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# Risk Assessment in Accident Prevention Considering Uncertainty and Human Factor Influence

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## 1. Introduction

Nowadays, every manufacturing enterprise, company providing services or transport wants to be successful. Its goal is to secure prosperity of business and to achieve it through manufacturing or services. The technological processes and equipment are closely linked with the industrial risks which have become the object of assessing their decrease on the acceptable level and last but not least permanent monitoring of risks from the side of enterprises as well as selected bodies of the public administration. Perception and awareness of the need to prevent rising the crisis phenomena is for the society as well as legal entities or natural persons very important. Overlooking and insufficient attention paid to the risks could have negative impacts for all people. An important part of the risk assessment process is also inspecting and monitoring the adopted measures in connection with the effort to decrease their number.

As it was mentioned the risks connected with the technical and technological processes can be a source of unplanned interruption of the manufacturing processes or can violate providing a service and can cause material losses, damage the environment, threaten the health and lives of people. They can endanger not only the participating employees but also inhabitants from the surroundings and in the case of a leakage of dangerous substances it can become the source of violating the nature, the environment and endangering the inhabitants for a long-time period, if not forever. In the time period of increasing demands on the security of the technological processes the prevention is becoming the dominant idea and this article deals just with this area. It characterises the selected areas of prevention of industrial accidents which are the basic assumption for securing the safety of the industrial processes.

One of the objectives of this article is to show a possible approach to assessing the risks of the industrial processes in the form of structured diagrams. The logical procedure coincides with the currently used procedures created on the EU level as well as the national structures. Our attention will be aimed at especially at the area of the industrial accidents and the process of the risk assessment of the industrial processes in the Slovak Republic.

The uncertainty and its influence is significant in the process of the risk assessment and it is valid especially when assessing the risk from the quantitative point of view. The variance of the results is caused especially by different approaches to assessing and presenting the risk.

However, an extensive investigation of uncertainty is missing here. In the next part of the article I will deal with the influence of the uncertainty in assessing the risks and I will show the main sources of its presence. Several investigations have been realised worldwide which are to find out the main sources of the uncertainty influence when assessing the risks. (Amendola et al., 2002)

The last part of this article deals with the main cause of rising the industrial accidents, namely with people – the human factor. The human factor operates in an interaction with the industrial accidents and plays an important role in their rise; however, it is affected also by the consequences of their demonstrations. Here we can mention its three positions. The first one is the often analysed position of people as the human error that is the main cause of developing the industrial accidents. James Reason (1990) analyses it thoroughly in his book "Human Error". In his next book "Human Contribution" he describes also another position of the human factor – the hero who is able to prevent the rise of the industrial accidents. It is just the position of the human factor whose causes and characteristic features are not investigated in depth and therefore there is the space for further research. Last but not least they are the people – the human factor who is affected by the rise of the industrial accidents and which puts them to a position of a victim. The victims can be the so called direct victims (dead, injured people…) and indirect ones (the families of the missing or dead people).

## 2. Risk assessment in industrial accident prevention

The effort of people to achieve higher and higher standard of living reflects in the dynamic development of technologies, which are, on the other hand, still more and more complicated and can lead to the industrial accidents. The industrial accidents as the explosion in Flixborough (1974) or in Seveso (1976) as well as the disaster of the firm Union Carbide in Bhopal (1984) or in Chernobyl (1986) as also a whole range of others have shown the failure of the technology, its attendance. Due to these failures a great number of people died, or the consequences of these accidents caused durable health damage, not to speak about the losses of the material values and environment which can be of a long-term character or even irreversible.

The aim of the first part of this chapter is to describe the environment of the industrial accidents in the EU and in the Slovak Republic and to show an algorithm for assessing the risks through structured diagrams which should be mainly used in Slovak Republic. The model created complies with the currently valid legal regulations in the area of prevention against industrial accidents and is in balance with the used procedures for practical risk assessment in Slovakia as well as the EU.

**Industrial accidents in the context of the EU and the Slovak Republic**

The company SWISS RE works out an annual overview and summary of natural disasters and anthropogeneous disasters (man-made disasters) according to selected criteria (see the note). For working out an overview I decided to use selected indicators from 1998 to 2008 and to create the table 1 which depicts an overview of technological disasters in a chosen time period and is divided in three groups. The main group is created by the anthropogeneous disasters where belong all technological disasters caused by people and are designated in the table and the graphs as MMD (man-made disasters). This group comprises explosions, fires, air disasters, naval disasters, road and railway disasters, collapse of buildings and bridges, mining disasters and terrorism. The anthropogeneous disasters where an explosion or fire arose or their combination create the second group and are designated as FED (fire and explosion disasters). There are disasters occurring in the industrial plants and warehouses, manufacturing processes working with petrol and gas, hotels and other buildings as well as remaining fires and explosions. The last group is created by accidents where an explosion, fire or leakage of hazardous substances in the industrial environment arose (factories and warehouses) are designated as ID (industrial disasters). In the table which is transformed into graphs I depict all three groups from the point of view of the overall number of the technological disasters, the number of victims and financial losses (million USD) during the time period of 1998 – 2008.

| | Number of events | | | | Number of victims | | Financial losses (mil. USD) | | |
|---|---|---|---|---|---|---|---|---|---|
| YEARS | MMD | FED | ID | MMD | FED | ID | MMD | FED | ID |
| 1998 | 219 | 34 | 19 | 9788 | 1445 | 94 | 3534 | 1454 | 835 |
| 1999 | 188 | 36 | 20 | 7238 | 723 | 189 | 4140,3 | 2551 | 2107,7 |
| 2000 | 230 | 34 | 20 | 9694 | 1368 | 349 | 3049 | 1334 | 773 |
| 2001 | 204 | 40 | 17 | 10247 | 921 | 371 | 24381 | 3748 | 2086 |
| 2002 | 214 | 27 | 14 | 13066 | 2111 | 1562 | 2130 | 935 | 915 |
| 2003 | 238 | 36 | 15 | 7914 | 1071 | 139 | 2320 | 1137 | 905 |
| 2004 | 216 | 44 | 15 | 7275 | 1330 | 47 | 2889 | 1713 | 887 |
| 2005 | 248 | 60 | 31 | 8935 | 692 | 162 | 5066 | 4095 | 2346 |
| 2006 | 213 | 42 | 21 | 8677 | 906 | 185 | 4043 | 2110 | 1722 |
| 2007 | 193 | 34 | 15 | 6923 | 611 | 163 | 4295 | 2145 | 1170 |
| 2008 | 174 | 45 | 24 | 5618 | 454 | 159 | 7812 | 5255 | 2146 |
| Total | 2337 | 432 | 211 | 95375 | 11632 | 3420 | 63659,3 | 26477 | 15892,7 |

(Source: Swiss Re, 1998 – 2008)

*Note: The company SWISS RE understands a disaster as an event when at least 20 people lose their lives, or the total amount of damages represents the sum of 72 million USD or the damages on property exceed 36 million USD*

Table 1. Overview of selected anthropogeneous disasters according to number of events, number of victims and financial losses

The table shows that the disasters in the industrial environment create a relatively great part of the anthropogeneous disasters especially from the point of view of their number and financial losses. Their impacts on the employees and inhabitants from this point of view are not negligible which is proved by the numbers of victims in the individual categories. The financial losses caused by the largest disasters in the industrial environment create a relatively great proportion of the anthropogeneous disasters in the individual years.

**Seveso II directive**

The growth of the number of industrial disasters is the reason why new methods rise or the old ones are modified, i.e. the so called systematic procedures are developed which attempt to increase the security in the industrial enterprises. An example is the implementation of the SEVESO II directive in the framework of the EU as the basic pillar of preventing serious industrial disasters in the member states. Forming the directive began after the consequences of the large industrial disasters in the 1970s and 1980s when the EU in 1982 adopted a directive on serious industrial disasters. The EU called this first document "SEVESO Directive" – it got its name after the Italian town Seveso where after an explosion in a chemical factory dioxin leaked and caused a mass intoxication of the inhabitants. The prevention of the serious industrial disasters was later adapted by the Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances also called "SEVESO II" which is aimed not only at the prevention of large disasters but also at reducing their consequences for people and the environment.
Due to serious industrial disasters (breaking the dam of the sludge bed in the Rumanian town Baia Mare which caused intoxicating the river Tisza, the explosion of the pyrotechnics factory in the Dutch town Enschede, the explosion in the factory for producing fertilisers in the French town Touluse) a requirement for updating this directive arose. In 2003 the Council Directive 2003/102/EC was adopted. It formulates the environmental objectives of the EU as well as the decisive procedures in adopting measures for achieving these goals. The objects of this legal adaptation are specific duties of the operators and corresponding bodies concerning the enterprises where the selected hazardous chemical substances can be found. These issues are solved from the view of supervising the risk management of the possible serious industrial disasters. This law concerns companies of heavy chemistry, firms dealing with pressurised gases, equipment working with a higher amount of ammonia (firms using refrigerating equipment), petrochemical operations, but also companies with a higher supply of oil substances, etc. It does not concern the military premises, transport of hazardous substance by pipelines, mining activities, garbage dumps, etc.

**EU study in the area of serious industrial disaster prevention**

In 2008 the EU – Vri (The European Virtual Institute for Integrated Risk Management) realised a questionnaire study whose aim was to acquire information about the transposition of the requirements concerning the SEVESO II Directive in the individual member states and its general procedure, practical experience with making use of the weaknesses and problems connected with its practical implementation, effectiveness of its implementation and the impacts of the directive on the competitiveness of the European industry and subsequently to respond to these comments (to improve the directive). The target industrial sectors for processing the questionnaire were as follows: production of metals, explosives, petrochemistry, pesticides, pharmaceutical industry, basic chemical production, plastics and rubber, production of energy and its distribution, food industry and beverages. The questionnaire assessment brought conclusions and lessons necessary for a partial updating of the directive and preparing new accompanying documents. The selected conclusions from the research realised are as follows:

- the respondents have recognised a possibility to work out next accompanying documents in some areas – the area with the highest priority is the analysing and assessing the risks (risk assessment),

- a problematic area is the non-universality of the approach of the risk assessment, insufficient criteria for quantifying the risk and methods, tools and data for implementing these procedures,
- a lot of enterprises work out more a qualitative rather than a quantitative analysis which can conceal a higher level of the result uncertainty,
- the procedure for the risk assessment according to the SEVESO II Directive should be harmonised with the legal standards for the given area in the given country. /SALVI, O. et al

Similarly the responsible bodies in the area of serious industrial disaster prevention recommend proposing and creating the European database for supporting the risk assessment and working out the other documents. There exist some "guaranteed practices" for working out the analysis and risk assessment, however, in general it is necessary to create a clear and understandable procedure for processing documents and most respondents are missing such a document.

If new accompanying documents are created, the following issued should not be forgotten:

- the criteria of risk acceptability (impacts and probability),
- the assessment of the security measure management,
- the assessment of emergency planning,
- the calculation of the dangerous events´ consequences (explosion, fire, spreading a toxic substance),
- the methodology taking into account prevention and protecting measures,
- the methodology for assessing the domino effects.

The final EU recommendations in the area of the questionnaire assessment head to two levels:

- creating an accompanying document which will deal with what is to be done step by step and will explain how the directive requirements are to be interpreted,
- creating manuals for individual industrial sectors which would specify the environment for risk analyses and procedures necessary for its processing (SMEs).

**Existing procedures for risk assessment**

The environment of preventing the industrial disasters in the EU member states is affected by obligations which result for them from the membership in the international organisations. The individual EU countries implement the directives in their legal guidelines and create new procedures for the risk assessment which should contribute to harmonising in the area of the industrial disaster prevention.

There are several procedures for assessing the risks of the industrial processes. Systematic procedures, methods and techniques are used. The systematic procedures are structured operations which utilise selected methods and techniques in the individual steps. In the Slovak Republic the risk assessment also fulfils the requirements of the laws introduced in the Figure 1.

The risk assessment is part of the risk management. Its activity as well as expending resources for preventing the rise of serious industrial disasters is often pushed to background both by the wide lay public and professionals during a time period when no crisis phenomenon arises. However, when any technological disaster occurs, e.g. the accident which happened on 27$^{th}$ October 1995 in VSŽ, a.s. Košice – the leakage of CO, on 2$^{nd}$ March 2007 in Nováky - the explosion of the delaboration hall – both of them in Slovakia, then the losses of lives as well as material prove that a lot of tasks in this area are fulfilled only in a formal way, their complex securing from the organisational, personnel, technical as well as material point of view is not solved. However, fulfilling these tasks is to be mutually harmonised and it is necessary to ensure them on a corresponding level.

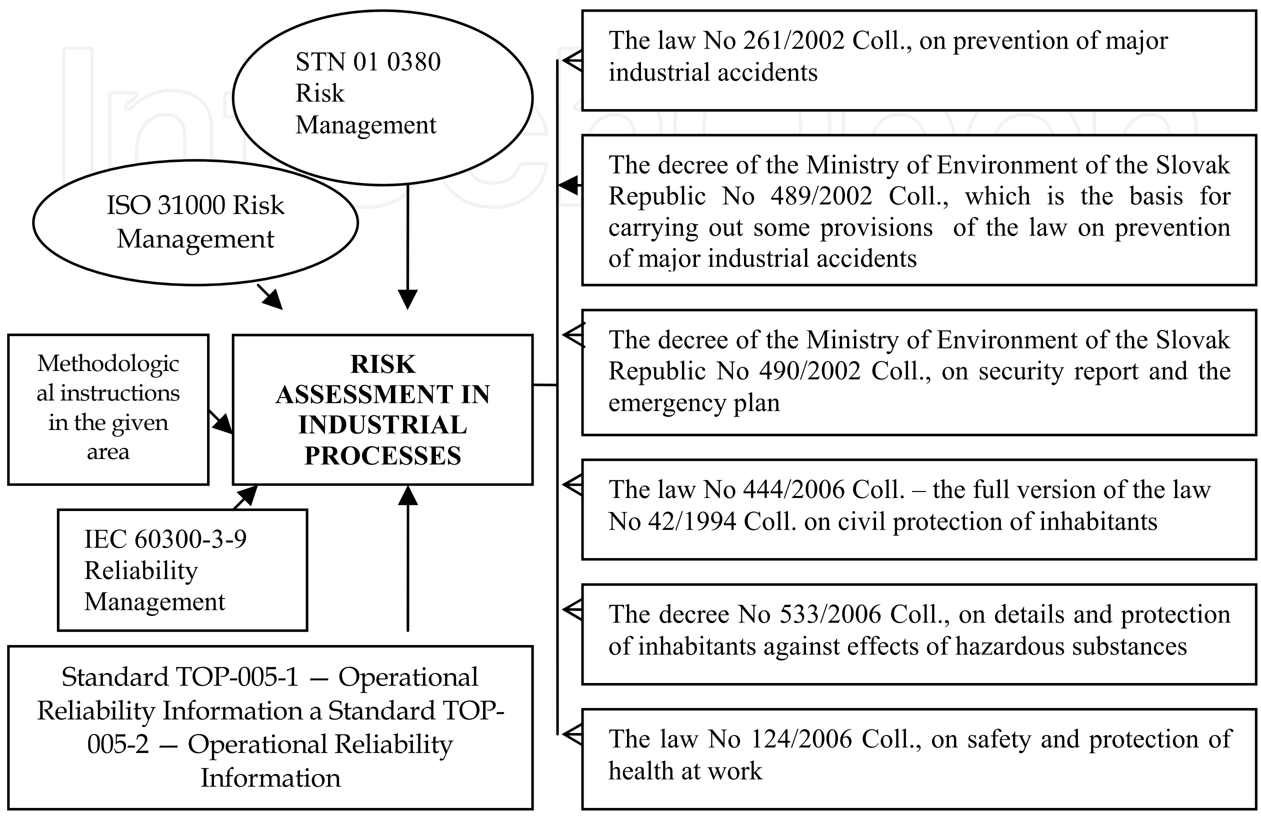
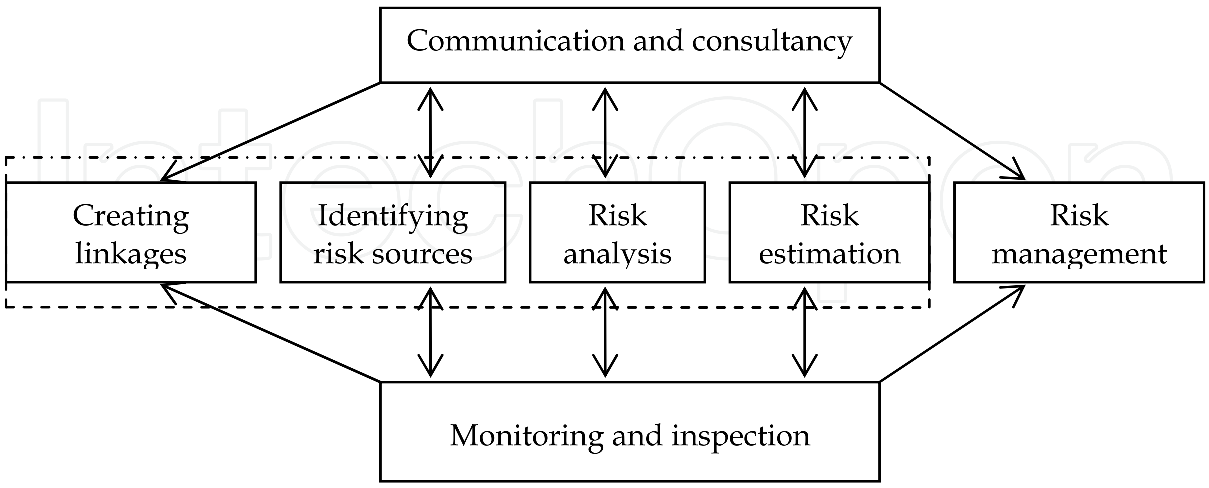



Fig. 1. Selected legal guidelines in the area of preventing the industrial disasters which require the risk assessment

**Prevention in risk assessment**

To avoid the industrial disasters, it is necessary to deal with prevention which is part of the crisis management model (prevention – preparedness – response – recovery). We utilise several procedures in the area of prevention whose main goal is to reduce the probability of the rise of the crisis phenomena or their negative impacts. One of these tools or more or less idea procedures or philosophy is the risk management, i.e. the process which is utilised not only on the microeconomic but also on the macroeconomic and global levels. Its procedures, methods and techniques contribute to reducing the probability of rising crisis phenomena and reducing their negative impacts which plays a positive role for the object assessed. It is implemented in different spheres of the social life and is applied in various forms in the practice. A consequent implementation of the risk management requires not only realising a thorough identification, analysis and risking assessment, their minimising by suitable procedures, but also a regular inspection of the measures realised.

In the Slovak Republic in the area of risk management the standard STN 01 0380 Risk Management is used, however, it has become outdated in several directions and the professional circles criticise it. If we wanted to identify the decisive phases of risk management we could realise it according to the standard ISO 31 000 Risk Management Guidance Standard. According to it the process of risk management consists of the parts depicted in the figure 2. The risk assessment (outlined by an interrupted line in the figure 2) in this standard includes creating linkages, identifying the risk sources, risk analysis and evaluating the risk (risk estimation).




*Source:* ISO 31 000, 2009 – adapted.

Fig. 2. Risk management according to the standard ISO 31 000

The individual phases are in the accessible sources, legal norms and regulations, methodological manuals frequently introduced in different ways and this fact can cause misunderstandings in communication in the given area (a problem is often caused by a translation from a foreign language).

The risk assessment should be based on a systematic identification of the risk sources, on detecting what can be damaged, on creating scenarios in the form of trees of knowledge, trees of failures, and assessing the probabilities and their consequences. Expressing the risk should always comply with the mathematical formulation and represents a product of the probability and consequences. The consequences are determined in continuation to the rate of the threatened activities through calculations, and the probability either by a qualified estimation, or based on the historical experience. Quantitative risk analysis has its unique place in determining the level of adequacy of the security measures in the area of industrial process security. The quantitative criteria are, from the point of view of the level of subjectivity which enters the process, more credible than the qualitative ones.

Risk assessment is the core of risk management. After its realisation, the corrective measures for carrying out the stabilisation of the system and decreasing the risks can be stated. Both phases are burdened by subjective as well as objective factors which affect their overall result (uncertainty). The objective factors comprise defining the real quantities when assessing the risk quantitatively. In practice it is a problem to define the probability and consequences of an undesirable phenomenon because often the relevant data required for stating the risk is missing.

**Existing procedures, methods and techniques for risk assessment**

Assessing the risks in the industrial processes and their decreasing has a whole range of specifics whose recognising and accepting is very important for improving the level of the safety of the whole society and its continual progress. There are lots of models and methods for assessing the risks, however, most of them use a special terminology and specify the same facts in a different way.

In Slovak Republic there should be used these types of systematic approaches:

- PRA (Probabilistic risk analysis)
- ARAMIS (Accidental Risk Assessment Methodology for Industries)
- MOSAR and others

PRA is also called quantitative risk analysis (QRA) or probabilistic safety analysis (PSA) is widely applied to many sectors. In many of these areas PRA techniques have been adopted as a part of the regulatory framework by relevant authorities (so do in the Slovak Republic). In other areas the analysis PRA methodology is increasingly applied to validate claims for safety or to demonstrate the need for the further improvement. The trend in all areas is for PRA to support tools for management decision making, forming the new area of risk assessment. In the Slovak Republic the approach is worked out in the document "Methodological Procedure for Risk Assessment of Hazardous Operations and Study of Companies in the Slovak Republic" (Ministry of Environment of the Slovak Republic, Bratislava, 2000). The document shows the advantages of implementing the PRA (probabilistic risk analysis) compared to other methodologies as well as its broad implementation. The usage of induction and deduction methods described by it is emphasised. Next systematic approach is MOSAR which is a relatively new, systematic approach for analysing technical and technological risks developed in France. It can be used for analysing both a new and existing system. Two of its basic modules are known, namely Module A and Module B. The principle consists in realising a double analysis. In the first step the macroscopic view is searching for risks created by transmitting a danger (the so called risks of proximity) and this is solved by the Module A. In the second step the risks of individual sources are analysed, here we make use of the so called classical methods of the risk analyses (Module B). In the framework of the first step, i.e. the macroscopic view the so called black-boxes are used. The key when we use them is a simplified view at the considered system depicted as the black-box. The inputs are entered and concrete outputs are picked up. The way from the input to the system to the output from it is not determined in a greater detail.

The European approach ARAMIS is a less utilised method. It serves for the risk assessment in the industry and combines the strengths of determinism and acknowledged objective regularities. Its aim is to create a unified procedure for the risk assessment in all companies which belong to the group which has to fulfil the SEVESO II Directive with the possibility of the mutual comparison of the "companies´ danger rate" regardless to the fact to which industrial sector they belong. This methodology was optimised for the gas industry, specifically for the company NAFTA, a.s. The methodology's output is to determine the risk rate, suggesting suitable measures with a subsequent investment aim of the company in the area of increasing the operation security. The systematic procedure ARAMIS is recommended for implementation in the Slovak Republic. Currently only few companies in Slovakia use it for working out the risk assessment. A thorough depiction of the method is shown in the figure 3.

The following types of analyses affect the selection of the methods and procedures of the risk assessment in an industrial environment:

- *the a priori analysis* is based on the phenomenon which is the source of the risk and has occurred in the past at least once. The nature of the object assessed, the probable behaviour of the phenomenon is known and thus we can a priori forecast its behaviour and properties in the future;
- *the a posteriori analysis* is used when the analyst has to work with information, phenomena and events about which he/she thinks can develop, although they have not happened in the past. It means that the risk is estimated based on the assumed behaviour of the phenomena which develop after the analysis.

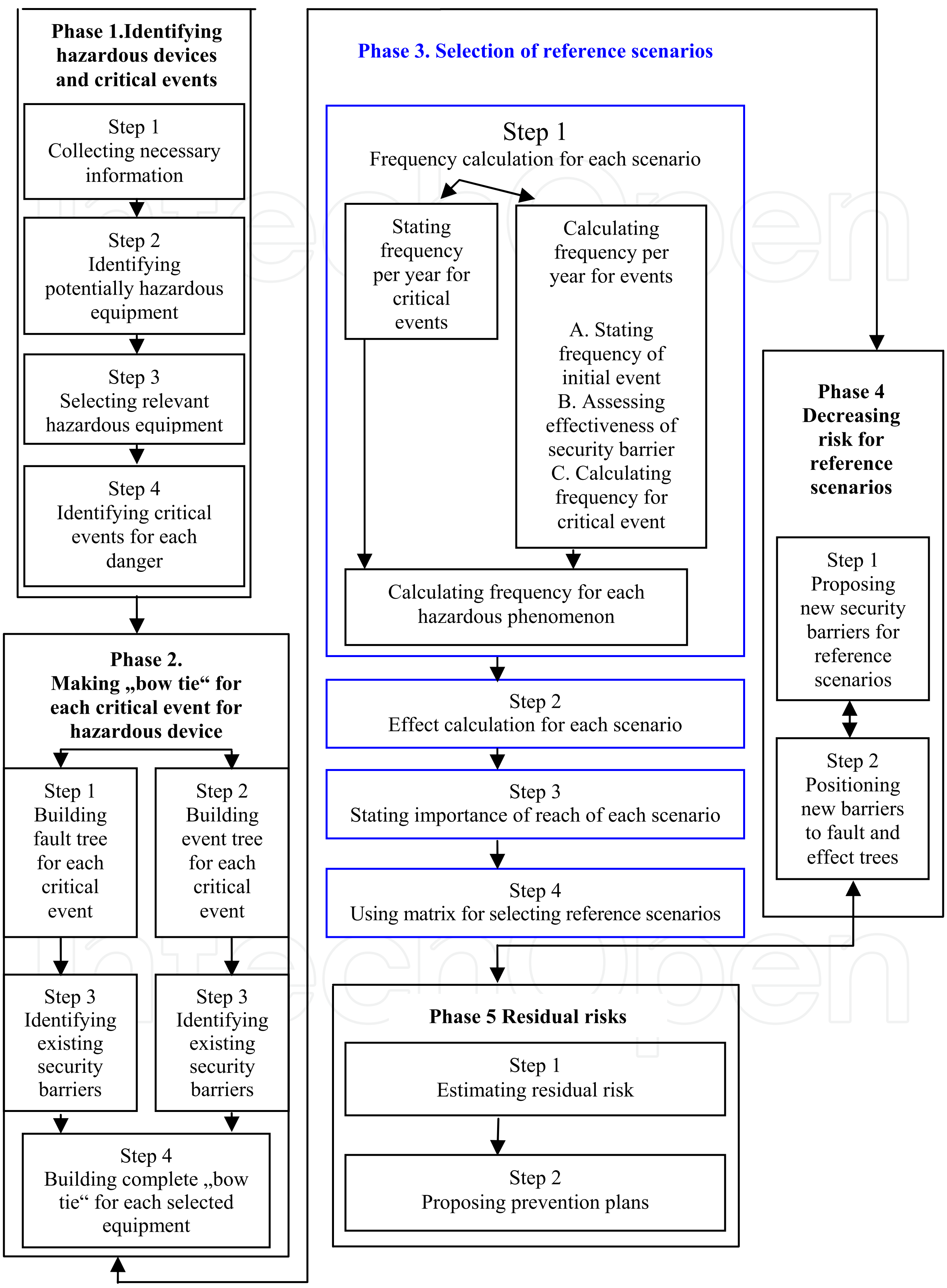



Fig. 3. Systematic approach ARAMIS (ARAMIS final user guide)

From the point of view of the inputs used and their character we distinguish:

- *the qualitative analysis* – is used for the qualitative estimation of the risk of a certain event, i.e. non-digital description consisting of identification and description of the risk sources, the relative verbal evaluation of the seriousness of the risk sources, identification, setting up and describing the accident scenarios;
- *the semi-quantitative analysis* – makes use of the semi-quantitative estimation of the risk of a certain event, i.e. the category of frequencies and effects and certain levels of seriousness are determined both verbally and quantitatively for the scenarios. The risk is stated similarly as in the qualitative risk analysis, however, the category of seriousness of the effects and scenario frequency are rendered more precisely;
- *the quantitative analysis* – a systematic procedure of numerical quantification of the expected number and effects of the potential accidents connected with the equipment or operation based on an engineering estimation, assessment and mathematical methods. (Paleček et al., 2000)

The decision about selecting the qualitative, semi-quantitative or quantitative analysis depends especially on the depths of the study and the purpose of the analysis realised.

The approach to the analysis from the point of view of stating the consequences and probabilities can be as follows:

- *the deterministic approach* – can be used if the problem formulated by one question or several questions can be answered clearly and understandably by one answer. The analysis itself is connected with a relatively simple determining of the causes, effects and impacts (by the relationships among them). We assume in the case of each problem it will have one result or one possible solution. It can happen that this approach does not result in any solution, i.e. there is no answer to the given question, or it cannot be answered. In this case only an approximate result is achieved. The uncertainty is not connected with a probabilistic result and is not easily detectable. When the effects which can develop are defined correctly we sometimes recognise the probability in the form of 100 % of the probabilistic occurrence or 0 % of the probabilistic occurrence (i.e. the phenomenon either develops or it does not);
- *the probabilistic approach* – is based on an assumption that several possible results of one assessed problem (situation) can develop. Probabilistic modelling aims at studying several results from the given data. The input data itself for the deterministic model cannot be used for a probabilistic study of the same problem. The probabilistic approach is currently preferred more. It is also recommended in the Slovak Republic for processing the analysis and risk assessment in the area of serious industrial accidents.

**Model for assessing risks of industrial processes**

Based on the previous information in the further text I characterise analyses affect the selection of the methods and procedures of the risk assessment. The subjects of investigating the model for the risk assessment are especially the technological processes in the industrial environment utilising hazardous substances. The systematic procedure created can form a supporting apparatus for analyses, especially in the SMEs. It is similarly usable for the analysis in the process of managing continuity in the operational company processes (*the business continuity management)* whose mission is to ensure the operation of all important processes inside the organisation if any unexpected events occur.

A systematic procedure serves the processors of the risk assessment of the technological processes with the presence of a hazardous substance for a better orientation in the given area as well as for approximating the fulfilment of the individual phases and will make the selection of methods and techniques for their application in the individual steps easier. The creation of a logical sequence of the phases and their steps according to which the analyst should proceed are emphasised. The phases of the risk assessment can be depicted by a simplified model which shows the involvement of the analysts, the responsible manager (decision-maker) and the working team to the overall process. The figure 4 shows the basic structure of the model of the risk assessment.

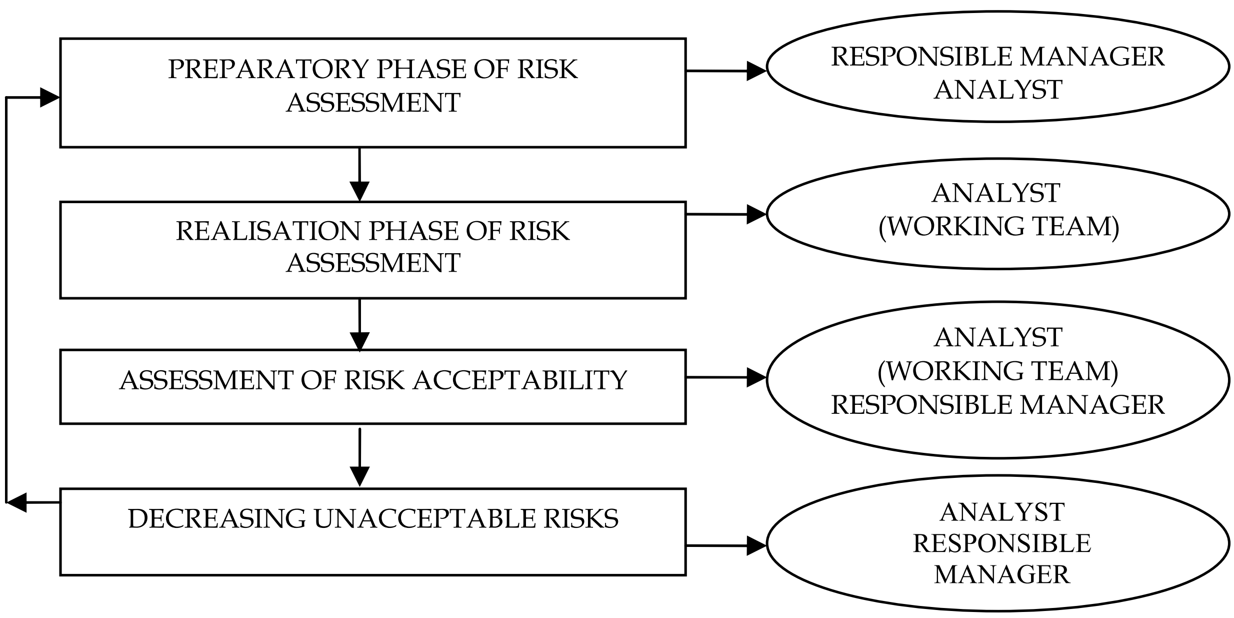



Fig. 4. Basic structure of the model of risk assessment

Further text explains the individual phases of the simplified model. As the first one, the preparatory phase of the risk assessment is characterised whose realisation is often underestimated or is not carried out correctly. The process of the risk assessment is implemented in the realisation phase and then the assessment of risk acceptability continues. Decreasing the risks is a decision which is realised on the basis of identifying unacceptable risks and subsequent work with them.

**Preparatory phase of risk assessment**

The preparatory phase of the risk assessment is followed by its implementation phase. In this part the risk analyst and the working group (if the decision is being made the presence of a responsible company manager is also necessary) are the most important players. The figure 5 depicts preparatory phase of risk assessment.
The figure 6 depicts the individual steps which create the realisation part of the risk assessment. Their interpretation as well as the content can differ in dependence on the

resources and type of the environment investigated as well as on the systematic approach used.

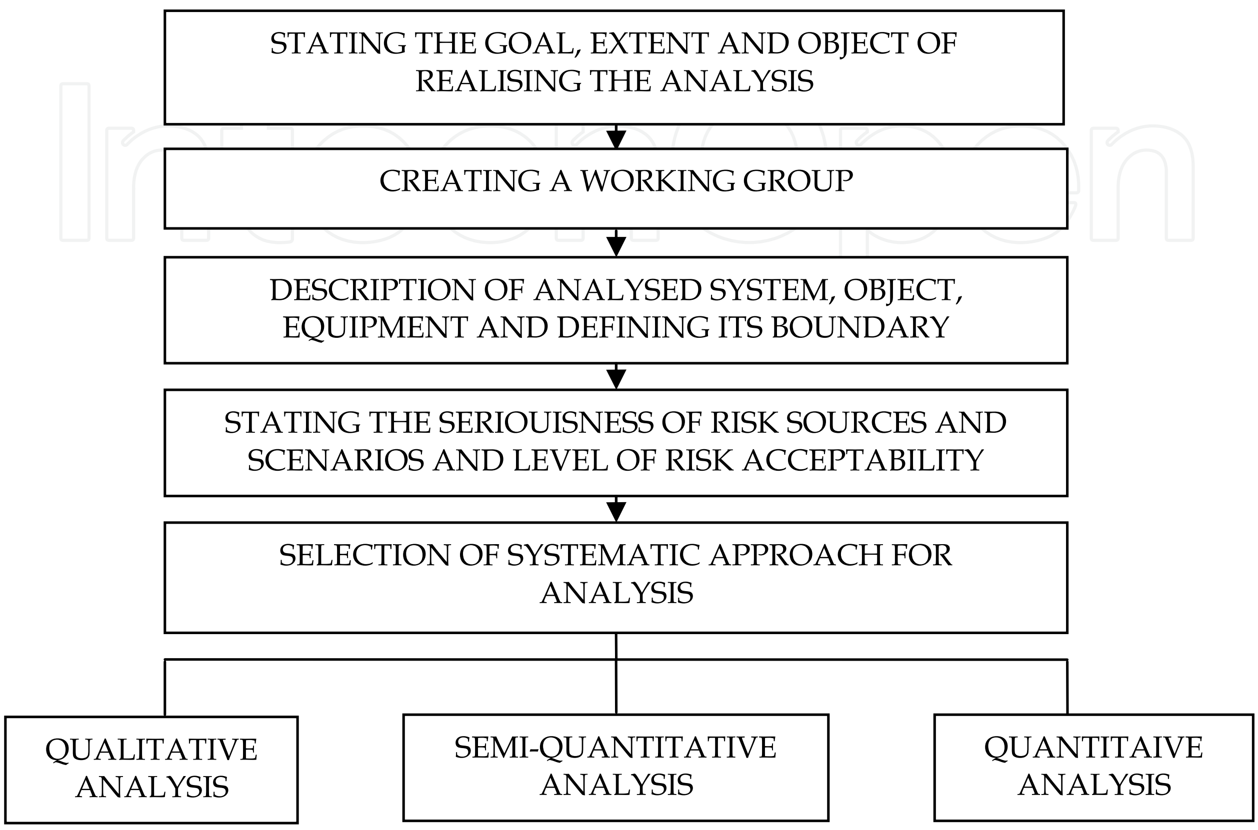



Fig. 5. Preparatory phase

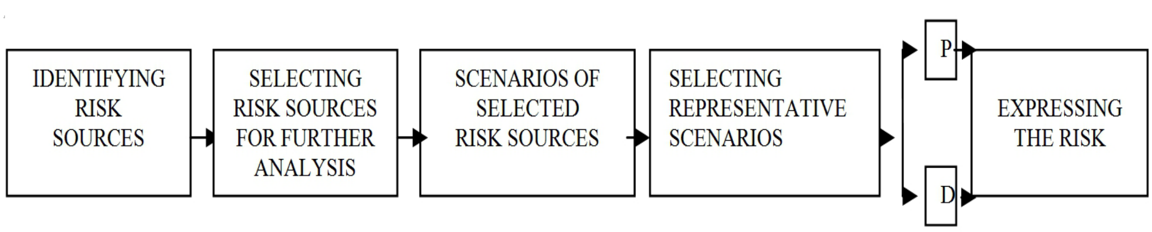



Fig. 6. Steps of implementation phase of risk assessment

**Assessment of risk acceptability**

The phase of stating the risk acceptability is important from the point of view of their further control. In most cases the criteria of acceptability are stated already in the preparatory phase of the risk assessment.
The decision about the acceptability, or unacceptability the risks is based on its two following levels:

- the negligible (acceptable) level of the risk – it represent a socially acceptable level of the risk in which the probability of occurrence of an adverse effect is small, the effects of its operation are moderate and the profit from the situation (the real or perceived one) is that large that the persons, groups or the whole society is willing to take the risk. It means that this level of risk does not require any regulation or other measures for its decrease neither from the point of view of people's health nor the protection of other live systems;
- the unacceptable level of the risk – requires inevitable taking of regulation measures or other specific measures for its decrease.

Every individual as well as every society has own values for the risk acceptability which are a compromise in many cases or sometimes a consensus reflecting its real "cultural", technological or operational maturity – in the technical practice often designated as the culture of operation. However, the term culture of operation comprises much more than the personal and technological security. It involves except for other things also the overall philosophy and approach of an individual or society to understanding the needs of the society.

## 3. Uncertainty in risk assessment

The second part of book chapter will talk about the uncertainty in risk assessment. It is known that results of any risk assessment are inevitably uncertain to some degree. Because of inevitable limitations of the risk assessment approach it must be acknowledged that the true risks could be higher or lower than estimated. In general, the word 'uncertainty' means that a number of different values can exist for a quantity, and 'risk' means the possibility of loss or gain as a result of uncertainties. The uncertainty should be divided into two categories: aleatory and epistemic. Aleatory stochastic uncertainty or due to randomness should result from bad knowledge of risk figures and their distribution, quantities such a failure rates, meteorological conditions at the time of release. Epistemic (reducible) is related to incomplete knowledge about phenomena of concern and inadequate matching available databases to the case under the assessment.

Besides, we know also the so called operational uncertainty. When comparing the physical models, the experience shows the importance of the human factor, e.g. using the same computer code by several specialists can lead to variations. The estimation variability of the commonly defined "representatives" of values expressing the risk and complexity of dangerous and main/temporary events which were identified by various experts from the teams, reflects the types of uncertainty, both operational and epistemic ones. If the values are defined as the "point assessment", in this case the variability is tied to an aleatory uncertainty. A different point assessment can be assumed for the main events or the parameters can be selected by an equal division.

**Benchmark studies**

EC´s Joint Research Centre in Ispra and RisØ National Laboratory were coordinators of projects that showed the acute presence of uncertainty when carrying out the risk assessments and emphasised the resources the uncertainty stems from and also the fact how it can decisively affect the final result of the analysis. In the first comparison study 7 teams carried out the risk analysis in a chemical factory at an undetermined place in Europe. Their results in spite of equal input data mutually differed which was caused especially by utilising different methods and approaches. It was detected in the risk identification phase that the scenario assessment by probabilistic and deterministic approach can lead to fully different conclusions. The comparison study consisted of five main phases: the documentation phase, three working phases and the assessment (enlarging) phase. The working phases include the qualitative and quantitative phase – through study of the technological process mechanisms through case studies. The uncertainty is in this case bound to a lot of components, inspection mechanisms which are used in the technological process and interactions between them and the human factor. On the other hand we count on an uncertainty which is linked with meteorological and environmental conditions. The table 2 shows an example of a difference when stating uncertainties (6th team chose deterministic approach).

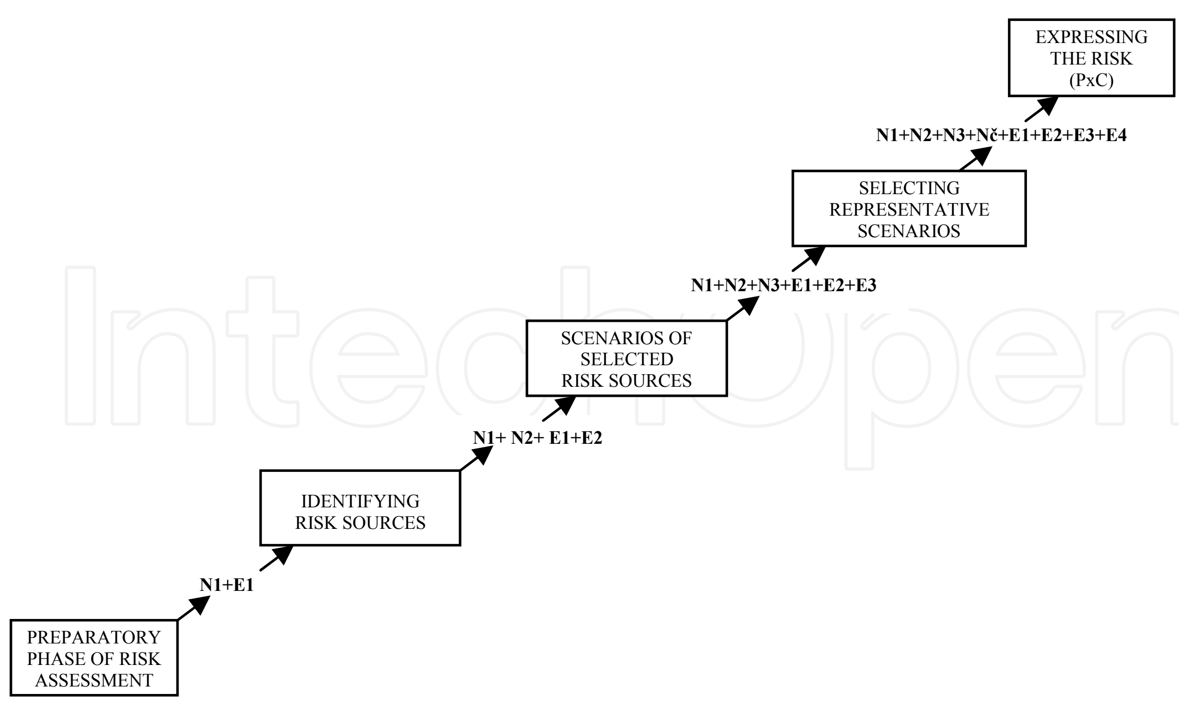
| S | Team 1 | Team 2 | Team 3 | Team 4 | Team 5 | Team 7 | Size Deviations |
|---|---|---|---|---|---|---|---|
| 1 | $9.10^{-7}$ | $1.10^{-6}$ | $1,4.10^{-3}$ | $9.10^{-7}$ | $1.10^{-6}$ | $1,8.10^{-7}$ | $1,8.10^{-7} - 1,4.10^{-5}$ |
| 2 | $1.10^{-5}$ | $3.10^{-6}$ | $1,4.10^{-5}$ | $9.10^{-7}$ | $7,3.10^{-7}$ | $4,6.10^{-7}$ | $7,3.10^{-7} - 1,4.10^{-5}$ |
| 3 | $4,8.10^{-4}$ | $4,8.10^{-6}$ | $8.10^{-3}$ | $5.10^{-7}$ | $5,4.10^{-7}$ | $1,3.10^{-5}$ | $4,8.10^{-6} - 8.10^{-3}$ |
| 4 | $1.10^{-6}$ | ------ | $4,6.10^{-6}$ | $9.10^{-7}$ | $8.10^{-7}$ | $1,8.10^{-6}$ | $8.10^{-7} - 4,6.10^{-6}$ |
| 5 | $2,8.10^{-7}$ | $1.10^{-8}$ | $5,7.10^{-3}$ | ----- | $2,3.10^{-6}$ | $4,9.10^{-6}$ | $6,4.10^{-10} - 5,7.10^{-5}$ |
| 6 | $5.10^{-7}$ | $1.10^{-8}$ | $4.10^{-8}$ | ----- | $5.10^{-8}$ | $5.10^{-7}$ | $1.10^{-8} - 5.10^{-7}$ |
| 7 | $6.10^{-7}$ | $1.10^{-6}$ | $5.10^{-6}$ | $9.10^{-7}$ | $4.10^{-7}$ | $4.10^{-7}$ | $4.10^{-7} - 6.10^{-6}$ |
| 8 | $1.10^{-6}$ | $5.10^{-7}$ | $1.10^{-6}$ | $4,5.10^{-7}$ | $1,3.10^{-5}$ | $4.10^{-7}$ | $4,5.10^{-7} - 1,3.10^{-5}$ |
| 9 | $3.10^{-6}$ | $3,4.10^{-7}$ | $1,5.10^{-5}$ | $9.10^{-7}$ | $2,2.10^{-6}$ | $8.10^{-7}$ | $3,4.10^{-7} - 1,5.10^{-5}$ |
| 10 | $2,4.10^{-6}$ | $1,5.10^{-7}$ | $2,1.10^{-3}$ | $2,7.10^{-6}$ | $6.10^{-6}$ | $5.10^{-7}$ | $1,5.10^{-7} - 2,1.10^{-3}$ |
| 11 | $5,5.10^{-9}$ | $1,5.10^{-9}$ | $1,2.10^{-7}$ | $1,2.10^{-7}$ | $4,7.10^{-6}$ | $1,4.10^{-7}$ | $1,5.10^{-9} - 4,7.10^{-6}$ |

Table 2. Probability of „top events“ of the individual 7 teams´ scenarios (Amendola, 2002)

The whole afore-mentioned procedure of assessing the consequences is full of uncertainties. In general we can thus say that there are two types of uncertainties: the uncertainty due to an incidental nature of the phenomena and uncertainties due to imperfect knowledge. The first type takes into account some phenomena and variables which incidentally change with time. The meteorological conditions can be such an example; it is impossible to determine with a 100 % certainty to forecast the direction and speed of the wind at a certain place of the space and at a certain time in the future, even if we knew exactly the conditions at present and in the past as well. The second type considers the lack of information which is presents at almost each step of the analysis. Our knowledge of phenomena following an unexpected leakage is not perfect and usually is based on empirical rules and observations of a limited number of accidents. The input parameters are also uncertain because exact conditions of accidents cannot be defined in advance. For an analyst to be able to cope with these uncertainties and insufficient knowledge, he/she usually has to state broad assumptions and to implement subjective judgement, i.e. an additional source of uncertainty into the whole procedure. The result is then characterised as an output of assessing the consequences with the occurrence of a whole range of uncertainties. The analysts and the decision-making segment should be aware of these uncertainties connected with the results of the risk assessment and to take them into account in the case of the risk-oriented decisions. Some uncertainty sources can serve as an example:

- the meteorological conditions,
- the conditions in the closed equipment (e.g. pressure, the state of the substance, the quantity of the substance in the vessel at the time of damage),
- the size and dimension of the opening,
- the proportion of the removed liquid,
- the drops in the material that leaked,
- the presence of an initiation resource and the exact initiation time,
- the behaviour of the flying ruins,
- the vulnerability of the persons and buildings, etc. (Paleček, 2000)

One of the methods how the uncertainty can be reduced is the repeating of the calculations for all possible combinations of uncertain input values and all possible changes of the used models and to assign them the individual uncertainties. However, this results in rising of an unbelievable large number of scenarios. In this case we can orient on a few important variables, or to choose some representative categories, we pay attention to calculating a significant expected frequency, as well as a great number of scenarios can be analysed and assessed or in the end the Monte Carlo simulation can be implemented. In the framework of the uncertain variables in assessing the risks the main attention should be paid especially to the correlation among them.




N- uncertainties, E- error

Fig. 7. Cumulating of uncertainties in phases of risk assessment

On the figure 7 there is shown gradualness of risk analysis where in each phase there are partial uncertainty and partial error increasing to the final N and final E. Each phase is characterized by its own uncertainty and errors and input uncertainty and errors from previous phase. Finally we need to count not just with results of risk analysis but also estimate an uncertainty related to final figure.

As a part of it, risk assessment is inevitably uncertain to some degree. And there is a question how issues of uncertainty are dealt with in existing safety regulations and in existing standards for risk analysis and management. I want to point on fact that there is a big need to deal with uncertainty and to count with it in risk assessment. Benchmark studies could serve as a guide to areas where caution must be taken when performing risk analysis.

## 4. Human factor influence on accident occurrence and demonstration

The last part will point out the problem which is very important to talk about. This is also the crucial part of crisis events occurrence and arising – the human factor. The aim of this part will be to show the human factor and his contribution to crisis events occurrence. The human factor will be assessed from two points of view as a hazard component which cause industrial accidents occurrence by errors and human as a hero element whose adaptations and compensations have brought troubled systems back from the bring of disaster.

In the past models of accidents dealing with the causes and relationships of accident rise were created. They insubstantially emphasized the human factor, it was only introduced as an immediate cause of events leading to an accident. Currently there is an effort to understand why and when the human factor affects the rise and development of serious accidents (it is the cause or part of accidents). What makes it possible to forecast, to prevent accidents as well as to decrease the share of the human factor on the rise and development of serious disasters? (Feyer, 2010)

The analysis of events which occurred and were caused by the human factor is one of the methods for creating the preventive measures. According to this method it is possible to foresee partially the human behavior in the crisis situations.

Over the past 50 years has been a dramatic widening of the scope of accidents investigation across many different hazardous domains:

- system and cultural issues (1960s Metal fatigue, Aberfan Inbrox)
- unsafe acts (errors and violations) (1970s Flixbourgh, Seveso, Tenerife TMI MT Erebus)
- equipment failures (hardware – software) (1980s Chernobyl Zeebrugge Bhopal PiperAlpha Dryden, 1990s Paddington Long Island Alabama Eschede, 2000s Linate Uberlingen Columbia). (Holla &Moricova, 2010)

Chemical incident statistics are very sketchy with respect to root causes and many reported incidents do not furnish much detail about the cause. Chemical safety and hazard investigation board published in 600K Report that:

- Among cases where the cause was known, 49% were as a result of mechanical factors, 39% from human factors and just 2% to weather-related phenomena, 10% causes not found,
- Among cases involving mechanical factors, an overwhelming 97% were attributed to general equipment failure; 63% of human factors cases were attributed to human error. (Garcia, 2002)

The high rate of general equipment failure among reported incidents suggests that mechanical integrity/maintenance issues are significant and from the human error that training and proper procedures should also be examined.
There should be introduced instances of accidents which were caused by failing the human factor or saving lives by human factor. The first of them is the *Chernobyl disaster.* An industrial accident of exceptional size had a lot of victims that cannot be counted exactly (the epidemiological analysis is not available). Various scientific studies assume from 9,000 to 475, 000 victims. The most frequent conclusions and maybe the most probable values are in several tens of thousands (30,000 to 60,000). The 1986 Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident (INSAG-1) of the International Atomic Energy Agency's (IAEA's) International Nuclear Safety Advisory Group accepted the view of the Soviet experts that "the accident was caused by a remarkable range of human errors and violations of operating rules in combination with specific reactor features which compounded and amplified the effects of the errors and led to the reactivity excursion." In particular, according to the INSAG-1 report: "The operators deliberately and in violation of rules withdrew most control and safety rods from the core and switched off some important safety systems."
Another example of the human factor failure in the environment of the nuclear power stations is the disaster *Three miles island* which happened at 4 am on 28th March 1979 and where the second nuclear reactor was partially melted. The operational building was contaminated and an extensive leakage of radioactivity to the environment also occurred. The investigation commission later designated for the reason of the accident a breakdown of the safety valve. The proportion of the human factor was that operators were unable to diagnose or respond properly to the unplanned automatic shutdown of the reactor. Deficient control room instrumentation and inadequate emergency response training proved to be root causes of the accident.
Last example is connected to another type of accident - nearly accident. As an example we can introduce the *Apollo 13* programme. Its objective was the third landing of the human crew on the Moon surface, this time in the area of Fra Mauro. The typical sentence: "Houston, we've had a problem," says how very close the crew was to a disaster. During the flight one of the oxygen tanks exploded and seriously damaged the service module. The consequences of this explosion were serious. Not only this situation caused the crew did not fulfill the task of this flight but it threatened the lives of the crew members. The Manned Spacecraft Centre (today Lyndon B. Johnson Centre) had to develop with an extreme effort emergency scenarios thanks to which they succeeded in transporting the crew alive back to the Earth. Hundred of people were involved in the rescue: off – duty controllers, astronauts, simulation technicians, contractors' personnel and many more. But this case is only to show how the team effort, and a magnificent display or sheer unadulterated professionalism, both in he spacecraft and on the ground brought the crew to the Earth alive. (Reason, 2010)
There is a stark contrast between unsafe acts and these intrepid recoveries. Errors and violations are commonplace, banal ever, they are as much as a part of human condition as another ordinary human activities. Successful recoveries, on the other hand, are singular and remarkable events.
The human factor in relation to the rise and demonstrations of the industrial accidents can play several roles. These roles are as follows:

- the human factor as the cause of the rise of the industrial accidents (hazard - human error),
- the human factor as the recipient of the negative consequences of the industrial accidents (victim - negative impact),
- the human factor as a hero or anticrisis factor (hero - heroic recoveries).

**Human factor as the cause of the rise of industrial accidents**

When the human factor fails, there is a whole chain of small errors which if occurred individually they would not have fatal consequences. However, from a certain point on the tragedy is unavoidable.

There are several definitions of the human error. One of them says that the error is an action or a decision which was not determined (planned) and which leads to undesirable result. Furthermore, the human error defines a certain fact, statement or decision which deviates from the standard and the result is an actual or potential unfavourable event. However, this event can but also need not lead to an unfavourable result.

There are several possible definitions and there are also many ways in which errors can be classified. When we are talking about deviations concerning the human error we should mention such deviations that could be from upright (trip or stumble), from the current intention (slip or lapse), from an appropriate route towards some goal (mistake), or in some circles, it could even involve straying from the path of righteousness (sin).Human error classification should be done based on possible generic classification based on action: omission, intrusions, repetitions, wrong objects, disordering, mistiming, blends etc.

In the industrial processes there are the following possible causes of errors and failure of the human factor: bad reflection of risks of the attendants; errors in communications; insufficient or incorrect knowledgeability of the employees, insufficient qualification, insufficient experience (lack of training) – practice, personality and health assumptions of the employees; failing to keep the working procedure; unsuitable working conditions and working environment; inattentiveness (momentary) of the employees and many others. (Malý, 2002)

**Human factor as hero (intrepid recoveries)**

Another perspective according to human factor, one that has been relatively little studied in its own right is human factor as a hero. This presents a human factor as an element whose adaptation and compensation have brought trouble systems back from the brink of disaster on a significant number of occasions. We have already presented an example Apollo 13 where human factor saved several lives of astronaut. Other examples to be mentioned concerned to intrepid recoveries are connected to aeroplane crashes for example British airways flight 09 from London Heathrow to Aucland then BAC 1 – 11 flight to Malaga and many others.

Reason (2010) presents:" I find the heroic recoveries of much greater interest and in the long run, potentially more beneficial to the pursuit of improved safety in dangerous situations (operations)."

**Human factor as recipient of negative consequences of industrial disasters**

As already mentioned people are in many cases the reason for rising industrial accidents and they also significantly affect their development. However, on the other hand people are also affected by them, tangibly by their negative consequences. The accidents affect the people – their lives, health, property but also the environment in dependence on the concrete form of the accident. The impacts on people can be divided into two groups, namely the impacts on the employees working in the company and impacts on the non-employees (the general public). The impacts of the industrial disasters on the employees according to their levels can be: death of the employee; serious damage of health with permanent consequences; serious industrial accident; light industrial accident; dangerous event (almost an accident); stress resulting from the situation arisen. (Zanicka Holla et.al, 2010)

Several scientific disciplines participate in solving the area of the human factor. They are especially disciplines as psychology, ergonomics, physiology, cybernetics, anthropology, hygiene, medicine, sociology and others. The human being as part of the working system is the most flexible, adaptable and valuable element, however, the most predisposed to making errors. An important role of the scientific disciplines which deal with the area of the human factor is to solve practical tasks in the real life, to increase the security, effectiveness and work comfort.

There is nothing in the people's history that would have prepared the human being for mastering the environment of the most modern technique, although we have adapted this technique to our capabilities and limitations. However, the technique is not sufficiently adapted to our psychical properties. In the field of the crisis management the area of the human factor is a cross-sectional area and therefore it is necessary to pay it increased attention.

## 5. Conclusion

The object of this article was the area of preventing the industrial accidents with an emphasis on the process of the industrial processes risk assessment, the influence of uncertainty on the results of the realised analysis and last but not least the position of the human factor in the process of the rise and operation of the industrial disasters´ effects. In Europe for the time being there are discussions concerning the utilisation of the same procedures, methods and techniques in the area of preventing the industrial disasters by the member states. This unification can bring positives but also negatives. One of the positives is the possibility to compare the results among individual companies and in this way to assess the level of their danger in the European context; however, this would be only possible in the area of serious industrial disasters, i.e. for the companies controlled by the SEVESO II Directive. The systematic procedure ARAMIS has been created and it is to serve these purposes, however, only a few countries are making use of it. The EU requirement also heads to utilising especially the quantitative approaches in regard to reducing the uncertainty rate in the analyses.

A problem could be also the variance of approaches used by individual countries, selecting the probabilistic or deterministic approach of stating the risk, the a priori or a posteriori approach, the qualitative, semi-qualitative approach. The selection of the procedure depends especially on the size of the company assessed, the pre-disposition of the employees (the educational and personality one) who carry out these analyses, the financial possibilities of the company or institutions and many others.

In my opinion the common approach which will work on the quantitative calculations can be selected only for the so called SEVESO companies which are monitored by the EU and have to work out these analyses based on the legal requirements. For other companies (but for the SEVESO firms as well) it is possible to state at least a structured approach. The structured approach should state how it is to proceed when assessing the risks phase by

phase and subsequently step by step in the framework of the individual phases. The auditor would choose the individual methods based on the criteria for the risk assessment. The utilised methods should be, in my opinion, at least semi-quantitative and of course, the quantitative methods should be preferred.
Another challenge for solving this area is to create a risk matrix which would be able to compare the quantitative expression of the risk components of several objects (loss of life, damaging health, damaging property, and environment). In such a case we would come to the issue of calculating the price of the human life by financial means which is today considered as non-ethical and impossible by many experts. Another problem is the presence of uncertainty in the risk analysis which causes deviations in the analysis results. It is necessary to identify the critical places in the analysis for the influence of uncertainty to be reduced as much as possible. In the Slovak Republic we are missing the investigation of uncertainty and due to this fact research and searching for critical places of uncertainty specific for Slovakia due to several differences compared with other countries in this region could be realised.
However, we must not forget that the human factor is the weakest segment in this process. According to several investigations and analyses the human factor is the most frequent cause of the rise of the industrial disasters. The analysis of the human reliability should create an integral part of the risk assessment. It would be suitable to create a methodological instruction for processing the analysis of the human factor reliability which is missing in Slovakia for the time being. Creating some space for a further investigation in the area of the human factor I see especially in researching the specifics of surviving and behaving the human factor (personality) in three positions identified.

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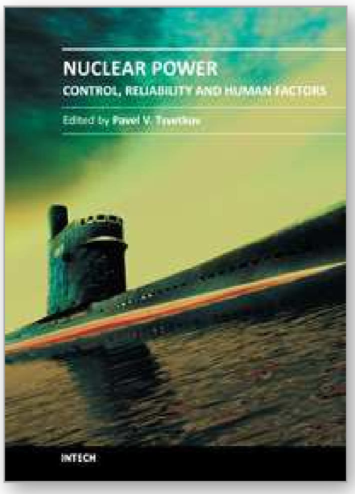


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Advances in reactor designs, materials and human-machine interfaces guarantee safety and reliability of emerging reactor technologies, eliminating possibilities for high-consequence human errors as those which have occurred in the past. New instrumentation and control technologies based in digital systems, novel sensors and measurement approaches facilitate safety, reliability and economic competitiveness of nuclear power options. Autonomous operation scenarios are becoming increasingly popular to consider for small modular systems. This book belongs to a series of books on nuclear power published by InTech. It consists of four major sections and contains twenty-one chapters on topics from key subject areas pertinent to instrumentation and control, operation reliability, system aging and human-machine interfaces. The book targets a broad potential readership group - students, researchers and specialists in the field - who are interested in learning about nuclear power.