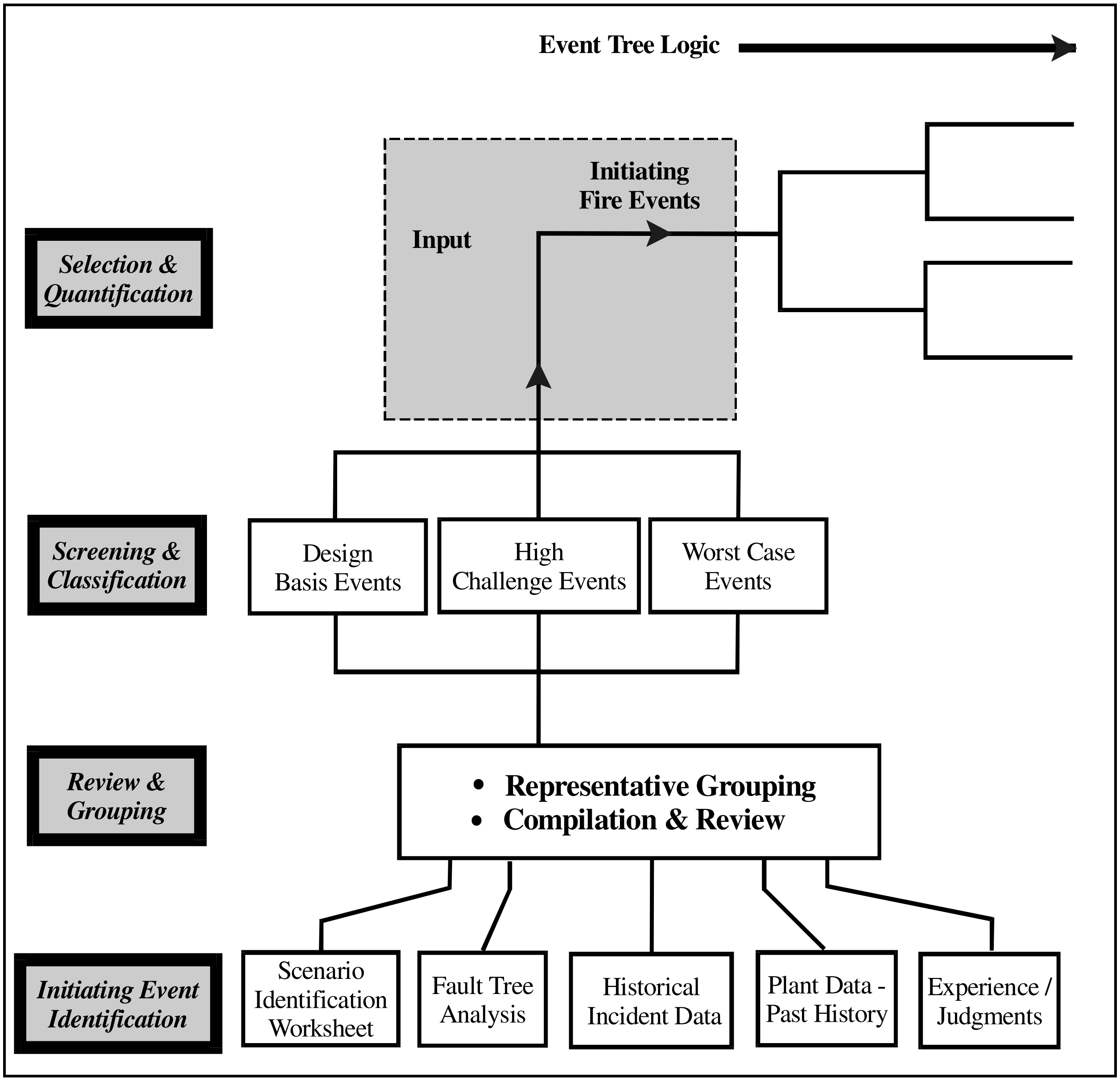
	[F]	[G]	[H]			[I]	[J]	[K]	[L]
			PROPERTY DAMAGE						[L] = [F] X [K]
BRANCH ID	BRANCH LINE PROBABILITY	INCIDENT OUTCOME	BUILDING DAMAGE	EQUIPMENT DAMAGE	STOCK DAMAGE	PRODUCTION DOWNTIME	LIFE SAFETY EXPOSURE	AGGREGATE EQUIVALENT MONETARY VALUE, $	ANNUALIZED F&E RISK $ / YEAR
1	.028	G 1	1	1	1	1	0	5k	140
2	.018	G 2	1	2	2	1	0	10k	180
3	.0009	G 3	3	3	3	3	0	1M	900
4	.004	G 1	1	2	1	1	0	7k	28
5	.014	G 2	2	2	2	2	0	25k	350
6	.0016	G 3	3	4	3	3	1	2M	3,200
7	.03	G 1	1	2	1	1	0	7k	210
8	.004	G 2	2	2	2	2	0	25k	100
9	.017	G 3	3	3	3	3	3	2.5M	42,500
10	.04	G 1	1	2	2	1	0	10k	400
11	.017	G 2	2	2	2	2	0	25k	425
12	.15	G 4	4	5	4	4	4	6M	900,000
	0.33							Total Annualized Risk; $/Year	948,433

① *Identifying initiating fire source events*

The initiating event is the first event that must be identified in constructing fire or explosion event tree scenarios. This event may be a system or equipment failure; a human error; a process upset; an external exposure such as an earthquake, a vehicle accident, arson, or a security failure, which when coupled with ignition, creates an initiating fire source event.

As depicted in Fig. 3.11, we want to use a systematic process for identifying, screening, and grouping initiating source fire events to keep the number of event trees and probability calculations manageable.

Fig. 3.11: Example of Input Approach for Initiating Fire Events



As illustrated in Fig. 3.11, identification sources for primary initiating events include:

- Scenario identification worksheets
- FTA
- Historical incident data
- Plant data, plant history
- Hazard surveys, experience, engineering judgements

The initiating events are grouped in such a way that the failure modes of each group would impose the same or very similar performance demands on the FPSs. Groups of initiating events are then screened further in terms of the likelihood and the consequences of possible outcomes. Initiating event groupings are then placed into a scenario classification scheme such as design-basis events, high challenge events, or worst case events which are defined in Sect. 3.5. The risk evaluation team selects the initiating event cases of interest to the risk-based study. This process will also determine how many ETAs will have to be conducted.

Initiating event analysis using qualitative FTA and quantification is addressed in detail in Chap. 4, Initiating Event Likelihood, and therefore will not be expanded on in this section.

② *Identifying pathway factors*

Pathway factors are those events that follow the initiating event in sequence. In constructing event tree logic, the analyst must identify significant and relevant pathway factors that will affect fire growth and propagation or mitigation of the initiating event. Intermediate pathway factor events represent both a conditional state and a function of time, which is very important to recognize when addressing conditional probabilities. Both propagating and FPS factors need to be identified.

Figure 3.12 provides an example breakdown of intermediate pathway events in terms of:

- Fire propagation factors
- FPSs (i.e., fire mitigation)

Some fire growth or propagation factors of interest in scenario development are:

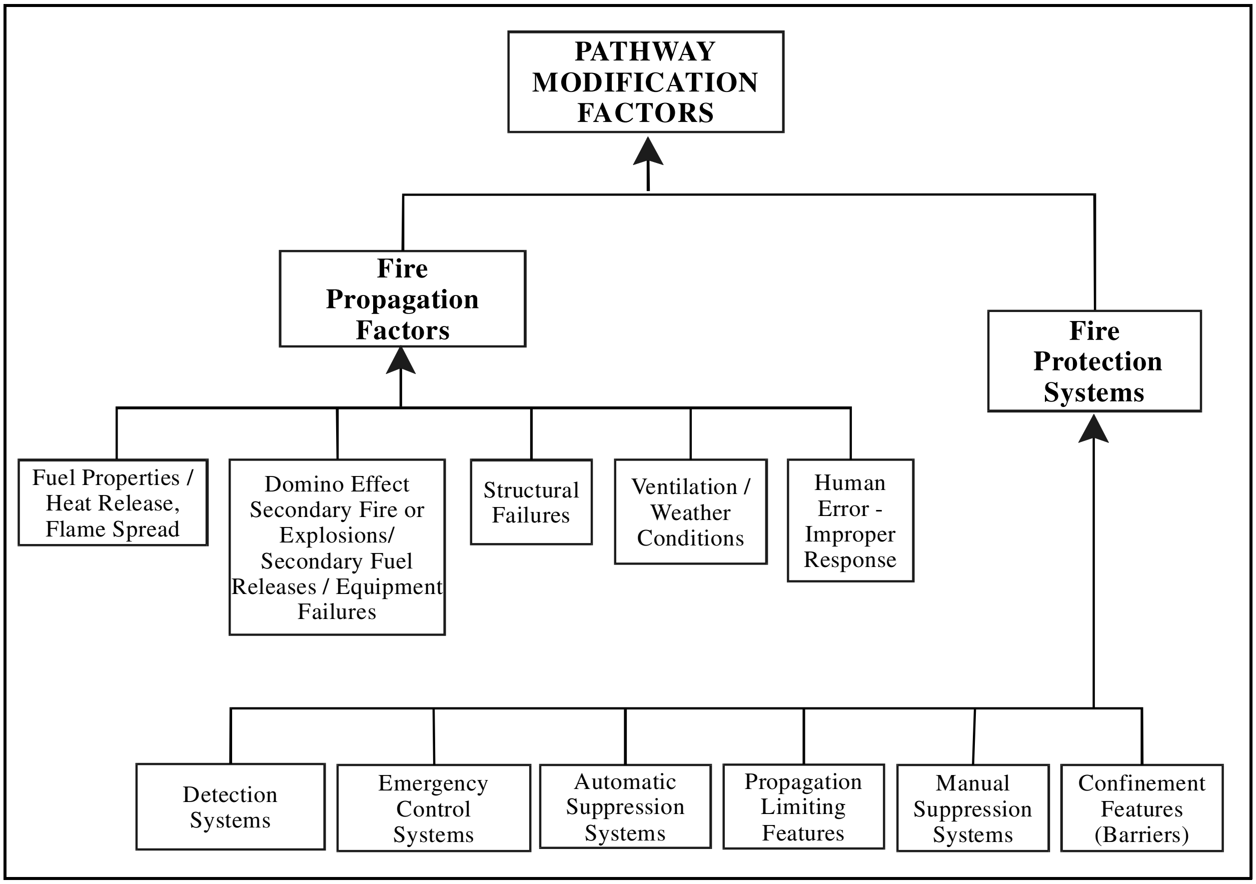
- Fuel properties (heat release rate)
- Flame spread and secondary ignition
- Ventilation effects
- Structural failures
- Operator emergency response

FPSs of interest are:

- Detection systems
- ECSs
- Automatic suppression systems
- Propagation limiting features (i.e., fire barriers)
- Manual suppression systems
- Confinement features (construction or separation features that confine a fire to the area of origin)

Fire growth and propagation factors are discussed in detail in Chap. 5, Exposure Profile Modeling. FPS performance is covered in Chap. 6.

Fig. 3.12 : Example of Some Pathway Factors



③ *Structuring the event tree branch logic*

The event tree displays the development of accident sequences, beginning with the initiating event and proceeding to the responses of the FPSs. The results are defined fire incident outcomes that can result from the initiating event. The FPS functions should be depicted chronologically, although many times the events may occur almost simultaneously. Both existing and proposed FPSs can be evaluated.

The first step in constructing the event tree is to enter the initiating event and FPSs that apply to the analysis. The initiating event is listed on the left side of the page (i.e., first event), and the FPSs are listed across the top of the page from left to right.

An example event tree is shown in Fig. 3.13 depicting the headings:

- Initiating Event Likelihood [A]
- Fire Protection System Events [B] → [E]
- Exposure Profile Consequence Levels [G] → [J]

The initiating source event is a frequency or likelihood (i.e., events/year). The pathway factor (i.e., FPS performance) are conditional probabilities (i.e., a number between 0 and 1).

Concerning the event tree structure:

- Event tree logic is from left to right
- This event tree indicates system success in the upward (YES) branch segments
  Probability of Success = 1 - Probability of Failure
- Branch line probabilities are calculated by multiplying the initiating event likelihood [A] and the conditional branch event segment conditional probabilities [B] → [E], for example:

  Branch lines (Branch I.D.) 6 and 12 could represent an uncontrolled fire scenario. If we wanted to estimate the annualized probability of an uncontrolled fire situation:

  $$\text{Branch Line 6 Probability} = [A] \times [B1] \times [\overline{C1}] \times [\overline{D2}] \times [\overline{E2}]$$

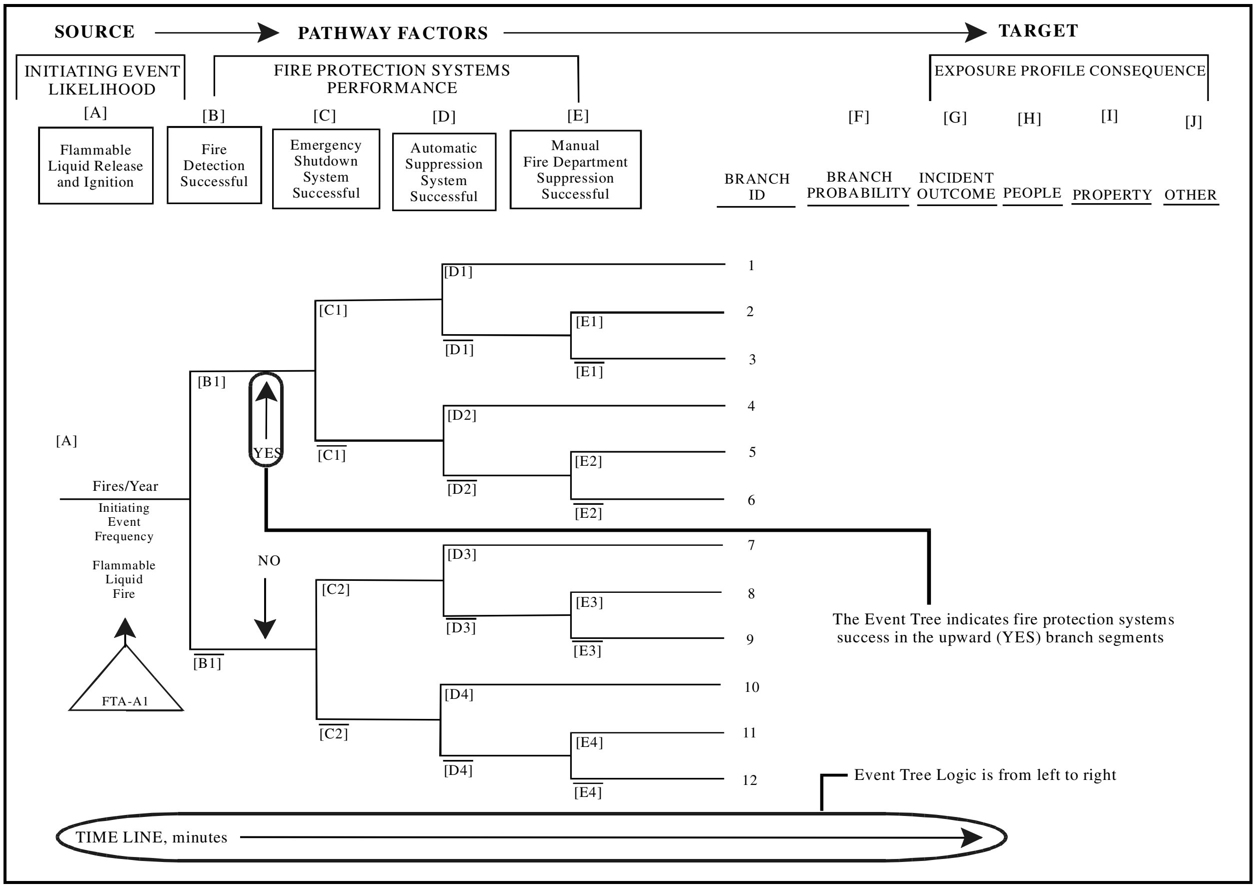
  $$\text{Branch Line 12 Probability} = [A] \times [\overline{B1}] \times [\overline{C2}] \times [\overline{D4}] \times [\overline{E4}]$$

  The line over the letter, (for example; $[\overline{C1}]$) indicates that this is a system failure branch.

NOTE: Chapter 7 on Risk Estimation provides detail on ETA probability calculations.

- Many fire or explosion incident outcomes are possible and are developed through different branches of the event tree. The event tree outcomes are then assessed according to potential exposure versus consequence level or category.
- The time line establishes a frame of reference for estimating FPS success probabilities and estimating the magnitude of the consequences at the time intervals. For example, a 10-min limit could be established as the point where structural steel damage could start to occur from a flammable liquid fire exposure. Therefore, to be successful in minimizing damage, we would want to detect, shutdown and suppress a fire before10-min elapsed.
  NOTE: Chapter 5, Exposure Profile Modeling, addresses time line development.

Fig. 3.13: Example: General Event Tree Structure

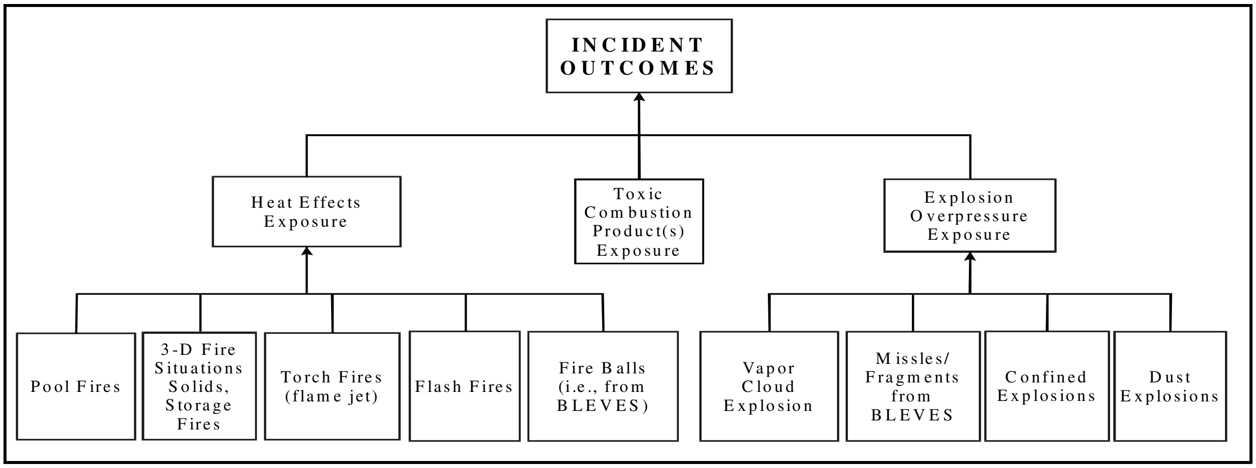


④ *Incident Outcome Assessment*

As presented in Fig. 3.14, potential incidents of primary interest in F&E risk-based evaluations include the following:

- Heat from a fire: pool fire, torch fire, flash fire, BLEVE
- Explosion overpressures: vapor cloud explosions, dust explosions, tank or equipment rupture or fragmentation
- Corrosive smoke or combustion products concentration, toxic gas concentrations

Fig. 3.14: Example of Some Fire and Explosion Incident Outcomes



NOTE: Incident outcome exposure and consequence assessment is addressed in detail in Chap. 5, Exposure Profile Modeling.

Incident Outcome Grouping

Of special interest in the F&E risk assessment process are those event tree scenario branch lines that represent:

- The best-case scenario
- The worst-possible case scenario
- Other likely case scenarios that may be of interest

Traditionally, in the fire protection industry, scenarios have been related to the following definitions, which were initially established by the fire insurance industry:

- Normal loss expectancy (NLE) – best case
- Probably maximum loss (PML) – other likely scenarios
- Maximum foreseeable loss (MFL) – worst case

Although there are different variations used in the definition of these loss expectancy levels, in general terms they can be defined as follows:

- NLE — This is the loss scenario assuming all detection and protection features are in service and operating as designed.
- PML — This is the loss scenario assuming the primary automatic protection system (i.e., such as an automatic water spray system) is out of service.
- MFL — This is the worst-case loss scenario, which usually assumes that all detection and automatic protection systems are out of service or ineffective and in many cases the loss severity is only limited by passive mitigation features (fire walls, separation, etc.).

Figure 3.15 provides a general event tree depiction of how these scenarios can be related to the branches of the event tree.

Fig. 3.15: Example of ETA Incident Outcome Grouping

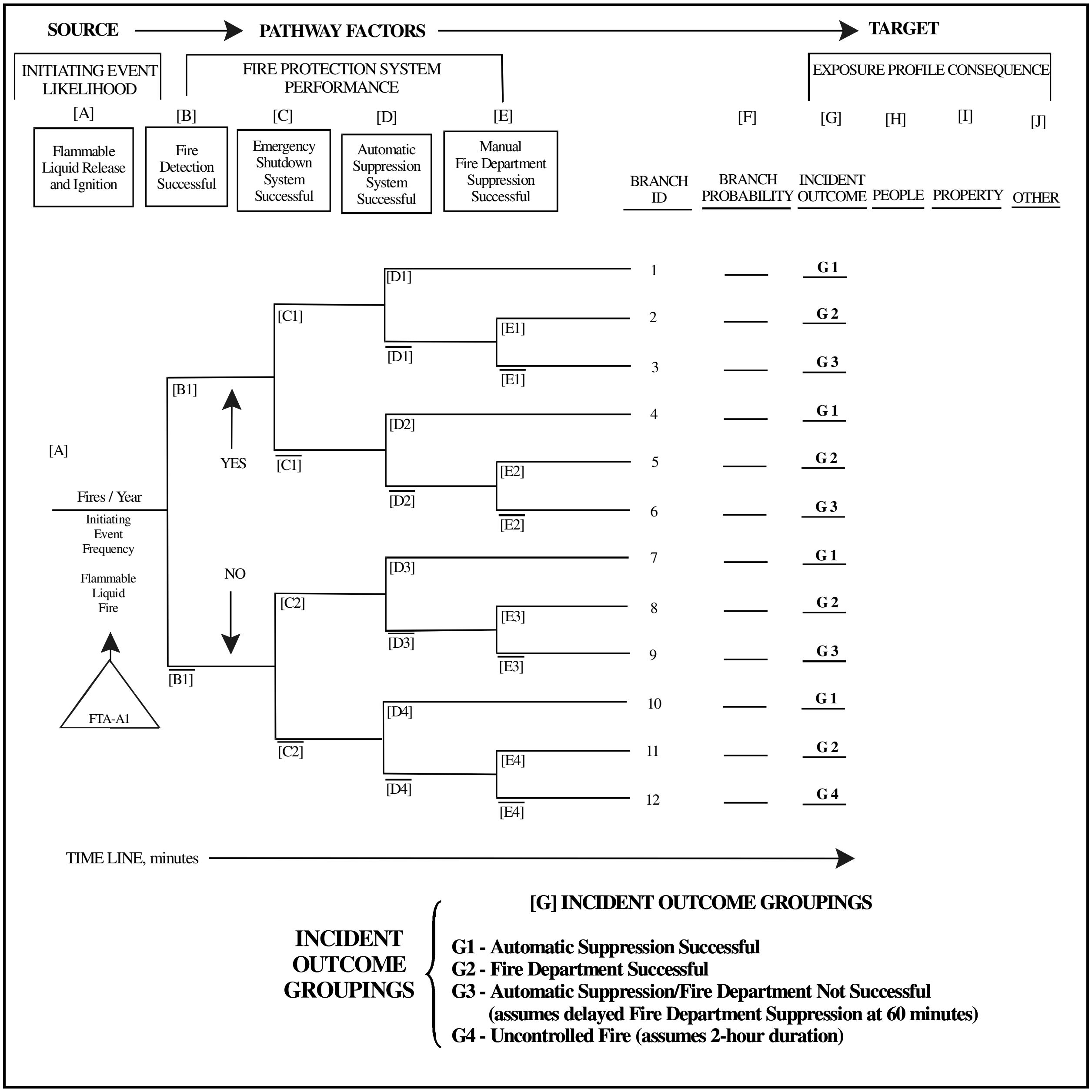


Table 3.2 provides an example of grouping scenarios based on the definition of loss expectancy.

Table 3.2: Loss Expectancy Grouping

GROUPED SCENARIOS	LOSS EXPECTANCY DEFINITION
G1 – Automatic suppression system successful	Best case situation generally related to an NLE – normal loss expectancy analysis
G2 – Automatic suppression system not successful/fire department successful	Selected probable case generally related to an PML – probable maximum loss analysis
G3 – Automatic suppression system/fire department not successful – assumes delayed fire department suppression at 60 min	Selected probable case generally related to an PML – probable maximum loss analysis
G4 – Uncontrolled fire – assumes a 2-hr fire duration	Worst case situation generally related to an MFL – maximum foreseeable loss analysis

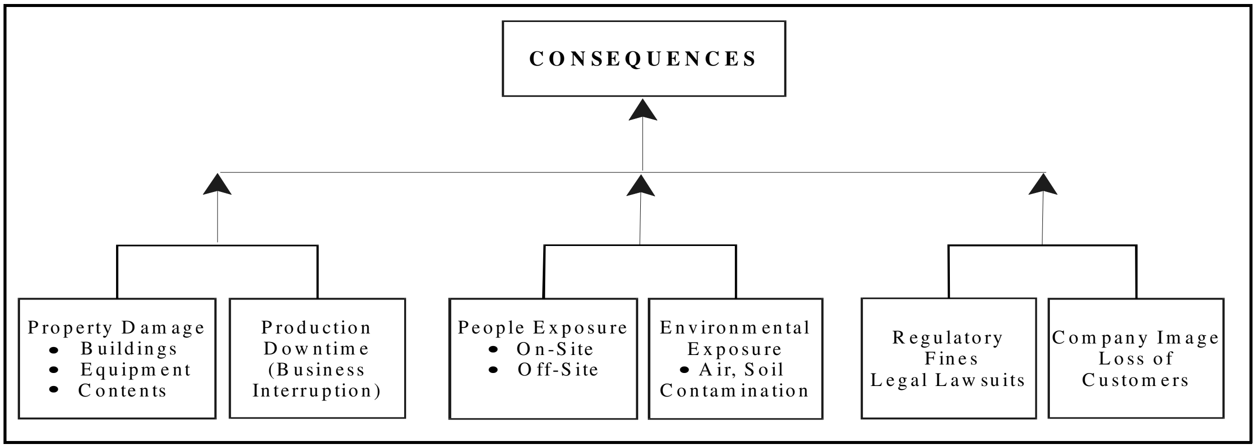
Chapter 7, Risk Estimation and Comparison, discusses how these scenario groupings are used in the development of graphical risk profiles.

⑤ *Identification and quantification of exposure and consequence levels*

Figure 3.16 provides a summary of some consequence concerns in F&E risk-based studies. The important thing to recognize here is that fire and explosion incidents represent a multi-consequence exposure, including property damage (PD), business interruption (BI), people exposure, environmental impacts, regulatory fines, and company image. Combined, these consequences can lead to very high monetary loss.

Chapter 5 addresses consequence assessment.

Fig. 3.16: Example of Some Consequence Concerns



⑥ ***Quantification of branch line probabilities***

Chapter 4, Initiating Event Likelihood, and Chap. 6, Fire Protection System Performance Success Probability, provide information on developing probability and likelihood estimates.

⑦ ***Quantify the risk***

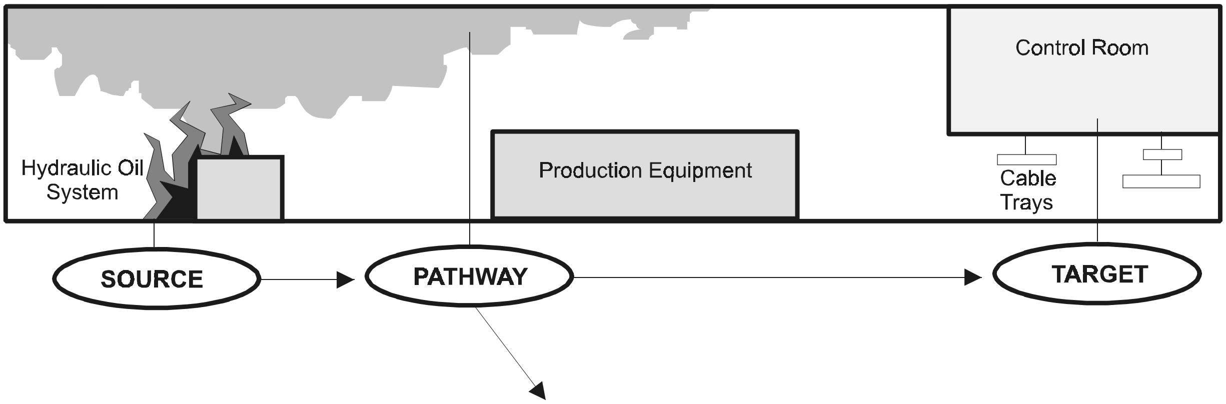
The likelihood of each incident outcome is determined by multiplying the initiating event frequency with the conditional probabilities of the FPS performance success along each path leading to that outcome. As illustrated in Fig. 3.10, risk is the product of multiplying the branch line likelihood with the consequence value. Risk estimation is described in Chap. 7, Risk Estimation and Comparison with Risk Tolerance.

3.3.2 Example Industrial Building ETA Structure

An example Production Building is shown in Fig. 3.17. Pathway Modifiers, which in this case are FPS options, are listed. Figure 3.18 presents an example event tree that could be used to evaluate risk levels versus fire prevention and fire protection options. Note how the sequence of events is set up:

Release and Ignition (Initiating Fire Event)	→	Automatic Detection Performance	→	Emergency Control Performance	→	Automatic Sprinkler System Performance	→	Control Room Barrier Performance

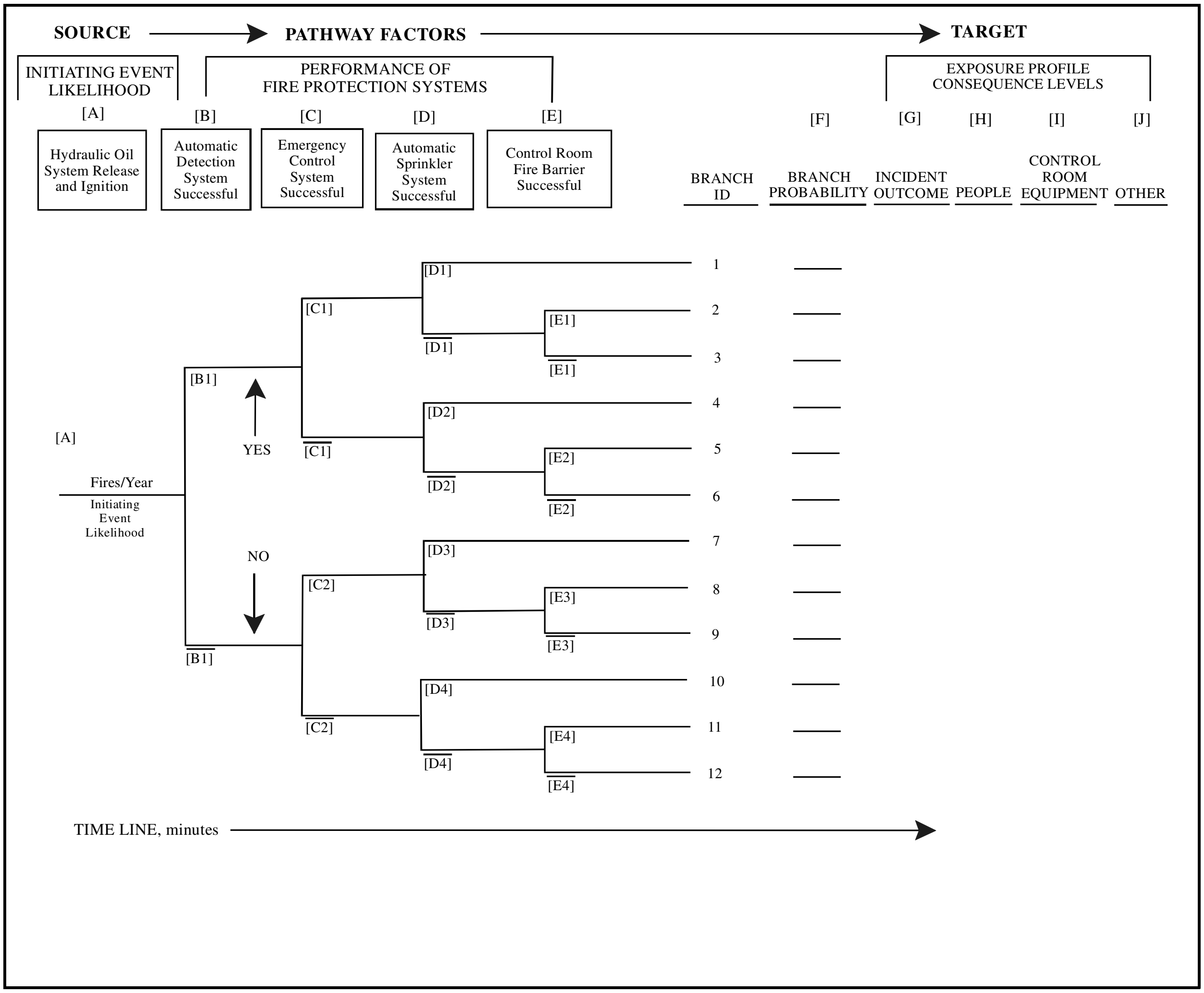
Fig. 3.17: Example of Potential Pathway Modifiers for a Production Building



PATHWAY MODIFIERS

- Fire Detection Systems Options
  - For hydraulic system
  - Above production equipment
  - For cable trays
  - In control room
- Emergency Control Systems Options
  - Interlocks for shutdown of hydraulic systems, production equipment, and electrical power
  - Emergency smoke removal system
- Passive Protection Options
  - Diking around hydraulic systems
  - Fire barriers around hydraulic oil systems
  - Control room fire barrier
- Automatic Suppression System Options
  - Local protection over hydraulic oil systems
  - Local protection over cable trays
  - Automatic sprinkler protection at ceiling level
  - Control room suppression system

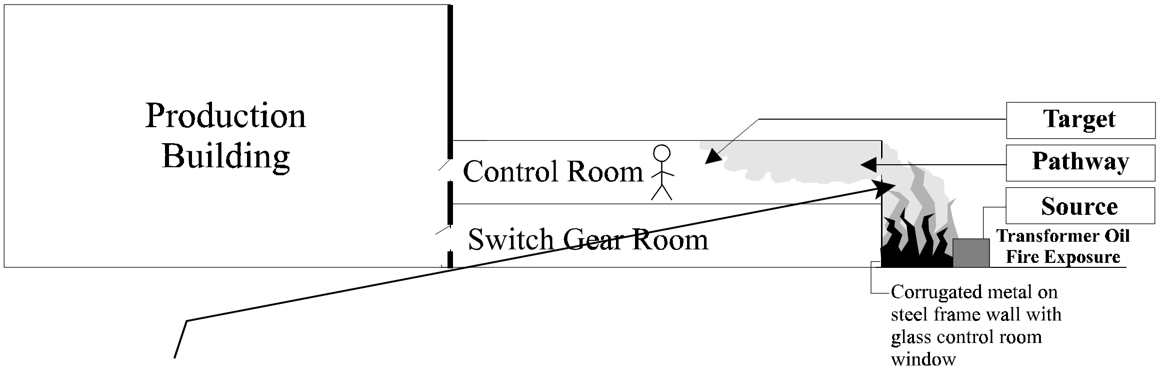
Fig. 3.18: Example Production Building Fire Risk Event Tree Structure



3.3.3 Example Exterior Exposure ETA Structure

Figure 3.19 shows an exterior transformer fire exposure. For example purposes, some pathway modifiers (FPS options) have been listed.

Fig. 3.19: Example of Potential Pathway Modifiers for an Exterior Exposure



PATHWAY
MODIFIERS

Fire Protection System Options:
- Automatic Water Spray
  - – Install as exposure protection between the transformer and wall
- Detection and Fire Brigade Response
- Upgrade Wall Integrity
  - – Upgrade existing wall to a 2 hr rated fire barrier wall
- Assumptions – Cost prohibitive to relocate transformer

Figure 3.20 provides an example event tree for what we will call risk reduction option 1, installation of an automatic water spray system to provide exposure protection between the transformer and wall.

Fig. 3.20: Example: Event Tree for Risk Reduction Option 1 – Automatic Water Spray

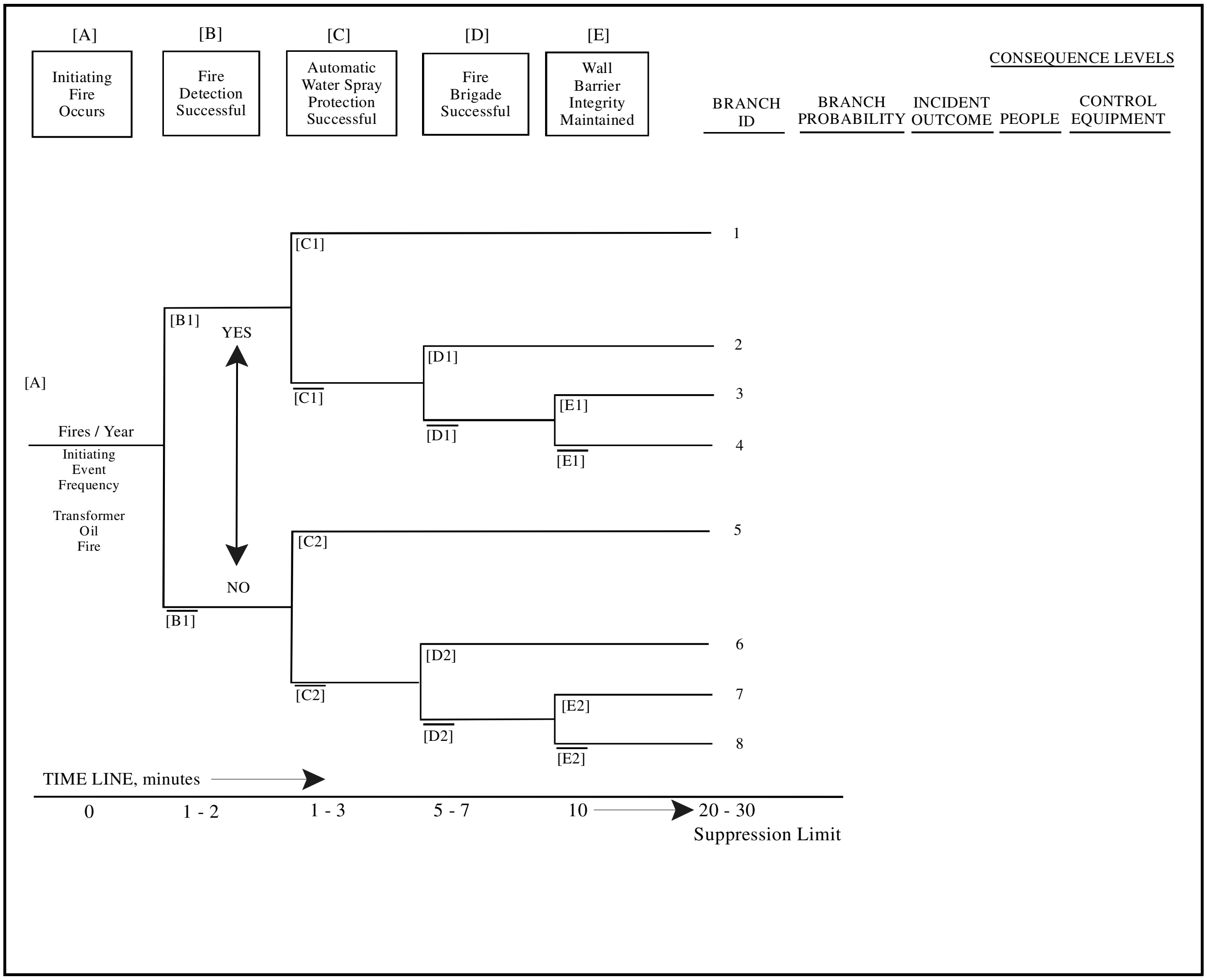
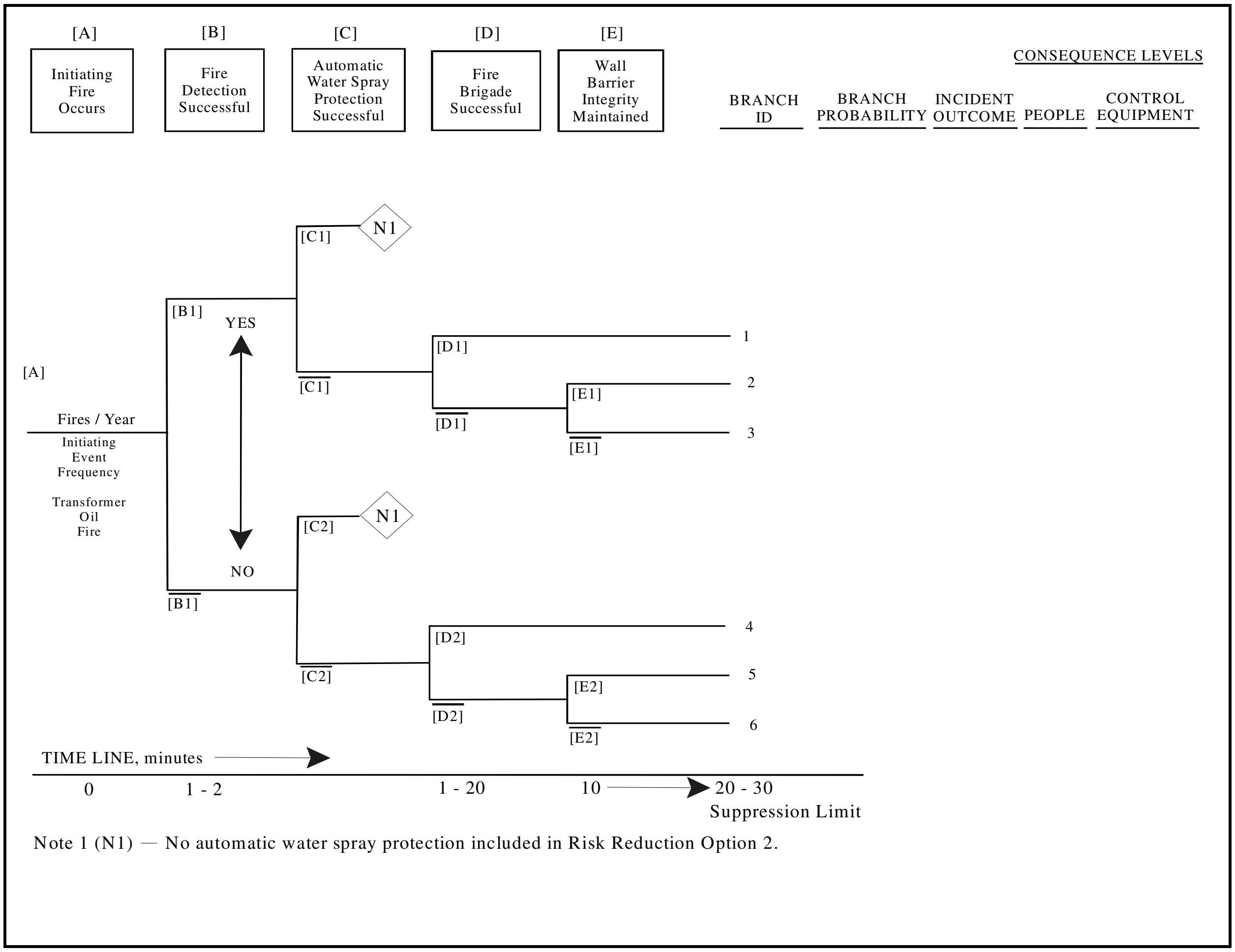


Figure 3.21 provides an example of a risk reduction option 2, upgrading the existing wall to a 2-hr rated fire barrier wall and relying on the fire brigade for fire suppression.

Fig. 3.21: Example Event Tree for Risk Reduction Option 2 – Fire Barrier Wall

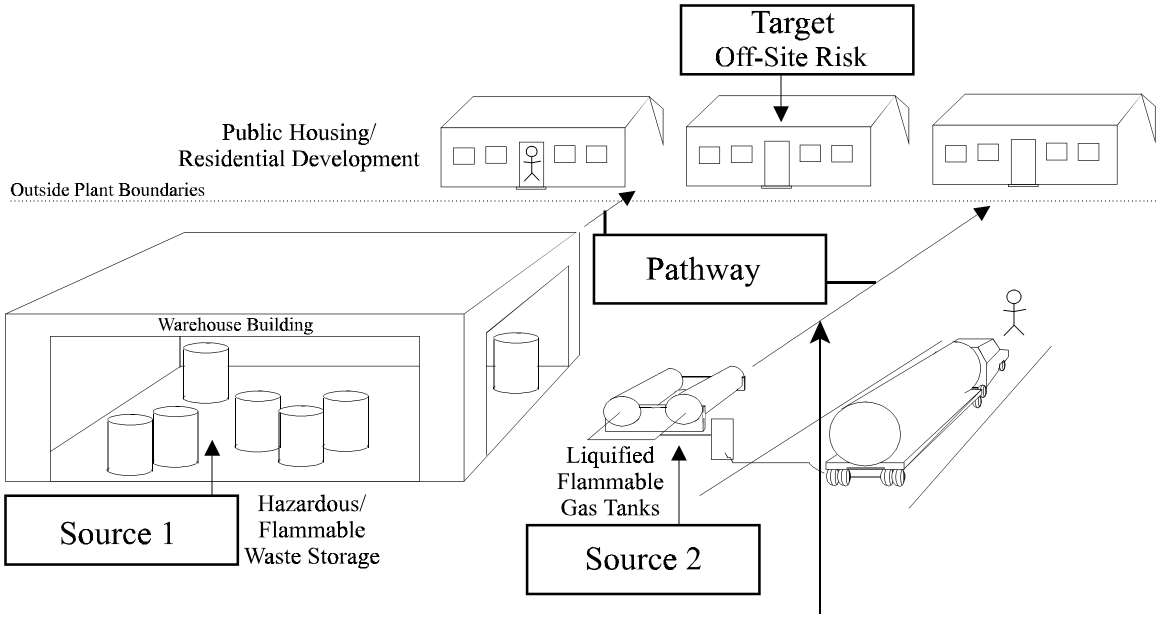


Note 1 (N1) — No automatic water spray protection included in Risk Reduction Option 2.

3.3.4 Example Off-Site Risk ETA Structure

Figure 3.22 presents an example for off-site risk. For example purposes, some pathway modifiers (FPS options) have been added to Source 2, Liquified Flammable Gas (LFG) Tanks.

Fig. 3.22: Example of Some Potential Pathway Modifiers for an Off-Site Risk



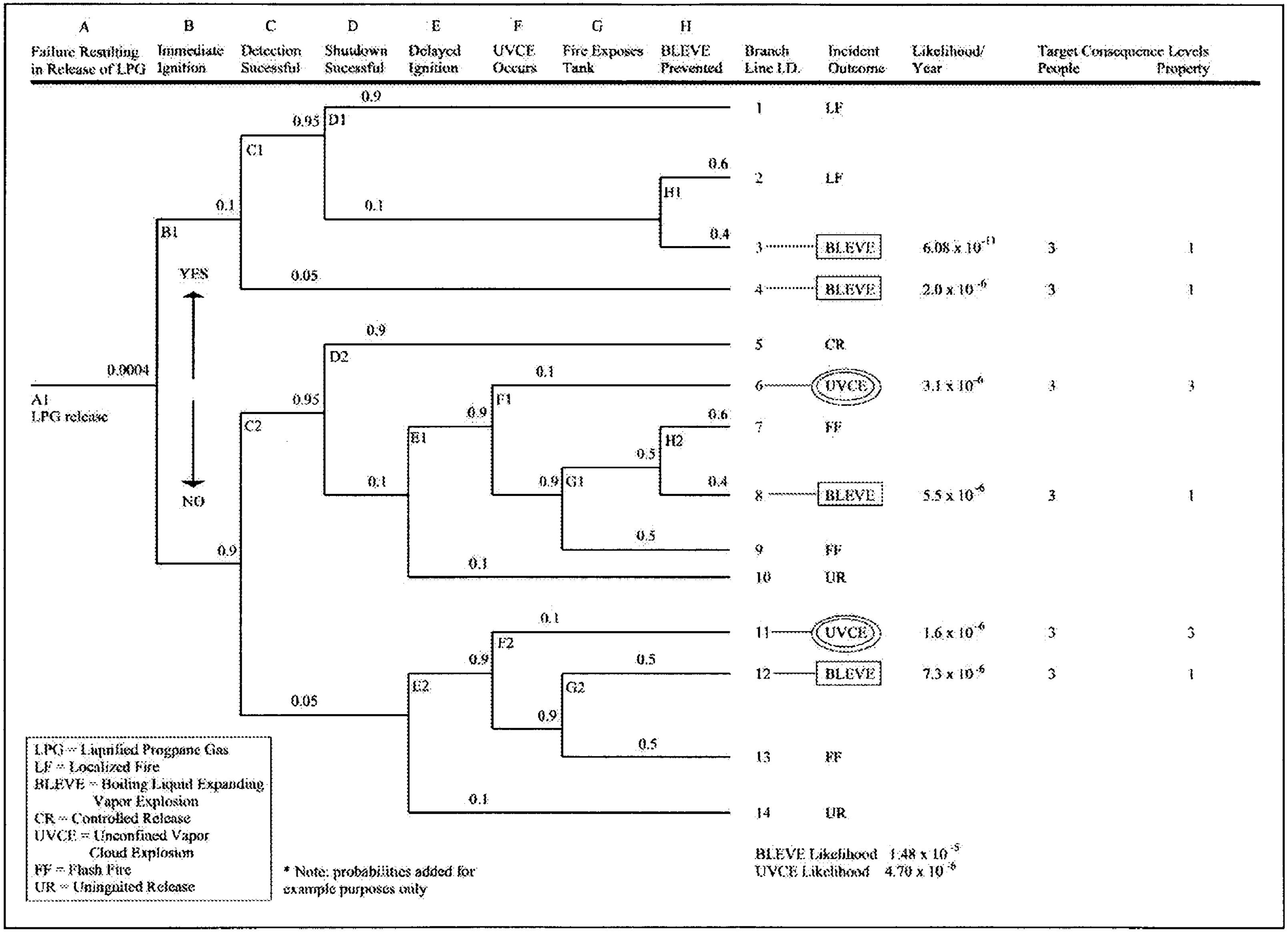
PATHWAY MODIFIERS

Fire Protection System Options:
- Automatic Detection Systems
  - Gas releases
  - Flame
- Emergency Shutdown Systems (ESS)
  - Automatic, Fail-safe isolation valves to minimize release size
- Automatic Water Spray Cooling on Tanks
- Fireproofing on Tanks
- Fire Department Response

Figure 3.23 provides an example event tree for off-site risk from a LFG tank. Following accidental release from containment, we need to examine the potential for immediate ignition creating a torch fire, emergency shutdown and isolation to reduce the release size or fire duration, and if there is not immediate ignition, the chances of delayed ignition resulting in a flash fire or vapor cloud explosion.

The modeled vapor cloud or BLEVE exposure distance, which could create major injuries and fatalities would be quantified as part of the consequence assessment. This is addressed in Chap. 5.

Fig. 3.23: Example Event Tree for Off-Site Risk from LFG Tanks



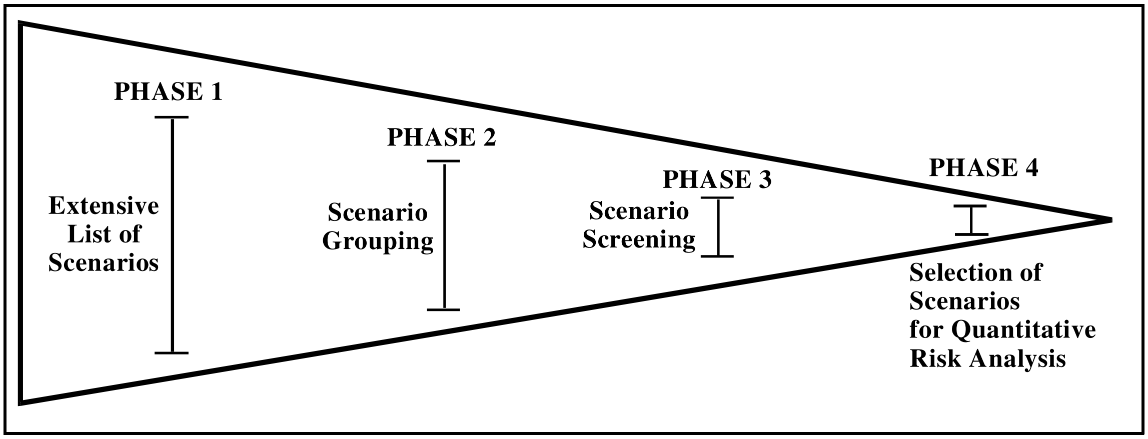
3.4 SCENARIO SCREENING

Scenario identification and screening can be approached in several ways, but generally includes four phases:

- Phase 1
  - Process system boundaries are defined and system description is provided (i.e., functional performance requirements of system and components).
  - Decisions are made regarding what human resource subject experts are needed (i.e., makeup of the scenario analysis team).
  - A method is selected for documenting the hazard and scenario evaluations.
  - An extensive list of potential scenarios is developed during team meetings.
- Phase 2
  - Scenarios from the extensive list compiled by the team are extracted or sorted out by subject expertise or action responsibility (engineering, environmental, fire protection, safety, operations, etc.).
  - Scenario analysis subject experts perform additional review on assigned scenarios and develop a representative grouping. Grouping can be based on hazard, incident outcome, exposure, consequence types, levels, or categories.
- Phase 3
  - A qualitative scenario risk screening approach is developed and agreed to.
  - Scenario analysis team members perform risk-based screening of scenarios within their subject expertise.
- Phase 4
  - Scenarios screened as potential moderate-high risk levels and risks that may be difficult to screen because of associated uncertainties are selected for quantitative risk analysis.

Figure 3.24 provides a general illustration of the scenario screening phases.

Fig. 3.24: Scenario Screening Phases



3.4.1 Phase 1, Extensive List of Scenarios

It is very important to have the extensive list of scenarios developed during team meetings with all the appropriate subject experts present. This provides an interactive identification of potential hazards and scenarios, along with discussion of loss prevention controls, design modifications, and actions or recommendations.

For one chemical process facility design project I worked on, there were five processes with defined process boundaries and system descriptions. The plant elected to use What-If analysis for hazard identification and scenario development. Each process was analyzed, including process and building ventilation systems, liquid waste handling systems, tank storage, and truck loading operations. Numerous What-If analysis worksheets were completed by the scenario analysis team and an extensive list of over 400 potential failure mode scenarios were developed. Approximately 20% of the scenarios involved fire or explosion potentials, which were examined further.

It should be noted that What-If analysis provides an adequate evaluation method for processes that are not highly complex and for processes that require a fair degree of operator monitoring and intervention. In general, for more complex processes, hazard and operability analysis (HAZOP) is typically used. For specific equipment failure mode analysis, failure mode and effect analysis (FMEA) is often used in combination with HAZOP or What-If analysis.

Reference

Detailed discussion of these methodologies is beyond the scope of this chapter. An excellent source for information on formal hazard analysis techniques such as HAZOP, FMEA, and What-If analysis is the Center for Chemical Process Safety's *Guidelines for Hazard Evaluation Procedures with Examples*.[1]

Figure 3.25 presents an example of one page of a What-If analysis worksheet. Notice the makeup of the team members. Significant initiating what-if failure mode events must be addressed in the analysis, and in most cases, each one will have one or more dominant failure causes. The term "significant" primarily involves failure modes that might reasonably be expected to occur, such as:

- Events that have occurred before on the same or similar systems
- Event modes subject to prevention system failures
- Other failure modes that may have not occurred yet but that are considered possible based on abnormal situations

Information about initiating events that have occurred or that might reasonably be expected to occur in the future can be obtained from:

- Operations and maintenance personnel who have had a long association with the equipment
- Plant specific experience, records
- The manufacturer or vendor of the system-related equipment
- Other users of the same equipment (i.e., industry data)

- Reliability data sources (i.e., published failure rate data)
- Subject matter experts
- Historical data base sources (discussed in Chap. 4)

Of these, the best source of information is usually people who know the facility, operations, and equipment. Although comprehensive history records and generic reliability data sources can also be a valuable source of information, they should be treated with caution for the following reasons:

- They are often incomplete.
- They seldom describe the full context in which the failure took place.
- By their very nature, they cannot describe failures that have not yet occurred.

In most cases, potential initiating events that have never occurred and that are considered extremely unlikely should not be listed. However, the decision to not list events should be tempered by carefully considering the failure consequences. If the consequences are likely to be very high, then less likely initiating events should be listed and subjected to further analysis. For instance, an event that might be dismissed as unlikely in the relatively safe environment of an industrial plant may be taken very seriously in a nuclear power plant, even though the probability of the failure may be the same in both cases.

The results of Phase 1 should be an extensive list of failure mode scenarios developed by a multi-disciplinary team.

3.4.2 Phase 2, Scenario Grouping

In Phase 2, individual team members extract hazards and failure mode scenarios that are within their subject matter expertise. For example, the Fire Protection team member would sort-out and concentrate on those failures, consequences, and controls that represent fire or explosion issues.

In Fig.3.25, Example What-If Analysis Worksheet, fire related issues would include failure and ignition potentials that could lead to hydrogen flash fire or explosion incidents and consequences (life safety exposure, property damage, production downtime, etc.) The reliability and performance of the hydrogen gas analyzer, nitrogen purge system, and process and area ventilation systems to prevent fire or explosion would need further evaluation by the Fire Protection team member.

There are several ways to group scenarios. One method involves grouping by hazard, dominant failure modes, and representation exposure category. Phase 2 scenario grouping is sometimes referred to as “binning.” As presented in Fig. 3.26, item 1, failure modes selected from the scenario analysis list are put into bins or groups according to hazard. In the Fig. 3.26 example, the fire hazard scenarios include hydrogen gas release and hydraulic oil release. These are initiating events that could lead to fire or explosion incidents. The numbers in the bins are the failure mode scenario identification numbers from the scenario analysis (refer to the first column in Fig. 3.25, Example What-If Analysis Worksheet).

This second level of grouping in Fig. 3.26 is the contributing factor breakdown:

- Hardware failure
- Emergency control system (ECS) failure
- Human error

Recognition of the dominant contributing factors to the failure mode event or scenario is important because it identifies trending in potential weak links such as human error, over-dependance on ECSs, or particular hardware failures.

The third level of grouping in Fig. 3.26 is a qualitative screening effort intended to sort hazard scenarios by an exposure category:

- Localized Exposure – localized effects, limited to immediate point of origin
- Moderate Exposure – moderate effects, limited to a defined area of origin (i.e., moderate size fire, small explosion)
- Major Exposure – large effect zone with potential for structural damage, and possible major injuries or fatalities (e.g., large fire, large explosion)

Typically those fire hazard scenarios that fall into the moderate-major exposure category are selected for risk screening (Phase 3) in which the potential likelihood of occurrence is qualitatively evaluated.

Fig. 3.25: Example What-If Analysis Worksheet

Company: XYZ Company

Method: What-if Analysis-Preliminary Designs Review **Date:** April 1, 2001

Number: Drawing: 177, Aluminum Dissolution Process, Rev. 1.0

Team Members:

Jim Smith – Engineering Project Manager
Tom Jones – Operations
Bill James – Industrial Safety
Al Jones – Maintenance Manager
Joe Vector – Fire Protection
Lisa Gray – Environmental
Jane Smith – Industrial Hygiene
Jim Brown – Design Engineer

Item	What if...?	Causes	Consequences	Controls	Actions
7.8	Cooling water supply fails low	Mechanical failure	Condenser overheats and fails resulting in potential fire in POG (POG = process off-gas ventilation system)	Procedures Training (valve alignment) Temperature and flow indicators	
30.1	Valve 136 fails closed	Human error Mechanical failure	**Potential for loss of nitrogen inert atmosphere resulting in potential hydrogen fire or explosion** Potential backflow into nitrogen line Potential to backflow dissolution solution into ENCLOS-X01 Potential spill of dissolution solution in process area	Procedures Training (Valve alignment) Flowmeter FIC-X01 Gas Analyzer X01 ENCLOS-X01 drain	
33.1	HEATER-1X fails on	Human error Electrical failure	Heater fire Potential overflow DISOLV-X01 to ENCLOS-X01 Potential spill of dissolver solution in process area **Potential explosion from vented hydrogen into POG** Potential backflow into process water line	Heater excess temperature alarm ENCLOS-X01 drain POG line ventilation rate Level switch X01 Valve X41 Gas Analyzer X01 Nitrogen purge to DISOLV-X01 and ENCLOS-X01	

Fig. 3.26 : Example of Fire and Explosion Hazard Scenario Grouping

1. Fire and explosion hazards from scenario analysis extensive list

6.2	11.2	20.3
	13.3	30.1
9.1	15.5	33.1

Hydrogen Gas Release and Potential Explosion

6.5	18.5
7.5	25.4
9.9	

Hydraulic Oil Release and Potential Fire

2. Dominant contributing factor breakdown

Hardware Failure	ECS * Failure	Human Error
6.2	9.1	13.3
	11.2	33.1
15.5	30.1	
20.3	33.1	

Hardware Failure	ECS * Failure	Human Error
6.2	7.5	
9.9	25.4	
18.5		

* ECS = Emergency Control System

3. Representative grouping by exposure category

Localized Exposure	Moderate Exposure	Major Exposure
6.2	11.2	20.3
	13.3	30.1
15.5	20.3	33.1
9.1		

Localized Exposure	Moderate Exposure	Major Exposure
6.5	18.5	
9.9	25.4	
7.5		

Localized Exposure – localized effects, limited to immediate point of origin

Moderate Exposure – moderate effects, limited to a defined area of origin (i.e., moderate size fire, small explosion)

Major Exposure – large effect zone with potential for structural damage, fatalities (e.g., large fire, large explosion)

3.4.3 Phase 3, Scenario Screening

In Phase 3, qualitative risk-based scenario screening is performed.

Risk Screening Approach

Fire hazards and scenarios selected for risk screening are evaluated using a qualitative risk-based screening approach. The following tables list example event likelihood and consequence categories that can be used for scenario screening.

Initiating event likelihood is defined as the likelihood of reaching the conditions necessary (i.e., exposed fuel, oxygen, ignition) to initiate a fire or explosion event. Table 3.3 presents an example of likelihood categories.

Table 3.3: Initiating Event Likelihood Categories

LIKELIHOOD CATEGORY	GENERAL DEFINITION
1 - Very Low	Very remote possibility of occurrence (e.g., 1/300 to 1/1000 years)
2 - Low	Possible to occur once over 2 – 3 times the useful life of the process (e.g., 1/100 years)
3 - Moderate	Possible to occur once over the lifetime of the process (e.g., 1/30 years)
4 - High	Possible to occur once per average process life-cycle (e.g., 1/15 years)
5 - Very High	Possible to occur occasionally (e.g., 1/5 years)

Table 3.4 presents an example of life safety exposure or consequence categories.

Table 3.4: Life Safety Consequence Categories

CONSEQUENCE LEVEL	GENERAL DEFINITION
1 - Low	First aid (minor injury associated with firefighting or evacuation)
2 - Moderate	Single person injury requiring hospital treatment
3 - Heavy	Multiple person injuries requiring hospital treatment
4 - High	Life threatening injury or death ON SITE
5 - Major	Life threatening injury/rad exposure or death OFF SITE

Table 3.5 presents an example of property damage categories.

Table 3.5: Property Damage Categories

CONSEQUENCE LEVEL	DAMAGE FACTOR RANGE (%)	GENERAL DEFINITION
1 - Slight	0 – 1	Limited localized minor damage not requiring repair
2 - Light	1 – 10	Significant localized damage of some components generally not requiring major repair
3 - Moderate	1 – 25	Significant localized damage of many components warranting repair
4 - Heavy	25 – 60	Extensive process equipment damage requiring major repairs
5 - Major	60 – 100	Major widespread damage that may result in facility major structural damage and the release of contaminated combustion products OFF SITE

Risk screening can also include other consequences of concern such as production downtime, environmental impact, company image, etc.

Table 3.6 provides an example of BI categories.

Table 3.6: Example of Business Interruption (BI) Categories

BI Levels	PRODUCTION DOWNTIME RANGE	AVERAGE PRODUCTION DOWNTIME, DAYS	GENERAL DEFINITION
1 – Slight	0 – 1 Days	0.5	Limited localized minor equipment damage not requiring repair, but clean up
2 – Light	1 – 10 Days	5	Significant localized damage of some equipment components generally not requiring major repair
3 – Moderate	10 – 30 Days	20	Significant localized damage of many equipment components warranting repair
4 – Heavy	30 – 90 Days	60	Extensive damage requiring major equipment repair & replacement
5 – Major	90 – 270 Days	180	Major widespread damage that may result in extensive repairs and equipment replacement
6 – Total	270 – 360 Days	300	Total downtime of the majority of the facility, up to one year

Table 3.7 provides an example of environmental impact categories.

Table 3.7: Example Department of Energy (DOE) Environmental Impact Rating

Environmental Impact. The following criteria pertain to the environmental damage that an accident might cause. Typical accidents will include spills, accidental discharges, or breaches of material tanks.	
1. *Negligible*	1 – Less than or equal to $50,000 in clean up costs 2 – Small spills or spills that do not immediately enter into the soil. Contamination that is quickly and readily cleaned up with on-site or locally available technology
2. *Marginal*	1 – Accidents resulting in greater than $50,000 and less than or equal to $1,000,000 in clean-up costs 2 – Minor soil contamination with nearly no potential for contaminant migration
3. *Critical*	1 – Accidents resulting in greater than $1,000,000 and less than or equal to $10,000,000 in clean up costs 2 – Significant on-site soil contamination 3 – Likely long-term migration of contamination off site or to water source. However, does not pose any short term threat
4. *Catastrophic*	1 – Accidents resulting in greater than $10,000,000 in clean up 2 – Groundwater or surface water in immediate danger of contamination

Risk Screening Matrix

Table 3.8 presents an example risk classification screening matrix. This is a 5 x 5 matrix for risk screening of combined life safety and property damage exposures. Similar matrices can be developed for production downtime, environmental impact, or other consequences of concern.

Table 3.8 : Example Risk Classification Screening Matrix

		LIFE SAFETY EXPOSURE CATEGORIES				
		1	2	3	4	5
INITIATING EVENT LIKELIHOOD CATEGORIES	5	A	B	B	C	D
	4	A	B	B	C	D
	3	A	A	B	C	D
	2	A	A	A	B	C
	1	A	A	A	B	C
		1	2	3	4	5
		PROPERTY DAMAGE CATEGORIES				

Table 3.9 presents an example of general action items associated with the risk classifications presented in Table 3.8.

Table 3.9: Risk Classification Actions Associated with Table 3.10

RISK CLASS	GENERAL DESCRIPTION	ACTIONS
A	Low Risk Events	Low risk levels; no further risk reduction actions required
B	Moderate Risk Events	Requires minor risk reduction improvements; generally addressed by codes, standards, company or industry practices
C	Moderate - High Risk Events	Generally requires further analysis to determine an optimal risk reduction strategy or reliability analysis of the proposed risk controls
D	High Risk	High risk; requires immediate risk reduction analysis

Table 3.10 provides an example listing of some selected fire hazard scenarios along with a risk screening classification using categories from Tables 3.3, 3.4, 3.5, 3.8, and 3.9. In some cases first-order fire models or explosion models would be run to support estimated consequence levels. The resources and methods discussed in Chap. 4, Initiating Event Likelihood, could be applied in the estimation of event likelihood categories.

Table 3.10 : Example Scenario Risk Classification Screening Table

SCENARIO I.D.	DESCRIPTION	INITIATING EVENT LIKELIHOOD	UNMITIGATED CONSEQUENCES		RISK CLASS	ACTION ITEM
			LIFE SAFETY	PROPERTY DAMAGE		
4.1.2	Furnace overheating	1	1	3	A	None
31.3	Incompatible materials entering heaters and furnaces	1	2	3	A	None
3.2.1	Combustible Metal; fire inside of glove box enclosure attached to top of dissolver	3	3	3	B	(1)
3.2.2	Flash fire or explosion inside the hydrogen off-gas exhaust ventilation system	3	3	4	C	(2)
3.3.1	Extraction; accidental solvent release and ignition	3	3	4	C	(3)
3.3.3	Extraction; chemical makeup fire	3	2	3	B	(4)
3.4.2	Drum lift hydraulic oil fire	3	1	2	A	None
3.4.3	Tanker truck loading fire	3	2	2	A	None

Action Item Summary

Table 3.11 describes the action items related to Table 3.10 and lists the corresponding action recommendation numbers.

Table 3.11 : Example Action Items Summary Table

ACTION ITEM	ACTION SUMMARY	ACTION REC. #	REMARKS
(1)	Glove box enclosure: • Hydrogen detection inside enclosure • Fire detection inside enclosure • Detection interlocks to shut down caustic feed pump (stops hydrogen generation) and automatically initiate a nitrogen purge	9.1	
(2)	Hydrogen off-gas exhaust ventilation system: • Stainless steel hydrogen vent lines • System bonded and grounded; classified electrical • Ventilation blower fan and exhaust air flow monitoring • Loss of blower fan or air flow interlocked to shut down caustic feed pump (stops hydrogen generation) and automatically initiates nitrogen purge	9.2	Risk Class – C Quantitative performance and reliability assessment of detection and emergency control system should be conducted
(3)	Solvent Extraction; Provide: • solvent release minimization design features • diking around columns handling solvent • automatic fire detection systems • manual fire fighting response plans • minimum 2-hr fire barrier walls around process	9.3	Risk Class – C Conduct further quantitative risk assessment to determine risk class and the need for additional or alternative fire protection measures
(4)	Solvent Extraction - chemical makeup area - Provide: • diking and containment provisions • automatic fire detection system • automatic fire suppression system for diked area • chemical drum handling procedures	9.4	

3.4.4 Phase 4, Selection of Scenarios for Quantitative Analysis

In Phase 4, scenarios screened as potential moderate-high risk levels and risks with associated uncertainties (either in the estimated risk level or involving optimal risk reduction alternatives) are selected for quantitative risk analysis.

For example, fire hazard scenario items in Table 3.10 listed as risk class B (moderate risk events) can be reduced to a lower risk level by improvements addressed by codes, standards, and industry practices.

In Table 3.10 there were some items identified as potential risk class C (moderate-high risk events generally requiring further analysis to determine an optimal risk reduction strategy or further analysis of the reliability for proposed risk controls). These items included:

- Hydrogen Off-Gas Explosion Potential
  - Scenario ID: 3.2.2
  - Action Items: (2)
- Solvent Release and Ignition Potential
  - Scenario ID: 3.3.1
  - Action Item: (3)

The associated action items in Table 3.11 indicate:

- For action item (2), conduct a quantitative performance and reliability assessment of hydrogen off-gas emergency control and explosion prevention system (gas detection, fire detection, shutdown interlocks, ventilation system, air monitoring, nitrogen purge system, etc.)
- For action item (3), conduct quantitative fire risk assessment of the Solvent Extraction Process to determine risk class and the need for additional fire protection measures.

Typically, these action items would be submitted to Management requesting approval and funding for conducting risk-informed, performance-based quantitative analysis.

3.4.5 Fire Event Classification

Groups of fire hazard scenarios screened as moderate-high risks should be bounded in terms of fire classification. Fire events can be classified as:

- Design-basis events
- High-challenge events
- Worst-case events

Table 3.12 provides general definitions for these classification.

Table 3.12: Example of Three Classes of Fire Initiating Events

FIRE EVENT CLASSIFICATION	GENERAL DESCRIPTION
DESIGN-BASIS FIRE EVENTS	REPRESENT FIRE-INITIATING EVENTS THAT CAN BE REASONABLY EXPECTED TO HISTORICAL PERSPECTIVE AND FUTURE LIKELIHOOD
HIGH-CHALLENGE FIRE EVENTS	REPRESENT FAILURE AND IGNITION CASES CONSIDERED POSSIBLE BUT THAT USU UNUSUAL OR UNIQUE SITUATIONS TO BE REALIZED
WORST-CASE FIRE EVENTS	REPRESENT FAILURE CASES WITH A VERY REMOTE LIKELIHOOD BUT WITH POTE SEVERITY AND CONSEQUENCES

FIRE EVENT CLASSIFICATION ALLOWS EVALUATION OF FIRE PREVENTION OR FIRE PROTECTION ALTERNATIVES THAT WOULD BE AVAILABLE TO PROTECT A BOUNDED GROUP OF SCENARIOS OR CLASS OF FIRE TYPES.

WHEN USING A STRUCTURED SCENARIO ANALYSIS AND RISK SCREENING FORMAT, THE LIKELIHOOD CHARACTERIZATION PROCESS PROVIDES AN INITIAL METHOD TO CLASSIFY AND BOUND INITIATING FIRE EVENTS. FIGURE 3.27 PROVIDES ANOTHER GRAPHICAL ILLUSTRATION OF THE INITIATING FIRE EVENT SELECTION PROCESS.

WHAT WE ARE MOST INTERESTED IN ARE THOSE DESIGN-BASIS EVENTS WITH A REASONABLE LIKELIHOOD OF OCCURRENCE AND FOR WHICH WE CAN ESTABLISH PERFORMANCE FPS REQUIREMENTS. HOWEVER, WE MUST ALSO EVALUATE POTENTIAL HIGH-CHALLENGE EVENTS. AS A SIMPLISTIC EXAMPLE, LET'S CONSIDER A HIGH VALUED WAREHOUSING FACILITY. WE HAVE IDENTIFIED DESIGN-BASIS SCENARIOS AND SET UP PERFORMANCE LEVELS FOR THE FPSS BASED ON THE BOUNDING DESIGN-BASIS EVENT. HOWEVER, THERE IS A CHANCE OF EXCESS SEASONAL INVENTORY AND DIFFERENT PRODUCTS BEING STORED IN THE WAREHOUSE AT VARIOUS TIMES. THIS STORAGE MAY BE PUT IN AISLES OR MAY CREATE A HIGHER STORAGE SITUATION. DEPENDING ON THE VALUE AND VULNERABILITY (I.E., AN ENHANCED RISK LEVEL) WE MAY WANT TO PROVIDE ADDITIONAL PROCEDURES AND ADDITIONAL FIRE PROTECTION MEASURES FOR THIS HIGH-CHALLENGE SITUATION. USUALLY, WE DO NOT RELATE FIRE PROTECTION PERFORMANCE REQUIREMENTS FOR WORST-CASE SITUATIONS AS IT IS NOT COST-EFFECTIVE. HOWEVER, WE WANT TO MAKE SURE THAT THE WORST-CASE LIKELIHOOD (I.E., A GAS LINE LEAK FROM THE HEATING SYSTEMS IN THE WAREHOUSE CREATES AN EXPLOSION POTENTIAL, ETC.) IS A VERY LOW, REMOTE PROBABILITY.

Fig. 3.27: Example of Initiating Fire Event Selection Process

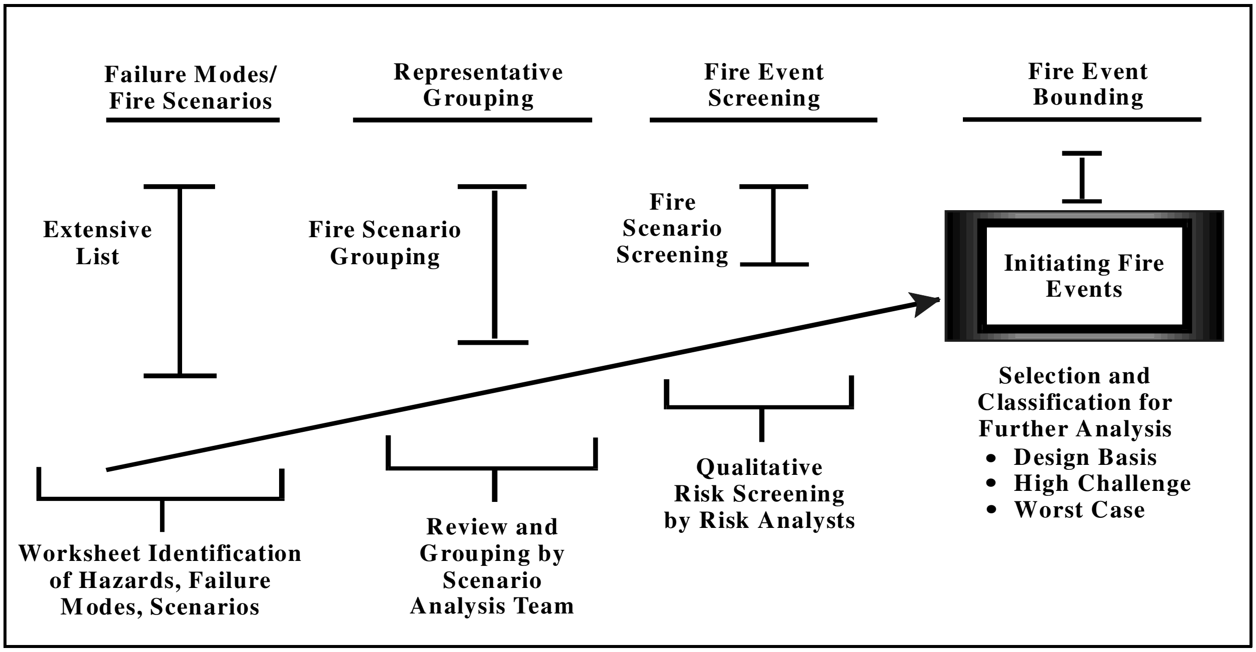
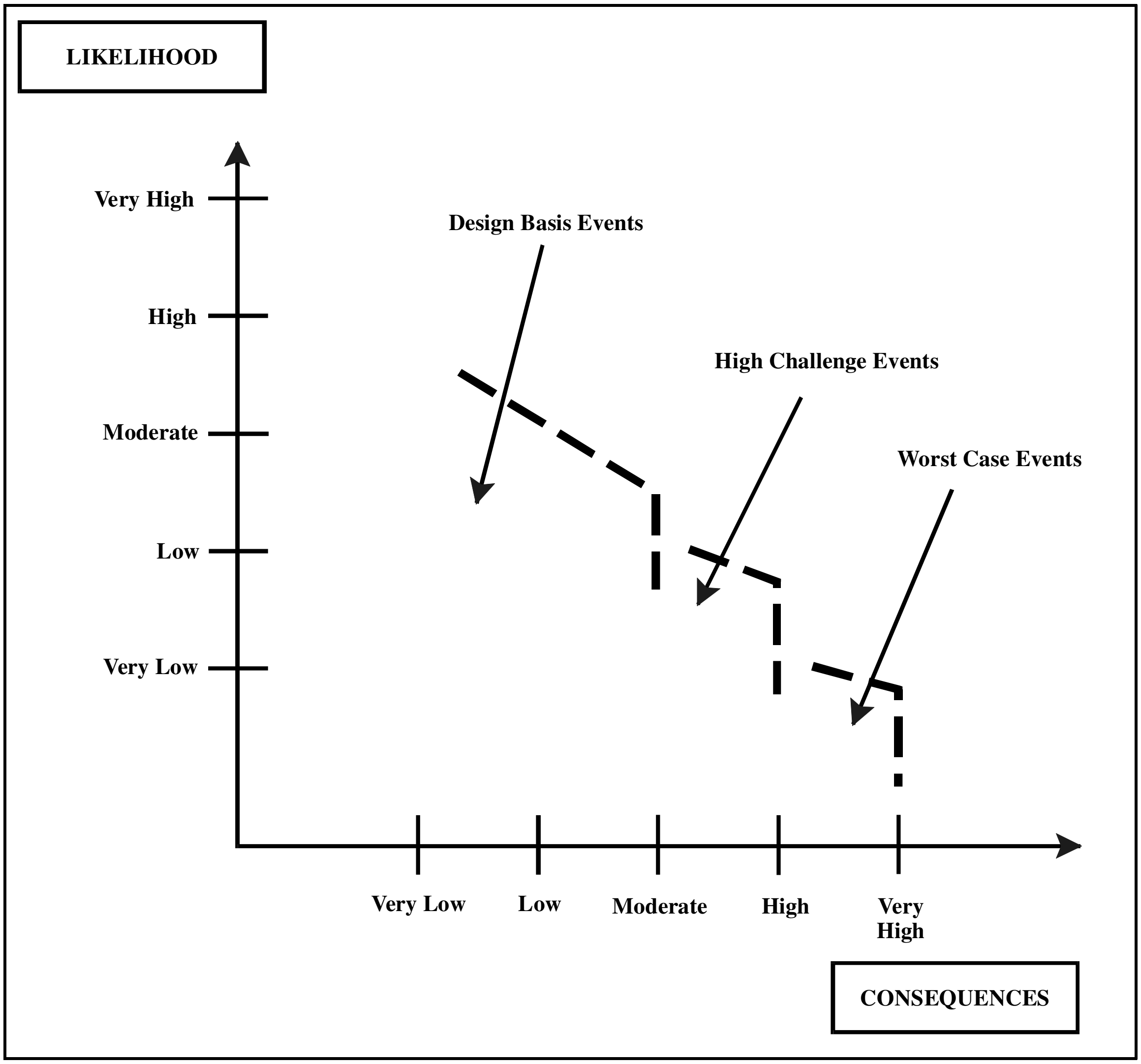


Figure 3.28 provides a general example of where fire event classifications may fit into a likelihood-consequence (i.e., risk) ranking approach.

Fig. 3.28: Example Risk Profile for Classifying Fire Events



Chapter 4, Initiating Event Likelihood, introduces methods for quantifying the likelihood of fire events that have been screened and selected for further quantitative risk analysis.

3.5 DISCUSSION

A good scenario analysis approach should provide:

1. A prediction of future potential failure events that could lead to F&E incidents. Just because an event has not occurred in the past does not mean it cannot occur in the future. Therefore, scenario analysis should be thought of as a forecasting tool.
2. A method for qualitative screening and bounding of fire events. Groups of hazards screened as moderate-high risks should be bounded in terms of fire classification:

design-basis, high challenge, worst case. This allows focus on the FPS alternatives available to protect a bounded group or class of fire types.

3. The overall scenario analysis process should provide a fulcrum for identification of those fire events or fire protection issues that may need "quantitative" risk assessment in order to make better risk-informed, performance-based fire safety decisions.

At this stage, what constitutes a reasonable fire event likelihood and significant severity is mostly based on the qualitative judgement of the scenario analysis team. Ignorance or error in judgements can yield an incomplete or inaccurate fire scenario analysis. Therefore, the scenario analysis team leaders should have knowledge in all of the steps described in this book, especially Step 4, Initiating Event Likelihood.

Site Surveys & Interviews

It is imperative to conduct a site survey to visually observe the specific facility or operation being analyzed. You cannot conduct a credible scenario-based hazard analysis sitting in an office reviewing submitted plant diagrams and procedures. In many cases, diagrams such as P&IDs have not been accurately updated to reflect field changes and recent modifications. Operator and maintenance procedures may look good on paper; however, the quality of training and implementation of these procedures needs to be addressed and evaluated at the plant site by reviewing logs, observing operations, and interviewing operations and maintenance staff.

Historical Data Review

An important part of developing credible F&E loss scenarios is conducting research and review of available historical loss incident data for fire or explosion hazards that may be similar to the ones being analyzed in the risk assessment project.

A review of the available information on loss incidents or available case studies can provide:

- A relative breakdown of consequential effects, in terms of type of fire or explosion and resulting damage
- Identification of contributing events or dominant failure modes (equipment related, human error, system related) that have led to fire or explosion accidents
- Identification of ignition sources and fire propagation contributing factors
- Information concerning the duration of the fire and the general effect of loss mitigation factors

NOTE: Chapter 4, Initiating Event Likelihood, provides discussion on the use of historical incident data and sources.

3.6 REFERENCES

1. Center for Chemical Process Safety (CCPS), *Guidelines for Hazard Evaluation Procedures with Examples (Second Edition),* American Institute of Chemical Engineers (AIChE), New York, NY. 1992.