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# Semiquantitative Risk Analysis – An EPSC Working Group

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Semiquantitative Risk Analysis (SQRA) tools like e.g. LOPA were developed for the assessment of scenarios which have previously been identified with Process Hazard Analysis (PHA) tools like e.g. HAZOP. These SQRA tools represent a scenario as chain of events with barriers preventing the propagation of the chain of events towards the final accident. Orders of magnitude are used to express frequencies, failure rates and consequences.
The risk acceptance criteria are a central element of each SQRA tool and are typically represented in a matrix having an axis for frequency and one for severity. These risk matrices are defined individually by each company as part of its SQRA tool.
Though some countries have defined risk acceptance criteria for individual or societal risk as part of Quantitative Risk Analysis (QRA), there is no generally accepted standard for SQRA applied to single cause – single consequence scenarios. The focus of the working group was therefore a comparison of the risk matrices of the participating companies with their individual risk acceptance criteria and application rules. These application rules – e.g. the use of modifiers or the assumed frequencies for initial events – have a significant influence on the risk level obtained by use of a risk matrix.
Key results of the discussion and comparison within the working group are:

- Risk acceptance criteria for 1 fatality as reference scenario differ only by one order of magnitude
- Companies using or not using modifiers are equally represented
- Criteria used for ALARP are similar for most companies
- In some cases differences in use of modifiers and risk acceptance criteria compensate resulting in a comparable risk level
- Application of company-specific risk matrices to an example case gave the same results for most participants, thus demonstrating that most risk matrices of working group members will arrive at a comparable risk level

While individual companies will often not share their risk matrix in public, the results of the working group can be shared, as the comparisons have been anonymized.
The matrices discussed in this study were submitted by major European companies from the chemical and oil & gas industries. As these companies are the leaders in their industries, the study will be of interest to others to compare and assess their practice.

## 1. Introduction

It is a standard procedure in the process industries to ensure the safety of plants and processes by performing Process Hazard Analyses (PHA) during the design of new plants and during the operating phase of existing plants. Semiquantitative Risk Assessment (SQRA) tools are widely used for assessing the risks of the scenarios identified by PHA. Typically these SQRA tools use orders of magnitudes for frequencies and severities, thus limiting the effort required for performing SQRA (compared with Quantitative Risk Assessment, QRA). This limited effort required for SQRA in combination with the validity of the results is the reason for its popularity and widespread use. The validity of the results obtained with SQRA is in accordance with the semiquantitative approach and is an important condition for making decisions on the quality of safeguards and need for risk reduction.

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LOPA is the most frequently used SQRA tool and was developed in the 1990s and propagated by CCPS (CCPS 2001) and other organizations. It is characterized by detailed procedures, a specific terminology and use of worksheets for documentation of the results. Among the SQRA approaches found in practice there are many varieties of LOPA, often not using the specific LOPA terminology and procedures, but based upon the same principles as LOPA. These basic principles of SQRA can best be described with the model of a chain of events as shown in Figure 1.

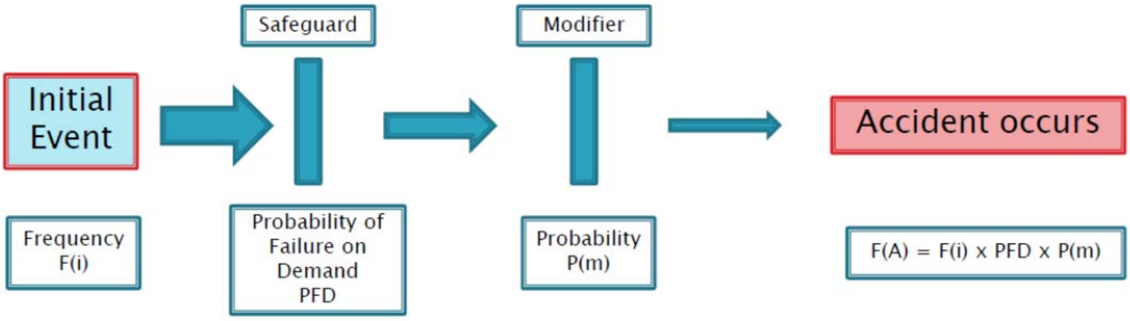


*Figure 1: Chain of Events as Basis for Semiquantitative Risk Assessment*

The frequency of an accident F(A) is the product of the following values:

- Frequency of the Initial Event F(i)
- PFD of safeguards
- Probability factor P(m) for modifiers (see chapter 3.4 for an explanation of this term)

From this chain of events the following steps can be derived which are the basis of every SQRA approach:

1. Describe a scenario as chain of events and determine the severity of final consequence
2. Determine the frequency of the initiating event and further factors influencing the frequency of the scenario like modifiers
3. Determine the existing countermeasures and their PFD
4. Using the results from step 2 – 3, calculate the scenario frequency
5. Using frequency and severity of the scenario, determine the risk of the scenario
6. Determine whether the risk is acceptable by applying company specific risk acceptance criteria

There may be variations in the detailed design of these steps. E.g. some companies start with determination of the risk without countermeasures/safeguards (raw risk) and the required total orders of magnitude of improvement by safeguards. This is then compared with the existing safeguards to determine if additional protection layers are needed. But in some way the steps listed above are included in every SQRA approach, no matter whether it operates under the name of LOPA or not.

The company specific risk acceptance criteria used in the last step to determine whether additional risk reduction is required, are in the participating companies documented in a risk matrix. The design and comparison of these risk matrices including the associated risk assessment procedures were the main topic of the EPSC working group.

## 2. The EPSC Working Group

The EPSC working group on SQ Risk Analysis was active from 2015 – 2018. The discussions started with a collection of risk matrices submitted in an anonymous survey conducted among EPSC members before the start of the working group. After some changes in organization and membership composition of the working group, a second survey was conducted exclusively among group members. The reason for this survey was to have updated versions of all matrices and to use only data from matrices of known origin from current working group members.

*Table 1: List of companies represented in the EPSC working group*

| | | | |
|---|---|---|---|
| **AkzoNobel** | **BG RCI** | **DSM** | **OMV Petrom** |
| **Baker Risk** | **Centrica** | **Dupont** | **Sasol** |
| **BASF** | **Clariant** | **Evonik** | **TÜV Austria** |
| **Bayer** | **Covestro** | **Lyondell Basell** | **TÜV Süd** |

Table 1 shows the list of organizations represented in the working group. Besides major companies from chemical and petrochemical industry also some consulting companies participated in the group.

## 3. Comparison of Risk Matrices

It was agreed within the working group not to disclose existing matrices which can be attributed to a company. Therefore Figure 2 shows a “synthetic” risk matrix which is best suited as starting point for the discussion of the risk matrices shared within the working group and the variations of the essential features like severity categories, frequency categories and risk levels. The features of this matrix were chosen so that they represent the “average” or most typical characteristics of the matrices shared within the working group. One of these features, the limit between the red (“unacceptable”) and yellow (“tolerable”) range, was for some matrices shifted by one order of magnitude to lower frequencies (see also chapter 3.5, risk acceptance criteria). It should be emphasized that the intention of this matrix is not to establish a standard, but to facilitate the discussion of the matrices in the working group.

| | $<10^{-5}$/yr | $10^{-5}$/yr – $10^{-4}$/yr | $10^{-4}$/yr – $10^{-3}$/yr | $10^{-3}$/yr – $10^{-2}$/yr | $10^{-2}$/yr – $10^{-1}$/yr | $10^{-1}$/yr – 1/yr | > 1/yr |
|---|---|---|---|---|---|---|---|
| **Catastrophic** | C | C | B | B | B | A | A |
| **Severe** | D | C | C | B | B | B | A |
| **Serious** | D | D | C | C | B | B | B |
| **Significant** | D | D | D | D | C | C | B |
| **Minor** | D | D | D | D | D | C | C |

| Consequence category | Effect on Human Health |
|---|---|
| **Catastrophic** | Multiple fatalities |
| **Severe** | 1 fatality / several severe injuries |
| **Serious** | Severe injury |
| **Significant** | Lost time injury |
| **Minor** | Minor injury without lost time |

| Risk level | Action required |
|---|---|
| **A:** very large, unacceptable risk | Process or design change required |
| **B:** Large, unacceptable risk | Risk reduction to reach at least risk level C |
| **C:** Undesirable Risk (tolerable if ALARP) | Check if further risk reduction is possible („ALARP“) |
| **D:** Acceptable risk | Ensure that risk is maintained at this low level |

*Figure 2: Synthetic Risk Matrix with typical features from matrices shared in the working group*

### 3.1 Consequence Categories

Though some companies define consequence categories for the fields of human health, environmental damage, financial loss and publicity, the example in figure 2 is limited to definitions in the field of human health because this field is the lead category and represented in every risk matrix shared in the working group. The matrices discussed in the group had between 3 – 6 consequence categories. A lower number is the result of a lower degree of differentiation, e.g. one or more fatalities condensed into one category. A higher number is achieved by a stronger differentiation, e.g. between onsite and offsite effects. In this case the same effect occurring offsite is classified one level more severe compared to the same effect occurring onsite.

### 3.2 Frequency Categories

The example matrix has 7 frequency categories, while for the matrices in the working group this number varied from 5 to 7. Each category comprises one order of magnitude. The most typical definition is the range between 2 powers of 10, as shown in the example matrix (e.g. $10^{-4}$/yr – $10^{-3}$/yr). The definition as full power of

10, e.g. $10^{-3}$/yr or $10^{-2}$/yr with rounding of all intermediate values is also occasionally used. Mathematically this means a shift of half an order of magnitude on the frequency scale. 3 of the matrices represented in table 2 (chapter 3.5) use full powers of 10 for definition of frequency categories. Due to this shift of the frequency scale the variation of the limit values in the "Unacceptable above" column (between $10^{-4}$/yr and $10^{-3}$/yr) is reduced for these 3 matrices from one order of magnitude to half an order of magnitude.

### 3.3 Risk Levels

3 risk levels are required as minimum to allow classification of a risk as "acceptable", "tolerable/ALARP" or "unacceptable". Due to additional differentiation within the "tolerable" and "unacceptable" range the matrices discussed in the working group had between 3 and 6 risk levels. An integral element of each risk matrix is a description of the risk levels with definition of the required measures for risk reduction. In most cases the required measures were described in a general way (e.g. starting in the "unacceptable" range, reduce the risk to reach at least the "tolerable/ALARP" range). This general requirement leaves flexibility in the selection of the risk reduction measures. A few companies define the required quality of the safeguards very precisely for each risk level (e.g. SIL 2 or SIL 3).
For the ALARP level, most of the participating companies did not have clear financial criteria for ALARP being fulfilled or not fulfilled.

### 3.4 Modifiers and Enabling Condition

A conditional modifier is a probability factor expressing the possibility that a chain of events can end up with different consequences, e.g. probability of presence of people or ignition source (CCPS 2014). In a similar way enabling conditions reflect that some scenarios can only occur under special operating conditions or circumstances. E.g. a cooling failure during a batch process can only lead to a runaway, if it occurs during the exothermic reaction step, but not during the less hazardous workup. Though originally introduced as element of LOPA, conditional modifiers and enabling conditions are also applied by other SQRA approaches.
These tools allow a higher accuracy in the assessment of frequency and risk of a scenario. But if applied incorrectly, there is the possibility of assessing a risk as too low. For this reason conditional modifiers and enabling conditions are used only by part of the participating companies. See also Gowland 2009 in a critical review on the Buncefield fire.
We conducted a survey among the members of the working group on the use of modifiers and enabling conditions with the following results:

- 8 companies participated in the survey
- 4 companies use modifiers and enabling conditions
- 4 companies do not use these tools

The most frequent applications of these tools are:

- Presence of people
- Probability of ignition
- Campaign production of different products with higher and lower risk

Reasons given for not using these tools are:

- Be on the conservative side
- Keep SQ risk assessment as simple as possible

### 3.5 Risk Acceptance Criteria

A key factor for the risk level obtained by application of a risk matrix are the risk acceptance criteria. Considering one specific consequence category of a matrix, the risk acceptance criteria can be described as the limit between the "Unacceptable" and "Tolerable/ALARP" and between the "Tolerable/ALARP" and "Acceptable" region. To facilitate a comparison of different matrices of the working group, a reference scenario involving 1 fatality as consequence category was chosen. The frequencies defining the "Unacceptable" (red) and "Acceptable" (green) range for all matrices shared in the working group were compiled in table 2. The "Tolerable" (yellow) range is simply the area between the red and green range, therefore no column for these values was included into the table.
Table 2 shows that the "Unacceptable" range for most matrices starts at $10^{-4}$/yr with 2 exceptions at $10^{-3}$/yr and one matrix with limits of $10^{-4}$/yr or $10^{-5}$/yr depending on the raw risk. Considering the risk levels obtained by use of the matrices, this variation is further decreased by the application rules, mainly the use of modifiers and assumptions for initial event frequencies. These factors and the target frequencies in table 2 often act in opposite directions. This can be illustrated in an example:

- **Matrix A:** Unacceptable range above $10^{-4}$/yr (conservative), use of modifiers allowed (less conservative)
- **Matrix B:** Unacceptable range above $10^{-3}$/yr (less conservative), no use of modifiers (conservative)

For both matrices A and B the two factors “target frequency” and “use of modifiers” are a combination of one conservative and one less conservative design element, so that the gap which must be closed by a safeguard (i.e. the required quality of the countermeasure), is very similar or equal for both matrices.
It should be noted that 3 matrices do not give a value for the “Acceptable” (green) range, thus expressing that fatalities are never acceptable. The values given in bracket either indicate the limit of the matrix on the low frequency side or a value used for practical application.

*Table 2: Frequencies for “Acceptable” and “Unacceptable” range in the matrices of the working group for a reference scenario “1 Fatality”*

| Matrix No. | Acceptable at or below (1/yr) | Unacceptable above (1/yr) | Remarks |
|---|---|---|---|
| 1 | $10^{-6}$ | $10^{-4}$ | |
| 2 | $10^{-4}$ | $10^{-3}$ | |
| 3 | $(10^{-6})$ | $10^{-4}$ | No Acceptable range for fatalities. |
| 4 | $10^{-7}$ | $10^{-4}$ | |
| 5 | $(10^{-6})$ | $10^{-4}$ | No Acceptable range for fatalities |
| 6 | $(10^{-5})$ | $10^{-4}$ or $10^{-5}$ | No acceptable range for fatalities. Unacceptable limit depends upon raw risk. |
| 7 | $10^{-6}$ | $10^{-4}$ | |
| 8 | $10^{-6}$ | $10^{-3}$ | |

## 4. Example for Risk Assessment and SIL Rating

All members of the working group were asked to apply their company specific risk matrix to an example case for risk assessment and SIL rating. The objective was to get a realistic information on the risk levels obtained by application of the matrices with the influence of the various factors discussed in chapter 3.5. The process section used for this purpose is represented in figure 3. It had been used previously by the ProcessNet working group for a similar purpose (ProcessNet 2017).

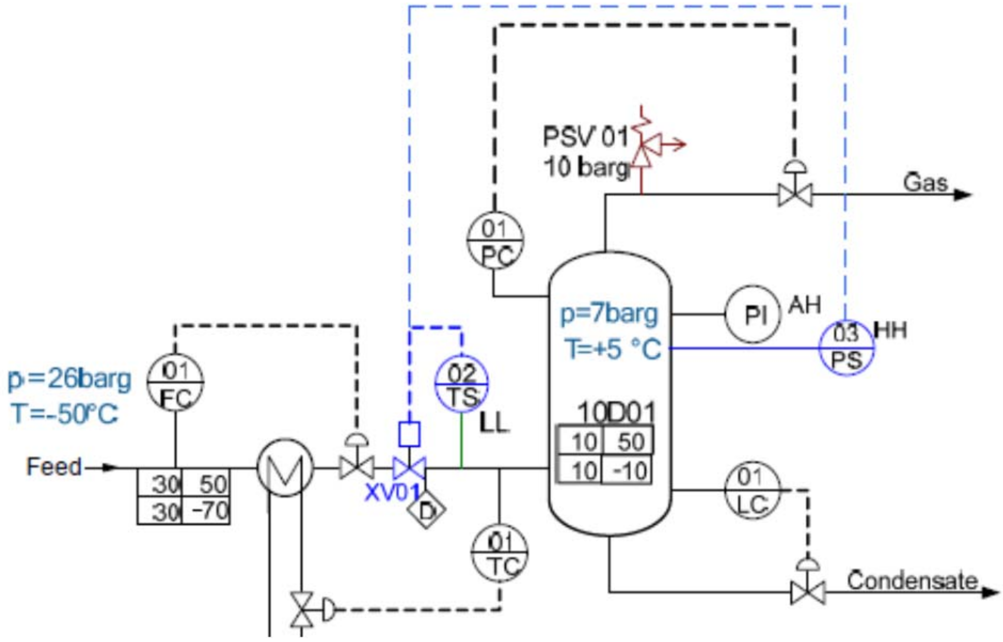


*Figure 3: Example for Risk Assessment and SIL-Rating used for comparison of risk matrices*

**Short process description:**
Feed (C1 – C5 hydrocarbons, 26 barg, -50 °C, 100 t/h) is heated and transferred into separation vessel D01 (7 barg and 5 °C). The gas phase leaves the vessel via PC01, the liquid phase via LC01.

**Hazards:**

- TS02 (LL) protects D01 from too low temperature (brittleness, loss of containment)
- PS03 (HH) protects D01 from too high pressure (loss of containment)
- 2 design cases for PSV:
  - Variant 1: PSV is sized for maximum feed
  - Variant 2: PSV is sized only for fire case and leaking XV01

The results of the SIL rating of the E&I devices TS02 and PS03 (variant 1 and 2) are shown in Table 3.

*Table 3: Results of SIL rating for Example case represented in figure 3*

| Results for TS02(LL) | | Results for PS03 (HH) Variant 1 | | Results for PS03 (HH) Variant 2 | |
|---|---|---|---|---|---|
| SIL 1 /No SIL | 0 | SIL 1/No SIL | 5 | SIL 1/No SIL | 0 |
| SIL 2 | 1 | SIL 2 | 1 | SIL 2 | 1 |
| SIL 3 | 6 | SIL3 | 1 | SIL3 | 6 |

7 companies participated in the survey. The numbers in the table indicate how many participants required the respective qualities of the safeguards. As some companies use DCS based interlocks instead of SIL 1 devices, both categories were counted in one group.

Most participants arrived at the same results. For TS02(LL) and PS03(HH) variant 2 there was only one exception differing by one order of magnitude. For PS03(HH) variant 1 there were 2 deviating results. The prominent SIL 3 requirement could be explained by the fact that the participant preferred an inherently safe approach for this kind of process. The high proportion of consistent results confirms that the factors discussed in chapter 3.5 in many cases compensate each other while the remaining differences can be explained by assumptions required for the risk assessment (e.g. number of fatalities as consequence of the scenario, initial event frequency etc.).

The results in Table 2 allow the summarizing assessment that the safety levels obtained with the risk matrices of the working group members are comparable and differ only to an extent that can be expected by application of a semiquantitative tool.

## 5. Conclusions

Comparison of the risk matrices shared by working group members showed that the risk acceptance criteria for one fatality as reference scenario differed only by one order of magnitude. The degree of agreement was still greater with the application of the matrices to an example case for risk assessment and SIL rating. The reason for this is that the other important factors influencing the risk level – use of modifiers and assumptions for initial event frequencies – often act in opposite directions. Thus design and application rules of most matrices are an interaction of more and less conservative elements which balance out to consistent risk levels differing only by one order of magnitude. These remaining differences are limited to an extent that can be expected with a semiquantitative tool. This allows the conclusion that use of semiquantitative risk analysis as described in chapter 1 and practised by the working group members yields a consistent risk level and is well suited for risk assessment in the chemical and petrochemical industry.

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