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Prevention and mitigation of injuries and damages arising from the activity of subliminal enterprises: A case study in Slovakia

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ABSTRACT

The paper focuses on risk sources under no legislative pressure in the field of prevention of major accidents. Despite this, they can represent significant sources of risk of accidents.

The aim of the paper is to present the results of the risk assessment associated with the operation of enterprises not regulated by the SEVESO III Directive (the so-called subliminal enterprises), to provide information on possible operational problems and to verify the applicability of recognized risk analysis methods for these specific sources of risk. Last but not least, its purpose is to point out that subliminal enterprises, due to their location close to residential areas or areas with a high concentration of population, pose a serious risk to the population.

The paper summarizes the results of the quantitative risk assessment of a specific enterprise not included in the Seveso Directive – a filling station. Filling stations are frequently located in built-up areas with a dense coefficient of habitability. Due to their number, location (e.g. close to residential areas), frequency of occurrence of persons in the area and handling of dangerous substances during normal operation, they can have negative or even tragic consequences to the life and health of the population.

Due to the non-existent risk assessment methodology for enterprises with subliminal quantities of dangerous substances and the lack of a systematic search for risk sources, a risk assessment procedure for these companies is designed.

1. Introduction

At present, there is an increasing emphasis on safety, protection of human life and health, the environment and the prevention of major operational accidents. By complying with applicable legal standards, using modern technology and preventive measures, it is possible to prevent the occurrence of emergencies. However, the risk of such events cannot be completely ruled out.

Currently, public safety issue in production and manipulation of dangerous chemicals deserves more attention, because various major accidents, such as fires, explosions and toxic gas leaks occur frequently. The issue of prevention of emergency events has become increasingly discussed (Gai et al., 2018).

In this context, the issue of the prevention of major accidents is also developing dynamically. Chemical accidents in close proximity to a populated area have the potential to be catastrophic with large number of casualties (Tahmid et al., 2020).. To prevent such major industrial accidents, many developed countries, including the US and EU, have implemented emergency management systems ranging from accident prevention, emergency preparedness, and emergency response to accident relief (Lee et al., 2016). At present, in order to prevent the occurrence of the accident, many countries have devoted lots of time to the research and development of safety management and risk assessment, future regulations of risk-based approach will require better incident scenario development (Mannan et al., 2016).

As stated by Gai: „Major accidents, like toxic gas releases, fires and explosions, may influence a large area. And thus, prevention of

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Abbreviations

ALOHA	Areal Locations of Hazardous Atmospheres
CPQRA	Chemical Process Quantitative Risk Analysis
CCPS	Center for Chemical Process Safety
EPA	Environmental Protection Agency
EU	European Union
LOC	Loss of Containment
LPG	Liquefied Petroleum Gas
MAs	Major accidents
OECD	Organisation for Economic Co-operation and Development
PSAs	Particularly serious accidents
RMP	Risk Management Program
SMEs	Small and Medium Enterprises
QRA	Quantitative risk assessment
UNECE	United Nations Economic Commission for Europe

emergency events is a necessary public protection measure to mitigate the health consequences of major accidents, but risk assessment is still required“ (Gai et al., 2018).

For enterprises with less amount of dangerous substances, no risk assessment for major accidents is required. Nevertheless, these enterprises can be considered a source of risk of a major accident. Their possible location, for example, in the immediate vicinity of residential areas or assembly areas, increases the risk to the population. In an accident in enterprises with a smaller amount of dangerous substances, significant damage to the environment can occur. Some industrial companies have already understood the need for implementing safety management, in addition to quality management and environmental protection.

The need for risk assessment of companies with a smaller amount of dangerous substances (subliminal sources of risk) arises from several factors, in particular:

- many past and recent accidents,
- the pressure to reduce the risks of these technological facilities,
- the pressure to reduce risks,
- the need for risk prevention in the phase of urban planning, i. e. when approving the location of new facilities in relation to inhabited or protected areas,
- the need for improving emergency preparedness,
- and, last but not least, as a possible simple target but also a means of terrorist attacks (Bernatík, 2016).

Most of the subliminal sources of risk are in small and medium-sized enterprises (SMEs) and, for example, Safety and Health in SMEs - a European priority states: “SMEs are the backbone of the European Union’s economy. There are around 19 million SMEs in various sectors and they employ approximately 75 million people, but more than 82% of all accidents at work and fatal injuries are reported in these SMEs " (European Agency for Safety and Health at work, 2019).

According to Braggato: „Thus the issue of the Safety Management System of Major Accident Hazards for the Small and Medium Enterprises (SMEs) is becoming important in Europe. For this subject, the Italian experience may be interesting to share. Italian SMEs are very strong and unlike Northern Europe, SMEs control a variety of industries with higher hazard, which are involved in the Seveso Directive. In Italy, there are about 1100 Seveso establishments, 52% lower-tier and 48% upper-tier. Some 60% of these establishments are operated by SMEs (75% of lower-tier and 45% of upper-tier), as may be inferred by the data provided by the Competent Authority“ (Bragatto et al., 2015).

Nowadays, it is possible to demonstrate that a number of past accidents could have been avoided if the establishment was critically audited on time and the necessary preventive measures were accepted. Nevertheless, major accidents still occur and in many cases have a significant impact on human life and health, property and environment (Sikorova et al., 2017).

The presented issue of prevention of major accidents of subliminal sources of risks is becoming a highly discussed problem by professional public worldwide. They especially focus on developing a method to improve safety management systems based on accident investigations (Accou and Reniers, 2019), quantitative risk analysis method to assess human safety in the case of an emergency event (Ma and Huang, 2019), application of safety management by different management plans to increase the efficiency in process safety (Heo et al., 2018), developing an appropriate safety management system or new methods and tools for small and medium enterprises (Bragatto et al., 2015). An example of the necessity of solving the prevention of serious accidents of subliminal sources of risks is also the explosion at the filling station during unloading, in Rome on December 5, 2018. The consequence of this emergency were 2 deaths and 17 injured, 6 of them in critical condition.

The need to address this issue stems from the long-term development of the area of prevention of major accidents, where stationary sources with the highest content of dangerous substances were first addressed. Attention was focused on managing the risk from potentially hazardous sites through appropriate choice of the uses of land surrounding the sites (Papazoglou et al., 1997), an examination of the major-accident record for explosives manufacturing and storage (Merrifield and Moreton, 1998), the examination of some principles underlying industrial practice in evaluating safety management system (Mitchison and Papadakis, 1999), quantitative risk assessment for the operation gasholders in the area of great industrial agglomeration (Bernatik and Libisova, 2004), the study of past accidents to avoid recurrence of similar situations in the future (Sales et al., 2007), major steps in the procedure for evaluating the consequences of accidents involving dangerous substances, especially during the storage, and loading/unloading activities. (Pintarič, 2007), wide attention was paid to the assessment of the direct risk for the population deriving from major accidents (fires, explosions, toxic releases) (Bonvicini et al., 2018)

At present, attention is being paid to mobile sources of risk, which are increasing the number of accidents during the transport of dangerous goods, specifically assessing the risks of spent fuel transportation and storage (Mirae et al., 2017), evaluation of the safety level of fuel transportation (Zhongyang et al., 2019), quantitative risk analysis of life safety and financial loss for road accident of fuel cell vehicle (Sun and Li, 2019). An example of an emergency in the transport of hazardous substances is the overturning and subsequent explosion of a tanker carrying 4000 gallons of aviation fuel (15 000 L). This event happened on February 20, 2020, in Indianapolis. The fire spread about 500 feet causing severe, catastrophic damage to the pavement and both sides of the bridge.

2. Basis of major industrial accident prevention

Major industrial accidents are crisis events that threaten human lives, property and the environment worldwide. The prevention and control of major accidents (MAs) and particularly serious accidents (PSAs) is drawing growing attention from the whole society (Wang et al., 2018). Therefore, the issue of prevention of such events and the resulting application of preventive measures in the industrial environment is of primary importance. The European Union aims to regulate this environment and to set rules for enterprises that are most at risk in terms of the concentration of dangerous substances. One of these tools is the SEVESO directive, which was created in 1996 and has already been amended twice (Holla et al., 2016; Ristvej et al., 2013).

In the European Union, the prevention of major industrial accidents was regulated in 1996 by the Directive on the control of major-accident hazards involving dangerous substances, also called SEVESO II, which focused not only on the prevention of major accidents but also how to limit their consequences for man and the environment.

Although the system established by the SEVESO II Directive has helped reduce the likelihood of major accidents and their consequences, it also identified several areas where changes would be appropriate. These are addressed by the new Directive of the European Parliament and of the Council on the control of major accident hazards involving dangerous substances () (hereinafter "SEVESO III Directive"), which amends and subsequently repeals the Directive 96/82/EC. 82/EC.

The main changes to this European legal document are of a technical nature. They are related to the changes in the classification of chemicals in the EU, as the scope of SEVESO II was based on the previous classification of chemicals (Directives 67/548/EEC and 1999/45/EC), which were repealed by the Regulation (EC) No 1278/2008. As a result, the SEVESO III Directive undergoes a comprehensive overhaul of Annex I of the SEVESO II Directive - harmonisation of hazard categories within the meaning of that Regulation.

However, the SEVESO III Directive also emphasises other areas - in particular:

- better awareness of EU citizens about the serious threats posed by industrial complexes in their vicinity,
- the obligation for business operators to inform the public concerned on how to behave in the event of an accident,
- more effective rules on participation of the public concerned in urban planning projects concerning the facilities covered by the provisions of this Directive,
- citizen access to justice if they have not been given adequate access to information or participation in decision-making,
- stricter standards for business inspections to ensure more effective enforcement of safety rules.

As an example of the implementation of the Seveso Directive into the national laws of the EU Member States, we present the case of the Slovak Republic. The Slovak Republic has been comprehensively addressing the issue of prevention of major industrial accidents since 2002 when Act no. 261/2002 Coll. on the prevention of major industrial accidents and the amendment of certain acts and its implementing regulations (Decree of the Ministry of the Environment of the Slovak Republic No. 489/2002 Coll., and Decree of the Ministry of the Environment of the Slovak Republic No. 490/2002 Coll.) was adopted.

Following changes in EU regulations, the EU Member States were obliged to transpose the SEVESO III Directive into their legislation by May 31, 2015. In the Slovak Republic, transposition took place with the adoption of the Act no. 128/2015 Coll., on the prevention of major industrial accidents and amendments to certain acts (hereinafter referred to as the "Accident Prevention Act") and subsequently its implementing regulation - Decree of the Ministry of the Environment of the Slovak Republic No. 198/2015 Coll., implementing certain provisions of the Act No. 128/2015 Coll., on the prevention of major industrial accidents and the amendment of certain acts. The aim of the Accident Prevention Act is to prevent the occurrence of major industrial accidents with the presence of dangerous substances and to limit the consequences of such accidents on human health, property and the environment.

In addition to the SEVESO III Directive, in the EU also the UNECE Convention on the Transboundary Effects of Industrial Accidents is in force. With respect to sustainable development and on the basis of the principles of international law and practice, the Convention aims to ensure the conceptual and systematic action of the Parties in preventing industrial accidents which may have transboundary effects, in preparedness for and management of industrial accidents, including limiting their effects on humans, environment and property.

In Europe, the Directive 2012/18/EU (Seveso III) strengthens the obligation to adopt a programme assuring the integrity of critical equipment at major hazard establishments (Milazzo et al., 2019). Enterprises that do not fall under the Seveso Directive are called subliminal enterprises and are covered by other laws. In the Slovak Republic, these enterprises fall under the effectiveness of Act No. 42/94 on civil protection of the population, as amended. In general, the issue of the prevention of major accidents of enterprises not covered by the SEVESO Directive is not comprehensively addressed by the European Union but is approached individually by the particular Member States.

The classification of enterprises under the SEVESO III Directive and individual national directives is carried out on the basis of the limit values of the dangerous substance held in an enterprise. In the case of subliminal companies, i.e. enterprises with the subliminal amount of a dangerous substance, there is no direct guideline for risk assessment and management and therefore there is not enough pressure to manage and reduce risks in their operation. An example of some very common enterprises not covered by the SEVESO Directive is presented in the table below.

According to Bernatík (2016), in some cases, a subliminal enterprise may pose a greater threat than an enterprise with an over-limit amount of dangerous substances located outside the inhabited area. Based on the observations and analysis of available information, we can state that there is no comprehensive approach to risk assessment in these enterprises, which would contribute to minimizing possible accidents and their consequences.

3. Existing risk assessment methods in relation to subliminal enterprises

Risk assessment and subsequent measures to eliminate it can contribute to the prevention of accidents and thus to the protection of human lives, property and the environment. In terms of environmental protection, they can possibly prevent the inappropriate installation of a new facility close to the population or a protected area. Such a risk assessment should be performed when designing a new facility, investigating major accidents to prevent their recurrence or during the operation phase of the facility, where the risk assessment contributes to better information on risk sources, consequences of the accident and vulnerable populations.

Quantitative risk assessment of major accidents has been published in various publications, the most important ones in this area include: Loss Prevention the Process Industries, Hazard identification, assessment and control (Lee, 2012), Guidelines for Chemical Process Quantitative Risk Analysis – CPQRA (Center for Chemical Process Safety, 2010), Layer of Protection Analysis: Simplified Process Risk Assessment (Center for Chemical Process Safety, 2000), 4 Methods for Determining and Processing Probabilities (Schüller, 2005), Guidelines for Quantitative Risk Assessment (Uijt de Haag, Ale, 2005) (see Table 1).

Risk analysis in technological processes is performed using a variety of methods. In his publication, Tixier summarizes the 62 best-known methods of risk assessment. It should be emphasized that most of these methods are referred to as partial methods because they only assist in the individual steps of the whole risk assessment process, e.g. in hazard identification, and consequence assessment. An overview of the partial methods for risk assessment is given in Table 2.

It is important to note that there is no single method for carrying out the whole risk analysis, in practice, it is necessary to combine several methods. Risk assessment methods are divided into qualitative and

Table 1
Examples of subliminal enterprises.

Dangerous substance	Facility	Type of substance
Chlorine [Cl]	water treatment plants, pools, swimming pools	toxic
Acetylene [C_2H_2]	storages of acetylene cylinders	flammable
LPG	filling stations, domestic storage tanks	flammable
Diesel Petrol	filling stations, fuel depots	flammable

Table 2
Partial methods used in risk analysis.

Method	Acronym
Safety Audit	SA
What if Analysis	WI
Preliminary Hazard Analysis	PHA
Relative Ranking	RR
Hazard and Operability Analysis	HAZOP
Failure Mode and Effects (Criticality) Analysis	FMEA (FMECA)
Fault Tree Analysis	FTA
Event Tree Analysis	ETA
Cause Consequence Analysis	CCA
Check List Analysis	CLA
Human Reliability Analysis	HRA
Hazard Analysis	HAZAN

quantitative methods.

The methods can also be divided into three categories (Tixier et al., 2002):

- deterministic - based on quantification of the consequences of an accident,
- probabilistic - based on the probability or frequency of an accident,
- a combination of the deterministic and probabilistic approach.

In general, the deterministic methods are used for the analysis of large industrial enterprises, probabilistic methods for the analysis of a selected part of the enterprise requiring a more detailed and thus more demanding analysis. The trend in risk assessment is the hierarchization of results, where especially for easily applicable methods, the results are presented as indices of the level of danger, the so-called index or screening methods (Bernatík, 2016). For risk sources with the worst indices, it is then recommended to perform a detailed analysis using more demanding methods. A similar new approach to the risk assessment of entire industrial enterprises is first the selection of significant sources of risk and in the second phase a detailed quantitative risk assessment of the most serious facilities selected in this way. Both approaches aim to reduce the number of industrial facilities assessed in detail, simplifying the entire risk analysis and focusing on the most serious sources of risk. It should be noted that there is no unique method for carrying out the whole risk analysis. In practice, it is necessary to combine several methods. The preparation of an appropriate comprehensive risk assessment procedure for subliminal enterprises was also based on these facts.

4. Proposal for a risk assessment procedure for enterprises with a subliminal amount of dangerous substances

Due to the non-existent risk assessment methodology for enterprises with the subliminal amount of hazardous substances and the lack of a systematic search for risk sources, a risk assessment procedure was proposed for these companies. The main criteria in creating the procedure were simplicity and versatility of its use for companies with various dangerous substances.

This idea is not novel. According to Bragatto, the risk-based approach is more suitable for audits at SMEs, which cannot waste too much time and resources in an exhaustive categorical audit (Bragatto et al., 2015).

According to Tang et al. “For the conventional risk analysis methods, related data are described by linguistic expressions so that the risk value cannot be quantitatively calculated. Therefore, most of these analysis methods only yield qualitative risk results (Tang et al., 2018).

In creating the algorithm, we started with the idea from Safety enhancement of chemical and process plants asks for innovative tools in order to support QRA studies (Rum et al., 2018). The main goal of the proposed algorithm was to determine whether a subliminal enterprise poses a threat to human life and health. When designing the procedure, the emphasis was also placed on the severity of the consequences of the accident, so that subliminal enterprises do not have to carry out demanding risk assessments in areas where they do not pose an increased risk to life and health. The procedure for the assessment of subliminal enterprises is focused on facilities with the presence of dangerous substances which, due to the subliminal amount of hazardous substances, do not fall under the SEVESO Directive but may pose a danger to the population in their vicinity.

The risk assessment according to the proposed procedure consists of performing four consecutive steps: (1) Identification of the source of the risk, (2) Preliminary risk assessment, (3) Detailed assessment of the social risk and (4) Risk management.

4.1. Identification of the source of the risk

The first step of the algorithm is to identify the source of the risk. It is performed by comparing the amount of present dangerous substances with a set limit, assessing the distance from the nearest residential development and determining the expected number of people in the building at the time of an emergency.

a) *Comparison of the amount of hazardous substances with the set limit*

In order to propose an assessment procedure for subliminal enterprises, it was first necessary to set a reference limit for the amount of dangerous substances in an enterprise for which a risk assessment was to be performed. The limit values of dangerous substances in the Slovak Republic, set by the Act on the Prevention of Major Industrial Accidents, are adopted from the European Seveso III Directive and only affect the largest sources of risk (82 companies). They do not include smaller facilities which, under certain conditions, may constitute significant sources of risk of a major accident. Therefore, the limits were compared with the Dutch approach in the CPR 18 E methodology, with the US limits set by the EPA (Environmental Protection Agency) for inclusion in the RMP (Risk Management Program), with the limits in the IAEA-TECDOC-994 integrated risk assessment manual and with the limits mentioned in the European ARAMIS project, which produced a new ARAMIS methodology.

The ARAMIS project aims at developing a new risk assessment methodology which allows assessing the risk level of an industrial plant by taking into account prevention measures against major accidents (Andersen et al., 2004). The results of the comparison for selected substances most frequently occurring in subliminal enterprises are shown in Table 3.

From the stated values of the limit amounts, it is clear that the limit values of the Slovak Act on the prevention of major industrial accidents are several times higher than indicated by the recommended and recognized international methodologies. The above difference points out to the need for assessment of the sources of risks with a smaller amount of dangerous substances than stated in the current legislation of the Slovak Republic. There can be several hundred to a thousand of such sources of risk in the territory of the Slovak Republic. From the comparison of limit values of dangerous substances in several countries,

Table 3
Comparison of limit values of dangerous substances.

Hazardous substances	Comparison of limit quantities of dangerous substances in tonnes			
	CPR 18 E	US EPA	IAEA TECDOC	ARAMIS
Ammonia [NH]	3	4.5	3	1
Chlorine [Cl]	0.3	0.3	0.3	1
Acetylene [C_2H_2]	10	x	10	1
LPG	10	4.5	10	1
Diesel, Petrol	10	x	10	1

limit values according to the ARAMIS methodology (Table 4) were used for the algorithm design. The methodology authors determined them mainly on the basis of the physical properties of the assessed substances.

If the amount of dangerous substances present in the facility is smaller than the stated limits, the negligible consequences of accidents are assumed and the assessment does not need to be continued.

a) Assessment of the distance of the nearest residential development

An important factor in the assessment of subliminal enterprises is the location of the assessed facilities. A subliminal enterprise located, for example, in a densely populated area may pose a greater threat to the population than a source of A or B risk category (according to the Act on prevention of major industrial accidents) located outside residential areas. Therefore, when assessing these enterprises it is necessary to consider the distance of the building with the subliminal amount of dangerous substances from the nearest residential zone.

The valid legislation of the Slovak Republic does not sufficiently address the distances between the enterprises with the presence of selected substances from residential zones. To design an algorithm for the assessment of subliminal enterprises, the determination of the distance was based on the data given in the Guidelines for Integrated Risk Assessment and Management in Large Industrial Areas (IAEA, 1998), which lists the recommended distances of industrial enterprises from populated areas (Table 5).

Estimation of the presence of persons in the assessed facility can generally be performed as the product of area and the population density (Equation (1)).

$$N = S \times h \quad [\text{persons}] \tag{1}$$

where: N- number of persons, S-area on which the facility is located (ha), h-population density (person/ha).

The population density for individual types of the territory is given in Decree no. 489/2002 Coll., as amended (Table 6).

When determining the number of persons in the assessed facility, it is necessary to consider whether it is accessible only to authorized persons (employees) or also to the public. In the latter case, the estimate of the persons present can be determined on the basis of operational data and experience.

4.2. Preliminary risk assessment

The second step is a preliminary risk assessment to identify the sources of danger. The selection of methods in this phase is diverse and wide, starting with the safety inspection, checklists and other techniques to the qualitative HAZOP method, which is also used in the Slovak Republic and is considered a verified method. At the end of this phase, a list of individual risk sources will be created, which will be used in the prioritisation phase to select risk sources for further analysis. The use of simpler methods, so-called index or screening methods, is proposed for the assessment of risk sources, their results are presented as risk indices (levels). For sources with the worst indices, it is recommended to perform detailed analysis with more demanding methods.

This approach aims to reduce the number of facilities in the enterprise assessed in detail, to simplify the whole risk analysis and to focus on the most serious sources of risk. For the initial assessment of subliminal enterprises with the presence of toxic substances, the CEI method is suitable. The F&E index method can be recommended for flammable and explosive substances. These methods meet the set criteria - applicability for dangerous substances without quantity limitation, simple interpretation of results, and low demands in terms of expertise and time consumption.

Table 4
Defined values of the limit amount of dangerous substances for assessment of subliminal enterprises.

Substance characteristics	Defined limit amount (kg)		
	Solids	Liquids	Gases
1. Highly toxic	10 000	1000	100
2. Toxic	100 000	10 000	1000
3. Oxidizing	10 000	10 000	10 000
4. Explosives classified with risk phrase R2	1000	1000	–
5.Explosive classified with R3	10 000	10 000	–
5. Flammable	–	10 000	–
6. Highly flammable	–	10 000	–
7. Extremely flammable	–	10 000	1000
8. Dangerous for the environment	100 000	10 000	1000
9. Classified with R phrases R14, R14/15, R29	10 000	10 000	–

(Source: ARAMIS Uijt de Haag et al., 2005)

Table 5
Reference values for distances of industrial enterprises from inhabited areas (Source: IAEA-TECDOC method manual).

Dangerous substances	Industrial activity	Distance from populated areas (m)
flammable substances or explosives	filling station	>50
	LPG station	>100
	pipe with flammable liquid	>50
	storage of pressure cylinders (25–100 kg)	>100
toxic substances	cooling facilities	>100
	storages of pesticides for sale	>50

If the assessed plant or a facility is located at a shorter distance than indicated in the table, a risk analysis must be performed.

a) Estimation of the presence of persons in the assessed object (staff, customers, others)

Table 6
Population density.

Description of the populated area	Population density (number of persons/ha)
Rural settlement (municipalities up to 2000 inhabitants)	10
Larger municipalities in the countryside (village, a town from 2000 to 5000 inhabitants)	20
External residential part of the city (municipality from 5000 to 20 000 inhabitants)	30
Cities (from 20 000 to 50 000 inhabitants)	60
Central residential part of the city (cities with more than 50 000 inhabitants)	80
External residential part of the city (local parts over 50 000 to 100 000 inhabitants)	90
Central residential part of the city (cities with more than 100 000 inhabitants)	160

(Source: Decree no. 489/2002 Coll., as amended)

4.3. Detailed risk assessment

The third step consists of a detailed risk assessment and a proposal for measures to prevent an emergency in facilities that have been assessed as significant sources of risk.

This step aims to quantify the social risk on the basis of the determined probability and consequences of the negative event on the analysed system or process and to assess its acceptability with respect to the set criteria. In accordance with Slovak law (Decree 198/2015), the social acceptability of the risk of an identified major industrial accident in terms of assessing the potential threat to the life of several persons is determined by an acceptable probability or frequency of major industrial accidents. This frequency is expressed by a numerical value Fpr according to the following relationship:

If it is a threat to the life of one person

$$F_{pr} = 10^{-5} \quad \text{for existing enterprises}$$

$F_{pr} = 10^{-6}$ for new enterprises and facilities

If it is a threat to the life of several persons

$$F_{pr} = 10^{-3}N^{-2} \quad \text{for existing enterprises facilities} \tag{2}$$

$$F_{pr} = 10^{-4}N^{-2} \quad \text{for new enterprises and facilities} \tag{3}$$

The result of quantitative risk analysis (QRA) is the individual and social risk.

- The individual risk represents the frequency of death of an individual following a case of facility failure (LOC). It is assumed that the individual is not protected and is exposed to adverse circumstances throughout the exposure period.
- Social risk is the frequency of an event in which more than one person dies at the same time. Social risk is represented by F–N curves, where N is the number of deaths and F is the cumulative frequency of events accompanied by N or more deaths.

In Europe, the Dutch convention is usually accepted. The social risk acceptability criteria used are shown in Fig. 1. In addition to the frequency of the event, the potential loss of human life is also decisive for the acceptability of social risk. The social risk is higher than the individual, as shown in the figure. The social risk for one fatal case is considered acceptable at a frequency of 10^{-5}, with an increasing number of fatalities, the acceptable frequency decreases. Unacceptable social risk is characterized by a frequency of 10^{-3} in one fatal case. With an increasing number of fatalities, the unacceptable frequency decreases again.

When designing this part of the algorithm, a suitable comprehensive methodology for a detailed risk assessment was selected. The most well-known methodologies include the already mentioned CPR 18 E methodology or the Quantitative risk analysis of a chemical process CPQRA and the ARAMIS methodology.

The Dutch CPR 18 E methodology is relatively popular in Europe and is often used in the preparation of safety reports. According to the latest OECD recommendations, the ARAMIS methodology is also recommended for a detailed risk assessment of subliminal sources of risk, but it is not sufficiently established in the conditions of the Slovak Republic yet. It is important to note that there is no unique method for performing the whole risk analysis, in practice, it is necessary to combine several methods.

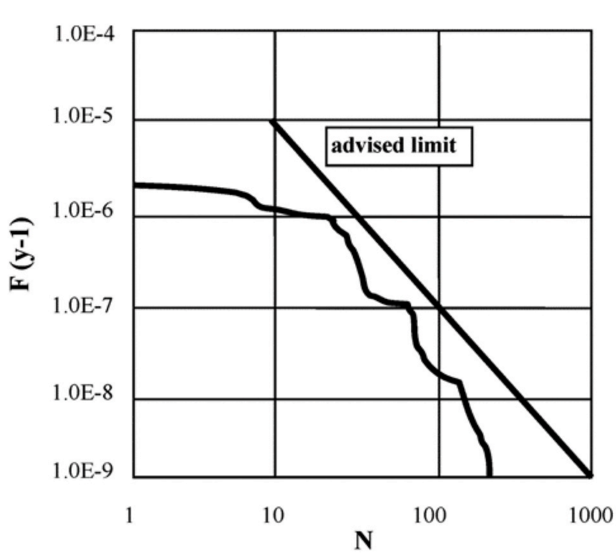

Fig. 1. Social risk curve. The x-axis represents the number of fatalities, the y-axis the frequency of events per year (Source: Uijt de Haag et al., 2005).

Based on the comparison of the mentioned methods, the CPR 18 E method was selected. It is the most frequently recommended method in most developed European countries. The method applies to all dangerous substances without quantity limitation.

However, due to the professional complexity of processing a detailed risk assessment, a separate risk assessment cannot usually be prepared by the operator of the subliminal source of risk. Therefore, the expert, preparing the study, has to select adequate detailed risk assessment methodology. The algorithm for the evaluation of subliminal enterprises is shown in Fig. 2.

4.4. Risk management

The last recommended step of the methodological procedure is risk management for facilities with unacceptable risk. For subliminal enterprises, some of the most important elements of the risk management system are recommended, including:

- Major accident risk assessment - performed every 5 years

or in the case of significant changes in the operational safety of the facility.

- Organisation and employees – to provide regular training, determine the responsibilities and authority of individual employees in terms of accident prevention.
- Facility operation management – to process and follow the safety procedures of individual technological facilities.
- Management of changes in the facility – to assess the risks before changes in technologies (changes in dangerous substances, changes in equipment).
- Emergency planning - preparation of an emergency plan and training (intervention training).
- Supervision - monitoring the effectiveness of the risk management system for the process of continuous improvement.

A range of measures can be recommended for the risk reduction process that can effectively reduce the risks of major accidents. Risk reduction measures can be generally divided into technical and organisational measures, in other respects into preventive (prior to an accident) and rescue (limiting consequences of an accident).

The basic approaches to risk reduction include:

- substitution of a dangerous substance for a less dangerous one,
- change of technology to a more modern one with less dangerous substances,
- reduction of stocks of dangerous substances to the necessary minimum - improvement of logistics in the supply and transport of dangerous substances,
- effective separation of the amount of dangerous substances in the facility - reduction of the amount of leaking substance.

The definition of preventive measures should be based on the Summary of the “Golden Rules” for the prevention of major accidents, which are set out in the OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response, Guidance for Industry. These are rules defined in general but universally applicable (Organisation for Economic Co-operation and Development, 2003).

Managerial responsibility:

- to be aware of the dangers and risks of the facility with dangerous substances,
- to promote a “safety culture” that is known and accepted throughout the enterprise,
- to implement a safety management system and to supervise its implementation,

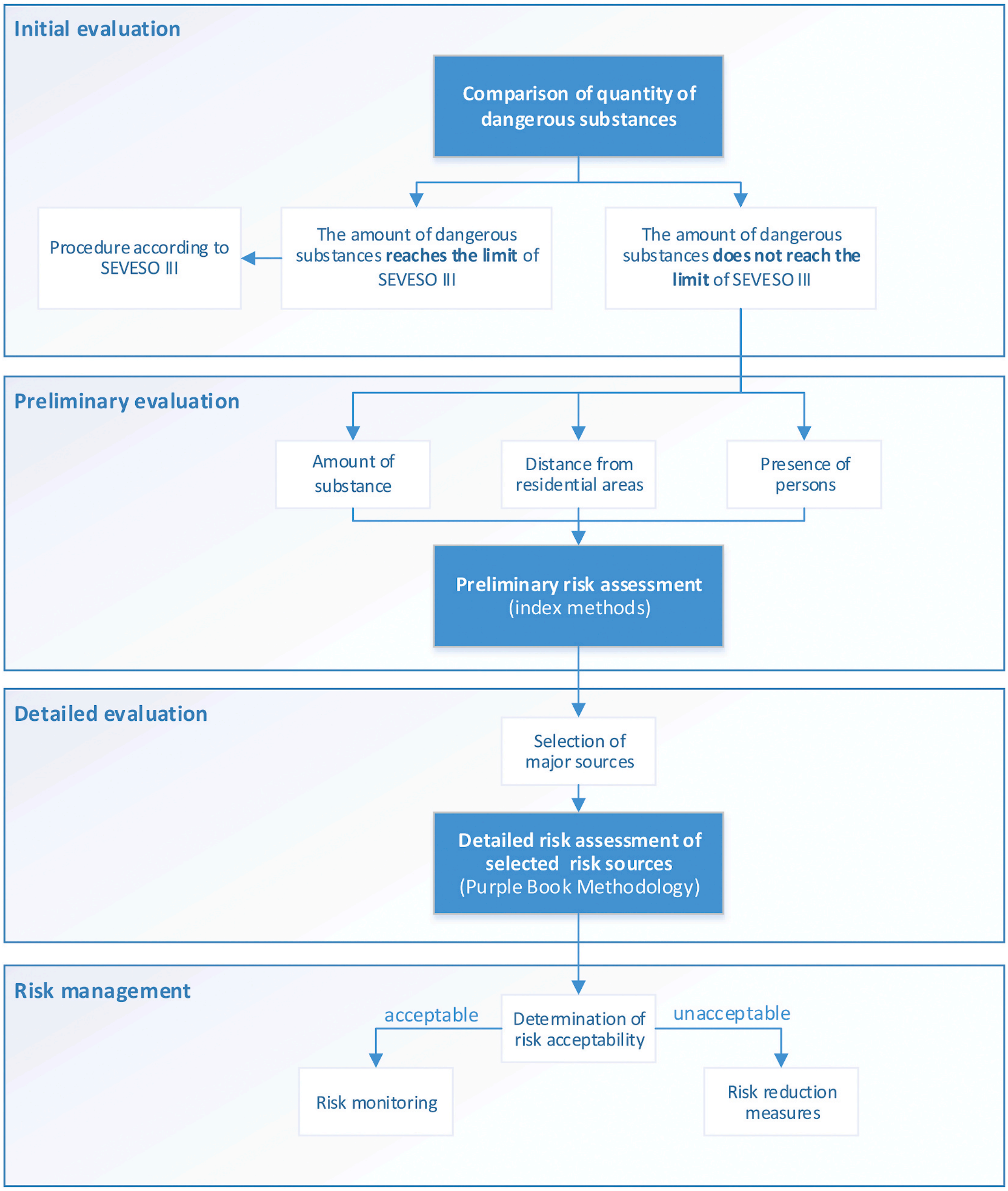

Fig. 2. Schematic representation of the proposed algorithm for assessment of subliminal enterprises.

- to use the principles of "internally safer technologies" in the design and operation of the facility containing dangerous substances,
- to be especially careful when managing change,
- to prepare for any accident that may occur,
- to help others perform their respective functions and responsibilities,
- to strive for continuous improvement.

The role of employees:

- to act in accordance with the company's safety culture, safety procedures and training,
- to be informed and provide information and feedback to management,
- be active in raising safety awareness and educating society.

5. Case study: Modelling consequences of an emergency event in an enterprise not covered by the SEVESO Directive

We present the application of the proposed methodological procedure of risk assessment at a specific subliminal enterprise - a filling station. Filling stations are very often located in built-up areas with a dense coefficient of habitability. All used data correspond to the specific conditions of a real company (Fig. 3). The filling station holds a relatively large amount of dangerous substances that does not reach the limit value set by the SEVESO directive. In the short term, it will also start to sell LPG. Table 7 presents the quantities of dangerous substances held within the station and the limit value resulting from the SEVESO Directive.

The presented Table 6 shows that the amounts of fuels and LPG are lower than the legal limits set for petrol, diesel and LPG.

a) Comparison of the amount of dangerous substances present in the filling station facility with the set limit according to the methodology

The limit amount for flammable liquids in the proposed algorithm was set per 10 000 kg. A comparison of the amount of fuel with the set limits shows that the set limit is exceeded by petrol 95 and diesel. Based

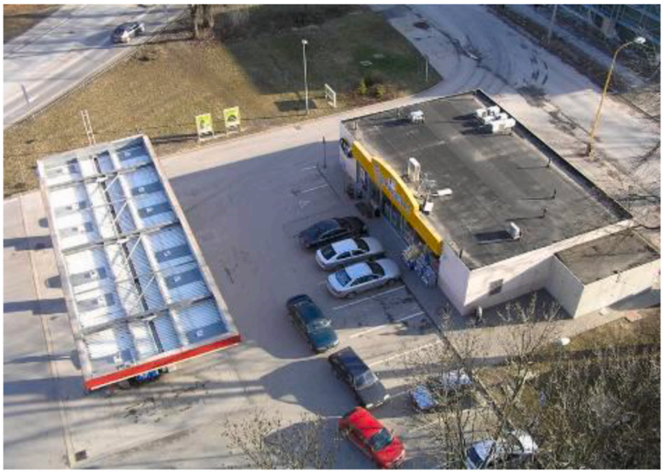

Fig. 3. Filling station facility.

Table 7
Dangerous substances in the filling station facility.

Dangerous substance	Facility	Quantity [t]	Limit value[a] [t]
Diesel fuel	storage tank	39.1	2500
	fuel truck	39.1	
Petrol „Natural 95“	storage tank	36.8	2500
	fuel truck	36.8	
LPG	storage tank	2.1	50
	fuel truck	22	

[a] - specified in Annex no. 1 of Act 128/2015 Coll.

on the comparison of the amount of dangerous substances in the filling station facility with the set limit amount, it was necessary to perform a preliminary risk assessment for LPG in the fuel truck. Even though LPG in the storage tank does not reach the set limit amount of 10 000 kg, the FEI method assessment was also performed for this source of risk, because in the event of a storage tank accident there is a danger of so-called domino effect, where an accident of one facility can cause a serious accident of another facility.

b) Assessment of the distance of the nearest residential development

The reference value of the distance of the filling station from the residential development in the proposed algorithm for the filling station was set at 50 m. Because there is a multifunctional building with residential premises in its the immediate vicinity, it is necessary to perform a preliminary risk assessment of the filling station.

c) Assessment of the presence of persons

The initial estimate of the presence of persons in the filling station facility is determined from the relationship:

$$N = S \times h \quad \text{[persons]} \tag{1}$$

where: N- number of persons, S- area on which the facility is located (ha), h-population density (person/ha).

$N = 0,15 \times 80$

N = 12 persons.

Based on the operational data, this number of people can be considered average, because more people may be present in the filling station facility, depending on the time of the emergency event occurrence.

4.5. Preliminary risk assessment

Preliminary risk assessment of the filling station will identify the sources of danger. The assessment of sources of danger will be performed using the F&E Index method, which is suitable for assessing the hazards of facilities where flammable and explosive substances are present.

4.5.1. Identification of sources of danger

The first step in the preliminary assessment of the filling station is the identification of internal and external sources of danger.

4.5.1.1. Internal sources of danger. The internal sources of the danger of an emergency event associated with fire, an explosion of fuel vapours and leakage of fuels and their vapours into the air are technological facilities of the filling station, where fuels are stored, loaded and unloaded, and also processes in which these liquids are handled (see Table 8).

4.5.1.2. External sources of danger. In addition to the internal sources of danger, which are located in the premises of the filling station, the filling station facility is also endangered by external influences. It can be, for example, a threat by watercourses, traffic, or other industrial enterprises located in its vicinity.

4.5.2. Application of the F&E index method in the filling station facility

The F&E Index method was used to assess the danger of the filling station facility in the process of LPG loading and unloading (see Table 9).

4.5.2.1. F&E index results for the filling station. According to the set F&E index and the degree of facility danger, the planned LPG storage tank will represent a **significant source of danger** in the filling station premises. In the event of an emergency**, the radius of the affected area is estimated at 35 m** (see Fig. 4).

The degree of danger was determined to be critical for the process of LPG loading and unloading from the fuel truck to the storage tank.

4.6. Detailed risk assessment

Based on the results of the F&E index method, the planned LPG storage tank will be a significant source of danger, and therefore a detailed assessment must be performed using the CPR 18 E "Purple Book" method.

The risk assessment using the CPR 18 E method consists of the following steps:

1. Identification of sources of danger (identified in step 2 - preliminary assessment)
2. Determination of emergency scenarios
3. Determination of failure frequency for technological equipment in fuel distribution
4. Modelling of leaks and effects of emergency scenarios

Table 8
Internal sources of danger.

Facility	Volume [m^3]	Technological process	Hazardous substance
fuel truck	45	loading of fuels into storage tanks	petrol, diesel
storage tank	55	fuel storage	petrol, diesel
LPG fuel truck	50	loading LPG into the storage tank	LPG
LPG storage tank	4,8	LPG storage	LPG

Table 9
Summary of the data of the F&EI method.

Name of enterprise		TYPE OF RISK SOURCES				
		LOADING/UNLOADING AND STORING OF FUELS				
Process unit	Material factor value	F&EI	Degree of the unit danger	Radius of the affected area (m)	Affected area (m^2)	Overall credit factor
LPG storage tank	21	137.6	serious	35	3837.5	0.92
LPG fuel truck	21	229.2	critical	56.3	9952.8	0.92

Fig. 4. The affected area in the event of an emergency scenario - the LPG leakage from the storage tank (70 m).

4.6.1. *Determination of emergency scenarios*

The determination of the most unfavourable situation in which the largest number of persons and the environment are endangered to the greatest extent by the effects of an explosion, toxicity or fire of leaked fuels is based on the estimation and determination of emergency scenarios. The selection of possible emergency scenarios is based on:

- the anticipated leakage of the maximum amount of particular dangerous substances,
- the largest area of the fire,
- possible danger to the surroundings by an explosion and radiant heat,
- the number of endangered persons in the affected areas.

The determination of emergency scenarios is significantly influenced by the types of dangerous substances, their fire-technical characteristics, handling, the technological process of production, and fire suppression and protection systems. In the filling station facility, these possibilities of LPG leaks from their storage and handling areas were identified as significant (see Table 10).

The first type of emergency scenario can be described as the worst-case scenario, which is defined as the maximum amount of the substance that can be released from the equipment (Markowski et al., 2017).

Table 10
Emergency scenarios.

Emergency scenario	Type of leakage	Cause of leak
LPG leakage from the storage tank	one-time leakage	damage to the safety valve, damage to the integrity of the tank shell when the car hits the tank, corrosion
LPG leakage during loading and unloading	one-time leakage of the entire quantity	damage to the integrity of the fuel tank shell
	continuous leakage of LPG during loading and unloading	rupture of the loading hose, or its incorrect installation on the connections with the loading pipe or the fuel truck, overfilling of the storage tank

4.6.2. *Determining the probability of a major accident*

To determine the frequency of failures for individual technological equipment of the filling station, estimates of representative events of leakage of dangerous substances from the CPR 18 E methodology were used (Table 11).

The total frequencies of the emergency scenarios were determined as the product of the failure frequency and the probability of immediate ignition and are given in Table 12.

4.6.3. *Determining the possible consequences of a major accident*

The determination of explosive, thermal and toxic effects of emergency scenarios was performed by the ALOHA programme. Consequences of releasing LPG were evaluated in detail.

The consequences of potential accidents were modelled for emergency scenarios:

- leakage of the entire amount of LPG from the storage tank,

Table 11
Failure frequency of technological equipment in the filling station facility.

Emergency scenario	Type of leakage	Failure frequency
LPG leakage from the storage tank	one-time leakage	5×10^{-7} year^{-1}
LPG leakage during loading and unloading	one-time leakage of LPG	5×10^{-7} year^{-1}
	continuous leakage of LPG	1×10^{-5} year^{-1}

(Source: Uijt de Haag et al., 2005)

Table 12
Total frequencies of emergency scenarios.

Emergency scenario		Failure frequency (F)	Probability of immediate ignition (P)	Total frequency of the emergency scenario ($F_c = F*P$)
LPG leakage from the storage tank		5×10^{-7} year^{-1}	0.5	2.5×10^{-7}. year^{-1}
LPG leakage during loading and unloading	one-time leakage of LPG	5×10^{-7} year^{-1}	0.4	2×10^{-7}. year^{-1}
	continuous leakage of LPG	1×10^{-5} year^{-1}	0.4	6. x 10^{-8}. year^{-1}

(Source: Uijt de Haag et al., 2005")

- leakage of the entire amount of LPG from the fuel truck during loading or unloading.

Due to the high complexity of modelling six representative weather classes, two basic situations were modelled:

- normal air stability 4. class = D, medium wind speed: 5 m.s-1 (most common conditions during the year),
- very stable conditions 1. class = F, wind speed low: 1.7 m.s-1 (worst dispersion, largest area affected - worst case scenario).

The obtained results (Table 13, Table 14) indicate that the consequences of emergency events depend on the weather situation and in the case of atmospheric stability type F represent the worst possible consequences. The results obtained using the ALOHA programme are displayed in text and graphic form (trace of a cloud of a substance with a given concentration, dose and yield of the source). The practical experience of using this software shows that the specified affected areas are conservative and thus represent the worst possible emergency scenarios.

Table 13
Leakage of the total amount of LPG from the storage tank.

Leakage of the total amount of LPG from the storage tank [2100 kg]			LPG storage tank	
			Atmospheric stability D	Atmospheric stability F
The liquefied gas escapes from the storage tank into the atmosphere and evaporates	Flammable vapour cloud is formed	60% DMV	107	181
		10% DMV	333	361
	A vapour cloud explosion initiated by an explosion	Serious damage to buildings [m]	94	171
		Danger to persons from serious injuries [m]	135	224
		Danger to persons from window glass [m]	289	456
Liquefied gas escapes from the storage tank and burns like a JET FIRE	Potentially fatal danger to persons from thermal radiation [m]		74	67
	2nd degree burns [m]		105	98
	Danger of serious injuries to persons outside buildings [m]		161	154
BLEVE	Max. diameter of a fireball [m]		74	74
	Burning time [s]		6	6
	Potentially fatal danger to persons from thermal radiation [m]		176	181
	2nd degree burns [m]		249	256
	Danger of serious injuries to persons outside buildings [m]		388	399

Table 14
Leakage of the total amount of LPG from the fuel truck during loading/unloading modelled by the ALOHA programme.

Leakage of the total amount of LPG from the fuel truck during loading/unloading [22 000 kg]			Atmospheric stability D	Atmospheric stability F
LPG escapes from the tank into the atmosphere and evaporates	Flammable vapour cloud is formed	60% DMV	129	239
		10% DMV	392	551
	A vapour cloud explosion initiated by an explosion	Serious damage to buildings [m]	118	228
		Danger to persons from serious injuries [m]	169	311
		Danger to persons from window glass [m]	360	620
JET FIRE	Potentially fatal danger to persons from thermal radiation [m]		65	51
	2nd degree burns [m]		93	77
	Danger of serious injuries to persons outside buildings [m]		144	124
BLEVE	Max. diameter of a fireball [m]		163	163
	Burning time [s]		11	11
	Potentially fatal danger to persons from thermal radiation [m]		403	410
	2nd degree burns [m]		569	578
	Danger of serious injuries to persons outside buildings [m]		889	904

4.6.4. *Risk assessment – social risk determination*

The previous text demonstrates the effects of the selected emergency scenarios. However, the impacts do not consider the real level of risk. The degree of risk most frequently applies to people. The more people will be present near the filling station premises, the greater the level of risk. However, the degree of risk does not correspond to the acceptability of the risk to society. The acceptability of the risk depends on the overall social situation in the area where the filling station premises are located. The social acceptability of risk was determined by assessing the worst-case scenario.

4.6.4.1. Estimation of the presence of persons. The filling station premises are located on a plot with an area of 2707 m^2, where the present persons (employees, customers) can move freely. With an estimated population density in the industrial-commercial zone of 80 people/ha (according to the Decree of the Ministry of the Environment No. 198/2015 as amended), the number of persons in the filling station area is approximately (0.27 ha x 80 people/ha) 22 people.

The presence of persons in the filling station premises during 24 h varies, depending on the day and nighttime. For the needs of the case study, the daytime is considered. The number of population affected by an emergency was determined following the methodology set out in the Purple Book (see Table 15). It is based on the assumption that it is possible to estimate the ratio of persons in buildings ($f_{pop,in}$) and outside

Table 15
Ratio of the presence of the population inside and outside buildings.

Time	$f_{pop,in}$	$f_{pop,out}$
Daytime	0.93	0.07
Nighttime	0.99	0.01

(Source: Uijt de Haag et al., 2005)

Table 16
Estimates of the number of persons in the building and outside the building on the filling station premises.

Number of persons	N_{in}	N_{out}
Day	20	2

buildings ($f_{pop, out}$). The values apply to residential and industrial areas unless other information is available. Estimates are given in Table 15 (see Table 16).

In the worst-case scenario, it is considered that there are 22 people on the filling station premises during an emergency.

When calculating social risk, it is assumed that some people are protected because they stay inside buildings. Therefore, different values are used for the proportion of the population that dies inside and outside buildings, and therefore the proportions of the population inside $f_{pop,in}$, and outside $f_{pop,out}$ the buildings must be determined. At the time of the emergency, some people will be in the building (N_{in}), some will be outside the building (N_{out}). The consequences of the emergency will be diametrically different for both groups of the population.

Based on experience, it is possible to estimate the probability of injury to the population inside and outside buildings. Inside the filling station building, persons are partially protected, as opposed to persons located outside. Following the CPR 18 E methodology used, the number of fatally injured persons inside the buildings was set at 20 * 0.14 = 2.8 (see Table 17). Persons outside buildings will be affected by heat in the event of a fire and will be fatally injured with the probability given by the probit value $P_E = 1$ (Uijt de Haag et al., 2005).

In the event of an LPG explosion, people outside the building will be affected by the explosive effects and will be fatally injured with a probability given by the probit value $P_E = 1$ (Uijt de Haag et al., 2005). Persons in the building are partially protected against the effects of explosions, therefore the number of deaths is reduced by a factor of 0.025 ($F_{E, in} = 0.5$).

4.6.4.2. Social risk acceptability assessment. In accordance with Slovak law (Decree 198/2015), the social acceptability of the risk of an identified serious industrial accident in terms of assessing the potential threat to the life of several persons is determined by an acceptable probability or frequency of serious industrial accident. This frequency is expressed by a numerical value Fpr according to the following relationship:

1. for existing enterprises and other facilities

$$F_{pr} = 10^{-3} \times N^{-2} \quad (2)$$

2. for new enterprises or facilities

Table 17
Estimation of the number of fatally injured in the building on the filling station premises.

Emergency scenario	$F_{E,in}$	$F_{E,out}$	Total
Fire	2.8	2	5
Explosion	0.5	2	3

$$F_{pr} = 10^{-4} \times N^{-2} \quad (3)$$

Where „N" is the number of endangered persons.

$$F_{pr} = 10^{-4} \times N^{-2}$$
$$Fpr = 10^{-4} \times 5^{-2} \quad (4)$$

In the final part of the social risk assessment, an assessment of its acceptability is performed by comparing the value of the calculated social risk for representative emergency scenarios (see Table 18) with the value of the acceptable risk F_{pr} determined according to equation (3). The social risk of an emergency is acceptable for these emergency scenarios.

5. Discussion

From the comprehensive results of the analysis of the consequences of emergency events according to emergency scenarios and the estimation of social risk, it can be stated that:

- The activity of the filling station creates preconditions for endangering persons located in the building on its premises or in its immediate vicinity.
- The LPG storage tank, which is to be located on the filling station premises, will represent a significant source of risk according to the set consequences. The risk of endangering persons resulting from the presence of LPG on the filling station premises will be highest in the event of an emergency during the LPG unloading from the fuel truck to the storage tank.
- If the entire amount of LPG leaks from the storage tank and the Jet Fire effect occurs, there is a potentially fatal danger to persons from thermal radiation at a distance of 100 m, 2nd-degree burns at a distance of 120 m and serious injury at a distance of 170 m from the tank. In this area, around 5 people will be at risk of fatal injuries with a probability of 2.5×10^{-7}. year $^{-1}$.
- If the Jet Fire effect occurs when LPG leaks from the tank, there will be a potentially fatal danger to persons from thermal radiation at a distance of 163 m, 2nd-degree burns at a distance of 93 m and serious injury at a distance of 144 m from the tank. In this area, 5 people will be at risk of fatal injuries with a probability of 2×10^{-7}. year $^{-1}$.

6. Conclusion

The presented paper deals with the issue of prevention of major accidents of subliminal sources of risk. The aim was to highlight the fact that the issue of accident prevention of subliminal sources is not currently addressed systematically. The current legislation pays attention to the prevention of serious industrial accidents and sets rules for enterprises that are most at risk in terms of the concentration of dangerous substances. However, no methodology for assessing subliminal sources of risk is available.

Based on the above facts, a methodological procedure for the assessment of subliminal sources of risks was proposed. The methodological procedure presents a possible risk assessment procedure for operators of subliminal enterprises in the case of voluntary risk assessment or administrative authorities in the case of risk assessment in the relevant territory.

The issue of the prevention of major accidents involving subliminal

Table 18
Social risk.

Emergency scenario	Calculated value of social risk	Determined value of social risk
LPG leak from the storage tank	$2{,}5 \times 10^{-7}$. year^{-1}	$10^{-4} \times 5^{-2}$
LPG leak from the fuel truck by loading and unloading	2×10^{-7}. year^{-1}	$10^{-4} \times 5^{-2}$

sources of risk must be followed by a broader discussion between competent persons. The need for a follow-up solution to these issues in the near future stems from the long-term development of the area of major accident prevention, where stationary sources with the highest content of dangerous substances were first addressed. At present, attention is turning to mobile sources of risk, which are increasing the number of accidents in the transport of dangerous goods. In the next phase, attention will certainly be focused on subliminal sources of risk, which in some cases may pose significant social risks.

Credit statements

Makka Katarina: Methodology, Investigation, Writing – original draft, Kampova Katarina: Conceptualization, Resources, Writing – original draft, Bernatik Ales: Methodology, Lovecek Tomas: Software, Resources, Rehak David: Writing – review & editing, Ondrejka: Software, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Accou, B., Reniers, G., 2019. Developing a method to improve safety management systems based on accident investigations: the SAfety FRactal ANalysis. Saf. Sci. 115, 285–293. https://doi.org/10.1016/j.ssci.2019.02.016.

Andersen, H., Casal, J., Dandrieux, A., Debray, B., Dianous, V. De, Duijm, N.J., Delvosalle, C., Fievez, C., Goossens, L., Gowland, R.T., Hale, A.J., Hourtolou, D., Mazzarotta, B., Pipart, A., Planas, E., Prats, F., Salvi, O., Tixier, J., 2004. Accidental Risk Assessment Methodology for Industries in the Context of Th SEVESO II Directive. Available from: (accessed March 2019). https://www.scribd.com/document/57458205/Aramis-Final-User-Guide.

Bernatík, A., 2016. Analýza Nebezpečí a Rizík. https://www.fbi.vsb.cz/export/sites/fbi/U3V/cs/materialy/U3V_AnalyzaRizik.pdf. (Accessed 13 March 2019).

Bernatik, A., Libisova, M., 2004. Loss prevention in heavy industry: risk assessment of large gasholders. J. Loss Prev. Process. Ind. 17, 271–278. https://doi.org/10.1016/j.jlp.2004.04.004.

Bonvicini, S., Antonioni, G., Cozzani, V., 2018. Assessment of the risk related to environmental damage following major accidents in onshore pipelines. J. Loss Prev. Process. Ind. 56, 505–516. https://doi.org/10.1016/j.jlp.2018.11.005.Bragatto, PA.

Bragatto, P.A, Ansaldi, S.M., Agnello, P., 2015. Small enterprises and major hazards: how to develop an appropriate safety management system. J. Loss Prev. Process. Ind. 33, 232–244. https://doi.org/10.1016/j.jlp.2014.12.016.

Center for Chemical Process Safety, 2000. Guidelines for Chemical Process Quantitative Risk Analysis – CPQRA, second ed.,. CCPS (New York).

Center for Chemical Process Safety, 2010. Layer of Protection Analysis: Simplified Process Risk Assessment. New York. https://doi.org/10.1002/9780470935590.

European Union information agency for occupational safety and health, 2019. Occupational Safety and Health in Micro and Small Enterprises. Available from:https://osha.europa.eu/en/themes/safety-and-health-micro-and-small-enterprises. (Accessed January 2019).

Gai, W.M., Du, Y., Deng, Y.F., 2018. Evacuation risk assessment of regional evacuation for major accidents and its application in emergency planning: a case study. Saf. Sci. 106, 203–218. https://doi.org/10.1016/j.ssci.2018.03.021.

Heo, S., Kim, M., Yu, H., Lee, W.K., Sohn, J.R., Jung, S.Y., Moon, K.W., Byeon, S.H., 2018. Chemical accident hazard assessment by spatial analysis of chemical factories and accident records in South Korea. International Journal of Disaster Risk Reduction 27, 37–47. https://doi.org/10.1016/j.ijdrr.2017.09.016.

Holla, K., Ristvej, J., Moricova, V., Novák, L., 2016. Results of survey among SEVESO establishments in the Slovak Republic. J. Chem. Health Saf. 23, 9–17. https://doi.org/10.1016/j.jchas.2015.03.003.

International Atomic Energy Agency, 1998. Guidelines for Integrated Risk Assessment and Management in Large Industrial Areas. IAEA-TECDOC-929. Available from: https://www-pub.iaea.org/MTCD/Publications/PDF/te_994_prn.pdf. (Accessed April 2019).

Lee, et al., 2012. Lees' Loss Prevention the Process Industries, Hazard Identification, Assessment and Control, fourth ed. Elsevier.

Lee, K., Kwon, H.M., Cho, S., Kim, J., Moon, I., 2016. Improvements of safety management system in Korean chemical industry after a large chemical accident. J. Loss Prev. Process. Ind. 42, 6–13. https://doi.org/10.1016/j.jlp.2015.08.006.

Ma, G., Huang, Y., 2019. Safety assessment of explosions during gas stations refilling process. J. Loss Prev. Process. Ind. 60, 133–144. https://doi.org/10.1016/j.jlp.2019.04.012.

Mannan, M.S., Reyes-Valdes, O., Jain, P., Tamim, N., Ahammad, M., 2016. The evolution of process safety: current status and future direction. Annual Review of Chemical and Biomolecular Engineering 7, 135–162. https://doi.org/10.1146/annurev-chembioeng-080615-033640.

Markowski, A.S., Siuta, D., 2017. Selection of representative accident scenarios for major industrial accidents. Process Saf. Environ. Protect. 111, 652–662. https://doi.org/10.1016/j.psep.2017.08.026.

Merrifield, R., Moreton, P.A., 1998. An examination of the major-accident record for explosives manufacturing and storage in the UK. J. Hazard Mater. 63, 107–118. https://doi.org/10.1016/S0304-3894(98)00192-7.

Milazzo, M.F., Bragatto, P., 2019. A framework addressing a safe ageing management in complex industrial sites: the Italian experience in "Seveso" establishments. J. Loss Prev. Process. Ind. 58, 70–81. https://doi.org/10.1016/j.jlp.2019.01.005.

Mirae, Y., Robby, Ch, Bo, G.K., Belal, A., Jaehyun, H., Sanghoon, L., Hyun, G., 2017. A software tool for integrated risk assessment of spent fuel transportation and storage. Nuclear Engineering and Technology 49, 721–733. https://doi.org/10.1016/j.net.2017.01.017.

Mitchison, N., Papadakis, G.A., 1999. Safety management systems under Seveso II: implementation and assessment. J. Loss Prev. Process. Ind. 12, 43–51. https://doi.org/10.1016/S0950-4230(98)00036-9.

Organisation for Economic Co-operation and Development, 2003. Guiding Principles for Chemical Accident Prevention, Preparedness and Response, Guidance for Industry. OECD, France, 2003. http://www.oecd.org/env/ehs/chemical-accidents/Guiding-principles-chemical-accident.pdf. (Accessed April 2019).

Papazoglou, I.A., Nivolianitou, Z.S., Bonanos, G.S., 1997. Land use planning policies stemming from the implementation of the SEVESO-II directive in the EU. J. Hazard Mater. 61, 345–353. https://doi.org/10.1016/S0304-3894(98)00142-3.

Pintarič, Z.N., 2007. Assessment of the consequences of accident scenarios. Involving Dangerous Substances. Process Safety and Environmental Protection 85, 23–38. https://doi.org/10.1205/psep06014.

Ristvej, J., Zagorecki, A., Hollá, K., Šimák, L., Titko, M., 2013. Modelling, simulation and information systems as a tool to support decision-making process in crisis management. In: Proceedings of the Modelling and Simulation 2013 - European Simulation and Modelling Conference, ESM 2013, EUROSIS, October 23-25, 2013, Lancaster, UK.

Rum, A., Landucci, G., Galletti, C., 2018. Coupling of integral methods and CFD for modeling complex industrial accidents. J. Loss Prev. Process. Ind. 53, 115–128. https://doi.org/10.1016/j.jlp.2017.09.006.

Sales, J., Mushtaq, F., Christou, M.D., et al., 2007. Study of major accidents involving chemical reactive substances - analysis and lessons learned. Process Saf. Environ. Protect. 85, 117–124. https://doi.org/10.1205/psep06012.

Schüller, J.C.H., et al., 2005. 4 Methods for Determining and Processing Probabilities. Red book, Netherlands.

Sikorova, K., Bernatik, A., Lunghi, E., Fabiano, B., 2017. Lessons learned from environmental risk assessment within the framework of Seveso Directive in Czech Republic and Italy. J. Loss Prev. Process. Ind. 49, 47–60. https://doi.org/10.1016/j.jlp.2017.01.017.

Sun, K., Li, Z.Y., 2019. Quantitative risk analysis of life safety and financial loss for road accident of fuel cell vehicle. Int. J. Hydrogen Energy 44, 8791–8798. https://doi.org/10.1016/j.ijhydene.2018.10.065.

Tahmid, M., Dey, S., Syeda, S.R., 2020. Mapping human vulnerability and risk due to chemical accidents. J. Loss Prev. Process. Ind. 68, 104289. https://doi.org/10.1016/j.jlp.2020.104289.

Tang, Y., Jing, J.J., Zhang, Z.D., Yang, Y., 2018. A quantitative risk analysis method for the high hazard mechanical system in Petroleum and petrochemical industry. ENERGIES 11, 1–18. https://doi.org/10.3390/en11010014.

Tixier, J., Dusserre, G., Salvi, O., Gaston, D., 2002. Review of 62 risk analysis methodologies of industrial plants. J. Loss Prev. Process. Ind. 15, 291–303. https://doi.org/10.1016/S0950-4230(02)00008-6.

Uijt de Haag, P.A.M., et al., 2005. Uijt de Haag et.al, 2005. 'Purple book' CPR 18E. http://content.publicatiereeksgevaarlijkestoffen.nl/documents/PGS3/PGS3-1999-v0.1-quantitative-risk-assessment.pdf. (Accessed March 2019).

Wang, B., Wu, Ch, Huang, L., et al., 2018. Prevention and control of major accidents (MAs) and particularly serious accidents (PSAs) in the industrial domain in China: current status, recent efforts and future prospects. Process Saf. Environ. Protect. 117, 54–266. https://doi.org/10.1016/j.psep.2018.04.025.

Zhongyang, L., Chunhua, Ch, Shengpeng, Y., Bin, W., Lijuan, H., Jin, W., Yican, W., 2019. Safety evaluation of spent fuel road transportation based on weighted nearest neighbor method. Ann. Nucl. Energy 127, 412–418. https://doi.org/10.1016/j.anucene.2018.12.036.