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Risk Reduction Possibilities Considering Equipment, Working Environment and Human Factor in Road Construction

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Abstract. **In modern road construction the work becomes even more intensive, requires maximum attention and concentration; therefore, practice and experience have been examined in the organization and implementation of labour protection measures. The objective is to study to what extent the road construction workers are influenced by dust containing crystalline silica that occurs in the process of asphalt concrete milling, based on Latvian and foreign studies. Additionally, the analysis is provided and the assessment of risk factors that occur during the milling process: noise, vibration and ergonomic risks.**

Keywords: **preventive measures, occupational risk, risk impact, silica, vibration, noise.**

I. Introduction

From a standpoint of labour protection, road construction is considered a comparatively dangerous industry since it includes practically all risk factors of working environment. Risks to safety and health of the employees can be caused not only by movement on roads under construction but also by disorder in a machinery cabin. Noise, abrasive dust, chemicals and vibration are created both by building machinery and various small mechanization means, evaporation from laid asphalt. The work is carried out both at negative temperatures and in very hot weather, under effect of UV radiation. From an ergonomic point of view, the work is hard. Overtime work is often practiced during the season. Each year many accidents take place with severe health problems, thereafter the employees get occupational diseases. Road construction works are carried out on the roadway with heavy traffic. This traffic can rarely be closed completely. Usually the roadway is divided into parts: on one of which road construction work is carried out, while on the other side traffic is organized in accordance with the provisions of regulatory enactments. The work is carried out close to traffic, which adds the existing risks - noise, vibration, dust – with possible injury risks.

Traffic that takes place also within the construction work area: trucks deliver materials for performance of road construction work, various building machines operate and move (graders, rollers, excavators and other machinery) increases the already existing labour risks. The studies have been carried out at a Latvian road construction enterprise.

Noise is now considered one of the public health hazards, which is becoming increasingly negative. More than half of European population live in a noisy environment, and for one third of them noise causes sleep problems. Intense noise is one of the main adverse industrial factors.

Noise at work is a global problem that covers many industries. According to estimations, in 27 EU member states 60 million employees, or 30% of manpower, are exposed to noise. It is characteristic of agriculture, mining, manufacturing and construction. More than 35% of employees in these industries are exposed to noise impact. The highest number of work-related hearing impairment cases is in mining, metal production, construction, transport and communications [1, 2].

Noise in road construction is a very common occupational risk factor, which is caused by the use of different work equipment, heavy machinery operation. Each of these facilities makes noise when working – chaotic sound combination of different frequencies and different intensities, which can be significantly higher than the occupational exposure limit level. Measurements carried out in the road construction industry indicate a noise level, which very often exceeds the lower exposure impact level of 80 dB (A), when various workers' hearing protection measures become necessary.

Very intense acute exposure to noise can cause temporary or permanent hearing loss – acoustic trauma. Meanwhile, continuous, long-term noise exposure could result in occupational hearing loss – irreversible and incurable hearing loss, which is one of the most prevalent occupational diseases in the world.

Degree of hearing loss is most often directly proportional to the length of service in a noisy environment, but it can develop already in the first few years, particularly rapidly – within the first 5 years. In addition, the noise hampers mutual communication, makes it difficult to perceive audible warning signals, hear various instructions and thus contributes to accidents at work. Besides, if the working environment is noisy, the worker is almost unable to warn other workers of the imminent danger, which also increases the risk of accidents.

Workers' exposure limit values directly depend on the work planning and work habits. For example, a noise level in an excavator cabin, depending on whether the cabin window or door is closed or not, will differ by 3–5 dB(A), while for a road construction worker, who works directly behind a device, noise can exceed a level of 90 dB(A), but 20 metres away from it the noise level will be below the dangerous value. Table 1 shows noises caused by certain road construction equipment [3,4].

TABLE 1

NOISE PRODUCED BY ROAD CONSTRUCTION EQUIPMENT

Equipment	Noise level, dB(A)
Jackhammer	88–108
Small angle grinder	92–103
Asphalt hand saw	92–106
Vibrating tamper	85–104
Asphalt mill	88–97
Excavator (cabin)	67– 83
Truck (cabin)	62–81
Frontal loader (cabin)	67–84
Road roller (cabin)	82–89
Bulldozer (cabin)	81–92
Asphalt paver	82–98

Vibration is a harmful occupational risk factor for workers in many professions. Both local and whole-body vibration is a common event in work processes associated with production and processing of various materials (wood, metal, etc.), as well as with operation and maintenance of various machinery (trucks, tractors, etc.) and equipment (production lines, motors, generators, etc.). Both types of vibration represent one of the most important risk factors in industries, such as timber and logging engineering, metalworking, vehicle manufacturing, servicing and repair, construction, power generation, food production, etc. In the study "Working Conditions and Risks in Latvia", the employers in the 2010 survey estimated that 29.9% of workers of their companies were exposed to vibration produced by hand tools, while 27.1% – to vibration generated by vehicles. Vibration disease is one of the most common and serious occupational diseases [5.6]

Vibration, like noise, is a wide-spread occupational risk in road construction, which is produced by the majority of road construction equipment that generates not only noise, but also vibrations when working. Vibration is generally based on insufficiently balanced rotary or reciprocating components. There are two types of vibration:

• hand-arm vibration – it is transmitted through the hands of the worker by work equipment, the operation of which is based on impacts and rotation;

• whole-body vibration – it is transmitted through the seat or feet of workers and affects the whole body.

Hand-arm vibration can lead to carpal tunnel syndrome or connective tissue breach in the wrist, which strains the nerves and blood vessels, causing tingling and pain sensations in the arms. Meanwhile, the whole-body vibration causes various spinal cord disorders. Vibration characterization and hygienic evaluation in practice mainly use the so-called vibration acceleration (Q, m/s2), which has definite occupational norms in order to determine when it is deemed to be harmful:

• Hand-arm vibration maximum occupational level (exposure limit value) is 5 m/s2, while the daily exposure effect value is 2.5 m/s2;

• Whole-body vibration maximum occupational level (exposure limit value) is 1.15 m/s2, while the daily exposure effect value is 0.5 m/s2.

Equipment used in road construction can cause a significant vibration level, which similarly to the noise level will depend on the technical condition of equipment and on specific work to be performed. However, much of the equipment used in practice often creates such a vibration level that exceeds both the daily exposure effect value and the exposure limit value; for example, concrete cutting saw creates the vibration acceleration of 2 to 6 m/s2, pneumatic jackhammer – 3 to 20 m/s2, but vibrating tamper – 4 to 25 m/s2. A similar principle applies to a vibration level created by heavy machinery: the older, bigger and worse in technical condition the machine is, the higher the vibration level generated by it.

II. DESCRIPTION OF VIBRATION

As to the whole-body vibration, the type of object being worked at – whether on a hard ground (gravel, asphalt, concrete) or on a soft ground (sand, marshy soil) – is of great importance.

New, modern road construction machinery usually does not create a vibration level well above the exposure limit value, while old machines can produce a very high vibration level. For example, T170 tractor has an average vibration of 1.5 m/s2, while a modern tractor creates an average vibration of only 0.5 to 1 m/s2. It should be remembered that some machines create both the general vibration (standing / sitting on a machine) and the hand-arm vibration (holding on to the steering wheel or railing) [6, 1].

Vibration produced by some road construction tools and machines is shown in Table 2 [3,7].

Chemicals and dust are commonplace in road construction. They occur both from used fuel (exhaust gases) and from asphalt and other materials used in road construction (for example, from asphalt-applied road signs and indicators). Both fuel and asphalt constituent products contain chemicals, such as toluene, xylene, benzene, and others.

TABLE 2

VIBRATION CREATED BY CERTAIN ROAD CONSTRUCTION EQUIPMENT

Equipment group	**Hand-arm vibration m/s^2**	**Whole-body vibration m/s^2**
Jackhammer	3 – 2 6	-
Small angle grinder	2 – 6	-
Asphalt hand saw	2 – 6	-
Vibrating tamper	4 – 2 9	-
Asphalt mill	0 . 2 – 7	.
Excavator (cabin)	0 . 7 – 4	0 . 2 – 4
Truck (cabin)	0 . 4 – 1 . 5	0 . 5 – 4
Frontal loader (cabin)	0.8– 1.5	0 . 2 – 2
Road roller (cabin)	0 . 7 – 2	0 . 4 – 4
Bulldozer (cabin) •	0.3 – 4	0 . 5 – 3
Asphalt paver	0.6 – 2	0 . 2 – 2 . 5

Their increased concentration may cause impact on the nervous system and lungs. Chemicals and dust can be divided into two large groups:

• chemicals that are released from various mixtures existing in road construction or from used fuel and maintenance products (oils, etc.);

• dust produced as a result of crushing, handling, cutting and grinding of various materials. It should be noted that dust produced in such processes consists of both silicon oxide as well as of other chemicals.

From a standpoint of different road construction processes, certain types of risk factors occur during each process [8, 9]:

• removal of old asphalt pavement and dismounting of road utilities (road curbs, bridge railings, etc.) – mainly occurrence of very high dust concentration, for example, during asphalt cutting the occupational concentration can be exceeded by 10–15 times, while when cutting concrete curbs – by 20–30 times and even more. Comparatively lower concentration of dust is when working with asphalt mills, however, depending on the nature of the object, here also a high concentration of dust may be;

• preparation of road covering for application of new pavement, laying of gravel, sand and waterproofing coating, road improvement (curbs, railings, etc.) – mainly occurrence of relatively low (occupational concentration may be not exceeded) or not too high (occupational concentration may be exceeded only slightly) concentration of dust;

• application of a new asphalt pavement, its levelling and compaction – mainly emission of volatile organic compounds at low to medium concentrations (exposure index, which indicates by how many times the occupational concentration is exceeded, fluctuates between 0.1 and 2.9), if works are carried out in an open area. However, if they are carried out in the territory with reduced air exchange (e.g., inner yards), the exposure index (EI) may be significantly higher. High exposure index will be observed also when pouring the pits with various bitumen or tar-containing masses.

According to measurements of occupational risks, dust quantity at the workplace of road milling machine driver is 0.45 mg/m, at the operator's workplace – 1.13 mg/m, occupational exposure limit value for abrasive dust – 2.0 mg/m3, silica – l mg/m3 [8].

When assessing the results of measurements, it can be assumed that at these workplaces the level of crystalline silica is comparatively high since it was not discernible at sufficiently high results of dust measurement.

If these measurements are compared with the results of measurements of concrete curb cutting using an angle grinder, they are relatively slightly higher, accordingly 172 mg/m3, and are discernible.

Accordingly, in the working environment noise of 96dB (A) – at the milling machine driver's workplace – and noise of 118dB (A) – at the operator's workplace – are well above the occupational exposure limit of noise.

In a survey of the workers in road construction, it was found that people are currently most affected by the psychoemotional work hazard – stress. Opinions almost equally divided between the noise and dust risk impact on the workers, Fig. 1.

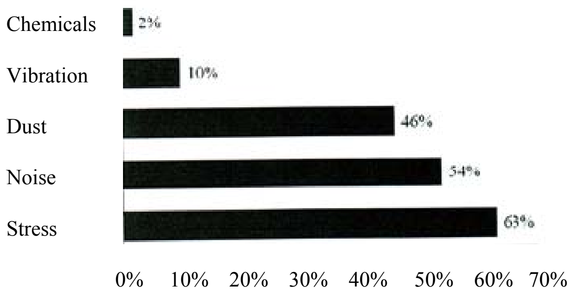

Fig. 1. A diagram of risks that affect the workers in road construction.

Workers of various road construction professions (road workers, building machine drivers, road masters, operators, etc.), performing different tasks participated in the survey. Several professions had additional duties affecting the choice of priority risk in the survey. For example, if a worker's basic profession is a welder, then additional positions are a fitter, asphalt-layer. Therefore, it can be considered that the survey results are subjective, because the workers find it difficult to determine high-priority risks.

It is also important to take into account each person's physiological condition and tolerance to these risks. Comparing the survey results with measurements of occupational risks and determination of risks, it can be concluded that they are compatible.

In abrasive dust measurements, insufficient attention is devoted to crystalline silica impact on workers' health. It should be taken into consideration that the asphalt concrete is a mixture of mineral materials and when milling it, certain concentration of silica is created, which may lead to the onset of silicosis. People at work are rarely exposed to impact of pure crystalline silica. Dust that they inhale at workplace usually consists of mixture of crystalline silica and other substances [10].

Unfortunately, currently Latvian state institutions and competent authorities have no equipment for measuring and determining the concentration of crystalline silica in the working environment. As a result of measurements, it is not possible to separate the abrasive dust existing in the working environment into different fractions in order to determine crystalline silica concentrations. [Data of the Laboratory of Hygiene and Occupational Diseases of Riga Stradins University].

To perform these measurements, it is necessary to apply analysis techniques, i.e., the determination of quartz content requires the use of X-ray diffraction or infrared spectroscopy with Fourier transformation – according to the standards of different countries [11]. Latvia does not currently apply such techniques, and the only way to make sure that the workers are not ill with silicosis is sending the employees to the annual mandatory health checks. Since it is not possible to clearly identify the initial level of silicosis development, then any reduction in contacts will mean a lower risk of getting ill with silicosis.

In order to minimize the likelihood of getting ill with silicosis, general preventive measures should be developed and maintained:

- avoiding risks;
- assessment of risks that cannot be avoided;
- development of a unified plan of general preventive activities (sending to mandatory health checks, observance of personal hygiene);
- priority of collective protection means over individual protection means;
- information delivery to workers, their training and instruction;
- organization and implementation of correct measurements of occupational risks.

To make an initial assessment and determine whether there is a significant risk of exposure to respirable crystalline silica, a simple flowchart of operations (shown below) should be used. Possible presence of fine particles of crystalline silica indicates the existence of a possible risk. If the risk is not expected, there is no need to take any particular measures. However, general principles of prevention should be certainly followed at all times, i.e., whether fine particles of crystalline silica occur during the work process (see Fig. 1).

Very little literature on road construction and its development is available in Latvia. Performance of measurements of crystalline silica concentration in the working environment is not possible technically since there is no respective equipment in Latvia. It is only possible to determine the total amount of abrasive dust in the working environment and then mathematically calculate the amount of possible crystalline silica.

A person who carries out the assessment of occupational risk shall take into account the probabilities of occurrence of such a hazard (duration, frequency) and the severity of its consequences, as well as consider all factors of the working environment, which pose or may pose a threat to the safety and health of workers, their possible interaction and the results of performed working environment measurements (see Table 3).

TABLE 3

RISK ASSESSMENT WORKING WITH ROAD MILLING MACHINE “WIRTGEN” 2100

Risk identification	**P**	**Q**	**Existing control and compliance**	**Risk level**	**Risk**	**Risk reduction measures**
1	2	3	4	5	6	7
1. Noise	Machine-emitted noise of 118 db(A), working for 8h, exceeds the exposure limit value of 87 db(A). Serious consequences 3	4	Regulations of the Cabinet of Ministers No.66 of 4 February 2003	12	High	1. Health check once a year. 2. Provision with qualitative hearing protective means 3. Periodic rest from noise and from wearing ear muffs
2. Dust at operator’s workplace	Dust formed during milling of pavement is 1.13mg/m^3. EI (exposure index)=l.13/2= 0.57>0.5 <0.75 Serious consequences 3	4	Regulations of the Cabinet of Ministers No. 325 of 15 May 2007	12	High	1. Perform dust concentration control once in 52 weeks. 2. Use individual protection means, if necessary
3. Dust at driver’s workplace	Occupational exposure concentration of dust – 0.45mg/m^3. EI=0.45/2= 0.23<0.5 Medium consequences 2	4	Regulations of the Cabinet of Ministers No. 325 of 15 May 2007	8	Medi um	1. Perform dust concentration control once in 104 weeks. 2. Use individual protection means, if necessary
4. Gaseous chemicals, at operator’s workplace: - carbon oxide,	EI=22.l/20= i,i>i; Serious consequences 3	4	Regulations of the Cabinet of Ministers No. 325 of 15 May 2007	12	High	1. Reduce the CO level in waste gases, incl. trucks collecting milled asphalt. 2. Perform repeated measurements, eliminate equipment faults. 3. Mandatory health check once in 3 years.
Nitric oxide – 3.26 mg/ m^3	EI=3.26/5= 0.65>0.5; Medium consequences 2	4	Regulations of the Cabinet of Ministers No. 325 of 15 May 2007	8	Medi um	1. Improve technical condition of engines. 2. Repeat measurements once in 52 weeks. 3. Mandatory health check once in 3 years.
Hydrocarbons - 223 mg/m^3	EI=223/300-0, 87>0.5; Serious consequences 3	4	Regulations of the Cabinet of Ministers No. 325 of 15 May 2007	12	High	1. Repeat measurements once in 24 weeks. 2. Engine adjustment. 3. Mandatory health check once in 2 years.

TABLE 4

RISK ASSESSMENT FOR WORK WITH JACKHAMMER

Risk identification	**P**	**Q**	**Existing control and compliance**	**Risk level**	**Risk**	**Risk reduction measures**
Abrasive dust	Dust formed when hammering off wells is1.82 mg/m^3, working for 2h. EI=0.23<0.5 Minor consequences 1	4	Regulations of the Cabinet of Ministers No. 325 of 15 May 2007	4	Low	1. Use hearing protection means. 2. Use a respirator at a work site when generating large amounts of dust.

For comparison purposes, we now consider the results of hazard assessment with other pieces of equipment in the working process of which the crystalline silica is or may be produced, and namely, a jackhammer and angle grinder “Makita”. Jackhammer is usually used to break the asphaltic concrete pavement. Risk assessment results are presented in Table 4.

Angle grinders used at construction sites for cutting of sidewalks, road pavement and border stones are usually equipped with cutting disks in a diameter of 220–230 mm. Risk assessment results are presented in Table 4.

TABLE 5

CRYSTALLINE SILICA RISK

	Is crystalline silica risk formed during the working process?
Changes in: working process legislation formation of materials. 2. Implementation of new technologies. 3. Working environment monitoring 4. Mandatory health checks	Whether fine particles are contained in any of materials formed in the working process
	Carry out the working environment risk assessment in relation to respirable crystalline silica.

It is established that dust contains from 10% to 70% of silica (fireclay, granite, mica, carbon dust), then its occupational exposure limit is 2 mg/m3.

Knowing that milled asphalt concrete contains granite chips and taking into account the measurements of abrasive dust concentration in the working environment – 0.45 mg/m3 at milling machine driver’s workplace and 1.13 mg/m3 at operator’s workplace – we can determine the limits of silica concentration at driver’s and operator’s workplaces:

- at driver’s workplace at minimum 10% concentration of silica, in the working environment it will be 0.045 mg/m3;
- at driver’s workplace at maximum 70% concentration of silica, in the working environment it will be 0.315 mg/m3;
- at operator’s workplace at minimum 10% concentration of silica, in the working environment it will be 0.113 mg/m3;
- at operator’s workplace at maximum 70% concentration of silica, in the working environment it will be 0.791 mg/m3.

The determined concentrations do not exceed the occupational exposure limit (OEL) of silica established in Latvia – l.0mg/m3, but by many times exceed the OEL for this dust in other countries.

In many countries the quartz level in air above 0.1 mg/m3 is already considered hazardous. In case of doubt, it should be assumed that quartz concentration is hazardous.

OEL of crystalline silica in various countries [13, 14, 17]:

- Austria – 0.15 mg/m3;
- Denmark – 0.1 mg/ m3;
- Finland – 0.2 mg/ m3
- Ireland – 0.05 mg/ m3;
- the Netherlands – 0.075 mg/m3;
- Great Britain – 0.3 mg/m3; (0.1 mg/m3 – recommended) [10];
- Latvia – 1.0 mg/ m3;
- USA – 0.05 mg/m3 [9].

Taking into consideration that all over the world the respirable crystalline silica in the working environment is considered extremely hazardous and, having evaluated the OEL of this substance which is 10 to 20 times lower than in Latvia, it would be necessary to review the OEL of silica in Latvia and reduce it, and as far as possible to acquire equipment that allows measuring crystalline silica concentration in the working environment.

The results of measurements are strongly influenced by weather conditions: outdoor temperature, relative air humidity, wind speed, since when milling the asphalt concrete the biggest amount of dust comes from the conveyor belt along which the milled material is delivered to the truck and from the milling machine roller. It is important to choose measuring points since it is not sufficient that measurements are only carried out in those two places where the driver and the operator are located at the time of measuring. They continuously make corrections of mill direction both on the right and on the left where dust concentration measurements may differ, which is proven by measurements carried out by NIOSH [16].

Compared to the two measurements made in points where at given time the driver and operator of milling machine were at our disposal, NIOSH carried out measurements in seven points, which considerably increased the reliability of results and the possibility of identifying more places of dust risk factors, including crystalline silica dust.

Also it should be taken into account that the water pressure is fed to 24 dust suppression nozzles. In our case, there is no information about water pressure on the nozzles; it significantly affects the reliability of measurements.

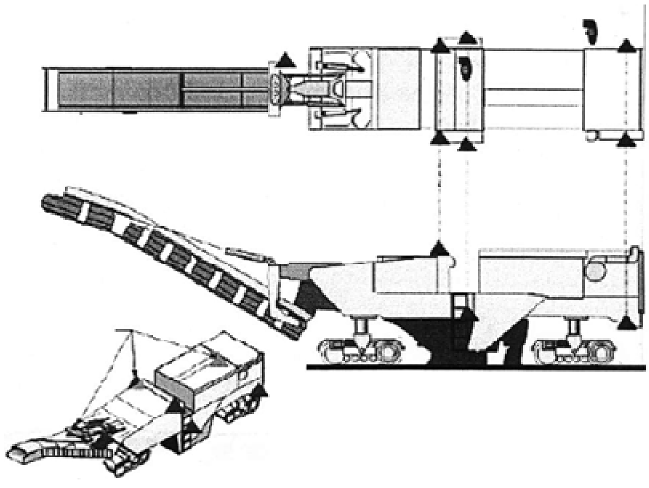

Fig. 2. Measurement points on a road milling machine.

There is also the possibility of increasing the number of water nozzles where it is needed in order to reduce the risk factors or improve the technical data of milling machine. For example, improving the flow of milled asphalt as a conveyor belt rollers become overgrown with dust of milled material.

Performing the measurements of occupational risks, they need to be made in at least four points where the milling machine control desk is located, and it is necessary to record the readings of delivered water pressure on cutting roller and on material feed conveyor belt.

III. Risk Reduction Possibilities in Road Construction Works

Special attention should be devoted to work organization on the road since the work is carried out close to traffic, which creates additional risk factors for the workers. Increased attention should be paid to delimitation of the construction work area by means of collective protection means (guide posts, cones, road signs) [15].

Important measures to be taken are timely maintenance and repair, if necessary, of building machines, equipment and hand tools to enable the workers to perform work with qualitative, technically sound equipment.

In risk reduction, great responsibility rests with foremen and road masters, who should pay special attention to labour protection issues, establishing daily work tasks for the workers.

Special attention should be devoted to the use of individual protection means. For example, when carrying out road construction works the workers usually do not use protective helmets in the absence of relevant risk factors (work at height, falling objects) while at the same time particular works take place with risk factors where protective helmets must be used (work in trenches, in the area of excavators and cranes, working under bridges, trestles, etc.), when the workers under work routine influence forget about existing hazards.

At the construction site it is often observed that workers in hot weather often work without protective outerwear, exposing themselves to solar ultraviolet radiation. In the summer workers do not use protective glasses against solar ultraviolet radiation and dust because the employer has not currently included these protection means into the issue list.

Therefore apart from labour safety instructions, the workers should be given thematic training in labour protection against these hazards. The labour protection specialist should be able to give relevant explanation to ensure that the employer would provide the employees with “unpopular” protection means.

Assessment of labour protection and health protection risk is for the benefit of both the enterprise and its employees. Mutual understanding is needed, which provides for active involvement of all employees into the risk assessment process; the employees should be involved and their opinions should be heard.

Risk reduction measures:

- proper choice and use of individual protection means;
- acquainting the employees with features of technological process, possible risks;
- P3 class respirators, most appropriate in road construction, which ensure protection against fine and toxic dust, such as dolomite, quartz, asbestos, flour, caffeine, ephedrine, metal containing dust, including manganese, chromium, lead and metal fume;
- contact time with the equipment exceeding specified occupational exposure limit values should be reduced;
- road construction workers should be provided with heated rest area;
- observance of personal hygiene;
- regular maintenance or replacement of individual protection means;
- education of workers on harmful dust impact upon body, dust reduction measures;
- regular dust concentration control in the working environment;
- regular maintenance of technical facilities and equipment;
- sending employees to mandatory health checks.

European risk prevention approach:

- avoiding risk factors;
- assessing those risk factors that cannot be avoided;
- eliminating risk possibility in the very beginning;
- adjusting work conditions individually;
- adjusting work conditions to technical progress;
- substituting hazardous risk factors for hazard-excluding or less hazardous risk factors;
- developing a comprehensive risk prevention policy;
- assigning priority to collective protection measures over individual protection measures;
- providing employees with respective instructions, training.

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