Hazard and Risk Identification

UNIVERSITY OF TORONTO

MINERVA
Safety Management Education

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Concept Definitions

Hazard – An intrinsic chemical, physical, societal, economic or political *condition that has the potential for causing damage* to a risk receptor (people, property or the environment).

A hazardous event requires an initiating event or failure and then either failure of or lack of safeguards to prevent the realisation of the hazardous event.

Examples of intrinsic hazards:

- *Toxicity and flammability* – H_2S in sour natural gas
- *High pressure and temperature* – steam drum
- *Potential energy* – walking a tight rope

Concept Definitions

Risk – A *measure* of human injury, environmental damage or economic loss in terms of both the *frequency* and the *magnitude* of the loss or injury.

Risk = *Consequence* x *Frequency*

Concept Definitions

Risk

Intrinsic Hazards → **Undesirable Event** → **Consequences**

Likelihood of Event

Likelihood of Consequences

Example

Storage tank with flammable material

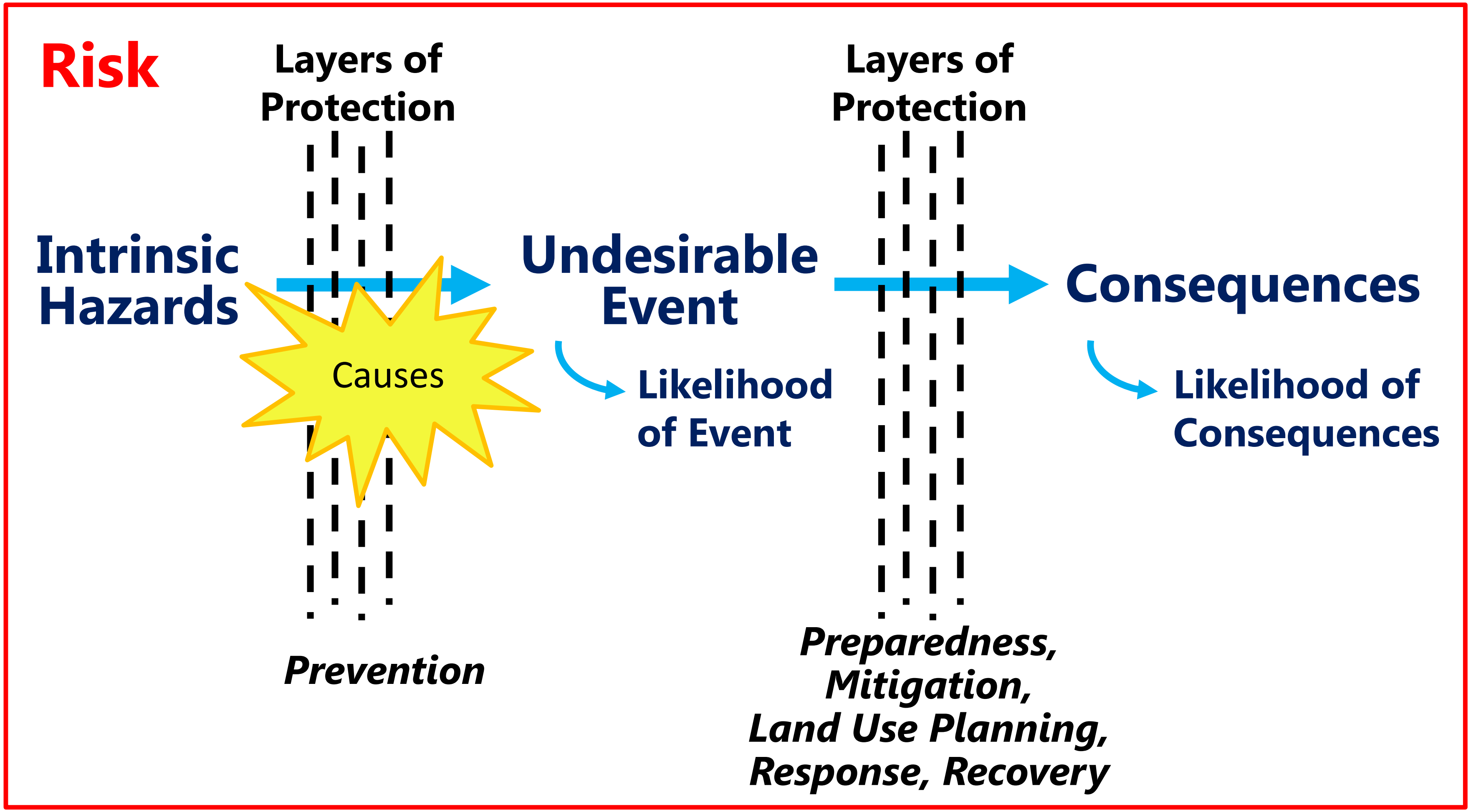
Spill and Fire

Loss of life/ property, Environmental damage, Damage to reputation of facility

Concept Definitions

Risk

Concept Definitions



Risky Activity: Jaywalking

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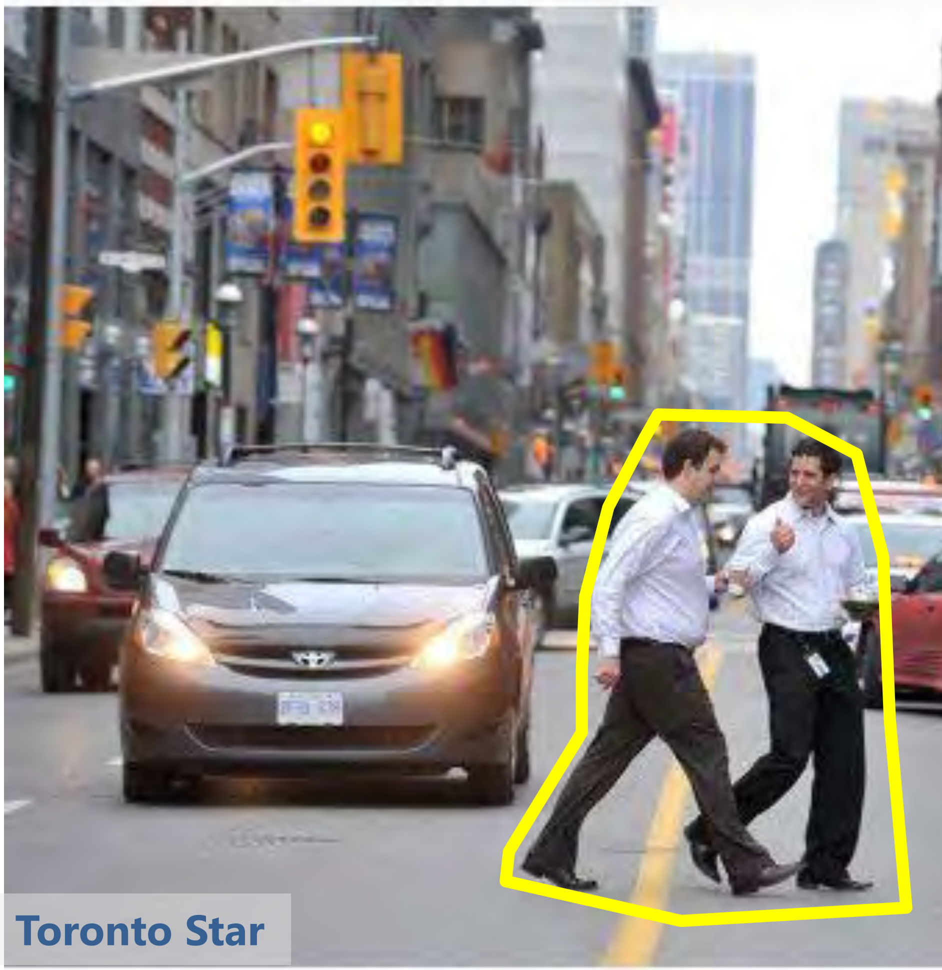


Toronto Star

Intrinsic Hazard

- Vehicles on road
- Speed of these vehicles

Cause

- Crossing the Road

Event

- Collision

Layer of Protection

- Cross walk

Risky Activity: Jaywalking

Consequences of the Event

- Death
- Severe Injury
- Broken Bones
- Fractured Bones
- Scratches
- No Injury

Frequency of the Event

- Every Day,
- Once a week
- Once a month
- Once a year
- Never

Risky Activity: Plane Landing

- Asiana Airlines Boeing 777 crash on July 6, 2013 at San Francisco International Airport
- 8 deaths and 180 injuries

Risky Activity: Plane Landing

Risky Activity: Plane Landing

Hazard
- Plane flight

Cause
- Potentially human error during runway approach

Event
- Crash during landing

Consequence
- Deaths

Risky Activity: Plane Landing

Hazard
- Plane flight

Cause
- Potentially human error during runway approach

Event
- Crash during landing

Consequence
- Deaths

If the frequency of the consequence is known, risk can be calculated.

Risk = *Consequence x Frequency*

Risky Activity: Plane Landing

Multiple Consequences can result from a crash during plane landing:

- Deaths
- Permanent Disability
- Injury Requiring Hospitalisation
- First Air

$$Risk_{crash} = \sum_i Consequence_{i,crash} \; x \; Frequency\ of\ Consequence_{i,crash}$$

All consequences must be expressed in the same units to calculate total risk.

Concept Definitions

Risk – A *measure* of human injury, environmental damage or economic loss in terms of both the *frequency* and the *magnitude* of the loss or injury.

Area where undesirable events can occur:

- Industrial facilities – resource extraction, processing, manufacturing, disposal, energy generation, transportation
- Third party environments – legislative, political, societal

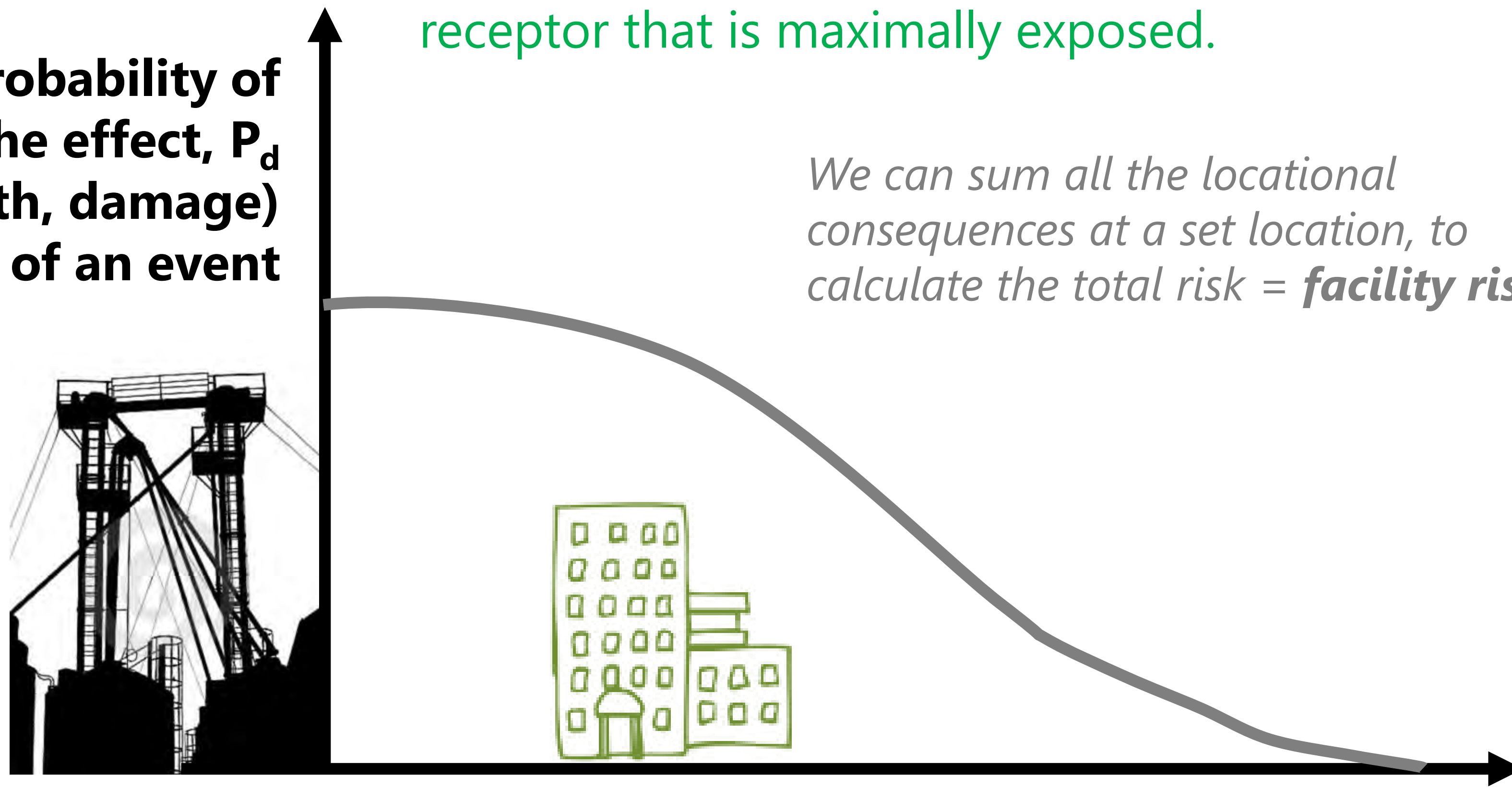
- **An individual**
- A community
- An environment
- A property
- A corporation
- Employees
- Shareholders
- **Society**

Types of Consequences

Locational Consequence – Outdoor IMMOVEABLE receptor that is maximally exposed.

*We can sum all the locational consequences at a set location, to calculate the total risk = **facility risk**.*

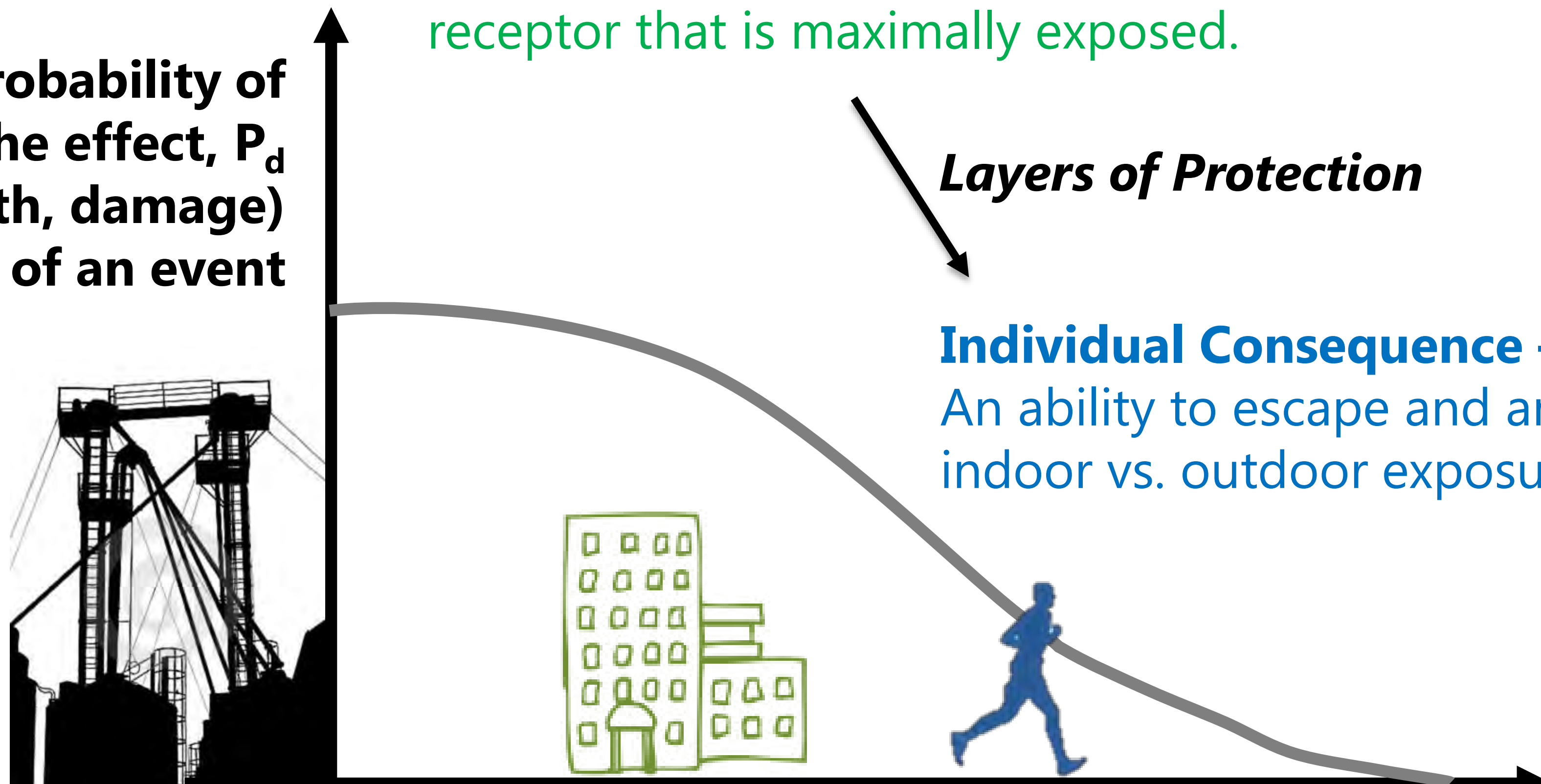
Probability of the effect, P_d (death, damage) of an event



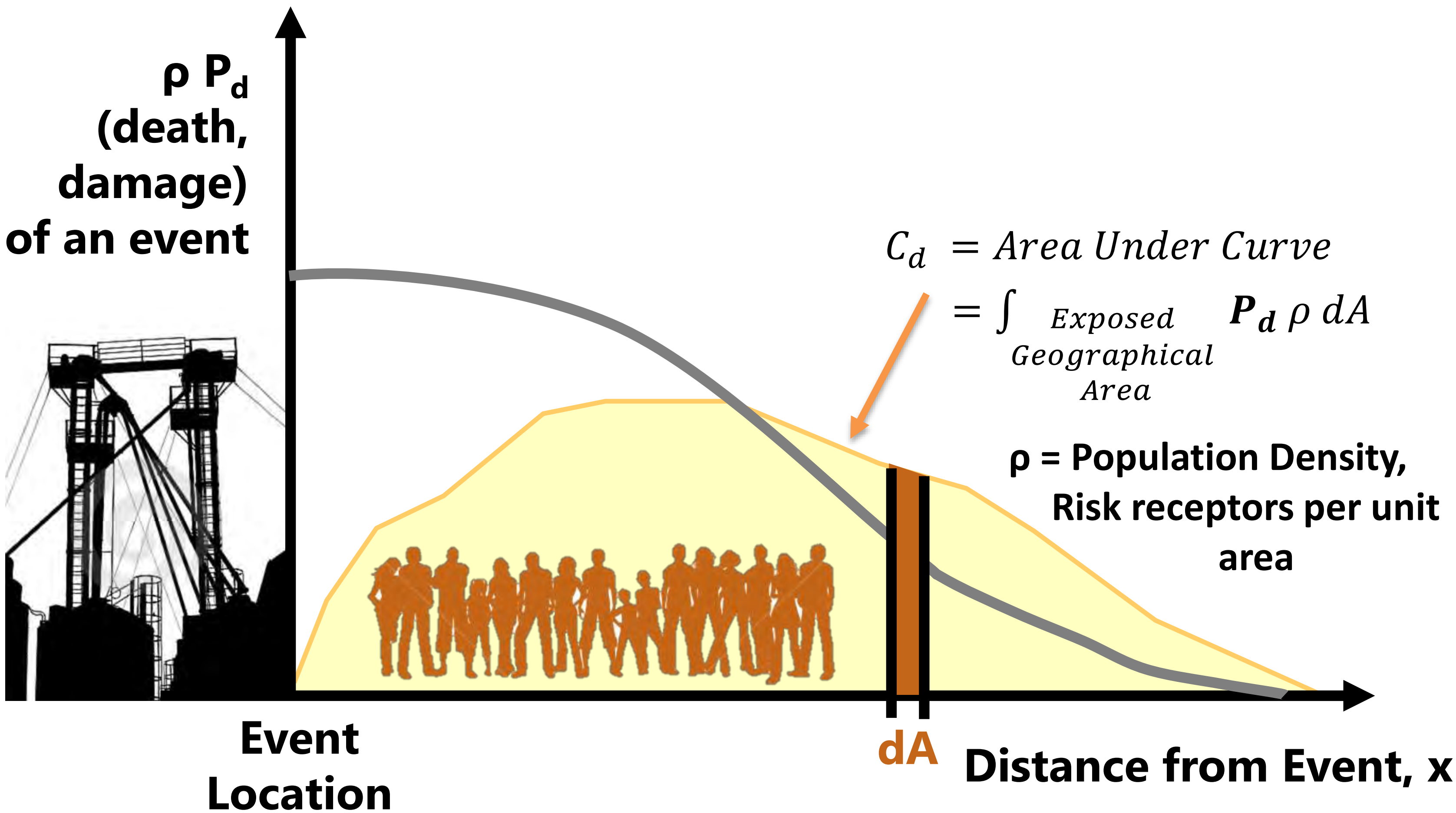
Event Location

Distance from Event, x

Types of Consequences



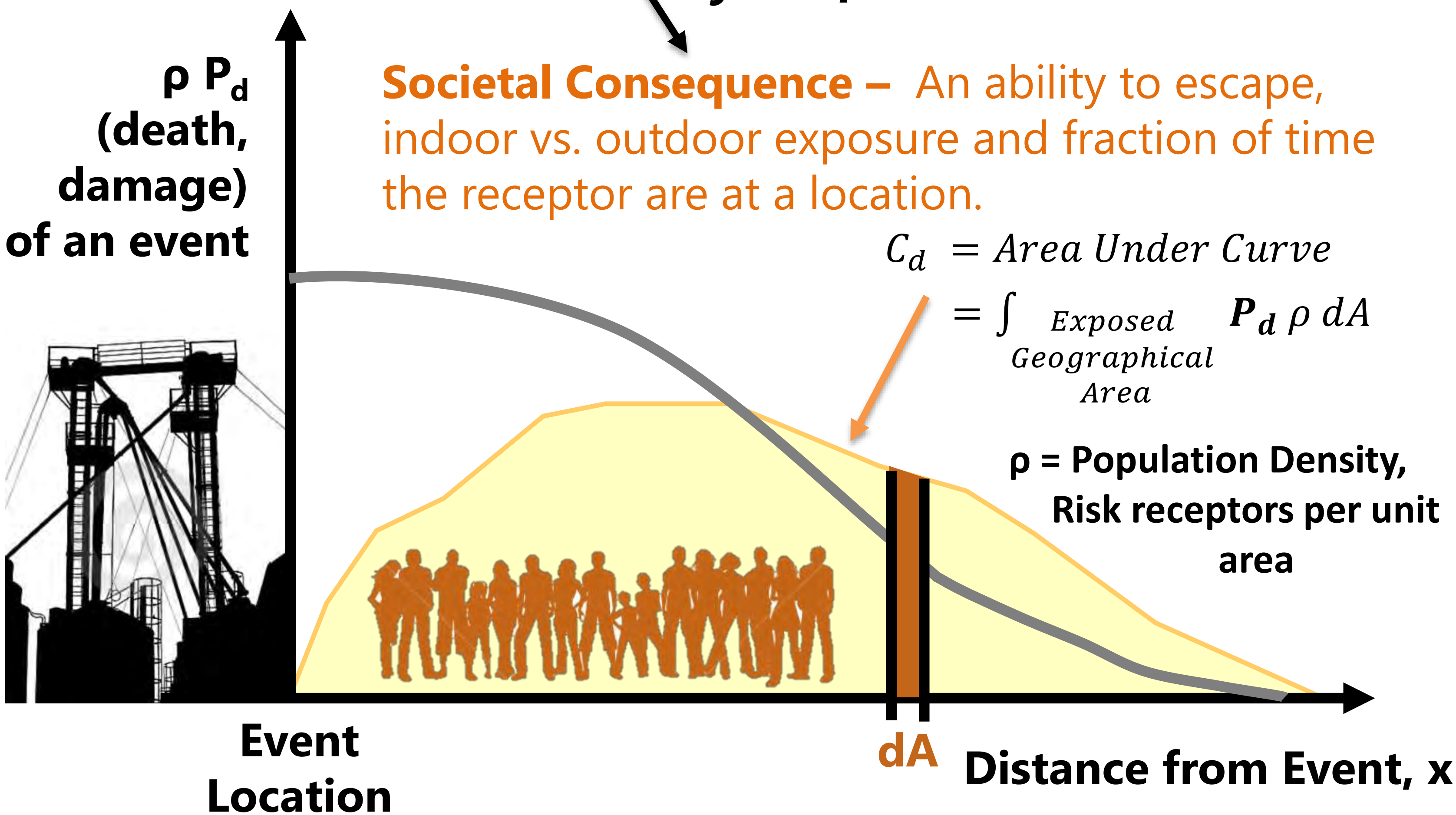
Aggregate Consequence – Outdoor IMMOVEABLE receptor.



Aggregate Consequence – Outdoor IMMOVEABLE receptor.

Layers of Protection

Societal Consequence – An ability to escape, indoor vs. outdoor exposure and fraction of time the receptor are at a location.



Different Types of Risk

Risk – A *measure* of human injury, environmental damage or economic loss in terms of both the *frequency* and the *magnitude* of the loss or injury.

Risk of harm can results from different types of activities:

Case 1 –A *repeated or planned activity* to a *unique risk receptor.*

Case 2 –R*epeated or planned activities* to a broad *population.*

Case 3 –*Random failure events.*

Different Types of Risk

CASE 1 - Risk of harm from a *repeated or planned activity* to a *unique risk receptor*.

This can be risk of death from a medical procedure for the patient.

- The patient may be told there is a 2% chance of death from an operation. This statistic is based on the total number of operations performed over some period and the fraction of operations that result in death.

Risk of death from the operation =

likelihood* * *consequence

Different Types of Risk

CASE 2 - Risk of harm from a *repeated or planned activity* to a *broad population*.

If we can extend the operation example further but now let's go beyond the one patient – consider the annual frequency of death from this operation across Canada.

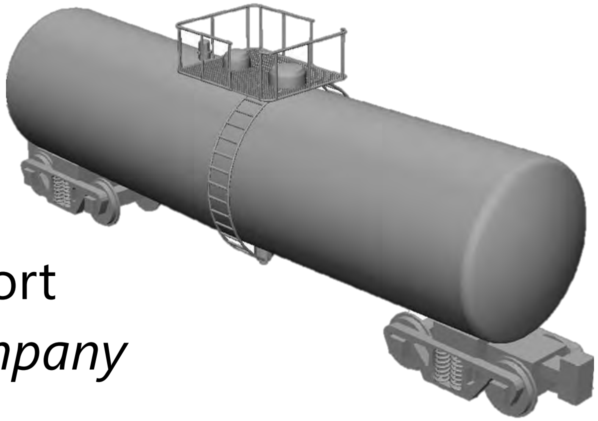
- Re-evaluate the previous statistic: in Canada, 2 out of 100 patients die annually from an operation.
- Frequency replaces likelihood because we are considering the occurrence of an event per year.

Risk [death annually from the operation] =

***frequency** [operation per year] * **consequence** [deaths per operation]*

Different Types of Risk

CASE 2 - Risk of harm from a *repeated or planned activity* to a *broad population*.



Example – Unloading a rail tank car

A company transforms the risks of repeated activities from a broad population to their cohort of operators – *it is important to note that a company will not assess risk for a specific operator.*

Hazard – Unloading a rail tank car

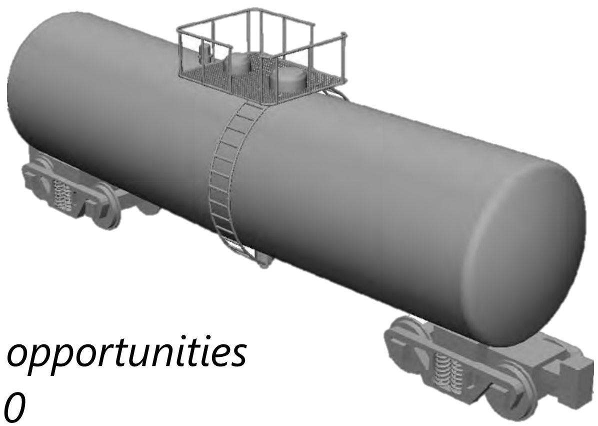
Event – Ignition of spilled chemical

Cause – Human error when uncoupling hoses

Consequence – 3rd degree burn to an operator

***Risk* = 1 in 100 chance per year an operator gets a 3rd degree burn**

Different Types of Risk



Example – Unloading a rail tank car

Let's break down how we arrived at the risk.

1. *Unloading rail tank car = 1000/year*
2. *Probability of human error when uncoupling hoses such that some chemical is released = 1 in 1000 opportunities*
3. *Probability that a significant amount is spilled = 1 in 10*
4. *Probability of some ignition source = 1 in 10*
5. *Probability of people being present = 1 (i.e. everytime)*
6. *Probability of not escaping a fire once ignited = 1*

Expected consequence = 3rd degree burns if exposed to fire

Risk of 3rd degree burns to *any* operator unloading rail tank cars

= frequency x consequence

= 1000/yr x (1/1000) x (1/10) x (1/10) x 1 x 1

= **0.01 per year or once every 100 years**

Different Types of Risk

CASE 3 - Risk of harm from *random failure events*.

Random failure events can be from driving a car.

- In Ontario, there are 2000 deaths per year due to car accidents.
- Again we evaluate the occurrence of these events over a standardised period - per year.

Risk [death annually per car accident in Ontario] =

***frequency** [car accidents per year]*

** **consequence** [deaths per car accidents]*

Units: Risk - consequence/ year

Frequency – events/ year

Consequence – consequence/ event

Risk: Jaywalking – Individual vs. Decision Maker

Concerns about Hazards - Points of View

Individual Receptor

- *Consequence* – What can happen to me as a result of an undesirable event?
  - Could I die? Could I get injured? Could I be inconvenienced?
  - Could my property be damaged? What would be level and type of problem damage, income loss and cost of the repairs?
- *Likelihood* – What are the chances?
  - That I could die? That I could get injured? That I could be inconvenienced?
  - That my property could be damaged?
- *Risk* – Measurement of the combined importance of the consequences and likelihood of those consequences.
  - This will be used to make judgements of about the acceptability of the **individual** risk.

Concerns about Hazards - Points of View

Safety Decision Maker - Societal or Aggregate View

- *Consequence* – What can happen to the individual receptors exposed to the risk source?
  - Could anyone die, get injured, be inconvenienced? How many?
  - Could there be any property damage or production loss?
  - Could there be any environmental damage? How much?
- *Likelihood* – What are the chances?
  - That anyone could die, get injured, be inconvenienced?
  - That any property could be damaged?
  - That there will be any environmental damage?
- *Risk* – Measurement of the combined importance of the consequences and likelihood of those consequences.
  - This will be used to make judgements of about the acceptability of the **societal** risk.

Concept Definitions

Risk Analysis– The development of a quantitative risk estimate based on an engineering evaluation of incident *consequences* and *frequency*.

Risk Analysis: Plane Crash

Societal Risk (fatality) = *Number of fatalities* per incidents
x Number of incidents per year

Societal Risk (financial) = *Cost* per incidents
x Number of incidents per year

Concept Definitions

Safety – Relative protection from the exposure to hazards that lead to *severe and sudden outcomes*. *Safety is a measure and is achieved if risk are judged to be acceptable.*

People are not completely logical when it comes to analysing risk versus the cost of safety.

Concept Definitions

Health – Relative protection from the exposure to hazards that lead to illness or disease. This measure deals with adverse reactions to *exposure over prolonged periods to hazards* that are usually less severe but still dangerous.

Types of Acceptable Risk

Voluntary Risk vs. **Involuntary Risk**

- Mountain Climber
- Driving

- Assembly Line Worker
- Commercial Flight

Individual Risk vs. **Societal Risk**

- Motorcycle Crash

- Plane Flight

Each person has a level of individual and voluntary risk they will tolerate for their own safety. However, when considering involuntary and societal risk, we must accept a standardised level of risk.

Acceptable Risk Criteria

- In **Canada**, there is no specific legislative number criterion for protecting workers or the public. The Canadian Society of Chemical Engineers suggested acceptable risk criteria for land use planning when considering process hazards from a processing facility.

- The **United Kingdom** and the **Netherlands** are the only countries to have specific risk criteria for protecting the public regarding land use planning. HOWEVER, no specific number criteria for protecting workers exists.

Acceptable Risk Criteria

- Given the lack of national standards for worker's acceptable risk criteria, each **company establishes their own specific risk acceptability criteria**.

- A company will set their acceptable risk criteria relative to other risks that society has already accepted (*i.e.* benchmark) such as the risk of death from driving to work, risk death from a fire at home.

- Criteria will hopefully be influenced by employees, peers, society and government – if the company's standards are not adequate, someone will eventually tell them.

What is Acceptable Risk?

Judgement Zone

Risk

De Minimus

A risk that is too small to generate concern

ACCEPTABLE RISK

1×10^{-6} deaths/year in a community

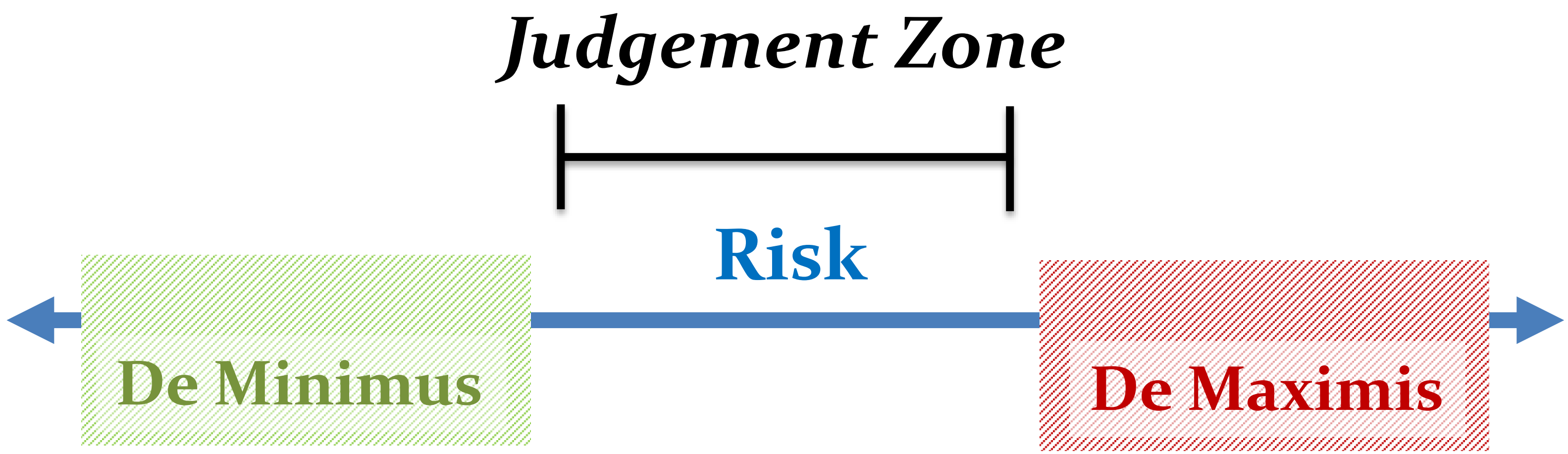
De Maximis

A risk that is too large and generates concern

UNACCEPTABLE RISK

1×10^{-3} deaths/year in a community

What is Acceptable Risk?



A risk that is too small to generate concern

A risk that is too large and generates concern

Toronto's Population = 3 million

Deaths per year

<3
Acceptable

>3000
Unacceptable

Acceptable Risk: Car Accidents

In 2010, there were 2,000 car accidents with 2227 victims.

The Canada-wide risk can be determined by accounting for the population of the nation (34 million)

$$Canada - wide\ Risk = \frac{2227\ fatalities\ per\ year}{34\ million\ population}$$

$$= 65\ x\ 10^{-6}\ deaths\ per\ year$$

ACCEPTABLE RISK ON A PER PERSON BASIS

Acceptable Risk: Ontario Workplace Injuries

In 2010, there were 184,099 people injured such that they could not go to work the next day.

There were 6.82 million workers in Ontario in 2010.

Ontario Injury Risk = 3 injures per year per 100 workers

Is this acceptable?

Who is responsible for risk?

The stakeholders responsible for identifying and managing risk include:

- *Employers*
- *Employees*
- *Government and other regulatory authorities*
- *Compensation and insurance provides*
- *The public*

In an organization, occupational health and safety involves everyone, from the chief executive officer to the worker. Employees and employers often are jointly responsible for occupational health and safety and employers are accountable for non-compliance.

Why bother with identifying hazards and risks?

- *Economics*
- *Legality*
- *Morality*
- Corporate image
- Employee and employer well-being
- Liability
- Insurance
- Professional Ethics
- Good corporate moral
- Employee recruitment

Why bother with identifying hazards and risks?

Morality

It is generally accepted that employers have moral responsibility their employees in providing a safe working environment

Economics

The indirect and direct economic costs of workplace accidents and illnesses are significant. Costs can be associated with the time lost from work, human pain and suffering, and the subsequent loss of moral and decline in worker efficiency and productivity.

Why bother with identifying hazards and risks?

Legality

Governmental legislation on occupation health and safety provides workers with the right to a safe work environment. In protecting workers, employers must exercise due diligence. For example, employers must take reasonable precautions appropriate for the circumstances. There are significant legal penalties for violating health and safety legislation; they can civil lawsuits and criminal prosecutions.

Checkpoint

This is a condition:

A. Health
B. Safety
C. Risk
D. Hazard

Answer: D

Checkpoint

This is considered to be an acceptable level of risk for societal or voluntary activities:

A. 1 in 10,000 deaths
B. 1 in 100,000 deaths
C. 1 in 1,000,000 deaths
D. 1 in 10,000,000 deaths

Answer: C

Checkpoint

This is the unit of risk analysis:

A. Cost per event
B. Fatalities per event
C. Fatalities per year
D. Extent of Injury per event

Answer: C

Checkpoint

Which of the following is a reason for a company to be interested in workplace safety?

A. Employee and employer well-being
B. Insurance
C. Corporate Image
D. Economics
E. All of the above

Answer: E

Checkpoint

Which of the following is a reason for a company to be interested in workplace safety?

A. Employee and employer well-being
B. Insurance
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D. Economics
E. All of the above

Answer: E

How do all these concepts fit together?

Hazards

Risks

Risk Assessment

Safety

Health

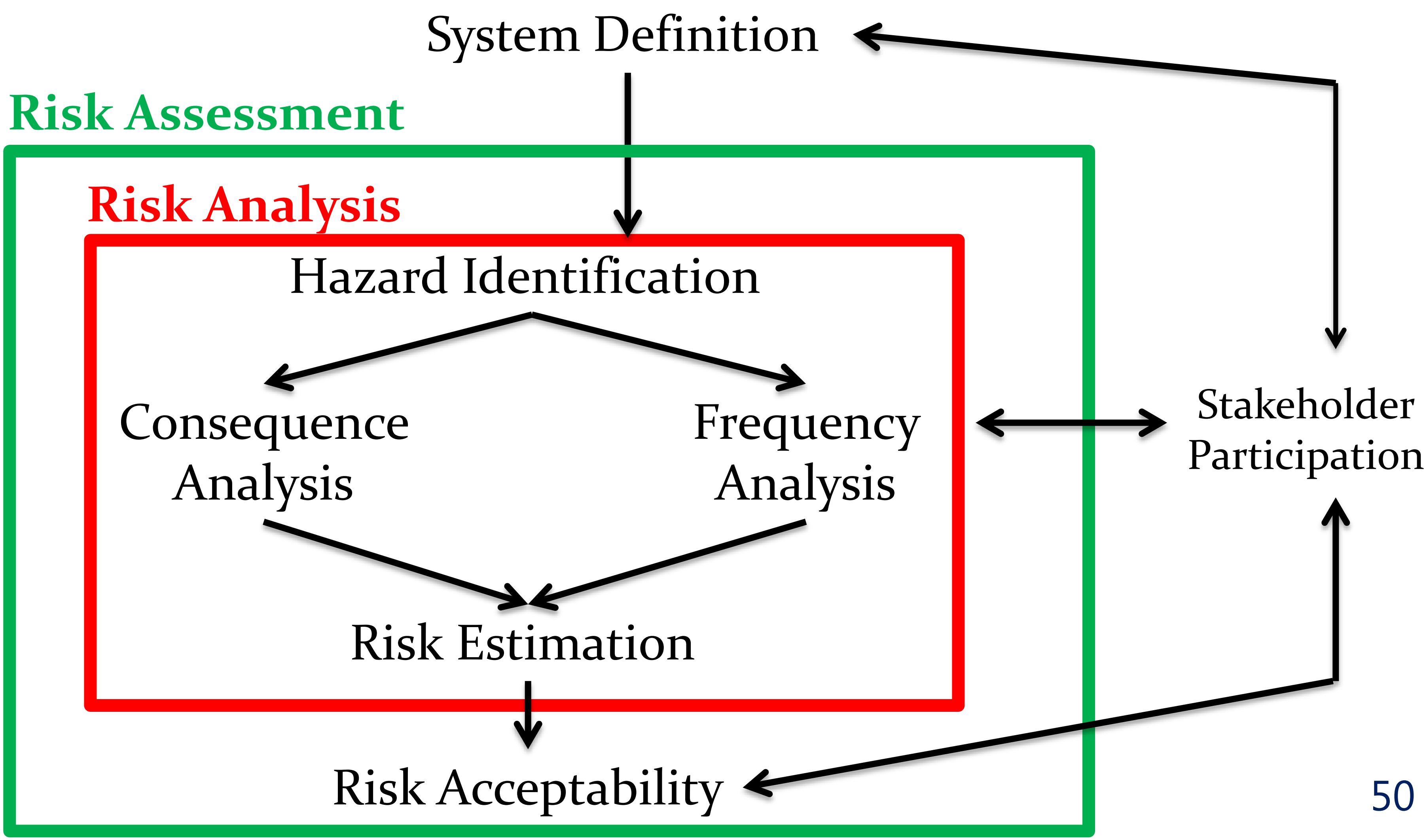
Stakeholders

Frequency

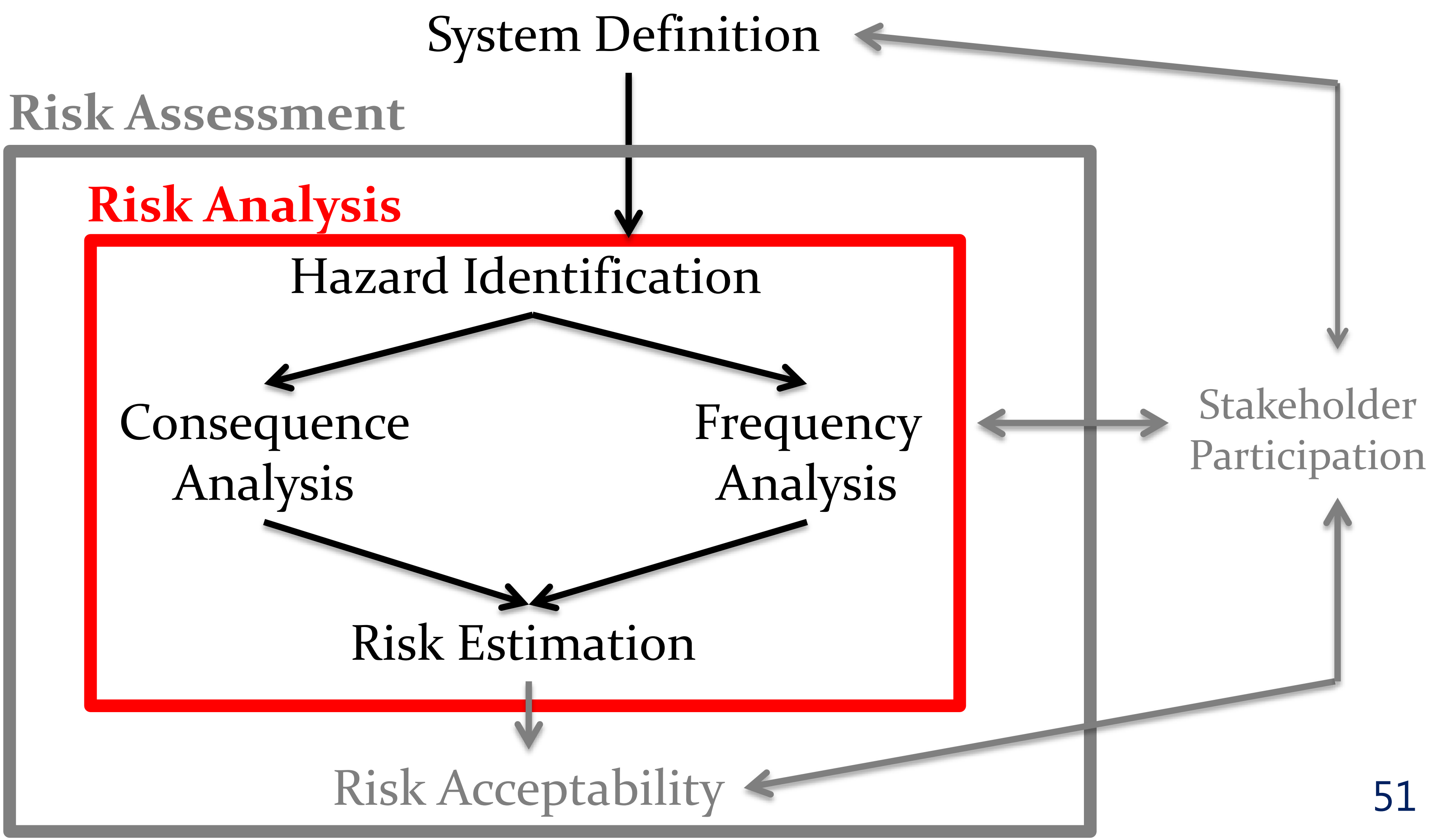
Risk Acceptability

Consequence

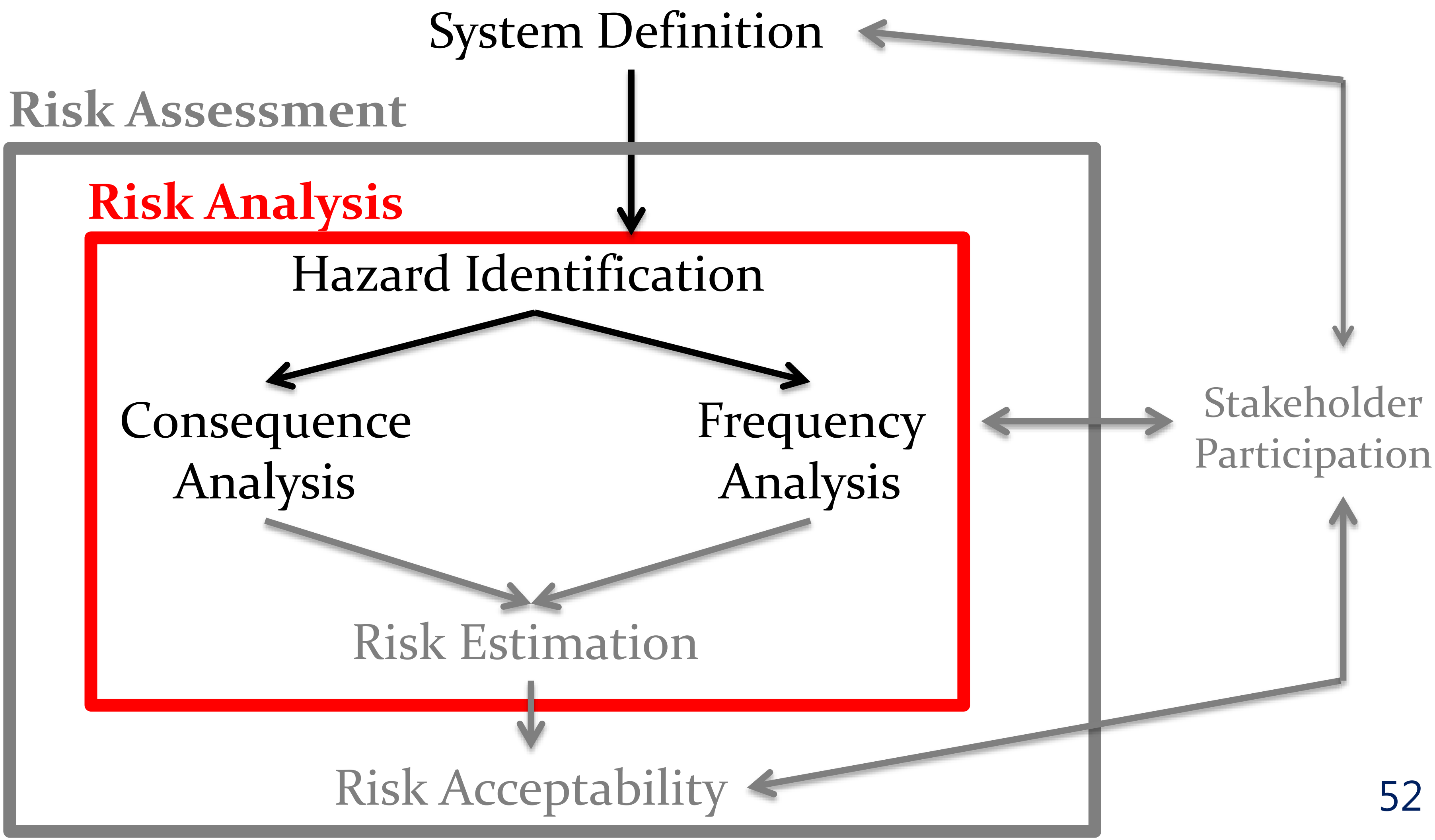
Hazard and Risk Framework



Hazard and Risk Framework



Hazard and Risk Framework



Hazard Identification

Hazard identification is conducted with a aim of understanding the intrinsic hazards associated with any given situation and their potential to cause damage.

Identify intrinsic *hazards*

↓

Think through hazard *event scenarios*

↓

Recognise the *consequences* of these hazard event scenarios and their *severity*

Let's get the hazard terminology right

Identified *Intrinsic Hazards*	**Undesirable *Hazardous Event***	***Hazard Effects***
Storage tank with flammable material	Spill resulting in an explosion and fire	Thermal radiation and explosion overpressure

Fires produce thermal radiation flux and explosions produce overpressure as well as projectiles. It is these conditions that can result in harm to people and property. It is important to be able to ***distinguish the events and effects of a hazard****.*

Where do we find hazards?

Hazards are often related to *energy*, most often potential energies.

- **Kinetic Energy**
  - Involved with *moving* equipment
  - Momentum is proportional to velocity squared. Equipment moving with higher speeds pose greater consequence. A car moving collision at a high speed will cause more damage.
  - *Machine guards* are good safeguards to keep people away from equipment with moving parts.

- **Potential Energy**
  - Associated with changes in elevation (a box placed on a high shelf) or pressure (a vacuum system).
  - Pipeline are typically elevated in chemical facilities which places liquids in tanks and vessels 5 – 20 m above ground.

Where do we find hazards?

Hazards are often related to *energy*, which can also include:

- **Heat**
  - Released from chemical reactions – unreacted molecules are a source of potential energy, when reacted heat is released.
  - Hot surfaces can initiate fires and explosions which can cause severe burn.

- **Electricity**
  - Hazards can result from electric shock, arcing incidents or electrical fires
  - Shocks are the most common and may occur through direct contact of an energised conductor or contacting two points at different electrical potentials. Shock can cause fatalities.

Hazards on different scales

Individual

Workers

Facility

Community

Hazards on different scales

Individual

Workers

Facility

Community

University Lab Injuries

Injuries that can involve you

Yale UNIVERSITY

- Michele Dufault, a final year Yale undergrad student, died when her hair got caught in a lathe when working alone in the Chemistry workshop at 2:30am.

Hazards on different scales

Individual

Workers

Facility

Community

Health Care Industry

Worker Injuries



- Healthcare workers have the greatest risk of workplace injuries and mental health problems than any other occupational group.
- Back injuries are the biggest worker injury issue
- 3.7 injuries per 100 full time employees

Hazards on different scales

Individual

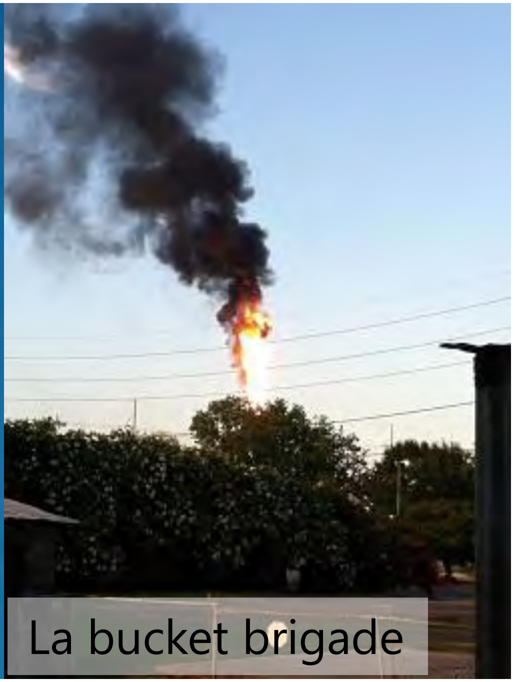
Workers

Facility

Community

Norco, Louisiana

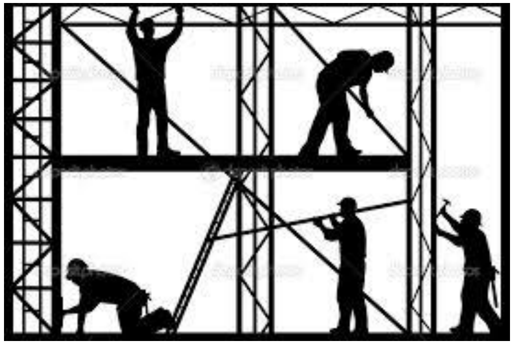
1988 – Shell Oil Refinery Explosion



- Resulted from an equipment failure
- Large releases of benzene, hydrogen sulphide, butadiene
- 7 deaths, 42 injuries and $400 million in damages

Hazards on different scales

Individual



Workers

Facility

Community

Gulf of Mexico, US

2010 – BP Deepwater Horizon Oil Rig Spill

- High pressure methane gas explosion
- 4.9 millions of barrels of oil spilled in gulf (780,000 m^3)
- 11 deaths, significant injury and deaths in wildlife population

Hazard Identification

Start to looking for energy sources or release mechanisms.

Energy Sources

- Leak from a flammable gas vessel into the air can create an ignitable mixture.
- This hazard can be minimised by using proper construction materials, regular leak testing and installing explosion proof electrical connections.
- These safeguards reduce the risk the likelihood of the hazard but cannot eliminate it.

Release Mechanisms

- Large reactors and vessels can be major problems given the volume of material stored.
- As tank size increases, surface area to volume ratios decrease. The ability for tanks to release heat is proportional to the surface area (d^2) and the energy content is proportional to the volume (d^3).

Hazard Identification – Primary Tools

- Common Sense
- Open mind
- Good understanding of physics, chemistry and thermodynamics
- Experience – first hand or access to historical data

- **Process Hazard Analysis**
  - Screening Level
  - Checklist
  - What-if
  - Failure Modes and Effects Analysis (FMEA)
  - Hazard and Operability Study (HAZOP)

Qualitative Techniques

All techniques seek to understand the physical components of the system, the operation and the factors influencing failure frequency.

*Process Hazard Analysis techniques present a **pro-active** and **systematic** approach for the identification, mitigation or prevention of hazards from a process, materials, equipment or human error.*

The purpose of Process Hazard Analysis :

- Determine the location of the potential safety problem
- Prevent or mitigate the improvement of safety measures of a problem
- Pre-plan emergency actions that should be taken if the safety controls fail

Process Hazard Analysis methods address:

- Any hazards in an process
- Previous incidents which could have resulted in catastrophic outcomes
- Engineering controls that can be used to prevent or mitigate hazards
- Consequences of hazards
- Human factors that could cause hazards

Process Hazard Analysis can miss some hazards…

- No method is capable of identifying all hazards in a system
- It is feasible for a hazard to be excluded from the scope if the engineering team is unaware of a hazard event scenario
- It is essential that the team seriously consider all hazard event scenarios

Hazard Identification – So many techniques, which one to choose?

Selecting a hazard identification technique is typically influenced by the following factors:

- Motivation
- Type of result needed
- Type of information available to perform the study
- Characteristic of the analysis problem
- Perceived risk associated with the subject process or activity
- Resource availability and preference of the analyst

Hazard Identification – Common Technique Application

	Screening Level	Checklist	What-if	FMEA	HAZOP
Research & Development	✓		✓		
Conceptual Design	✓	✓	✓		
Pilot Plant Operation	✓	✓	✓	✓	✓
Detailed Engineering	✓	✓	✓	✓	✓
Construction	✓	✓	✓		
Routine Operation	✓	✓	✓	✓	✓
Plant Expansion or Modification	✓	✓	✓	✓	✓
Incident Investigation	✓		✓	✓	✓
Decommissioning	✓	✓	✓		

Hazard Identification – Qualitative Techniques

- *Screening Level* is the recommended starting point to through evaluation of all significant hazards

- This screening level technique should be immediately followed by more detailed analysis for *identified hazards* that warrant further examination.

- When all significant potential undesirable events are identified then their *consequence and frequency* will be investigated.

- Risk evaluation then produces a *risk ranking list* which allows management to set priorities and define alternative *risk control* measures.

Hazard Identification – Moving beyond Screening Level

- Once a Screen Level is complete then other more detailed methods can be applied

- Hazard and Operability Study (HAZOP) is recommended as the second analysis stage of **process systems**

- Failure Modes and Effects Analysis (FMEA) is recommended for the second, more detailed qualitative analysis complex **equipment or machinery**.

Let’s now discuss each of the qualitative hazard identification methods in more detail.

Screening Level For Hazard and Risks Identification

- Focus on *identifying major hazards that could lead to severe consequences*.

- This technique can be applied to:
  - Existing permanent and temporary processes, equipment and machinery during the implementation phase of a Process Safety/ Risk Management Programme
  - New facilities during their conceptual design and detailed engineering phases
  - Major modification to existing facilities

This PHA technique…

- Uses a *process-focused protocol* to identify potential undesirable events
- Relies on participation of *front-line personnel* through physical inspections

We'll now walk through the individual steps of performing screen level.

Overview of the Procedure

1. Collect and review **information** about the facility
2. Divide the facility into **process sections**
3. Compile a list of **intrinsic hazards** for each process section (ie. chemical, equipment and external events).
4. Identify **hazardous events** in each process section
5. Evaluate the potential **causes**.

STEP 1

Collect *general information* about the engineering facility:

- Facility plan, equipment layout, map, transportation routes
- Equipment and process descriptions
- Chemicals handled
- Spill containment and emergency response systems
- Environmental, occupational health and safety, process safety, loss control quality management systems
- Incident history

STEP 2

Divide the facility into *process sections*. This will enable consideration of the all process areas, auxiliary services including transportation and distribution facilities.

Let's consider an example of process sections at a product distribution business:

At the company site

- Storage
- Loading
- Electrical supply
- Wastewater treatment system
- Firewater protection system
- Shops building
- Fuel depot

External to the company site

- Rail transport
- Truck transport
- Marine transport
- Distribution terminals
- Customer sites

STEP 3

List potential inherently hazardous items for each process section. *Ask yourself what can go wrong?*

- Equipment
- Chemicals
- Electrical systems
- Facility's building structure

This information can be collected by interviewing operators and engineer designers, reviewing previous hazard studies and by inspecting each of the process sections.

Hazard identification in a screening level involves consideration of:

- The hazards of each process section
- Previous hazardous incidents
- Engineering and administrative controls
- The consequences of engineering and administrative control failure
- Human failure
- Maintenance programmes
- Process safety, safety and loss control programmes

There are some helpful tools for identifying hazards associated with each process section:

- **HazMat checklist** – properties of the chemical and material hazards
- **Compatibility matrix** – consequences of interaction between chemical or materials
- **Equipment Hazard checklist** – overview of potential operating failures
- **External Initiating Factors checklist** – events induced by adjacent facilities or natural causes

A ***HazMat** checklist* is a useful tool for rigorously understanding the *hazards and potential consequences of **materials***.

Company:
Location:
Date:

Participants:

By:

Hazard Review Section:

Materials, Chemicals or Components	Physical State (Liquid, solid, powders)	Quantity (Throughput or inventory)	Operating Pressure	Operating Temperature	Compressed or Liquefied Gas	Fire	Explosion	Oxidiser	Corrosive	Reactive	Radiation	Air or Water Pollutants	Smells/Fumes	Toxic – Acute /Chronic	Detonation	Ground Contaminant

It is also useful to consider how materials in each process section will interact. A **compatibility matrix** is a useful tool.

	Chemical 1	Chemical 2	Chemical 3	Chemical 4	Chemical 5	Chemical 6	Chemical 7	Chemical 8	Chemical 9	Chemical 10
Chemical 1										
Chemical 2										
Chemical 3										
Chemical 4										
Chemical 5										
Chemical 6										
Chemical 7										
Chemical 8										
Chemical 9										
Chemical 10										

An ***Equipment Hazard*** *checklist* is a useful tool for rigorously understanding the *hazards and significant losses associated with equipment* in each section.

Company: Participants: By:
Date:
Location:

Hazard Review Section:

Equipment or Workspace	Stationary or Mobile	Operating Pressure	Mechanical Energy	Pressurised Systems	Heat	Extreme Cold	Electrical Energy	Impact/ Collision	Falling/ Flying Objects	Radioactive	Confined Space	Noise	Sharps	Seismic	Rock/ Mud Flow	Capital Value >$500k	Production Value >25%

An ***External Initiating Factors** checklist* is a useful for understanding hazards from adjacent facilities or environments in additional to natural events.

Company: Participants: By: Date:
Location: Hazard Review Section:

Process Area	Geotechnical Events							Other External Events								Operating Events					
	Seismic Activity	Avalanche/ Landslide	Soil Shrinkage/ Consolidation	Erosion	Waves	Flows and Drainage	Containment (normal, surge)	Drought	Flooding/ Rain/ Snow Melt	Extreme Cold/ Ice Cover	Extreme Heat	Extreme Winds	Fog	Forest Fire	Hail	Internal Flooding	Maintenance Activity	Construction	Sabotage/ Vandalism	Night Work	Power Failure

STEP 4

Pair each inherent hazard (chemical, material, equipment, initiating factor) with an action to develop a list of *hazardous events*.

- Release
- Fire
- Exposure
- Failure

Here is an example of a selection of hazardous event list for a chemical plant:

Process Section	Hazardous Event
Natural Gas Supply	Jet Flame
Process Steam Supply	Boiler Explosion
Feed Gas Preparation	Spent Catalyst Bed
Reformer Unit	Firebox Explosion
Shops Building	Drum Spillage
Fuel Depot	Gasoline Leak from Tanks
Carbon Dioxide Injection System	Liquid Spill
Methanol Separator	Gas Release and Fire
Distillation Section	Pool Fire
Electrical Supply	Pool Fire
Cooling Tower	Carryover Emission

STEP 5

List all major *potential causes* of identified hazardous events.

Use **checklists to organise the causes** into 5 categories:

- *Open-ended loss of containment* – drains, vents, relief valves, etc.
- *Internal agency* – disintegration of rotating machinery, blockage, etc.
- *External agency* – collision, weather, seismic, etc.
- *Equipment failure while operating* within design conditions due to deterioration, faulty maintenance or improper replacement of materials.
- *Equipment failure by exceeding design limits* on pressure, temperature and composition

Finishing up a Screening Level

- Develop a scope for a more detailed hazard identification analysis (i.e. HAZOP).
- Identify opportunities for improvement:
  - Physical plant (design, maintenance, technology)
  - Employee training
  - Management systems/ integration
  - Emergency response
- Assign priorities to improvement opportunities based on the priority of the risk they are designed to address
- Assign responsibility
- Follow up

Checklists

- A checklist is a detailed **lists of known intrinsic hazards or hazardous events** compiled based on past experience facility design and operation.
- Questions are answered with a 'Yes' or 'No'
- Hazards are identified through compliance with established standards

It is essential that checklists be validated for system before use.

Checklists

Purpose

- Identify hazards
- Check compliance with a set of standard procedures

Reviews

- Existing systems – tours, inspections, interview
- New process – team member review of process drawings

Results

- Responses to standard checklist questions
- List of hazards and suggested corrective action

Categories and Questions

- **Causes of Accidents**

  Process equipment, human error, external events
  - Is the process equipment properly supported?
  - Is equipment properly identified?
  - Is the system designed to withstand a tsunami?

- **Facility Functions**

  Documentation and training, instrumentation, construction materials, piping, pumps, vessels, control systems, alarms, etc.
  - Is it possible to distinguish between different alarms?
  - Is pressure relief provided?
  - Is the vessel free from external corrosion?
  - Are sources of ignition controlled?

Advantages

- Can be used by non-system experts
- Capture a wide range of historical experience and knowledge
- Ensures common or obvious problems are not overlooked

Disadvantages

- Limited application to new systems
- Inhibits creative thinking about new hazard identification
- Overview hazards that have not been previously identified

Final details of the Checklist procedure

- The simplest process hazard analysis techniques
- Provides quick results and communicates information wells
- Good way to account for learned lessons
- NOT a good method for identifying new or unrecognised hazards
- Application requires good knowledge of the system and standard operating procedures
- Requires regular updating and auditing

What-if analysis

- Experienced personnel brainstorm a series of 'What if' questions.
- Each question represents a potential failure or hazard in the facility
- If it is possible for a hazard to occur then the safeguards must be evaluated for the severity of the consequence

Examples

Equipment failures – *What if … a pump fails?*
Human error – *What if … an operator fails to clean up a chemical spill?*
External events – *What if … there is a rapid snow melt?*

What-if analysis

Purpose

- Identify hazards and consequence to develop risk mitigation strategies

Requirements

- Process descriptions, drawings and operating procedure
- Preliminary list of what-if questions

Analysis Procedure

- Go through the system process, starting with the introduction of the feed until the end of the process
- Ask ‘what-if’ at each process stage

Results

- Recommendations on the effects of removing hazards

Overview of the procedure

1. Collect and review information about the facility
2. Divide the facility into process sections
3. Select a question and identify:
   - Hazards
   - Consequences
   - Severity
   - Likelihood
   - Recommendations
4. Repeat Steps 4 – 6 until process is complete

Here is an example of **what-if questions** for a plant:

Area	What-if	Hazard and Consequence	Previously Addressed	Safeguard	Recommendations?
Chemical 1	Connects to the wrong line when loading off truck?	1) Released into the air - an explosion is possible 2) Gets wet - bacteria will grow and become useless.	No	1) Lines are sized differently 2) Labelled 3) Colour coded 4) Use a reliable vendor	1) Vacuum system to remove dust 2) Perform a moisture test
	Truck's ignition is on while unloading?	Exhaust fumes – adverse health effects	No	None	1) Turn engine off 2) Local ventilation system
	The dust collector fails?	Dust accumulation – adverse health effects	No	None	1) Place an alarm with lights and horns in the truck unloading area.

Final details of the What-if procedure

- One of the most commonly used process hazard analysis techniques
- One of the least structured techniques
  - Applicable to a large range of systems
  - The experience of the analyst determines if the technique will be successful
- Useful when making a change to a process section
- Can be applied to a system at any point in its life cycle

Failure Modes and Effect Analysis

- Lists ways equipment can fail and the effect on the system.
- Bottom-up analysis
- Uses a spreadsheet to detail each hazard, cause, frequency, consequence and proposed safeguard

Failure Modes and Effect Analysis

Purpose
- Assess component failures and the hazards caused
- Develop recommendations for better equipment reliability

Requirements
- Process descriptions, drawings and operating procedure

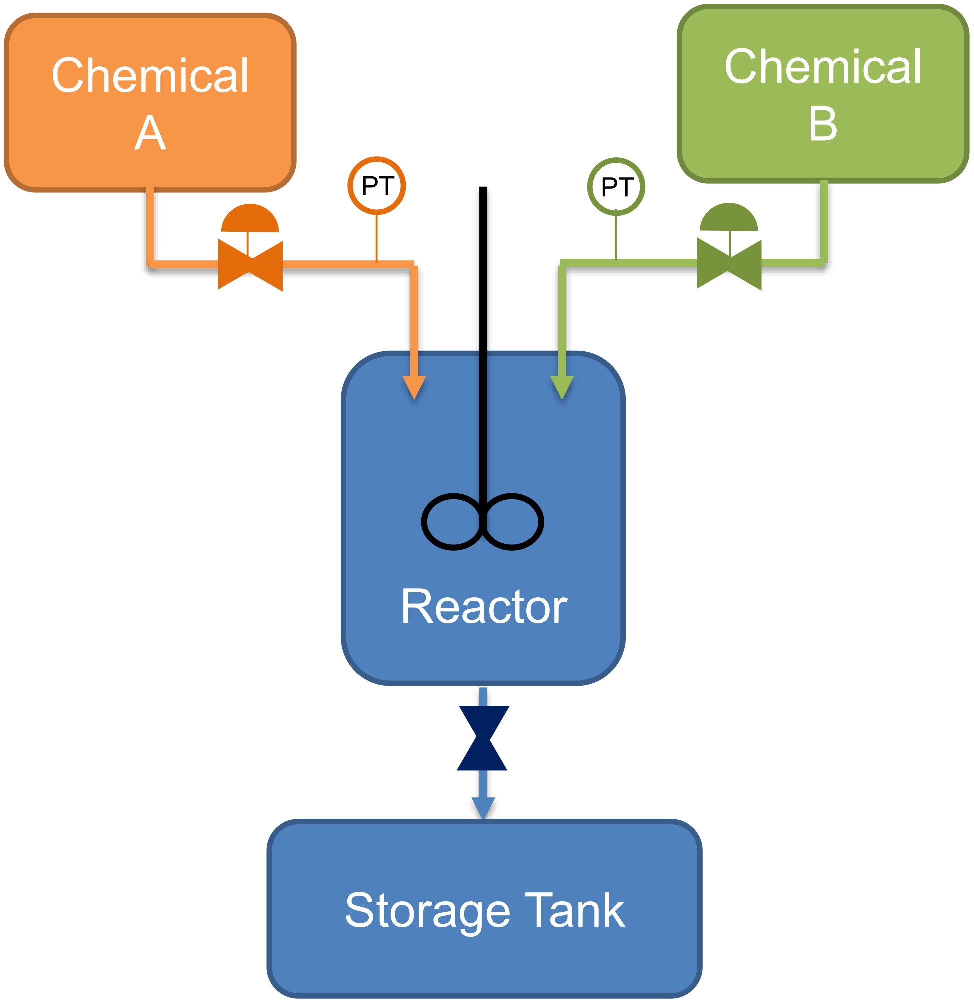
Analysis Procedure
- Go through the system process, starting with the introduction of the feed until the end of the process
- Complete the FMEA table

Results
- Recommendations on safeguards to avoid hazards associated with equipment failures

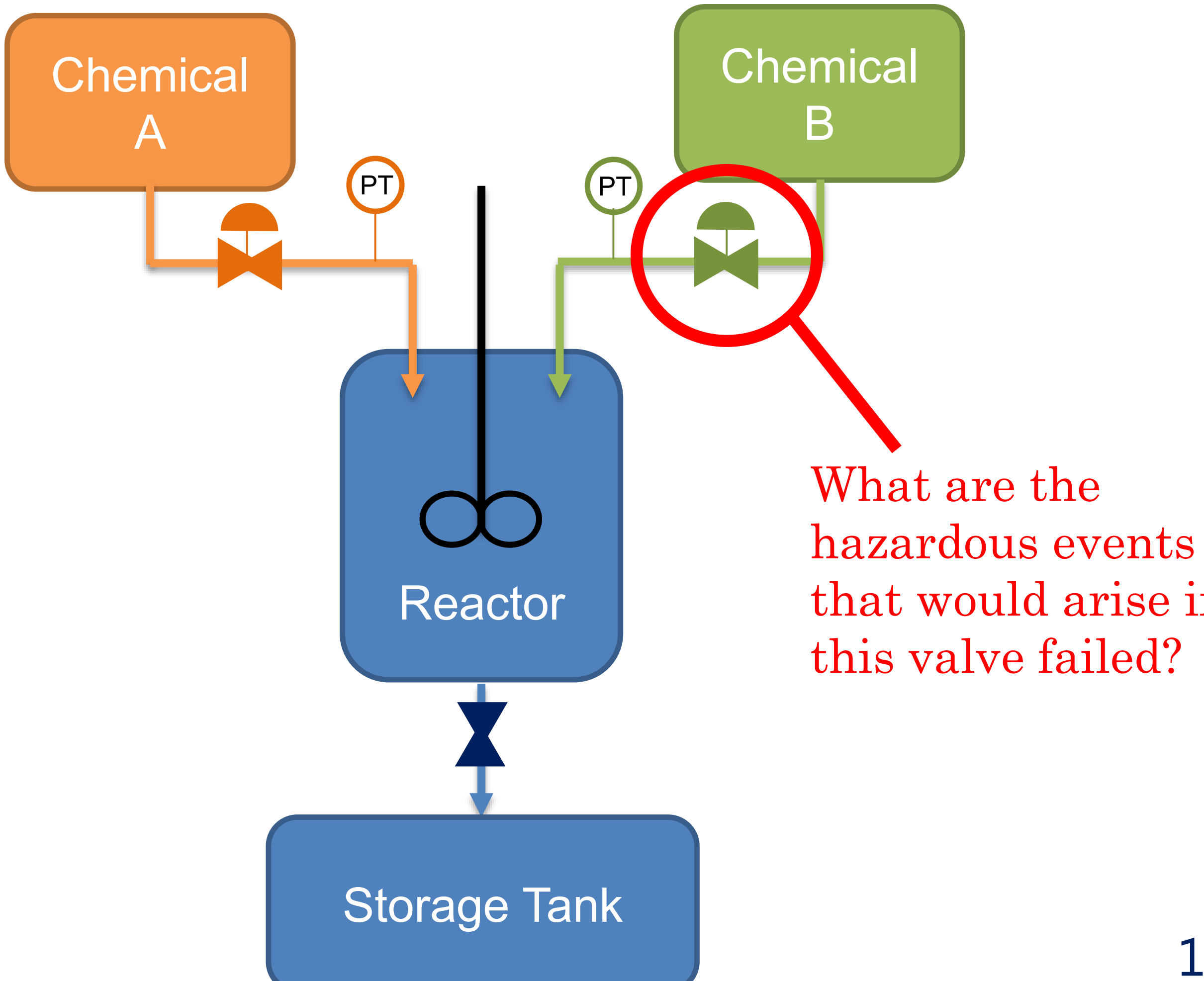
Keywords for FMEA analysis

- Crack
- Rupture
- Plugged
- Leak
- False start or stop
- Loss of function
- High or low pressure
- High or low temperature
- Overfilling
- Failure to open or close
- Failure to start or stop

What are some point of failures in this chemical system?



What are some point of failures in this chemical system?



Here is a FMEA example for valve failure on chemical B:

Date: October 15, 2013 Page: 7 of 25 By: Minerva
Plant: Chemical Toronto
System: Reaction System

Item	Identification	Description	Failure Modes	Effects	Safeguards	Actions
3.1	Valve on the chemical B solution line	Motor-operated and normally open for chemical B service	Fails closed	No flow of chemical B Carryover of chemical A to the storage and released in the enclosed work area	Flow indicator on chemical B line Chemical A detector and alarm	Consider alarm/ shutdown of system for low chemical B flow Consider using a closed storage tank or ensure adequate ventilation of enclosed work area

Final details of the FMEA procedure

- Very structured process hazard analysis technique that is reliable for evaluating systems
- Easy to learn and apply the technique
- Can be time-consuming and expensive as the technique doesn't directly identify process sections where multiple faults could occur
- The technique may not identify areas of human error in process sections
- Procedural review is not easy

Hazard and Operability Study

Structured brainstorm using guide words to identify *hazards* (health, safety and environmental) and *operations* in a system.

Purpose

- Systematic identification of hazards

Requirements

- Process descriptions, drawings and operating procedure

Analysis Procedure

- Evaluate deviations from normal operation as potential hazards

Results

- Understand hazards and consequences for process sections
- Recommendations of safeguards as a protection against the hazards

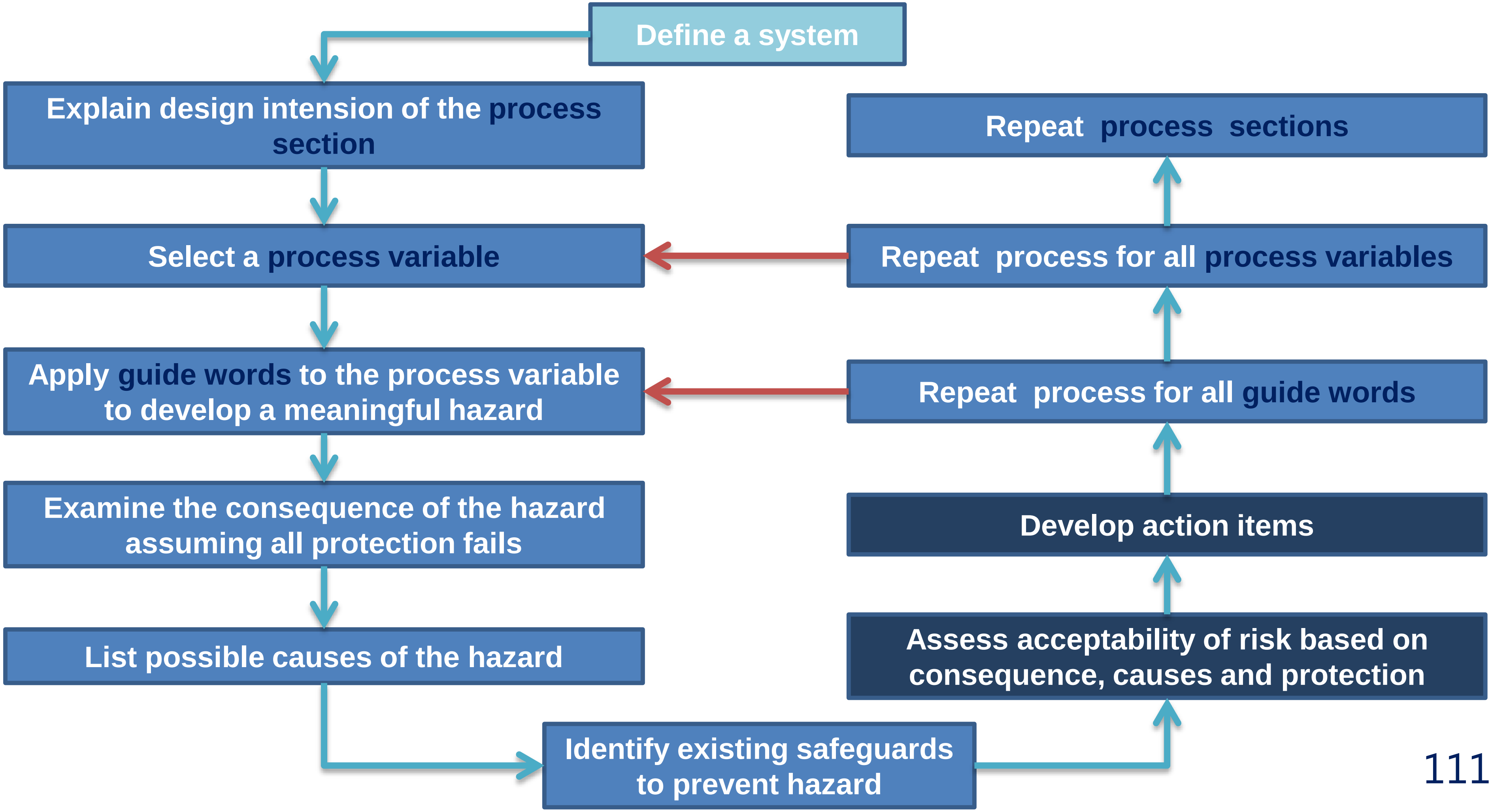
Before going through details of the HAZOP procedure, let's review some *relevant terminology*:

Intentions	How the process operations are expected to occur
Hazard	Departures from the design intentions
Causes	Ways the hazard might occur
Consequences	Results of the hazard
Safeguards	Provisions for reducing the frequency or decrease the severity of the consequence of the hazard
Actions	Suggestions for the procedural changes, design changes or further study

When performing a HAZOP there are *several general hazard types* of you should focus on:

- Leak
- Rupture
- Reaction
- Static
- Corrosion or Erosion
- Relief
- Sampling
- Testing
- Maintenance
- Start-up
- Shutdown
- Service Failure

Over view of the Procedure



What is meant by *process variables*?

- Flow
- Pressure
- Temperature
- Level
- Time
- Composition
- pH
- Speed
- Frequency
- Viscosity
- Voltage
- Mixing
- Addition
- Separation
- Reaction

Be aware not all combinations make sense!

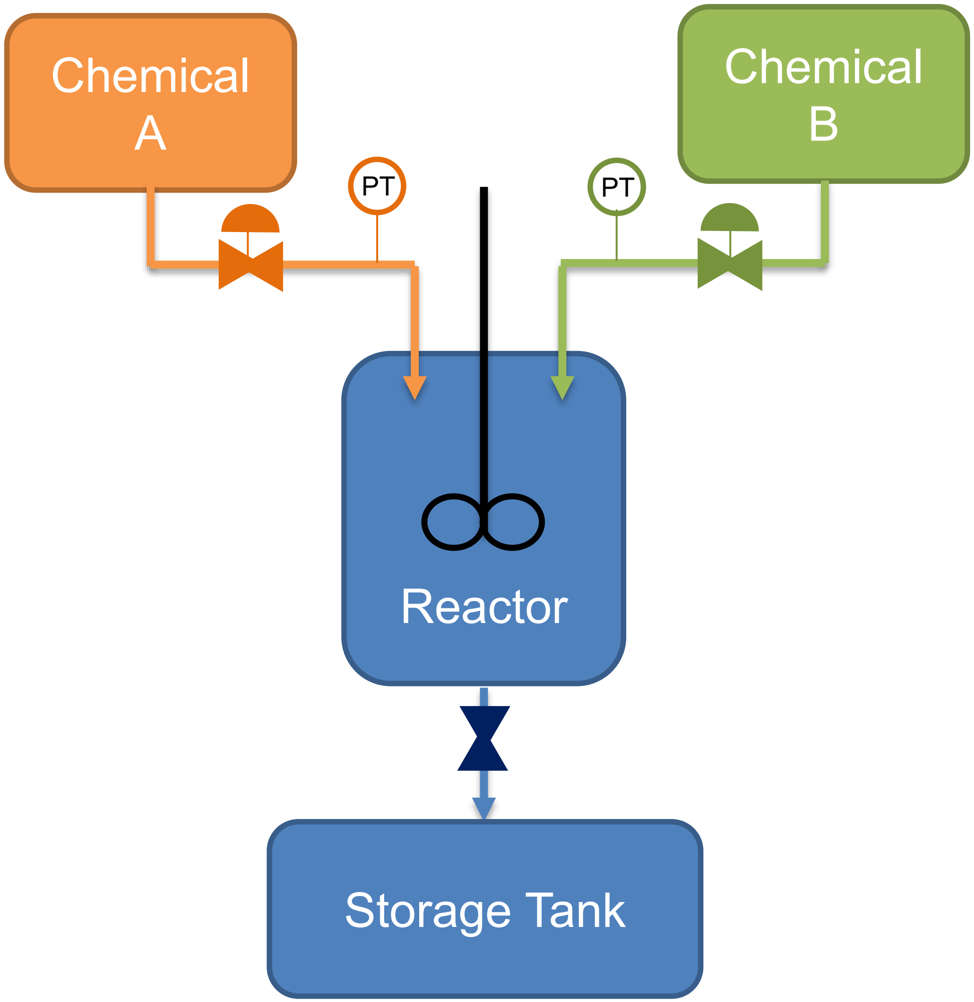
HAZOP uses guide words to identify process deviations which could lead to hazards:

Guide Words	Meaning
No, not	Not doing what was intended
More (high, long, …) Less (low, short, …)	Doing more, or less, of what is intended, quantitative increase or decrease
Part of, As well as	Doing it differently; qualitative decease or increase
Reverse	Doing something else; logical opposite of the intent
Other Than	Doing something else; complete substitution

Guide Word + Process Parameter = Process Deviation

Example: *Less* *Flow* *No reaction*

Example of hazards resulting from process deviations



Process Variables

Flow, Temperature, Pressure

Guideword + Process Variable Combinations

- *No* **Flow** of Chemical A
  = No reaction
- *High* **Temperature** in reactor
  = degradation of product
- *Low* **pressure** in storage tank
  = flow out of reactor accelerated

This technique makes some inherent assumptions…

- Hazards are detectable with careful review
- Engineering facilities are designed and operated to appropriate standards
- Hazards can be controlled by a combination of equipment, procedures
- This technique is conducted with openness and good faith by competent analysts

This identification procedure has ***limitations***:

- Requires a well-defined system
- It is time consuming
- Provides no numeric ranking of hazards
- Requires trained personnel to conduct
- Focuses on one-event failures

Advantages

- Creative and open-ended
- Rigorous and structured procedure
- Very versatile
- Identifies ***both*** safety and operational hazards

Disadvantages

- Can be time-consuming
- Critical that experienced analysts are involved in the process
- No distinction between low and high probability and consequence hazards

The aim of a HAZOP is to identify the cause of the process deviation which could lead to hazards.

Summary of Hazard Identification Techniques

What are the end products?

- A list of intrinsic hazards
- A list of hazardous events and existing/ potential prevent/mitigation strategies:
  - Event scenarios
  - Their potential causes
  - Existing safeguards
  - Possible additional safeguards
- A list of potential consequences and their frequency
  - Low chance of burn injuries or death,
  - Moderate change of damage to process equipment,
  - Low change of injury or death from toxic gas inhalation

Summary of Hazard Identification Techniques

How are these techniques conducted?

- Checklists are often completed by a knowledgeable individual such as a design engineer.

- What-if, FMEA and HAZOP hazard reviews are done in teams involvement at minimum a facilitator, design engineer and representatives from the operations team (engineer, coordinator).

- *It is always a good idea to review the results of any hazard review with representatives from the operations team and/or asset owners.*

Checkpoint

Process Hazard Analysis presents techniques what purpose:

A. Identification of hazards
B. Mitigation of hazards
C. Prevention of hazards
D. A , B and C
E. A and C

Answer: D

Checkpoint

Process Hazard Analysis should be conducted in parallel with:

A. Common sense
B. An open mind
C. A good understanding of physics, chemistry and thermodynamics
D. All of the above
E. None of the above

Answer: D

Checkpoint

For routine plant operation, which Process Hazard Analysis tool is the best to use?

A. Screening Level followed by FMEA
B. Checklist followed by HAZOP
C. Checklist and What-if
D. Screening Level, What-if or HAZOP
E. Screening Level, Checklist, What-if, FMEA or HAZOP

Answer: E

Checkpoint

Which of the follow is false about checklists as a hazard identification technique?

A. The method is applicable to new systems
B. It is possible to capture a range of historical system knowledge
C. Ensures that common problems are not overlooked
D. New users are able to use the approach

Answer: A

Checkpoint

Which best describes a failure modes and effect analysis approach?

A. Bottom-up analysis

B. Top-down analysis

Answer: A

Hazards caused by Human Error

Materials, equipment and electrical components in a process can be attributed to hazards. However, human factors can also cause errors which lead to hazardous events.

What causes workplace injuries?

- *4% are due to unsafe work conditions*
- *96% result from unsafe worker actions*

Unsafe behaviours are often repeated when observed as being "safe" (ie not injured).

John Foster (Dupont)

Rail crossing Video – first time no injury, second attempt near miss

The Safety Iceberg

What lies below the water?

Major Facility Accidents (BP Oil Spill)

Medical treatment
First aid care
Near miss incidents

Most errors happen below the water, they are small and often go unnoticed by upper management. It is essential to focus on this level of hazards as they commonly propagate into larger hazards over time.

Understanding Human Limitations

Human error can be best prevent by understanding the main factors which mediate the limitations of human behaviour:

- Attention
- Perception
- Memory
- Logical Reasoning

Understanding Human Limitations

Attention

- Huge amounts of information overloads humans in the workplace and attention on a task can only be sustained for short time, about 20 minutes.
- Workers are prone to fatigue and errors when their attention is not focused.
  - *Information Bottleneck* – attention can only be focused on a small number of tasks.
  - *Habit Forming* – If a task if repeated often then we tend to completed it without any conscious supervision. Regular, repetitive behaviours can cause mistakes.

Are you still focused on hazard identification?
Take a quick stretch.

Understanding Human Limitations

Perception

- Safe interaction in the workplace requires correct perception of hazards – information can be easily misinterpreted.
    - *Interpreting the senses* – we interpret information we sense rather than perceiving it directly. Errors can be minimised by making information more visual.
    - *Signal Detection* – More intense stimuli cause more powerful responses. Danger signs in the workplace are purposely designed to provoked a response.

Traffic lights signal to stop with a red light (most dangerous) then yellow and finally green to go (no danger).

Understanding Human Limitations

Memory

- The amount of information expected that workers remember can cause great stress.
  - *Capacity* – Short-term memory has very limited capacity.
  - *Accessibility* – It can be difficult to access details stored in our memory.
  - *Levels of processing* – Learning material at great depth helps us more reliability remember information.

Understanding Human Limitations

Memory

Take a look at these risk related terms.

Quantitative Analysis	Effect Modelling	Risk Management
Bow-tie	Probit	Continual Improvement
Layers of Protection	Fixed Limit	Stakeholders
ALOHA	Toxicity	Learning Loop

Understanding Human Limitations

Memory

How many of those risk terms can you remember?

Understanding Human Limitations

Memory

On average, people can remember no more than **7** individual items at one time.

If you were told these terms were grouped into three topics, it is likely your retention of this information would have been improved:

Quantitative Analysis	**Effect Modelling**	**Risk Management**
Bow-tie	Probit	Continual Improvement
Layers of Protection	Fixed Limit	Stakeholders
ALOHA	Toxicity	Learning Loop

Understanding Human Limitations

Logical Reasoning

- Not all people are good at logical thinking but technical situations require logical procedures.

- Severe implications can result from failures in reasoning and decision making in engineering facilities.

Design Principles for a Good System

To prevent hazards caused by human error, it is essential that a system inhibit people from making mistakes easily.

There are 6 design principles for creating a good system:

- User-centred Design
- Managing Information
- Reducing Complexity
- Visibility
- Constraining Behaviour
- Design for Errors

Design Principles for a Good System

User-centred Design

- There is often a difference in how the user thinks about the system and the system itself. This discrepancy happens because the system designer rarely becomes the system user.
- The design needs to think about the expectations and intentions of the user.

Design Principles for a Good System

Managing Information

- We are easily distracted which cause us to forget essential tasks.

- Maintenance tasks are an example of easily omitted tasks:
  - *At home* – How large is your pile of laundry or dishes by the sink?
  - *At an engineering facility* the same issues arise. When workers are under time pressure, replacing worn gaskets can be overlooked.
  - A simple solution to both examples would be to include these maintenance items on a daily checklist or put them into your calendar.

Design Principles for a Good System

Reducing Complexity

- The more complicated a task, the more likely there will be human error.
- By structuring tasks to be as simple as possible, our ability to manage information is improved.
- For example, this online module was organised into 6 sections that were placed in a logical sequence. This was done to reduce complexity of the material and facilitate the learning process.

Design Principles for a Good System

Constraining Behaviour

- If it were possible for a system to inhibit a user from performing any dangerous actions then there would be no accidents. This is impossible as the real world is too complicated!
- ‘Forcing functions’ is a concept that is useful when trying to push users to follow a series of steps.

An example of constrained behaviour is a cash machine.
- Before you can walk away with your cash, the machine prompts you with lights and a sound to first remove your cash card. This prevents the user from walking away without their card.

Design Principles for a Good System

Design for Errors

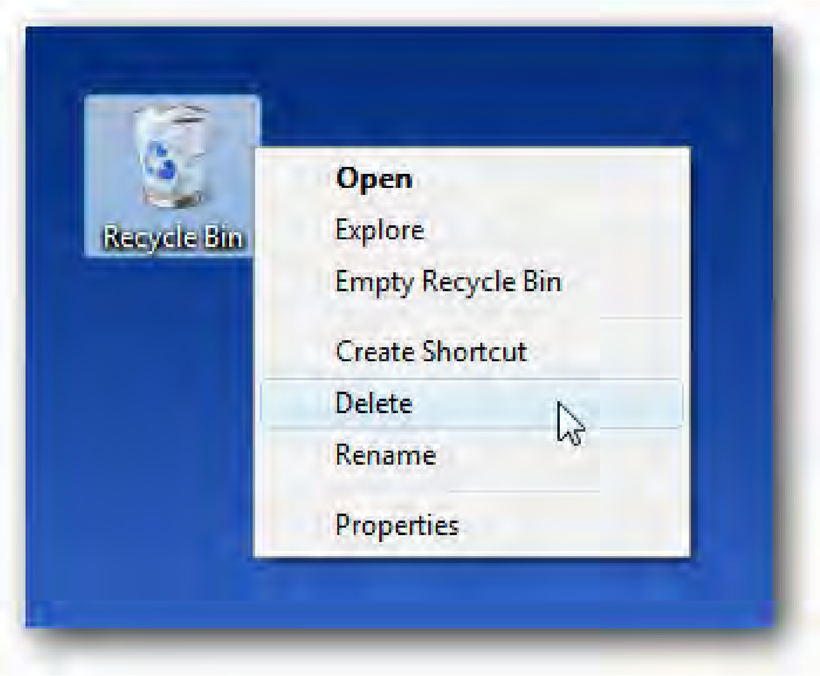
- When a system is designed, you must assume that mistakes will happen. When these mistakes happen, it is necessary that essential systems be designed to recovery from these human errors.

- It should be difficult for the user to proceed with actions that are non-reversible.

Design Principles for a Good System

Design for Errors

Before permanently deleting files from your computer, you are prompted asking if you are sure you want proceed.



Design Principles for a Good System

Visibility

- When the user is able to perceived how their actions will influence the system, there are fewer human errors.

*Prior to the nuclear incident at Three Mile Island, an example of **poor user visibility** was reported. Experienced operators were not able to comprehend the implications of elevated reactor temperatures. Their inability to perceive the negative feedback that reactors elevated temperatures would have on the plant lead them to underestimate the situation's severity.*

A Culture of Safety

- Human error cannot be blamed solely on the worker.

- The management team in an organisation play an important role in the overall safety at the facility. Decisions at this level are key to fostering a culture of safety – this thinking lays the foundation for accident prevention.

- A safety culture represents the values, attitudes, competencies and behaviour patterns of the workers and management team. This actions and beliefs drive quality of the organisation's health and safety programmes.

A Culture of Safety

A shared perspective about the importance of safety and preventative measurements at all levels of an organisation is central to a positive safety culture.

Factors that contribute to a positive safety culture:

- Felt Leadership
  - Commitment from the CEO and management

- Policies and principles of safety
  - All illnesses and injuries can be prevented – the goal is zero
  - Management is responsible for safety
  - Adherence to safety is a condition of employment
  - Employee involvement is essential

A Culture of Safety

Factors that contribute to a positive safety culture:

- Follow safe procedures – be seen doing it – believe it

  This thinking influences employee through:
  - Strong personal involvement
  - Setting an example
  - Building commitment to urgency, accountability, willingness
  - Setting high standards and expecting no less from others

Stop Programme

Behaviour based safety through peer observation

- Hi!
- I see that you have your proper personal protection equipment for the job you are doing; that's good.
- I am however concerned about how you are lifting the equipment, you could hurt yourself. May I suggest an alternative approach to lifting.

A Culture of Safety

Factors that contribute to a positive safety culture:

- Tools to get the job done
  - Expertise in safety resources
  - Procedures and development
  - Communication and motivation
  - Audits and investigations
  - Rituals

A Culture of Safety

Factors that contribute to a positive safety culture:

- Good communication and shared goals that extend beyond the workplace
  - Instilled values and believes will be practiced by workers irrespective of what work they are doing, where they are doing it or who is watching.
  - Practicing safe practices at home is important as off-the-job injuries cause personal suffering to the injured person and their family.

Summary

Hazards generated by human error can be understood through the factors governing the **limitations of human behaviour**: attention, perception, memory, logical reasoning.

Designing a good system to prevent human error can be achieved following key principles: user-centred design, managing information, reducing complexity, visibility, constraining behaviour, and designing for errors.

Once a good system is designed, instilling a **culture of safety** is essential to developing an organisation. In this culture, each employee exhibits a mindset and behaviour that ensures that their well-being leaving the workplace is the same or better than when they arrived – *a commitment to zero injuries*.

Checkpoint

What is the percentage of occurrences that unsafe worker actions the cause of workplace injuries?

A. <5% of occurrences
B. >15% of occurrences
C. >50% of occurrences
D. >75 of occurrences
E. >95% of occurrences

Answer: E

Checkpoint

Human error can be blamed solely on the worker:

A. True

B. False

Answer: B

Checkpoint

What are factors that contribute to limitations of human memory?

A. Capacity, processing levels and accessibility
B. Capacity, aptitude and processing level
C. Capacity and interest level

Answer: A

Checkpoint

Designing a system for errors is defined as:

A. Inclusion of safeguards to prevent hazardous events caused by human error
B. Inclusion of safeguards to mitigate hazardous events caused by human error
C. It should be difficult for the user to be proceed with actions that are non-reversible
D. Essential systems affected by inevitable mistakes from human error should be designed to recover

Answer: C

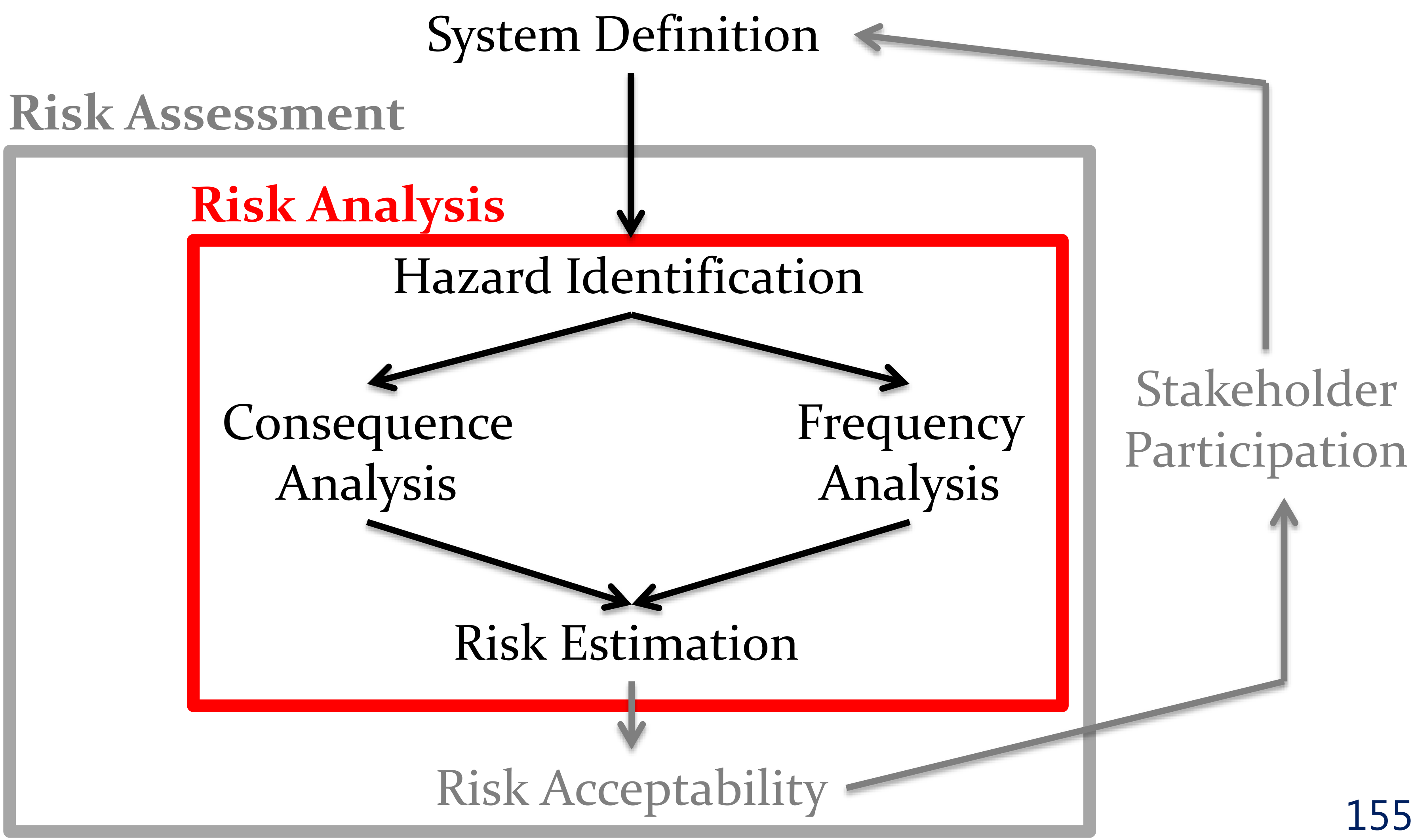
Checkpoint

What is meant by a "commitment-to-zero"?

A. Zero worker sick days
B. Zero worker accidents
C. Zero workplace hazards

Answer: B

Hazard and Risk Framework



Review of the end product from Process Hazard Analysis

- A list of intrinsic hazards
- A list of hazardous events and existing/ potential prevent/mitigation strategies:
  - Event scenarios
  - Their potential causes
  - Existing safeguards
  - Possible additional safeguards
- Some analysis techniques may also generate a list of potential consequences and their frequency
  - Low chance of burn injuries or death,
  - Moderate change of damage to process equipment,
  - Low change of injury or death from toxic gas inhalation

Overview of the Procedure

1. Identify the **consequence** of each hazard
2. Categorise each consequence
3. Evaluate the **frequency** of each consequence
4. Categorise these frequencies
5. Prioritise hazards based on categorised consequences and frequencies using a **risk matrix**
6. Use the risk matrix to **rank risks** from each hazard
7. Develop **action plans** for high-risk events

STEP 1

Identify consequences of each hazardous event and classify each with respect to relevant risk receptors:

- Employee safety and health
- Public safety and health
- The environment
- Production
- Equipment and machinery
- Company reputation and market share

STEP 2

Categorise consequences according the level of event severity.

Categorise *hazard* ***consequences*** with these tables:

Category	Consequences to the Public	Consequence to Employees
1	No injury or health effects	No injury or occupational safety impact
2	Minor injury or health effects	Minor injury or occupational safety impact
3	Injury or moderate health effects	Injury or moderate occupational illness
4	Death or severe health effects	Death or severe occupational illness

Category	Consequences to Capital Loss, Facility/Equipment Damage
1	< $100,000
2	$100,000 - $1,000,000
3	$1,000,000 - $10,000,000
4	> $10,000,000

Category	Environment Consequences	Consequence to Production Loss	Consequence to Market Share Loss
1	< $1,000	< 1 week	< 1 week
2	$1,000 - $10,000	1 week – 1 month	1 week – 1 month
3	$10,000 - $100,000	1 – 6 months	1 – 6 months
4	> $100,000	> 6 months	> 6 months

STEP 3

Estimate the frequency range of each consequence.

How many times per year will this hazard consequence happen?

STEP 4

Categorise consequences according the level of event severity.

Three levels of severity can be selected:

- Least stringent
- More stringent
- Most stringent

Categorise the ***frequency** of hazard consequences* with these tables – pick least, more and most stringent cases:

Least Stringent

Category	Frequency Range	Description
1	< 0.02 / year	Not expected to occur during the facility's lifetime (about 50 years), but possible
2	0.02 – 0.05 / year	Expected to occur no more than once during the facility's lifetime
3	0.05 – 1 / year	Expected to occur several times during the facility's lifetime
4	> 1 / year	Expected to occur more than once a year

Categorise the ***frequency** of hazard consequences* with these tables – pick least, more and most stringent cases:

More Stringent

Category	Frequency Range	Description
1	< 0.001 / year	Remote – A series of failures, with a low probability of occurring within the facility's lifetime
2	0.001 – 0.01 / year	Unlikely – A failure with a low probability of occurring within the facility's lifetime
3	0.01 – 0.1 / year	Probable – A failure which can reasonably be expected to occur once within the expected lifetime of the plant.
4	> 0.1 / year	Frequent – A failure which can reasonably be expected to occur more than once within the facility's lifetime.

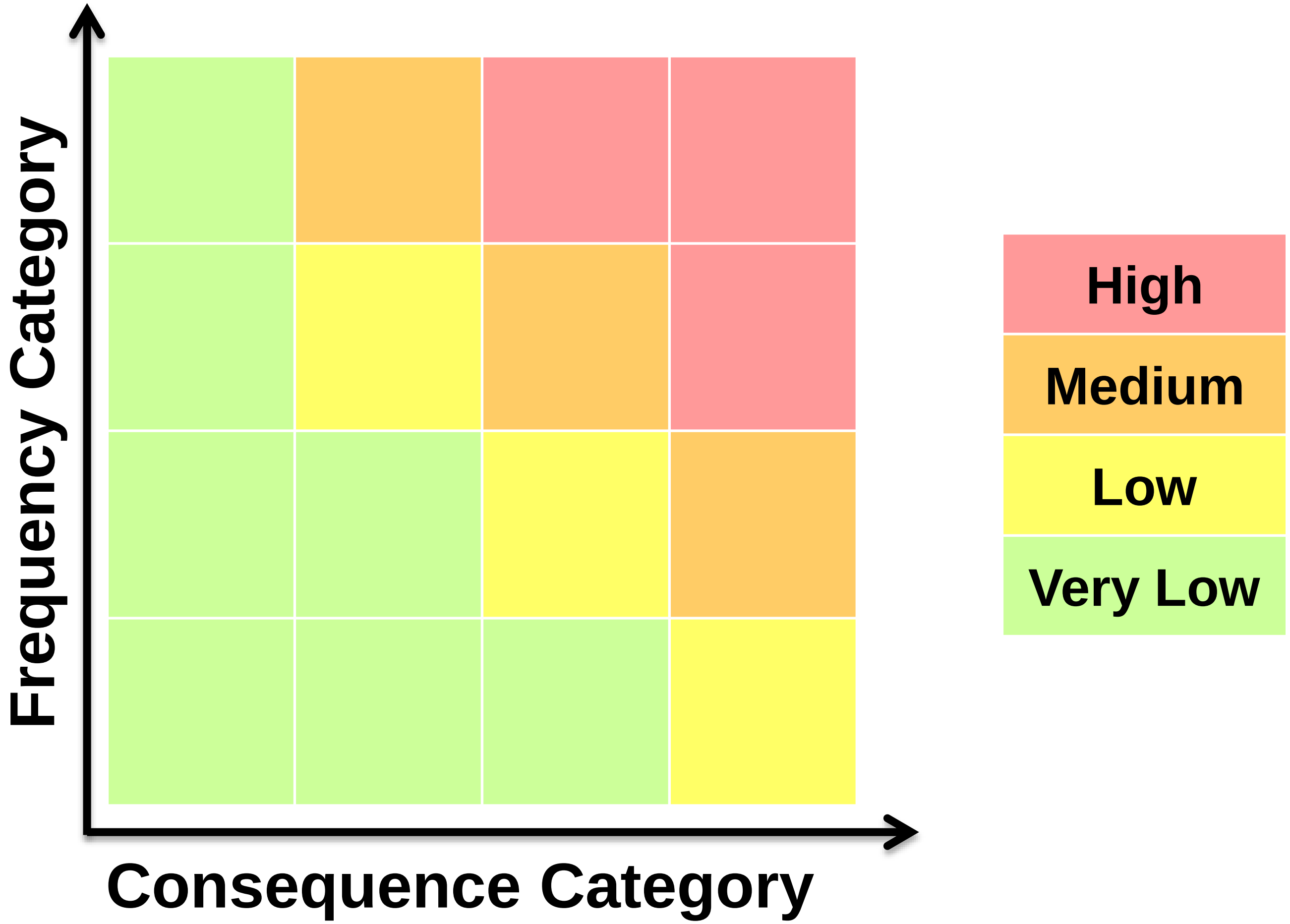
Categorise the ***frequency** of hazard consequences* with these tables – pick least, more and most stringent cases:

Most Stringent

Category	Frequency Range	Description
1	< 10^{-6} / year	Remote – A series of failures, with a low probability of occurring within the facility's lifetime
2	10^{-6} – 10^{-4} / year	Unlikely – A failure with a low probability of occurring within the facility's lifetime
3	10^{-4} – 0.01 / year	Probable – A failure which can reasonably be expected to occur once within the expected lifetime of the plant.
4	> 0.01 / year	Frequent – A failure which can reasonably be expected to occur more than once within the facility's lifetime.

STEP 5

Rank each hazardous event with a *risk matrix*.



Hazardous event categories in the risk ranking matrix.

High (H)	Should be mitigated with engineering and/or administrative controls to a risk ranking of LOW or VERY LOW within a specified time frame (i.e. 6 months).
Medium (M)	Should be mitigated with engineering and/or administrative controls to a risk ranking or LOW or VERY LOW within a specified time frame (i.e. 12 months).
Low (L)	Should be verified on a continuous basis to ensure procedures or controls are in place.
Very Low (VL)	No mitigation required.

STEP 6 - Rank the risk association with each hazard

Process Area	Hazardous Event	Potential Cause	Existing Safeguards to Prevent Event	Expected Future Frequency (#/year)	Risk Receptors						Maximum Event Risk Score	Comments	Recommended Actions
					Public			Employee					
					Consequence Score	Frequency Score	Risk Score	Consequence Score	Frequency Score	Risk Score			
Natural Gas Supply	Fireball and jet flame from transmission line	Above ground pipeline rupture from impact of heavy machinery	None	1/20	4	1	L	4	3	H	H	No physical impact protection where pipe comes out of the ground	Install collision protection at main inlet to plant process area; Improve line labelling and develop unique colour coding for piping.
Natural Gas Supply	Gas release with H_2S traces	Upstream failure to treat gas at source	None	1	2	1	VL	2	1	VL	VL	None	Check H_2S in gas supply.

Note: This is risk matrix is simplified. A complete matrix includes risk score for all risk receptors (public, environment, employees, production, capital equipment and market share).

STEP 7

For each hazardous event, develop *safeguards*, including action plans for any interactions between adjacent units and the emergency response on site.

Summary

Risk analysis estimates the risk from hazards to individuals, populations, property or the environment.

This analysis follows the two steps:

- **Hazard identification**
  - Definition of undesirable events and the type of potential damage
- **Risk estimation**
  - Measure of the level of health, property or environmental risks
  - Consequence and frequency analyses

It is important that **no value judgements** be included from risk analysis.

Checkpoint

Risk Analysis is best described as:

A. Consequence and frequency analyses
B. Hazard identification and risk estimation
C. Hazard identification and risk acceptability
D. Hazard identification, risk estimation and risk acceptability

Answer: B

Checkpoint

Once hazards are identified, how is risk analysed?

A. Consequences and frequencies are identified and evaluated through a risk matrix
B. Consequences and frequencies are identified and evaluated through a risk matrix followed by a ranking procedure
C. Consequences and frequencies are identified and evaluated through a risk matrix followed by a ranking procedure and development of action plans

Answer: C

Checkpoint

Hazard consequences are categorised with tables. Which of the following is not a standard table?

A. Consequences to the public
B. Consequences to the worker
C. Consequences to management
D. Consequences to capital loss
E. Consequences to market share

Answer: C

Checkpoint

Hazardous events classed as medium risks should be managed in the following manner:

A. No mitigation required, redesign system to ensure hazard prevention
B. Should be verified on a continuous basis to ensure that procedures and controls are in place
C. Should be mitigated with engineering and/ or administrative controls to achieve a lower risk ranking with 12 months
D. Should be mitigated with engineering and/ or administrative controls to achieve a lower risk ranking with 6 months

Answer: C

Checkpoint

Value judgements are a key component to the risk estimation procedure?

A. True

B. False

Answer: B

Automotive Case Study – Health Hazards

In a Canadian manufacturing plant of a global automotive company, many engineering activities are conducted in design, part production, assembly, testing and quality assurance areas. The plant produces and assembles vehicle parts including engines, pumps, fans and electronics.

The manufacturing processes by 400 plant employees and some are performed using automated technologies and equipment. Use of people or machines to perform tasks is dependent on cost, time, quality and worker health and safety.

The plant operates 3 shifts per day. There are production lines including machining equipment, conveyers and overhead cranes, punch presses and paint-spray booths.

Automotive Case Study – Health Hazards

Workers at the plant have reported several different health problems. The following information has been received by the head engineer:

1. In a recently installed assembly area, workers have to bend to the ground throughout the day to attach several small parts onto a vehicle chassis. Some works developed lower back pain, likely due to repetitive bending. For one of the workers, the problem is so severe that he was advised by his doctor to stay off work for two weeks so his back can recover.

   The manufacturing engineers who designed the assembly operation had wanted to use an automated system but this option was not deemed to be economic. A manual operation was used but industrial ergonomics was not taken into account because of a lack of expertise.

Automotive Case Study – Health Hazards

Workers at the plant have reported several different health problems. The following information has been received by the head engineer:

2. An increased incidence of respiratory illness has been reported over past month by workers operating near the paint-spray booths. Many of the paints and solvents used in the booths are known to be the cause of respiratory illnesses. Works are not supposed to be exposed to these substances because the paint-spray booths were designed to be ensured all materials exit the paint through a high-capacity ventilation system. No tests have been carried out on the ventilation system or the plant air quality so it is uncertain whether or not there have been any paint-spray booth leaks.

Automotive Case Study – Health Hazards

Workers at the plant have reported several different health problems. The following information has been received by the head engineer:

3. In an area of the plant where metal cutting occurs, works are required to wear protective eyewear. However, workers operating in this area have started to report minor eye injuries. It is common knowledge that workers do not routinely use the protective equipment; the eyewear is frequently observed to be hanging on nearby hooks or loosely hanging around workers' necks. Workers complain that they find the protective eyewear to be uncomfortable and do not think it is needed or important. The plant manager knows of this behaviour but overlooks it since enforcing the eyewear use seems to make workers unhappy and less productive.

Automotive Case Study – Safety

Let’s consider the same automotive facility again but this time we’ll look at a safety related concerns.

Automotive Case Study – Safety

The head engineer wants to ensure that plant provides a safe and healthy environment. An engineering health and safety consulting company was hired to do a health and safety audit of the plant. The consulting companies report included the following issues:

1. An expert on fires and explosions notes the extensive use of natural gas in the plant could lead to an explosion in some circumstances. The potential for an explosion could develop if a sufficient natural gas leak. Which could lead to severe worker injuries or deaths. Detection of natural gas concentrations in the plant is monitored by sensors. Only one sensor is installed in the plant but not in the main area where accumulation of natural gas would be likely to occur. In addition to the concern for the only having the single sensor installed, the expert noted the sensor was not connected to an automated natural gas shut-off system. Without a shut-off feature, the severity of an incident would increase.

Automotive Case Study – Safety

The head engineer wants to ensure that plant provides a safe and healthy environment. An engineering health and safety consulting company was hired to do a health and safety audit of the plant. The consulting companies report included the following issues:

2. Gas line maintenance is required every quarter; no evidence of maintenance had been found since the gas lines were installed four years ago. This maintenance procedure involves checking for and fixing gas leaks. Workers also require training on procedures to prevent an explosion; this training had not been conducted and workers were not aware of the potential explosion hazard. No written procedure relating to explosions were found within the plant.

Automotive Case Study – Safety

The head engineer wants to ensure that plant provides a safe and healthy environment. An engineering health and safety consulting company was hired to do a health and safety audit of the plant. The consulting companies report included the following issues:

3. The plant was found to contain toxic materials that can harm the health of people and animals. The storage area for these hazardous substances was not found to be sufficient in containing the chemicals in the event of an explosion. Release of these substances could lead to illness or deaths among members of the public and could also harm the environment.

Hazard and Risk identification answers the following questions:

What can go wrong? How? Why?

What are the consequences?

How likely are these consequences?

What is the risk?

Finding Hazards

Hazards are commonly related to energy:

- Human error
- Kinetic energy
- Potential energy
- Heat
- Electricity

In addition to energy sources, human error can be attributed to most workplace accidents.

96% of workplace injuries are caused by unsafe worker actions

Human Error as a Cause of Hazards

As engineers designing a facility, we must be aware of the **limitation of human behaviour**. This includes a workers or operator's attention span, perception, memory and logical reasoning abilities.

When human error is identified as a hazard in a process, we must acknowledge that the worker cannot be solely blamed. An organisation's management team plays a key part in overall safety.

Instilling **a safety culture** in an organisation is essential to reducing the number of worker caused accidents to zero.

Hazards, Risk, Sources and Receptors

A **hazard connects risk sources with risk receptors**. These system components include:

- Risk *sources*
  - Industrial facilities
  - Roadways
  - University laboratories

- Risk *receptors*
  - Plant Operators and workers
  - Students at a University
  - Shareholders
  - Community
  - Environment
  - Regulators

Hazard Identification Methods

Process Hazard Analysis techniques are used to identify hazards. **Qualitative methods** we discussed include:

- *Screening Level analysis*
- *Checklists*
- *What-if analysis*
- *Failure Modes and Effects Analysis (FMEA)*
- *Hazard and Operability Study (HAZOP)*

These techniques present a **pro-active** and **systematic** approach for the identification, mitigation or prevention of hazards from a process, materials, equipment or human error.

Generalised Process Hazard Analysis Procedure

1. Break down the system into process sections
2. Identify the intrinsic hazards in each section (chemical, material, equipment, human)
3. Evaluate the cause of each hazard to develop a hazardous event

Additional steps for What-if, FMEA and HAZOPs

4. Determine the consequence of each hazardous event
5. Estimate the frequency of each hazard consequence

Estimating Risk

We can use hazard-related frequency and consequence information to determine the associated risk.

Consequences and their frequency can be ranked in a **matrix** to estimate risk.

Risk = Estimated consequences of a hazardous event x
Frequency of the event's occurrence

Risks are ranked as **very low**, **low**, **medium** and **high**

Risk analysis

Provides an objective basis for **comparing hazards**, alternatives and risk control measurements

This analysis procedure is also of great importance for **response planning for emergencies**

There many types of risks that may be identified:

- *Event Risk*
- *Facility Risk*
- *Individual Risk*
- *Societal Risk*
- *Voluntary Risk*
- *Imposed Risk*
- *Safety Risk Environmental Risk*
- *Equipment Risk*
- *Shareholder Risk*

Hazard and Risk Framework