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APLIKACE METODY VÝBĚRU K EFEKTIVNÍMU ROZHODOVÁNÍ O DRUHU ANALÝZY RIZIK - PŘÍPADOVÁ STUDIE

APPLICATION OF CPR 18E METHOD FOR EFFICIENT DECISION MAKING PROCESS OF RISK ANALYSIS CASE STUDY

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SUMMARY:

This article is concerned with technological risks evaluation of units/devices containing dangerous substances in terms of current law regarding prevention of serious accidents with the purpose of minimalizing the process cost. We are putting forward the application of "Purple Book" method CPR 18E which allows to decide whether it is necessary for the identified source of danger to undergo a highly sophisticated and expensive quantitative risk analysis or not. On the case of cooling unit of a food manufacturing company where the cooling is provided by ammonia liquefied by pressure and in the secondary circuit by a nontoxic, non-flammable and non-explosive propane-1,2-diol,use of "Purple Book" method CPR 18E has proved, that it is not necessary in the next phase to subject the unit to a quantitative analysis and thereby significantly reduce costs for risk assessment.

KEYWORDS: *CPR 18E method, dangerous substances, food manufacturing company, qualitative risk analysis, quantitative risk analysis, risk assessment, technological risk, units/devices.*

INTRODUCTION

Civil protection relating to possible occurrence of serious accidents in manufacturing process when dealing with dangerous hazardous substances is specified in the EU guideline [1], which was incorporated into the national legislation in 2015 [2-4]. Enterprises must usually, in order to fulfil one of the basic requirements of the directive, perform risk analysis of considerable number of units or devices which contain or store the hazardous substances.

Risk analysis, which is usually a relatively difficult process can be realized through number of methods [5, 6], with which costs are associated and related to. The cost amount is a type of analysis function. Qualitative methods (screening) require, due to their speed and easiness, lower requirements for personal and material resources. Also, the simplicity of computation require relevantly lower need for financial means in comparison with quantitative analysis (scooping) [7]. There are also hybrid methods, which are, however, usually complicated due to their ad hoc character, which prevents their wider practical application [8].

The aim of this paper is to submit the use of CPR 18E "Purple Book" [9] method of which outputs allow, on the level of sufficient reliability, to decide whether it is or it is not necessary for the examined unit/device containing hazardous materials to conduct quantitative risk analysis in the next phase. Thereby the process of risk analysis will not only get faster but also simultaneously, its economic effectivity will be secured in the sense of fulfilment of legislative requirements [2]. This method can be used both by private

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and public subjects, which from the aspect of hazardous substances, do not fall under the acts [2-4], but might present serious risk for employees, ambient population and environment [10].

1. CURRENT STATE ANALYSIS

Legal entities and entrepreneurs operating units/devices containing toxic, flammable and explosive substances should actively take part in serious accident prevention and take responsibility for their safe operation [11]. An operator of a facility falling under the group A or B under the relevant act must ensure effective fulfilment of the given requirement on the basis of serious accident risk assessment for the purpose of drawing up a safety report or program [2]. However, there are many companies that do not fall under the competence of the legislation [2-4]. Nevertheless, they can represent a serious risk to employees, population and environment from the aspect of their location and amount of hazard substances. In compliance with the concept of population protection, these companies should follow the above-mentioned complex of laws [10].

As described in the Figure 1, a risk assessment of a serious accident includes the following phases [12]:

- risk identification;
- risk analysis;
- risk evaluation.

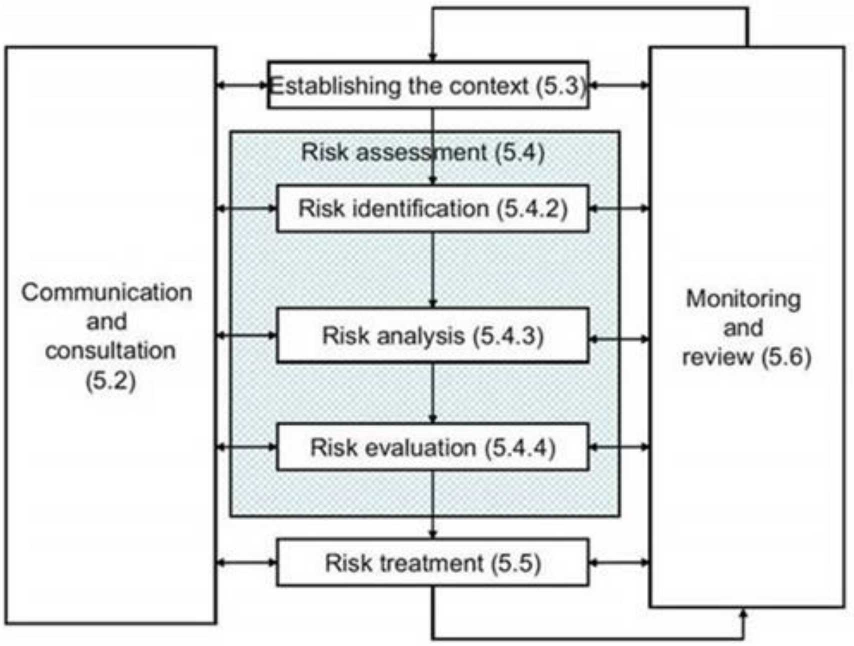

Figure 1. **Risk management process** [12]

For technological risk identification, risk analysis and evaluation several methods and software tools are available. The list of the most used ones is provided in the final report [6] or different literature [5]. Working group carries out process of risk assessment, choses the particular method or tool in accordance with the Act to meet its requirements. The implementing legislation provides content requirements of risk assessment of serious accident, the extent of assessment and a method of implementation [2]. The risk assessment techniques are based on simpler or more difficult physical models, which determine not only expenses but also accuracy and correctness of received results. Therefore, all users have to first evaluate whether the prerequisites of the method in question or software for the risk evaluation by currently applicable regulation are fulfilled, then analyze whether available data files have sufficient corresponding value in relation to an accident or risk, which are monitored. In parallel, computation of required financial resources is necessary. Only then it is possible to estimate and subsequently evaluate the risks. The results interpretation is possible only in the extent, which is determined by the prerequisites of a method, and model, which is assumed by the methodology [13].

In general, it is possible to state that the costs and reliability of achieved outputs related to application of different individual methods is considerably increasing in a range of qualitative, semi-qualitative (ranking) and quantitative methods [6]. Therefore, it is obvious that companies will stand before a decision of which method of risk evaluation to apply to minimize related costs and receive sufficiently reliable outputs. From this point of view it is highly effective to use the “Purple Book“ CPR 18E method which allows to decide whether it is necessary for an assessed unit/device to realize a highly expensive quantitative risk analysis [9].

The submitted case study is suitable for entities dealing with toxic, flammable and explosive substances for better and easier application of the “Purple Book“ CPR 18E method. The mentioned method is especially suitable for the needs of decision making process regarding the necessity of quantitative analysis application.

2. APPLIED METHODS AND INSTRUMENTS

The application of “Purple Book“ method CPR 18E for the needs of decision-making process generally rests on gradual application of the following steps [8]:

a) Division of objects into independent units or devices.

b) Degree of danger calculation consistent with equation (1) where symbol $B_s^{T,F,E}$ represents indication number representing the degree of real/actual danger of assessed unit/device in relation to toxicity *T*, flammability *F* and explosiveness *E* hazardous substance *s*, Q_s [kg] amount of hazardous substance *s* present in the unit/device, O_1 factor of unit/device type, O_2 factor characterizing location of the unit/device, O_3 factor of operating conditions, expressing the amount of a substance which will be in a gaseous state after a leak and finally $G_s^{T,F,E}$ [kg] a limit value of hazardous substance *s* determined on the basis of physical characteristics and data regarding its toxicity *T*, flammability *F* and explosiveness *E*.

$$B_s^{T,F,E} = Q_s \times O_1^{T,F,E} \times O_2^{T,F,E} \times O_3^{T,F,E} \times (G_s^{T,F,E})^{-1} \quad (1)$$

Factor values $O_1^{T,F,E}$, $O_2^{T,F,E}$, $O_3^{T,F,E}$ and limit values $G_s^{T,F,E}$ are subtracted from relevant tables of a manual or are calculated or computed by through a procedure described in the manual.

c) Determining the value of summative indication numbers B^T for toxicity *T* in accordance with equation (2), B^F for flammability *F* according to the equation (3) and B^E for explosiveness *E* by using equation (4) where symbols $q \cap r \cap u \in \mathrm{N}$ represent number of toxic, flammable, event. Explosive substances located in the assessed unit/device and N is a symbol for set for all natural numbers.

$$B^T = \sum_{s=1}^{q} B_s^T \quad (2)$$

$$B^F = \sum_{s=1}^{r} B_s^F \quad (3)$$

$$B^E = \sum_{s=1}^{u} B_s^E \quad (4)$$

d) Determining a set of points on the boundary of an object in a maximum distance of 50 m from each other.

e) Residential areas identification in a nearby area of a unit/device.

f) Selective numbers value calculation S^T for toxicity *T* in accordance with the relation (5), S^F for flammability *F* according to the relation (6) and S^E for explosiveness *E* by using a relation (7) to each point on the boundary of the land/property and each identified residential zone.

$$S^T = (100 \times L^{-1})^2 \times B^T \quad (5)$$

$$S^F = (100 \times L^{-1})^3 \times B^F \quad (6)$$

$$S^E = (100 \times L^{-1})^3 \times B^E \quad (7)$$

Symbol *L* [m] in equations (5) - (7) represents the nearest distance of a unit/device containing hazardous substance to an assessed area while the distance from this area must be at least 100 m.

g) Unit/device is chosen for quantitative risk analysis when:
   - unit/device selective number is higher than one in relation to residential area;
   - unit/device selective number in a certain point on the object border is higher than one and higher than 50% of maximal selective number in an assessed point.

To determine the distance of places on the company land border and the nearest distances to residential areas from a unit/device containing hazardous substance we used laser gauge/measurer Leica DISTO™ D810 touch (200 m), by Leica Geosystems manufacturer and electronic theodolite Eth 2, by Carl Zeiss Jena GmbH allowing automatic subtraction and registration of angles.

Regarding other methods when processing the case study, we used on-site interviews and documents regarding the hazardous object/building to acquire necessary input information/data necessary to assess the risk of a unit/device.

3. RESULTS AND DISCUSSION

The case study is presented on a cooling unit of a food manufacturing company X which does not fall under the legal competence [2], however, presents a considerable risk for the employees.

a. Characteristics of the source of hazard/danger

Company X is located on an area of approx. 6.5 hectares at the border of an industrial complex, which then continues to Old Town city part. There are approximately 600 employees in the operation of the company. The operation unit containing the hazardous substance is located 153 m on the southeast from the enterprise making pastry and desserts (residential area A) and 148 m to the south from the police department building (residential area B). There are apartment buildings approximately 251 m (residential area C) to the north-east. To the west from the source of the hazard and almost about at the same way as is the police department, a high school is located approx. 353 m (residential area D) which was not included in the assessment due to its distance from the source of danger. The wind direction of largely the speed of 2.9 to 3.3 m s^{-1} is southwest, so the nearest residential zones would probably be vulnerable to a possible accident.

The liquid ammonia in the amount of approx. 2.06 t is handled in the building. It is liquefied by pressure and represents a primary source of cooling. The secondary cooling source is non-toxic, non-flammable and non-explosive propane-1,2-diol. Ammonia is located in the engine room in the pressure vessel, which is part of a cooling system. The pressure vessel is refilled annually. Part of the machine room is steel, seamless pipes for ammonia distribution with a maximum operating pressure of 1.6 MPa. The cooling circuit consists of a high-pressure part consisting of a pressure vessel, a compressor and a liquid separator and a low-pressure part formed by an expansion vessel with a capacitance probe to control ammonia levels.

The revision of the pressure vessel is carried out once a year. Pressure and temperature are measured continuously. Ventilation in the engine operates on a natural basis by using emergency ventilators, which have non-explosive motors. The protection of the cooling system is provided with safety valves discharging ammonia into the atmosphere in case of an excess of a maximum working pressure. To ensure greater staff safety and working environment ammonia leak detectors are installed in the machine room.

A hose of a $3/4^{R}$ diameter is available for destruction of ammonia leaking from the device which connects to a water connection located in the engine room. In the machinery room in case of fire or other event there are available fire extinguishers based on inert gases (inergen - 52 % N_2, 40 % Ar and 8 % CO_2), powder, water foam and mist.

The building has an emergency plan in case of leakage of ammonia, evacuation plan, local operating procedure and activities recording plan during an accident. Each department has a plan for dealing with hazardous events. To increase the operational safety within the company, safety drills are being organized and safety measures audit takes place every five years.

b. Risk assessment and decision on the necessity of the subsequent quantitative analysis

Object under consideration only operates a single unit with a single dangerous substance, ammonia. Because ammonia is a toxic substance, flammable and explosive at the same time, it was necessary in the process of risk assessment to consider all of these effects.

In the first phase, it was necessary to set the values of indication numbers for toxic $B^{T}_{NH_3}$ flammable $B^{F}_{NH_3}$ and explosive $B^{E}_{NH_3}$ effects NH_3 according to equation (1). For the calculation, it was first necessary to subtract or calculate the values of all the needed input parameters according to manual [9]. The amount NH_3 in unit Q_{NH_3} = 2 060 kg.

A unit-type factor O_1 = 1 is for toxic and flammable effects NH_3 since it is a process unit and a factor reflecting the location of the unit O_2 = 0.1, because the unit is placed inside a building. Factor including the influence of operating conditions O_3 = 10, because at operating temperature 21°C the mist pressure reaches $p_{0,NH_3} \approx 0.89$ MPa > 0.3 MPa (3 bars).

For explosive effects NH_3 is valid $O_1 = O_2 = O_3 = 1$ consistent to manual [9].

Toxicity threshold $G^{T}_{NH_3}$ = 3 000 kg, was derived from lethal concentration LC_{50,NH_3} [rat, inh, 1h] = 5 100 mg m^{-3} h^{-1} [10].

Flammability threshold $G^{F}_{NH_3}$ = 10 000 kg same as for any other flammable substances [9] and finally the explosiveness threshold $G^{E}_{NH_3}$ = 4 348 kg was calculated on the basis of energy trinitrotoluene equivalent value NH_3 in the air $ETF^{Air}_{NH_3}$ = 0.23 [15].

The input data to calculate indication numbers according to a relation (1) are together with the value for explored unit presented in Table 1.

Table 1

Input data for indication numbers calculation and values of indication numbers of assessed unit

Ammonia amount in a unit [kg]	**Factors of operating conditions**			**Threshold** [kg]	**Indication number value** *B*
	O₁	***O₂***	***O₃***		
2 060	1.0	0.1	10.0	$G^{T}_{NH_3}$ = 3 000	$B^{T}_{NH_3} \approx 0.687$
	1.0	0.1	10.0	$G^{F}_{NH_3}$ = 10 000	$B^{F}_{NH_3} \approx 0.206$
	1.0	1.0	1.0	$G^{E}_{NH_3}$ = 4 348	$B^{E}_{NH_3} \approx 0.474$

Calculation of selective numbers has been implemented according to the manual [9], both for selected points on the boundary of the object and also for the adjacent residential zones, as seen in Figure 2. The area and boundaries of company's land were entered into the Cartesian coordinate system in which the abscissa is coincident with the north - south direction and the ordinates with the east – west direction. The NH_3 was localized to the beginning of the coordinate system. Then, the coordinates (x; y) were assigned to each of 1 to 29 points on the boundary of the object, including residential areas A, B, C, points representing the shortest distance to the unit. Finally, for the individual points on the boundary of the company and potentially vulnerable residential zones, distance *L* was detected to the unit and selective numbers were calculated for toxic, flammable and explosive effect according to equation (5) - (7). The values of selective numbers together with the input data are recorded in the Table 2.

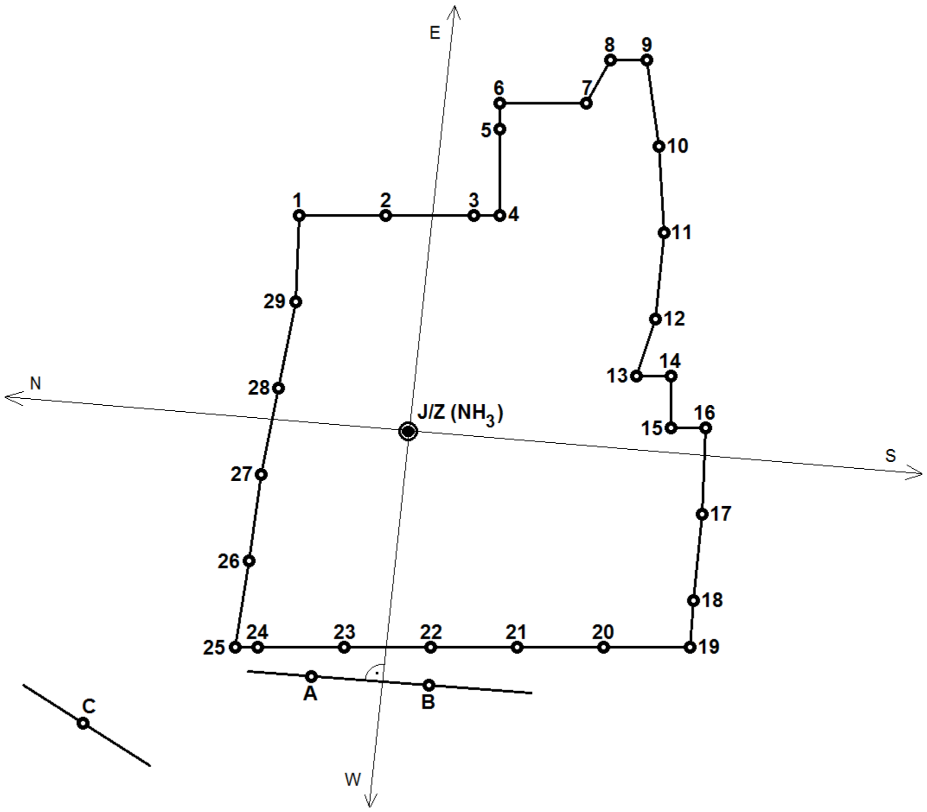

Figure 2. **The nearest boundaries of residential areas A, B, C from the assessed unit and land boundaries with defined points designated for selective numbers calculation**

A = pastry and desserts manufacturing company; B = Police Dept. building; C = residential area boundary; J/Z (NH_3) = process unit/device with ammonia; N = north; S = south; E = east; W = west.

Table 2

Values of selected numbers calculation for assessed unit

Place indication	**Coordinates**		**Distance *L* from unit** [m]	$S^T_{NH_3}$	$S^F_{NH_3}$	$S^E_{NH_3}$
	x [m]	**y** [m]				
1	- 63	125	140	0.351	0.075	0.173
2	- 13	125	126	0.433	0.103	0.237
3	38	125	131	0.400	0.092	0.211
4	53	125	136	0.371	0.082	0.188
5	53	175	185	0.201	0.033	0.075
6	53	190	200	0.172	0.026	0.059
7	103	190	218	0.145	0.020	0.046
8	117	215	250	0.110	0.013	0.030
9	138	215	283	0.086	0.009	0.021
10	145	165	218	0.145	0.020	0.046
11	148	115	188	0.194	0.031	0.071
12	143	65	159	0.272	0.051	0.118
13	132	32	138	0.361	0.078	0.180
14	152	32	158	0.275	0.052	0.120
15	152	2	153	0.293	0.058	0.132

Place indication	Coordinates		Distance *L* from unit [m]	$S_{NH_3}^T$	$S_{NH_3}^F$	$S_{NH_3}^E$
	x [m]	y [m]				
16	172	2	172	0.232	0.040	0.093
17	170	- 48	176	0.222	0.038	0.087
18	165	- 98	193	0.184	0.029	0.066
19	163	- 125	205	0.163	0.024	0.055
20	113	- 125	169	0.241	0.043	0.098
21	63	- 125	140	0.351	0.075	0.173
22	13	- 125	126	0.433	0.103	0.237
23	- 37	- 125	130	0.407	0.094	0.216
24	- 87	- 125	152	0.297	0.059	0.135
25	- 100	- 125	160	0.268	0.050	0.116
26	- 92	- 75	105	0.623	0.178	0.409
27	- 85	- 25	L $<$ 100 86	not determined	not determined	not determined
28	- 75	25	L $<$ 100 79	not determined	not determined	not determined
29	- 65	75	103	0.648	0.189	0.434
A	- 56	- 142	153	0.293	0.058	0.132
B	13	- 148	148	0.314	0.064	0.146

A = pastry and desserts manufacturing company; B = Police Dept. building; C = residential area boundary;
$B_{NH_3}^T \approx 0.687$; $B_{NH_3}^F = 0.206$; $B_{NH_3}^E \approx 0.474$.

The distance *L* was measured with a laser instrument or calculated using the cosine theorem to the known size of the angle that was found by the electronic theodolite for two horizontal directions given by the selected points on the boundary of the company which distances were known.

Values of selective numbers were calculated for points 27 and 28 because their distance *L* from the unit was less than the required 100 m. As the value of selective numbers $S_{NH_3}^T \cap S_{NH_3}^F \cap S_{NH_3}^E < 1$, it is not necessary to subject the unit to quantitative risk analysis, by this the entity in question significantly minimizes costs. A safe distance from the source of danger calculated using equation (5) assuming $S_{NH_3}^T = 1$, is about 83 m, which was why the high school building was not included into the risk assessment for its considerable distance from unit *L* = 353.

CONCLUSION

In accordance with the acts and policies regarding the civil protection, an issue of providing adequate security for operations/manufacturing with the presence of hazardous substances was discussed. Implementation of effective preventive measures can be taken only on the basis of prior risk assessment, which usually requires the use of considerable amounts of financial resources. In order to minimize costs of the process of assessing technological risks it appears appropriate to apply the method of "Purple Book" CPR 18E. Its outputs allow on a sufficient validity level to decide whether it is necessary for an assessed unit/device containing dangerous substance to conduct quantitative risk analysis, which presents an enormous financial burden [16].

A case study was submitted for the application process of a "Purple Book" CPR 18E method to the cooling unit of a food company using in the primary circuit pressure liquefied ammonia and in the secondary circuit non-toxic, non-flammable and non-explosive monopropylenglycol. The resulting outputs allow for a risk analysis process to exclude highly sophisticated and economically demanding quantitative analysis, and possibly replace it with one of the qualitative methods, allowing to significantly reduce the cost of the operator units with hazardous material.

The present case study can be used both by legal subjects and individuals working with the unit/device containing flammable, explosive and toxic substances falling within the competence of the legislation on the prevention of major accidents. It can also serve as a model for private and public entities, which from the quantitative aspect of hazardous substances do not fall under the scope of the law, but might pose a serious risk to employees, surrounding communities and the environment.

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