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ENVIRONMENTAL QUALITY ASSESSMENT AND MODELLING IN HIGH-RISK INDUSTRIAL SITES IN LATVIA

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The industrial risk situation during the past 20 years in 50 high-risk industrial sites in Latvia was investigated. Overall, the study results show that the level of industrial risk within Latvia's high-risk companies has fallen significantly. Modernisation of equipment and automation of process management were deemed to be the most effective risk reduction measures. A great deal of experience has accumulated in Latvia in the field of quantitative risk assessment. However, the comparability of the results of the work carried out is limited, because different input data and assumptions have been utilised in the calculations by various specialists. Computer modelling of the harmful impact zones resulting from accidents should be consolidated in risk assessments so that as far as possible the harmful effects on human health and the environment arising from accidents can be assessed more comprehensively and diversely. There is a need to develop common methods for probabilistic risk assessment. The study also shows that, in contrast to many European countries, acceptable risk norms are yet to be ratified in Latvia which is hindering the formulation and implementation of targeted risk reduction policy by executive governmental institutions.

Key words: *accidents, risk assessment, computer modelling.*

INTRODUCTION

Latvia's ice-free ports of Ventspils, Liepāja and Rīga ensure a stable transit corridor for freight between the West and the East throughout the year. On average, between 40 and 50 million tonnes of assorted freight are handled by Latvian ports annually. Freight is mainly transported across the territory of Latvia by rail and via pipelines. Annually, an average of 18–20 million tonnes of oil products and 1–1.2 million tonnes of chemical products are transported by rail to Latvian ports. A large proportion of the raw materials handled through Latvian ports is classified as hazardous freight, which is associated with a certain risk throughout the process of their transportation and handling. Unfortunately, on several occasions during the past two decades the potential risk of hazardous freight transportation and handling processes has manifested itself in the form of accidents, which has cost a number of human lives and caused serious environmental pollution.

The goal of the study was to assess changes in the risk situation within high risk companies in Latvia during the past 20 years, as well as to describe the main approaches to risk reduction which helped these companies to reduce the level of industrial risk related to their operations most effectively. The study was aimed at a comparison of the assumptions and input data of quantitative risk assessment methods practiced in Latvia, as well as the improvement of environmental modelling capabilities within risk assessments. Another task was the identification of possibilities for the application of risk assessment results in the formation of safe living space in Latvia and other European countries.

MATERIALS AND METHODS

Quantitative risk assessment projects conducted in Latvia and their results were examined. The method of comparative analysis was used in the study. This gave the opportunity to evaluate the homogeneity of the methods of risk assessment and to characterise differences in the results obtained. The study covered quantitative risk assessment conducted in more than 20 sites considered to have high risk. The assessments covered the whole territory of Latvia and the period from 1990 till 2010.

Risk assessments with a quantitative risk are denoted as having both numerically assessed risk components: the probability of the occurrence of an undesirable event and the impact of the consequences arising from the undesirable event. Numerical risk assessment results can also be presented for the complex risk characteristics of both components, e.g. the individual risk value or the social risk value. Individual risk characterises the probability of the death of an individual not connected with the operation of a hazardous site when he or she is at a certain point in relation to the hazardous site. Individual risk applies to the cumulative threat which the hazardous site poses over a period of one year. In risk assessments, risk isolines are often drawn around hazardous sites, which demarcate the zones with a certain level risk around a hazardous site. In contrast, the social risk value describes the seriousness of an accident or the number of potential victims in a single accident.

The first quantitative risk assessment in Latvia was conducted by specialists from the English firm, Technica Ltd. headed by Professor E. Bloker from the Netherlands and recruited by Ventspils City Council. The subject of the study was the industrial risk posed by the Port of Ventspils. The Port of Ventspils plant, now known as "A/s Ventamonjaks", was built in 1977 for the export of liquid ammonia. Two massive isothermal reservoirs, each with a capacity of 30 000 m^3, were built practically in the city centre for ammonia storage.

The Dutch specialists' risk assessment results gave evidence that this site posed an unacceptably high risk to the population of Ventspils. Figure 1 shows the individual risk contours acquired in 1991, which point to a very high level of risk within a large section of the city's territory.

In the middle of the 1990s, the management of "Ventspils nafta" and its counterpart at the Inčukalns' subterranean gas storage facility showed interest in determining the level of industrial risk posed by their enterprises and its targeted reduction. A numerical risk assessment of Ventspils nafta's technological processes was conducted by the scientific consultancy firm "Risks un audits" in 1996. The results of the study testified to the extremely high level of risk posed by many of the company's technological processes. The individual risk level ranged from $P_{let} = 1 \times 10^{-3}$ to 1×10^{-4}. The main causes of the heightened risk were identified as:

- outdated technological equipment;

- a low level of automation within process management;

- inadequate action capabilities in emergency situations.

Similar conclusions were drawn following the first numerical risk assessment at the Inčukalns subterranean gas storage facility, which was conducted in 1998.

Currently, quantitative risk assessments with determination of the probability of accidents and modelling of the harmful impact of the consequences of accidents have been conducted for more than 20 high risk sites in Latvia. Moreover, during the past 10–15 years, several repeated risk assessments have been conducted at many high risk sites, which allows to conduct a comparative analysis of changes in the risk situation at the sites in question and in Latvia as a whole.

Calculations of the spread of the harmful impact of accidents were made with ALOHA 5.4.1 computer software developed to meet the requirements of US federal services.

RESULTS

Dutch risk management specialists conducted repeated risk assessments for the Port of Ventspils facility in 1994 and 1997; but the risk assessment conducted in 2001 was carried out by Latvian specialists. After each risk assessment, comprehensive risk reduction programmes were developed and implemented within the company. The results of the first repeated risk assessment conducted in 1994 led to significant improvements in the field of risk management. In 1991, the risk management factor at the Port of Ventspils facility was rated at 2.9 points in the initial risk assessment conducted; in 1994, the risk management factor had already fallen to 1.5 points. The risk management factor provides a complex characterisation of the safety level of work organisation and work performance. Initially, the work safety level at the Port of Ventspils facility was three times lower than in averagely comparable Western enterprises; later, after the partial implementation of the first risk reduction programme, the safety level only slightly trailed behind the average level of Western countries.

Following the complete performance of the first risk reduction programme, another repeated risk assessment was conducted in 1997. The results confirmed the usefulness of the risk reduction measures implemented and showed signifi-

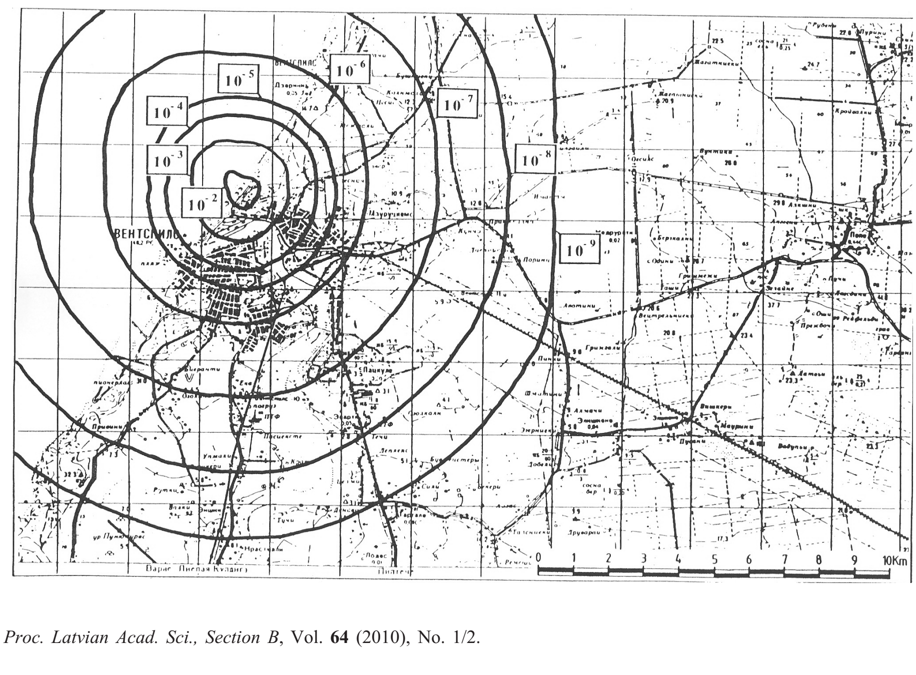

Fig.1. Individual risk contours of Ventspils port plant acquired in the 1991 risk assessment.

Fig. 2. Individual risk contours of Ventspils port plant acquired in the repeated risk assessment conducted in 1997.

cant and positive changes in the Ventspils risk situation map (Fig. 2). Moreover, in the 1997 assessment, the risk management factor at the Port of Ventspils was assessed as 1, which fully conforms to the risk management level of Western companies.

Analysing the risk management measures conducted by the "Ventspils nafta" company, now known as "SIA Ventspils nafta Termināls", during the past 15 years, the conclusion is that "Ventspils nafta" has also achieved very important results in the area of improving the risk situation. Table 1 shows the results of repeated risk assessments collated according to individual technological site groups. For example, initially the probability of a major accident on a railway load und unloads facility was 10^{-3}; after the construction of new facilities the probability of an accident during the process of unloading oil products was reduced by two to three degrees. There was a similar reduction in the probability of accidents occurring in newly built and modernised pumping stations, at bolt control points in new trunk pipelines and at reservoir parks.

Table 1

PROBABILITY OF THE OCCURRENCE OF WORST CASE ACCIDENT SCENARIOS AT "SIA VENTSPILS NAFTA TERMINĀLS"

Risk site	1996 assessment	2001 assessment	2006 assessment
Railway load and unload facility	1.1×10^{-3}	3×10^{-5}	1.8×10^{-5}
Pumping station	3.5×10^{-3}	6.2×10^{-5}	1.3×10^{-5}
Bolt network	6.6×10^{-4}	3.5×10^{-5}	3.3×10^{-7}
Reservoir park	2.3×10^{-5}	1.4×10^{-6}	5.7×10^{-7}

In performing the analysis of the risk reduction measures implemented at "SIA Ventspils nafta Termināls" and at the Inčukalns gas storage facility, they were divided into seven groups as follows:

- technological equipment modernisation;
- technological process automation;
- installation of additional safety equipment ;
- introduction of safety monitoring;
- improvement of work equipment and working conditions;
- introduction of organisation risk management measures;
- employee and public information.

Of the risk management measures listed above, modernisation of equipment had the greatest impact on the risk level of the two enterprises studied. The replacement of the old technically and functionally obsolete Soviet era technological equipment resulted in a significant reduction in the number of technical defects, idle time and repair costs. The introduction of contemporary technological process management and safety automation systems also raised the overall safety level of the enterprise by one or two degrees.

Overall, the majority of the high-risk Latvian enterprises studied during the reporting period have modernised their old technological equipment and installed new, more or less, modern and contemporarily equipped technological equipment. Unfortunately, the study showed that not all of the hazardous enterprises currently operating in Latvia have made significant investments in increasing the safety of their technological processes. Such a situation in which companies posing various degrees of risk are operating in Latvia is to a considerable extent related to the fact that acceptable risk norms have not been legally ratified in Latvia. Worldwide and in Europe, there are various approaches to the determination of acceptable risk norms. In the Netherlands, Australia and Russia these are prescribed by law. In the Netherlands, the relevant legislation prescribes that the individual risk posed by industrial sites beyond the site territory must not exceed $P_{let} = 1 \times 10^{-5}$, whereas for newly built sites, it must not exceed $P_{let} = 1 \times 10^{-6}$. Risk norms are also prescribed in the Netherlands for social, or group, risk which specify the permissible number of victims in a single accident. In other countries, such as France or the United Kingdom, acceptable risk norms are integrated into the internal regulatory enactments of the responsible governmental supervisory institutions.

Different data regarding the probabilities of unfavourable events occurring and differing assumptions specifying the size of accidents have been utilised in quantitative risk assessment projects conducted in Latvia, as well as in making calculations of the spread of the harmful impact of the consequences of accidents. This is related to the fact that, unlike in the Netherlands, methodological guidelines for the performance of numerical risk calculations have not been developed in Latvia.

In order for the risk assessment results to be mutually comparable, it is important to adhere to certain assessment principles and assumptions when conducting numerical risk assessments. Otherwise, risk assessments conducted by various specialists can differ by as much as several degrees. The determination of the scope of the consequences of an accident and the distribution radius of its harmful impact have the greatest effect on the risk assessment results. To illustrate the problem, we consider a typical accident scenario – an LPG leak from a damaged pipeline. Even though the concept of an accident is always associated with something major, i.e., the complete collapse of a pipeline, in our case; practice shows that the probability of such accidents is much lower than that of a small leak resulting from a sealing defect, or that of a partial leak caused by small holes in the pipeline. Accordingly, all of the aforementioned instances will differ in terms of both the probability of the defect occurring and the sizes of LPG leaks that could leak out during a given period of time. Data is given in Table 2 regarding the frequency of the occurrence of such events, which are taken from the methodological guidelines of the Dutch quantitative risk assessment (Anonymous, 1999).

Table 2

FREQUENCY OF THE RECURRENCE OF PIPELINE DEFECTS

Type of pipeline defect	Annually frequency of recurrence
Full bore rupture	3×10^{-7} m^{-1} y^{-1}
Leak	2×10^{-6} m^{-1} y^{-1}
Sealing defects	5×10^{-6}

In addition to the factors that influence the scope of accidents, accident-damaged equipment, accident locations and the physical-chemical properties of the leaked substance, as well as meteorological conditions at the time of the accident are highly significant in determining the radius of the spread of the harmful impact of the consequences of the accident. For a clear illustration of the contention stated above, we will consider a few ammonia leak scenarios, which will characterise how the radii of the harmful impact of accidents change depending on the aforementioned factors. Calculations of the spread of the harmful impact of accidents were made with ALOHA 5.4.1 computer software. Firstly, we will consider the differences in harmful impact distribution zones between an instant leak and a continuous leak. In both scenarios, the total quantity of leaked ammonia is the same. However, in the case of an instant leak, ammonia leaks from its cistern through a large hole within one minute, whereas in the second instance the contents of the cistern empty through a smaller hole over a ten minute period. The two degrees of the toxic impact zones of ammonia are shown in Figure 3, A and B, respectively. The first toxic impact degree with 5000 μg · g^{-1} and larger concentrations is characteristic of a lethal outcome zone in which a human's chances of survival are close to zero. The second

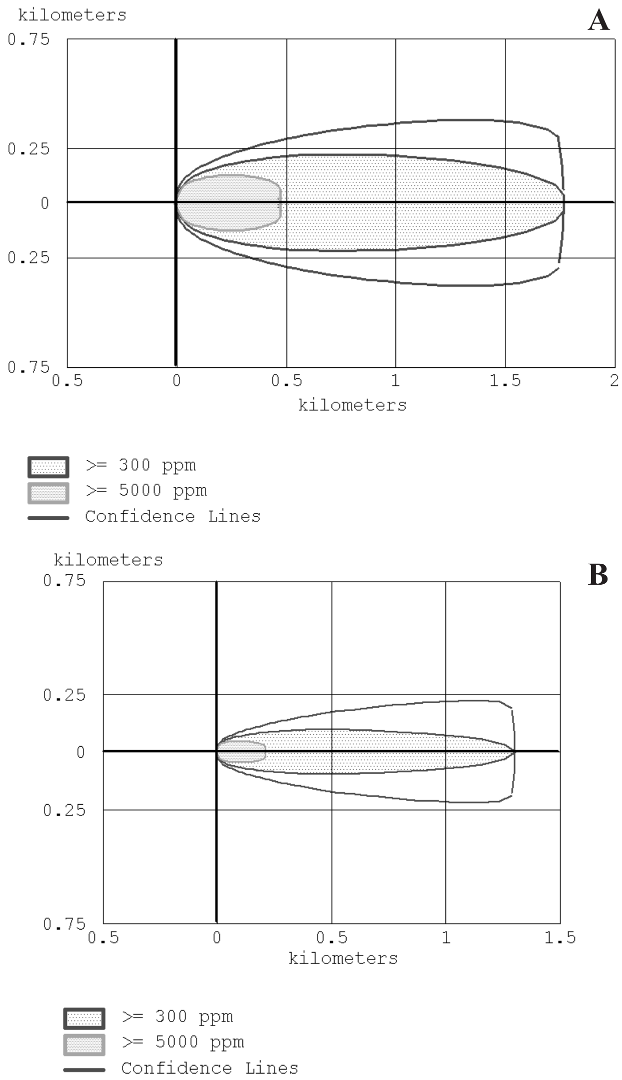

Fig. 3. **A.** Toxic impact zones of ammonia from instant ammonia leak; **B.** Toxic impact zones of ammonia from a continuous ammonia leak.

zone, with ammonia concentrations ranging from 300 to 5000 μg · g^{-1}, is a life-threatening zone in which health problems and individual lethal outcomes are expected. The results of the computer modelling of the spread of the harmful impact of an accident demonstrated that, in the event of an instant leak, lethal concentrations will spread over a radius of 476 metres from the accident location, whereas life-threatening concentrations will spread across a radius of up to 1.8 km. In contrast, if the same quantity of ammonia leaks out over a ten minute period, lethal concentrations will spread across only 214 metres, where life-threatening concentrations will spread across a radius of 1.3 km.

Secondly, we will consider the differences between a harmful impact zone resulting from a leak of liquid gas through the damaged lower part of the cistern and one in which a gas-type phase has leaked through the damaged upper part of the cistern. Computer modelling results are shown in Figure 4. It is not difficult to ascertain that, in the event of a gas-type phase leak, as a result of an accident the harmful impact of the accident will cover a much smaller radius

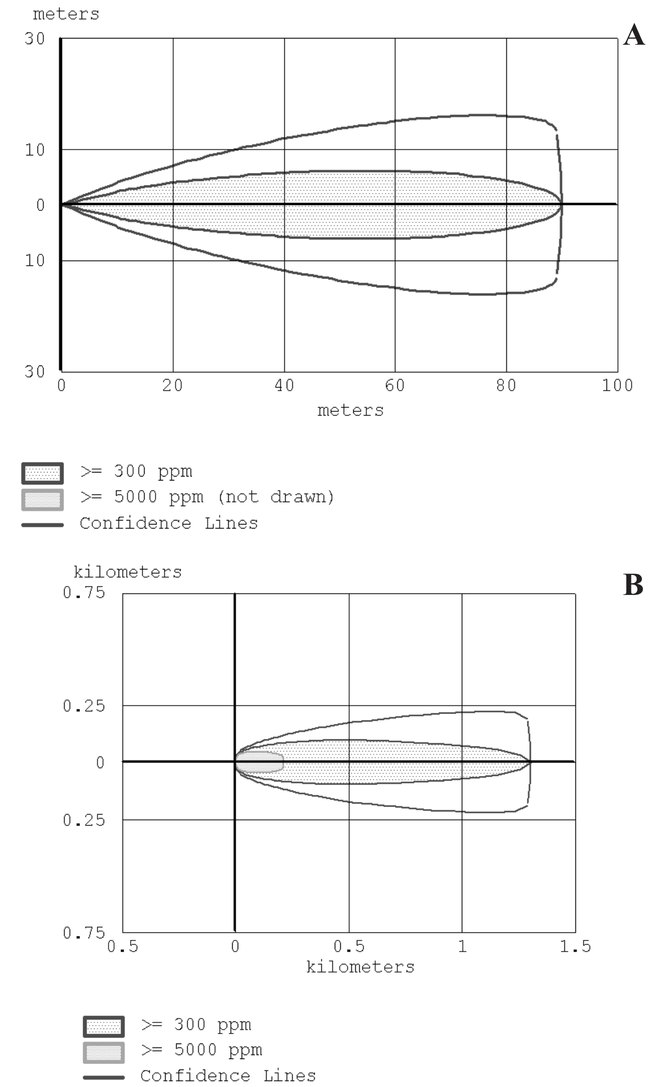

Fig. 4. **A.** Toxic impact zones caused by ammonia leak from upper part of cistern; **B.** Toxic impact zones caused by ammonia leak from lower part of cistern.

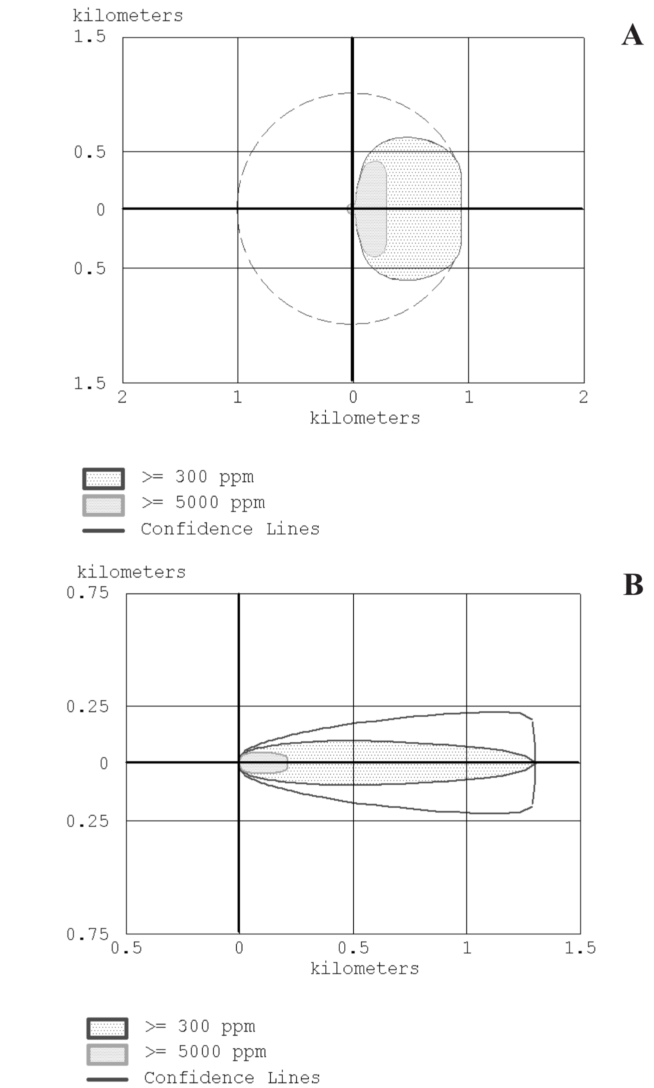

Fig. 5. **A.** Toxic impact zones from ammonia leak when there is no wind; **B**. Toxic impact zones from ammonia leak with wind speed of v = 5m/s.

from the location of the accident. Lethal concentrations will not spread further than 22 metres, whereas life-threatening concentrations will reach only 90 metres. In contrast, the danger posed by an accident in which a liquefied phase leaks out through a hole with the same diameter would be much greater. Lethal concentrations would spread ten times further and reach 214 metres, whereas life-threatening concentrations will spread across a radius of 1.3 km from the location of the accident.

In turn, the differences in the spread of the harmful consequences between an accident occurring in calm weather conditions and one that occurs when there is a wind speed of 5 m/s are shown in Figure 5. Comparing the zones visible in the images, in the event of no wind or only a slight wind, the area of the threatened zone (territory threatened by the accident) is much greater than if there is a wind speed of 5 m/s and more. A powerful wind will carry the ammonia fumes in the direction of the wind and gradually dilute it with masses of clean air. In very windy conditions, hazardous concentration in the direction of the wind may spread further than when there is no wind, but the threatened zone will be narrower and its spread much reduced.

DISCUSSION

Analysis of various literature sources and methodological guidelines (Anonymous, 1999; Anonymous, 1980; Duijm and Carrissimo, 2001; Nielsen, 2001) shows that in international risk assessment practice there is no unified approach to determine the values of many important risk assessment factors. Taking the large of number of significant risk factors listed above into account, in this section we will consider only one — the selection of meteorological data. Practically all authors believe that for risk calculations it is best to utilise genuine meteorological data that have been accumulated over a long period of time in the immediate proximity of the site. Unfortunately, weather stations are not positioned in the immediate vicinity of all sites.

In instances in which there is a lack of adequate data on meteorological conditions in the immediate proximity of the site, US risk assessment guidelines recommend (Anonymous, 1980) making risk calculations subject to neutral atmospheric stability pointers and a wind speed of 3 m/s. According to the Pasqvill-a scale, atmospheric stability classes are divided into six groups from A to F, where Class A conforms to highly unstable weather conditions and Class F denotes very stable weather conditions. Class D denotes neutral atmospheric conditions according to the Pasqvill-a scale. In turn, to characterise worst case scenarios the American specialists recommend making calculations of the spread of the harmful impact of accidents subject to atmospheric stability Class F and a wind speed of 1 m/s. In contrast, recommendations are given in Dutch quantitative risk assessment methodological guidelines (Anonymous, 1999) for the performance of risk calculations subject to several stability classes and wind speeds.

In risk calculations, it is important to take into account the differences between typical meteorological conditions at night and during the day. During the day, the atmosphere is usually unstable with larger air mass turbulence, which induces a more rapid reduction in toxic concentrations. Accordingly, in daytime, hazardous concentrations of chemical substances usually do not spread as far as in stable meteorological conditions, which are more characteristic of night-time in particular. Meteorological parameters utilised by the specialists of "PSI Risks un audits SIA" in their quantitative risk assessments are given in Table 3.

Table 3

METEOROLOGICAL PARAMETERS UTILISED BY "PSI RISKS UN AUDITS SIA"

Wind speed (m/s)	Atmospheric stability classes	
	Day	Night
1	B	E
3	C	D
5	D	D

Acceptable risk norms are necessary for governmental administrative institutions to make an appropriate decision regarding the operating terms and conditions of a hazardous site based on risk assessment results. Acceptable risk norms have not yet been prescribed nationally in Latvia, but there is the Ventspils precedent. With Ventspils City Council Decree No. 32/5 of 24 March 1994, acceptable risk norms have been ratified within the territory of the city of Ventspils. The individual risk level outside the territory of sites in Ventspils must not exceed the level of $P_{let} = 1 \times 10^{-6}$ and the group (social) risk must not exceed the level of 10^{-5}. The Dutch risk norms were taken as the platform for the Ventspils acceptable risk norms, because the Netherlands is one of those European countries that have resolved risk management issues on a national level most seriously (Vrijling *et al*., 2006). The first Dutch risk level maps were compiled 25 years ago, which showed the serious threat posed to a large section of the population. During this period, the responsible governmental institutions have worked seriously together with local governments on risk level reduction programmes aimed at increasing safety levels within hazardous enterprises to reduce the probability of the occurrence of potential accidents and to reduce the scope of the consequences of such, as well as territorial development planning to reduce the number of inhabitants present in high risk zones, either indefinitely, or for a long period of time. As a result of the implementation of a targeted national risk reduction policy, in 2010 there will be no hazardous enterprise in the Netherlands with a potential risk level outside the company's territory that exceeds the level of $P_{let} = 1 \times 10^{-6}$.

V.M. Trobojevic has summarised information on the approach of European countries to the determination of criteria for acceptable risk. His study shows that there is no common position in Europe on either the way in which legally acceptable risk norms ought to be determined nor in regard to levels of acceptable risk (Trobojevic, 2003). A summary of the criteria for acceptable risk is provided in Table 4.

As shown by Trobojevic's study, the highest acceptable individual risk limit of 3×10^{-6} has currently been ratified in the United Kingdom. The opinion of other countries included in the study on the level of acceptable individual risk more or less concurs. The opinions of the countries included in the study also vary on the level of acceptable social risk. Even though the efforts of specialists from the responsible service bodies in European countries to develop common acceptable risk criteria for European Union states have not yet resulted in any crowning achievements, discussion on this subject are ongoing.

The study conducted shows that during the past 20 years there have been a significant reduction in the level of indus-

Table 4

COMPARISON OF INDIVIDUAL RISK CRITERIA

IRPA*	UK	The Netherlands	Hungary	Czech Republic
10^{-4}	Intolerance limit for members of the public			
10^{-5}	Risk has to be reduced to the level as low as reasonable practicable (ALARP)	Limit for existing installations	Upper limit	Limit for existing installations. Risk reduction must be carried out
3×10^{-6}	Land use planning limit of acceptability			
10^{-6}	Broadly acceptable level of risk	Limit for new installations and general limit after 2010	Lower limit	Limit for new installations
10^{-7}	Negligible level of risk			
10^{-8}		Negligible level of risk		

*IRPA, individual risk per annum

trial risk prevalent within Latvia's hazardous enterprises. Many high-risk sites have made significant investments in the modernisation of their technological equipment and automation of process management. Sufficient experience has been accumulated in Latvia in the area of quantitative risk assessments, which allowed to assess objectively the probability of the occurrence of potential accidents and harmful impact zones arising from the consequences of accidents. However, the study revealed significant differences in the risk assessments conducted by various specialists, which raised a need to develop methodological recommendations for the performance of quantitative risk assessments. In order for governmental administrative institutions to be able to prescribe and implement risk management policy consequently, legally binding acceptable risk norms of Latvia must be developed and ratified.

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VIDES KVALITĀTES NOVĒRTĒŠANA UN MODELĒŠANA PAAUGSTINĀTA RISKA RŪPNIECISKOS OBJEKTOS LATVIJĀ

Pētījums aptver 20 paaugstināta riska rūpnieciskos objektus Latvijā un riska situācijas izmaiņas tajos pēdējo 20 gadu laikā. Kopumā pētījuma rezultāti liecina, ka industriāla riska līmenis Latvijas paaugstināta riska uzņēmumos ir būtiski samazinājies. Kā efektīvākie riska samazināšanas pasākumi tika atzīti iekārtu modernizācija un procesu vadības automatizācija. Latvijā ir uzkrāta liela pieredze kvantitatīvo risku novērtējumu jomā, taču veikto rezultātu salīdzināmība ir ierobežota, jo dažādu speciālistu veiktajos aprēķinos ir izmantoti atšķirīgi izejas dati un pieņēmumi. Riska novērtējumos būtu jāpastiprina avārijas seku kaitīgās iedarbības zonu datormodelēšana, lai pēc iespējas vispusīgāk un pilnīgāk varētu novērtēt avāriju seku kaitīgo iedarbību uz cilvēku veselību un vidi. Minētie apsvērumi izvirza nepieciešamību izstrādāt vienotus skaitliskā riska novērtēšanas metodiskos norādījumus. Pētījums arī parāda, ka Latvijā, atšķirībā no daudzām Eiropas valstīm, pagaidām nav apstiprinātas akceptējamā riska normas, kas valsts pārvaldības institūcijām traucē izstrādāt un īstenot mērķtiecīgu riska samazināšanas politiku.