Overview of the risk assessment process
Content

• Overview of Risk Analysis
• The Quantitative Risk Analysis Process
• Different Approaches
• Frequency and Consequence Assessment
• Sources of Uncertainties
• General Conclusions
RISK ANALYSIS, RISK ASSESSMENT, RISK MANAGEMENT

Risk analysis
- Hazard identification
- Risk estimation

Risk evaluation
- Risk tolerability
- Analysis of options

Risk reduction
- Decision making
- Implementation/monitoring

IEC 300-3-9 (1995)
Objectives

• To provide a general overview of quantitative risk analysis for industrial establishments

• To be able to understand the key elements of the quantitative risk analysis process

• To understand and make familiar the main approaches and techniques for quantitative risk analysis
What is Risk?

Risk = set of <scenario, frequency, consequence>

What may go wrong?

How frequently could it occur?

How dangerous is it?

Risk = hazard / safeguards
What is Quantitative Risk Analysis?

complex, but well structured process, to provide a measure of the risks associated with the process, storage and transport of hazardous substances

Identify Hazards
Estimate the Risks associated to possible accidents scenarios leading to damage

Final objective
Determine components, safety measures, and/or human actions necessary for plant safety
Who are the main players?

- Plant Operator
- Competent Authority
- Risk Analysis
- Chemical establishment
- Public
Risk assessment is a complex process

- It requires **specific expertise** in risk analysis itself

- It requires **specialised knowledge** about the object being analysed (e.g., chemical process safety)
EVALUATE A RISK ANALYSIS

- Evaluators should understand the fundamentals of risk assessment
- It is recommended there is access to an expert with specialized knowledge of industrial risk assessment
In the Safety Report ...

- to **demonstrate** that a particular **scenario no longer presents** a major-accident hazard due to the measures in place
- to **demonstrate** that the **extent** of the effects of a particular scenario have been **limited**
- to **demonstrate** the efficiency and the effectiveness of **mitigation measures** put in place
- to establish whether the activity is **acceptable** or not
- to establish whether **further mitigating measures** are necessary
- to provide information for competent authority obligations (e.g., emergency plans, land-use planning)
OUTCOME OF A RISK ANALYSIS

AN ESTIMATE OF THE RISK

RISK  =  
FREQUENCY X SEVERITY

How many and how often?
TEN COUNTRIES WITH THE HIGHEST ANNUAL MOTOR VEHICLE DEATH RATES, MID-1990s

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>DEATHS PER 100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Portugal</td>
<td>24.9</td>
</tr>
<tr>
<td>(2) Greece</td>
<td>23.3</td>
</tr>
<tr>
<td>(3) Venezuela</td>
<td>22.3</td>
</tr>
<tr>
<td>(4) Russian Federation</td>
<td>22.3</td>
</tr>
<tr>
<td>(5) Slovenia</td>
<td>14.3</td>
</tr>
<tr>
<td>(6) Cuba</td>
<td>18.3</td>
</tr>
<tr>
<td>(7) Poland</td>
<td>18.3</td>
</tr>
<tr>
<td>(8) Mauritius</td>
<td>17.8</td>
</tr>
<tr>
<td>(9) Colombia</td>
<td>17.4</td>
</tr>
<tr>
<td>(10) Hungary</td>
<td>17.0</td>
</tr>
</tbody>
</table>

From 2002 INTERNATIONAL ACCIDENT FACTS (Second Edition). Published by the National Safety Council (NSC) using WHO statistics

www.nsc.org
HAZARDOUS INSTALLATION
HYPOTHETICAL EXAMPLE

For example, for the atmospheric tank, you might have the following (hypothetical, not a real situation)

$10^{-3} \times \frac{1}{1000} = \text{Small fire, 1 tank destroyed}$
Risk of 1 tank destroyed = 0.01% = $1/1000 = 10^{-3}$
Acceptable or unacceptable?

$10^{-5} \times \frac{1}{100,000} = \text{Explosion, 2 workers injured}$
Risk of 2 workers injured = 0.002% = $2/100,000 = 2 \times 10^{-5}$
Acceptable or unacceptable?

$10^{-6} \times \frac{1}{1,000,000} = \text{Major fire, > 5 people killed}$
Risk of 5 people killed = 0.0005% = $5 \times 10^{-6}$
Acceptable or unacceptable?
STARTING POINT

Initiating event (undesired) = loss of containment (LOC)

- e.g., vessel rupture or leak, pipe rupture, the developing event:
- fire, explosion, release of toxics

Accident Scenario
The centre of the diagram is the *loss of containment* event (LOC).

The bow-tie left side depicts the overall possible *causes*.

The left-side vertical bars refer to the measures (barriers) in place to **prevent** the release of dangerous substances and control escalation.

The bow-tie right side describes possible *accidental scenarios*.

The right-side vertical bars in the bow-tie right side refer to the measures to **mitigate** consequences.
TYPICAL CONSEQUENCES

Fire

Explosion

Toxic release

Damage
\[ R = f(C) \]

Accident scenario

\[ R = f(C) \]

Prevention

Mitigation

Consequence

Frequency
Frequency and Consequence Assessment
Frequency Assessment

Expert judgement

Use of databases

Other Methods
- Fault-Tree Analysis
- Event-Tree Analysis
- Markov

How frequent is it?

Different Scenarios associated with the same LOC

Basic events
CONSEQUENCE ASSESSMENT

How dangerous is it?

Used to estimate:

• the extent to which damage may occur as a consequence of an accident
Toxic release

- **TOXIC RELEASE**
  - **LIQUID PHASE**
    - **ON GROUND**
      - Pool formation and evaporation
    - **IN WATER**
      - Liquid/liquid dispersion
  - **INSOLUBLE FLUID**
    - Pool formation
  - **SOLUBLE FLUID**
  - **GAS, VAPOUR PHASE**
    - **HIGH VELOCITY**
      - Less dense than air
      - Dispersion for turbulence (buoyant)
    - **LOW VELOCITY**
      - More dense than air
      - Dispersion for gravity
Fire

- Pool Fire
- Flash Fire
- Fireball
- Jet Fire
From Damage to Consequences

- **VULNERABILITY**
  - **POPULATION**
  - **INFRASTRUCTURE**

- **PHYSICAL DAMAGE**
  - **DAMAGE CRITERIA**
  - **PROBIT MODELS**
Consequence Assessment in practice

• It is an **expert activity** (often conducted by external consultants) and **expensive**

• It is not only conducted for risk assessment purposes (e.g. **emergency planning**, LUP)

• Sophisticated software tools are very **expensive** although some **freeware is available** (ALHOA, etc)

• Input and output data are not reported in a standardised way, which makes **interoperability** amongst different packages very difficult
Risk Calculation & representation

- **Frequency**
  - Acceptable
  - ALARA
  - Unacceptable

- **Consequence**
<table>
<thead>
<tr>
<th>Severity Category</th>
<th>Qualitative Definition</th>
<th>Quantitative Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>catastrophic</td>
<td>multiple fatalities</td>
</tr>
<tr>
<td>2</td>
<td>major</td>
<td>single fatality, multiple injuries</td>
</tr>
<tr>
<td>3</td>
<td>very serious</td>
<td>permanent disabling injury</td>
</tr>
<tr>
<td>4</td>
<td>serious</td>
<td>serious injury, full recovery</td>
</tr>
<tr>
<td>5</td>
<td>minor</td>
<td>lost-time injury, short absence from work</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Severity Category</th>
<th>Qualitative Definition</th>
<th>Quantitative Definition (p.a.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cont.</td>
<td>Continuous</td>
<td>Weighting factor</td>
</tr>
<tr>
<td>A</td>
<td>likely once in next year</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>possible but not likely</td>
<td>0.1</td>
</tr>
<tr>
<td>C</td>
<td>unlikely</td>
<td>0.01</td>
</tr>
<tr>
<td>D</td>
<td>very unlikely</td>
<td>0.001</td>
</tr>
<tr>
<td>E</td>
<td>remote</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
Individual Risk
annual frequency of occurrence of the reference damage (e.g., the death), in any point of the geographical area, for a person present

This is a useful figure to characterise the risk in a given location.
Risk Acceptance Criteria

What is acceptable depend upon current societal tolerance
- What is tolerable today may not be considered as tolerable tomorrow
- What is tolerable somewhere may not be tolerable somewhere else
Risk Criteria

Individual Risk

- $10^{-5}$ to $10^{-4}$: Risk Unacceptable
- $10^{-4}$ to $10^{-3}$: RISK REDUCTION
- $10^{-3}$ to $10^{-2}$: Risk Acceptable

Societal Risk

- $10^{-5}$ to $10^{-4}$: Risk Unacceptable
- $10^{-4}$ to $10^{-3}$: RISK REDUCTION
- $10^{-3}$ to $10^{-2}$: Risk Acceptable
Uncertainty: example

BEQUAR Benchmark
Fabbri et al., J Hazard Mater. 2009 Mar 15;162(2-3):1465-76
• Analysis completeness can never be assured

• Uncertainty on the estimated risk figure cannot be avoided, however sensitivity studies can help filling the gap

• Transparency in the process is essential (hypothesis, data and modelling)

Risk Analysis is not necessarily important to get the exact (absolute) figure of risk. The overall process of risk analysis helps improving awareness of the critical aspects of the plant
Training Workshop on Chemical Accident Prevention Program

Thank you