Risk Matrix as a Tool for Risk Assessment in the Chemical Process Industry

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BASF – The Chemical Company
The world’s leading chemical company
Global presence
The Ludwigshafen site: The world’s largest integrated chemical complex

Site area: 7.11 km²  
Employees: 39,000  
Contractors: ~ 6000  
Buildings: ~ 2,000  
Chemical Plants: ~ 200  
Roads: 115 km  
Rail track: 211 km  
Above-ground piping: 2,000 km  
Power consumption: 6.1 billion kWh  
Steam requirement: 18 mill. tons  
Cooling water cons.: 1.25 bill m³  
Employees: 39,000  
Contractors: ~ 6000

BASF Group: Sales by segment in 2003

<table>
<thead>
<tr>
<th>Segment</th>
<th>Billion € (change compared with previous year in percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance Products</td>
<td>7.6 (-4.8%)</td>
</tr>
<tr>
<td>Chemicals</td>
<td>5.8 (+8.2%)</td>
</tr>
<tr>
<td>Agricultural Products &amp; Nutrition</td>
<td>5.0 (+2.0%)</td>
</tr>
<tr>
<td>Plastics</td>
<td>8.8 (+3.7%)</td>
</tr>
<tr>
<td>Other</td>
<td>1.4 (+7.2%)</td>
</tr>
<tr>
<td>Oil &amp; Gas</td>
<td>4.8 (+14.1%)</td>
</tr>
</tbody>
</table>
Ammonium Nitrate Explosion at BASF Lu in 1921

What is Process Safety?

Interdisciplinary effort to prevent fires, explosions and accidental chemical releases

Performance Expectations:
- Safety reviews are conducted for existing and new processes/facilities (BASF Group Directive – SHE)
- Documented plant safety concept and periodic review
- Current, complete documentation is available, e.g. safety relevant parameters, protective devices, P&I diagram, hazardous area-classification, fire protection concept, etc
- Investigation of all incidents and communication of lessons learned
- Management of change system is implemented
Definition of Risk

\[ R = P \times S \]

- **R** Risk
- **P** Probability (expressed as frequency)
- **S** Severity

The term risk may be used qualitatively or quantitatively
Risk Assessment as Part of a Safety Review

If an incident with severe consequences such as danger to human life or the environment can be triggered by a primary cause, which cannot be reasonably ruled out, the chain of events between the primary cause and incident must be interrupted by a protective measure such as a pressure relief device or a Safety Instrumented System.
Qualitative Risk Assessment (2)

Qualitative estimation of the frequency of occurrence

- Scenarios requiring more than one independent simultaneous primary fault as initiating event are not taken into account

- Only those primary faults are considered which cannot be reasonably ruled out on the basis of operational experience

Example 1: Rupture of a cooling water pump (continued)
Principles of a risk matrix

A risk matrix

- Is a semi-quantitative tool
- Uses orders of magnitude
- Can be adjusted to company specific acceptance criteria
- Does not require special skills or software
- Is relatively easy to use

BASF Risk Matrix

<table>
<thead>
<tr>
<th>BASF</th>
<th>Risk Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Severity</td>
</tr>
<tr>
<td>P 0</td>
<td>S 1</td>
</tr>
<tr>
<td>P 1</td>
<td>S 2</td>
</tr>
<tr>
<td>P 2</td>
<td>S 3</td>
</tr>
<tr>
<td>P 3</td>
<td>S 4</td>
</tr>
<tr>
<td>P 4</td>
<td></td>
</tr>
</tbody>
</table>
Elements of the BASF Risk Matrix

Frequency classes

- $P_0$: Happened a couple of times (once per year or more often)
- $P_1$: Happened once (Approx. once in 10 years)
- $P_2$: Almost happened, near miss (Approx. once in 100 years)
- $P_3$: Never happened, but is thinkable (Approx. once in 1,000 years)
- $P_4$: Not plausible (less than once per 10,000 years)

Severity classes

- $S_1$: On site: Potential for one or more fatalities
- $S_2$: On site: Potential for one or more serious injuries (irreversible)
- $S_3$: On site: Potential for one or more lost time injuries
- $S_4$: On site: Potential for minor injuries, or irritation
Elements of the BASF Risk Matrix

Risk classes and Risk Reducing Measures

<table>
<thead>
<tr>
<th>Risk Class</th>
<th>Risk Level</th>
<th>Risk Reducing Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Extreme, totally unacceptable risk</td>
<td>Process or design change preferred</td>
</tr>
<tr>
<td>B</td>
<td>Very large, unacceptable risk</td>
<td>Process or design change, or one protective device of SIL 3 (PSV, Class A)</td>
</tr>
<tr>
<td>C</td>
<td>Large, unacceptable risk</td>
<td>Process or design change, or one protective device of SIL 2 (PSV, Class A)</td>
</tr>
<tr>
<td>D</td>
<td>Medium, acceptable risk, which should be further reduced</td>
<td>One monitoring device of high quality with documented testing or administrative procedure of high quality</td>
</tr>
<tr>
<td>E</td>
<td>Small, acceptable risk, which should be further reduced</td>
<td>One monitoring device or administrative procedure</td>
</tr>
<tr>
<td>F</td>
<td>Very small, acceptable risk</td>
<td>None</td>
</tr>
</tbody>
</table>

How to use the BASF Risk Matrix

Conventions
- **No credit** is taken for existing safeguards when determining the risk class
- **Full credit** is taken for normal reliability of instrumented control and operator control when determining the frequency of an event
- The protective devices listed as risk reduction measures for risk classes B and C are the minimum requirement, the implementation of additional monitoring devices is highly recommended (layers of protection)
How to use the BASF Risk Matrix

Determination of frequency

- Use good judgement
- Evaluation by the interdisciplinary process review team (Orders of magnitude)
- Applicable data from literature

Determination of severity

- Use good judgement
- Practical experience
- Quantitative methods such as dispersion calculations.
How to use the BASF Risk Matrix

Dealing with less likely consequences

- Form separate pairs of severity and corresponding probability and determine the risk class for each pair
- Use the most severe risk class to represent the scenario
- Combining the frequency of an initiating event with the most severe but unlikely consequence would result in the wrong risk class

Example 1: Rupture of a cooling water pump

A 50 kW-cooling water pump made of brittle construction material (e.g. gray cast iron) is inadvertently operated with blocked-in water. Undue overpressure may occur by thermal expansion and cause rupture of the casing. Because of the brittle construction material flying debris is to be expected.

Evaluation of frequency:
The operation takes place 10 times per year.
VDI guideline 4006/2 suggests an error probability of $10^{-3}$ for a task, which is simple and has often been performed with little stress and with sufficient time available in familiar situations.
Thus a frequency of $10^{-2}$ per year or once in 100 years ($P_2$) can be inferred.
Example 1: Rupture of a cooling water pump (continued)

If there is no personnel near the pump, the severity can be classified as S₄ (potential for minor injuries or irritation).

Result: Risk class F (P₂S₄; very small, acceptable risk)
Example 1: Rupture of a cooling water pump (continued)

10% of the time (frequency $P_3$) personnel is expected to be near enough to that particular pump to sustain a serious injury (severity $S_2$).

Result: Risk class D ($P_3 S_2$; medium, acceptable risk, which should be further reduced).

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The probability of the injury being fatal is about 10%. Thus the frequency for somebody being present and fatally hit by debris is $P_4$.

Result: Risk class E ($P_4 S_1$; small, acceptable risk, which should be further reduced).
Example 1: Rupture of a cooling water pump (continued)

The worst case risk class is D, requiring one monitoring device of high quality, e.g. a high pressure switch, to shut off the pump.

<table>
<thead>
<tr>
<th>BASF</th>
<th>Risk Matrix</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
</tr>
<tr>
<td></td>
<td>S₁</td>
</tr>
<tr>
<td>P₀</td>
<td>A</td>
</tr>
<tr>
<td>P₁</td>
<td>A/B</td>
</tr>
<tr>
<td>P₂</td>
<td>B</td>
</tr>
<tr>
<td>P₃</td>
<td>C</td>
</tr>
<tr>
<td>P₄</td>
<td></td>
</tr>
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</table>

Example 2: Explosion of a stirred reactor

In a stirred reactor containing a heat sensitive reaction mixture, ingress of water would produce a strongly exothermal reaction causing the reaction mixture to decompose explosively.
Example 2: Explosion of a Stirred Reactor caused by Ingress of Water

Exothermic reaction and initiation of vigorous decomposition

Ingress of water

Reaction mixture reacts exothermically with water

Ingress of water via feed line

Ingress of water from vessel jacket

Ingress of water from offgas header

Back-flow of water from downstream equipment

Ingress of water for rinsing

Leak of vessel jacket

Use of water as heat carrier medium

Explosion of vessel

Example 2: Explosion of a stirred reactor
Example 2: Explosion of a stirred reactor

According to operational experience ingress of water is presumed to occur about once in ten years (P₁, “happened once”).

Even relatively small amounts of water would result in an explosive decomposition causing rupture of the vessel and flying debris with the potential of serious injuries (S₂; combination P₁S₂).

Assuming that the probability of the injuries being fatal is 10 %, a combination of P₂S₁ can be derived. In both cases the risk class is classified as B.

<table>
<thead>
<tr>
<th>Risk Matrix</th>
<th>Severity</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S₁</td>
<td>S₂</td>
</tr>
<tr>
<td>P₂</td>
<td>A</td>
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</table>

Example 2: Explosion of a stirred reactor

Since I/E-protective devices would not prevent the scenario from occurring, the risk has to be reduced by design change and organizational protective measures e.g.

- use of non-aqueous heat carrier medium instead of water
- installation of a spool piece at the connection to water supply for rinsing the vessel
- highly reliable visual control for remaining water in the vessel after cleaning operations.
The BASF Risk Matrix is a tool to perform semi-quantitative risk assessments. It reflects BASF’s philosophy on maximum acceptable risk and the determination of what additional measures are necessary or not to reduce the risk. It presents a further development of the qualitative risk assessment method.

Analysis of incidents in the BASF Group during recent years shows that most incidents occurred not because of wrong risk assessments but since hazards had not been detected in advance. Emphasis has therefore to be laid on early identification of hazards. Only hazards which are identified can be countered by appropriate safeguards.

Conclusion