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Research article

INTEGRATED MODEL OF HEALTH RISK ASSESSMENT FOR WORKERS HAVING TO WORK OUTDOORS UNDER EXPOSURE TO COOLING METEOROLOGICAL FACTORS

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Natural resources extraction involves continuous exposure to cooling meteorological factors typical for open production grounds. This necessitates relevant health risk assessment and management of health risks caused by exposure to these harmful occupational factors. However, the available risk assessment models do not provide a possibility to perform complete assessment of the existing risks created by exposure to meteorological hazards.

The study design included the following. We performed hygienic assessment of working conditions and health of workers employed by "Samotlorneftegaz" Joint Stock Company (JSC) who had to perform their work tasks under exposure to cooling meteorological factors on open production grounds; the assessment involved calculating the group health risk. Individual peculiarities were assessed using subjective (547 people took part in questioning) and objective assessment methods (76 people took part in estimating thermal state of their bodies and 54 people participated in thermometry with cold stress). Finally, we assessed prior and posterior risks.

The prior group risk assessment made it possible to identify risk groups who had a significant risk of developing occupational and non-occupational diseases and to rank working places as per health hazards. The posterior risk assessment confirmed the results produced by the prior risk assessment regarding potentiating negative effects produced by cooling meteorological factors. The assessment of developing general and local thermoregulation disorders revealed that certain individual peculiarities made a substantial contribution to their development. Among them, we can mention long-term outdoor work (60 % of work time or more) under exposure to cooling meteorological factors; a chronic pathology; tobacco smoking. The results produced by this study allowed us to suggest an integrated model for risk assessment, management and communication about health risks caused by working under exposure to cooling meteorological factors.

Keywords: *outdoor work, oil production, cooling meteorological factors, health risk assessment, prior risk, posterior risk, individual peculiarities in outdoor work.*

In the Russian Federation, 69.7 % of all the regions are completely or partially located in areas with arctic climate and climate that is considered just as harsh [1].

Almost 80 % of all natural resources in the country (more than 90 % of natural gas and 75 % of oil) are concentrated in the northern regions [2, 3]; naturally, such global companies as PJSC Rosneft Oil Company and PJSC Gazprom have large production complexes there.

Although technological processes applied in oil production have never ceased to develop,

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health risks for workers employed in the industry remain rather high [4, 5, 6–9].

Technological processes at oil production enterprises involve spending a lot of time outdoors since workers have to cover long distances during a work shift moving from one place to another. Several authors mention a possibility that working conditions might deteriorate due to indirect effects produced by cooling microclimate and resulting changes in intensity of impacts exerted by some other harmful occupational factors on workers' bodies [10–15]. Complex exposure to adverse and (or) hazardous occupational factors as well as to adverse climatic conditions creates high occupational risks[1]. Therefore, it is vital to assess and manage health risks for workers who are exposed to cold at their workplaces [16].

There is no available procedure for assigning working conditions into a specific hazard category as per exposure to cooling microclimate on open grounds [17]. This creates certain difficulties for performing hygienic assessment of working conditions and health risk assessment as well as for accomplishing preventive activities aimed at mitigating this risk factor.

The existing risk assessment models mostly concentrate on meteorological parameters when it comes down to exposure to cooling meteorological factors [18–20]. However, they do not provide a possibility to assess the existing risk integrally, including its aspects related to work record, working process peculiarities, and individual reactions to cold.

Our research goal was to develop an integrated model of health risk assessment for workers who have to work outdoors under exposure to cooling meteorological factors.

Materials and methods. Our study concentrated on health and working conditions of workers employed at an oil production facility. It was conducted at the following production grounds belonging to Samotlorneftegaz Joints Stock Company (JSC): the oil treatment and pumping workshops No. 1 and 2 (OTPW No. 1 and 2); the oil treatment and deposit workshops No. 1 and 2 (OTDW No. 1 and 2); and the environmental recovery workshop (ERW). Several occupational groups participated in the study including operators of the dehydrating and desalting unit (DDU operators); compressor unit operators (CU operators); operators dealing with units for pumping working substance into a bed (PWSB operators); repairmen [21].

Climate on the analyzed territory is harsh with the overall cold season lasting up to 270 days. The region is located in the climatic zone II (III) with average winter temperature being -18 °C.

Hygienic assessment of working conditions was based on the results produced by production control (PC) and special assessment of working conditions (SAWC) for the period from 2014 to 2018.

Microclimate at workplaces was assessed in accordance with the Guidilines R 2.2.2006-05[2]. The equivalent temperature was determined as per data obtained by daily monitoring of air temperature and velocity that was performed by the information and analytical system (IAS) of the enterprise.

Prior health risk caused by exposure to occupational noise, whole-body vibration, chemicals in workplace air, work heaviness and cooling microclimate on open grounds in the cold season [21] was assessed as per the previously developed models[3].

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The prevalence of various pathologies among workers was analyzed as per results produced by periodical medical examinations (PME). Overall, 1063 workers participated in them [5]. To detect any statistical differences in workers' health, we created two study groups made of workers who spent the shortest period per week outdoors and the longest one [5]. Overall, group I included 616 workers with the following occupations: DDU operators (192 people), repairmen (80 people) and process unit operators (344 people). They had to perform their work tasks on open grounds for a period from 10.5 to 14.0 hours a week, that is, up to 35 % of the total working time. Group II was made up of 447 workers including DDU operators (128 people) and repairmen (319 people) who spent from 24 to 31 hours a week working on open grounds, that is, 60 % of their total working time or even more.

Posterior risk was assessed in accordance with the guide[4]. We chose 95 % confidence interval as a statistical reliability measure ($p < 0.05$).

Individual peculiarities related to working on open grounds were assessed using subjective (547 people took part in questioning) and objective assessment methods (76 people took part in estimating thermal state of their bodies[5] and 54 people participated in thermometry with cold stress[6]).

We questioned the workers using our own original questionnaire. It contained 35 questions about working conditions, occupation, work record, health, lifestyle, and some other factors.

Thermal state of workers' bodies was estimated in normal conditions, 2 hours prior to working under exposure to cold and 2 hours after it. We used the following direct indicators to describe thermal state: body and skin temperature, self-feeling of being warm or cold, and heat content. Body temperature was taken in the axillary crease; skin temperature, on five different spots on a worker's body surface. Overall, we took more than 1000 measurements [21].

Local thermoregulation disorders with cold stress were estimated in a specially allotted warm room at the studied enterprise prior to starting work in cold outdoor conditions. An examined participant spent 10 minutes in sedentary posture to provide thermal adaptation; then, according to the procedure, a worker had to submerge his hands into cold water and keep them there until local discomfort occurred. Then, the temperature was measured in dynamics during 25 minutes until it reached its initial level.

All the results were statistically analyzed with MS Excel 2010 and Statistica 10 applied software packages.

Results and discussion. We calculated prior health risks caused by exposure to major harmful occupational factors, work record at selected workplaces being taken into account [5, 21, 22]. The results are provided in Table 1.

Occupational noise was the leading health risk factor at most workplaces. Cooling microclimate on open grounds was also identified as a leading health risk factor at certain workplaces, including PWSB operators of KNS-6 (group pumping station) at the OTPW No. 1 and repairmen dealing with DNS-4 (booster pump station) and KNS-6 at the ERW [21].

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Table 1

Prior health risks for workers with different work record of work under exposure to harmful occupational factors

Work record, years	Prior risk					
	Noise	Microclimate in cold season	Whole-body vibration	Work heaviness	Chemical factor, non-carcinogenic risk	Total risk
DDU and DNS-1 operators at the OTPW No. 1						
10	*0.133*	0.02	≤0.02	≤0.02	0.000453	*0.151*
15	**0.162**	0.02	≤0.02	≤0.02	0.00053	**0.179**
20	**0.184**	*0.05*	≤0.02	≤0.02	0.00059	**0.225**
25	**0.203**	*0.10*	≤0.02	0.02	0.00063	**0.297**
30	**0.218**	**0.16**	≤0.02	*0.05*	0.00067	**0.376**
DDU operators of CRP at the OTDW No. 1						
10	**0.184**	0.02	≤0.02	≤0.02	0.00023	**0.201**
15	**0.219**	0.02	≤0.02	≤0.02	0.00027	**0.235**
20	**0.245**	*0.05*	≤0.02	≤0.02	0.00030	**0.283**
25	**0.267**	*0.10*	≤0.02	0.02	0.00032	**0.354**
30	**0.286**	**0.16**	≤0.02	*0.05*	0.00034	**0.430**
PWSB operators of KNS-1E at the OTPW No. 1						
10	*0.093*	0.02	≤0.02	≤0.02	0.000347	*0.111*
15	*0.116*	0.02	≤0.02	≤0.02	0.000409	*0.134*
20	*0.134*	*0.05*	≤0.02	≤0.02	0.00045	**0.178**
25	*0.149*	*0.10*	0.02	≤0.02	0.00049	**0.250**
30	**0.162**	**0.16**	*0.05*	≤0.02	0.00051	**0.332**
PWSB operators of KNS-6 at the OTPW No. 1						
10	*0.055*	0.02	≤0.02	≤0.02	0.000043	*0.074*
15	*0.069*	0.02	≤0.02	≤0.02	0.000051	*0.088*
20	*0.082*	*0.05*	≤0.02	≤0.02	0.000056	*0.128*
25	*0.093*	*0.10*	≤0.02	≤0.02	0.00006	**0.184**
30	*0.102*	**0.16**	≤0.02	≤0.02	0.00006	**0.246**
TAKAT-1,2,3 vacuum compressor operators at the OTDW No. 1						
10	*0.119*	0.02	≤0.02	≤0.02	0.000233	*0.137*
15	*0.145*	0.02	≤0.02	≤0.02	0.00027	**0.162**
20	**0.166**	*0.05*	≤0.02	≤0.02	0.00030	**0.208**
25	**0.184**	*0.10*	0.02	≤0.02	0.00032	**0.281**
30	**0.199**	**0.16**	*0.05*	≤0.02	0.00034	**0.361**
VKS-28 vacuum compressor operators at the OTPW No. 2						
10	**0.166**	0.02	≤0.02	≤0.02	0.00035	**0.183**
15	**0.199**	0.02	≤0.02	≤0.02	0.00041	**0.215**
20	**0.223**	*0.05*	≤0.02	≤0.02	0.00045	**0.262**
25	**0.245**	*0.10*	≤0.02	≤0.02	0.00049	**0.321**
30	**0.262**	**0.16**	≤0.02	≤0.02	0.00051	**0.380**
Repairmen of DNS-4 and KSP-6 at the ERW						
10	*0.055*	0.02	≤0.02	≤0.02	0.01473	*0.088*
15	*0.069*	0.02	≤0.02	≤0.02	0.01488	*0.101*
20	*0.082*	*0.05*	≤0.02	≤0.02	0.01499	*0.141*
25	*0.093*	*0.10*	≤0.02	0.02	0.01507	**0.212**
30	*0.103*	**0.16**	≤0.02	*0.05*	0.01514	**0.295**

Note: health risk rates that correspond to significant risk of occupational diseases ($Risk_{OD} \geq 0.16$) are given in bold; moderate risk rates that correspond to significant risk of non-occupational diseases ($Risk_{OD} \geq 0.05$ and < 0.16) are given in italics.

It is obvious that different occupational factors make different contributions to the total risk; these contributions can be either significant or insignificant for occupational diseases occurrence depending on a workplace. Significant total risk rates for occupational diseases occurrence (more than 16 %) were detected for workers with work record being 10 years who worked as DDU operators at the central reservoir park (CRP) grounds in the oil treatment and deposit workshop No. 1 and vacuum compressor unit (VKS-28) operators in the OTPW No. 2. Significant total risk was established for those workers with work record being 15 years who worked as DDU operators of the booster pump station (DNS-1) in the OTPW No. 2 and TAKAT-1,2,3 vacuum compressor operators in the OTDW No. 1. Workers with their work record being 20 years had significant total risk at workplaces of PWSB operators at the group pumping station (KNS-1E) in the OTPW No. 2. Those with work record being 25 years had this level of risk at workplaces of PWSB operators at the group pumping station KNS-6 in the OTPW No. 1 and repairmen at the booster pumping station DNS-4 and group pumping station KSP-6 in the environmental recovery workshop (ERV) [21].

Exposure to cooling microclimate makes a substantial contribution to occupational and non-occupational incidence among workers [5]. This contribution made by cooling meteorological factors to the total health risk varied depending on work record and a workplace. It was insignificant during the 1st year of working and rose to 65.1 % when work record reached 30 years. When work record was equal to 5 years, the contribution made by cooling meteorological factors varied from 13.3 % for DDU operators at the central reservoir park (CRP) grounds in the oil treatment and deposit workshop No. 1 to 37 % for PWSB operators at the group pumping station KNS-6 in the OTPW No.1. When work record reached 30 years, the contribution made by cooling meteorological factors to the total risk rose to its maximum and varied from 37.2 % for DDU operators at the CRP grounds in the OTDW No. 1 to 65.1 % for PWSB operators at the KNS-6 in the OTPW No. 1 (Table 2).

Table 2

Contributions made by cooling meteorological factors to the total health risks at the examined workplaces depending on work record

Occupational group	Workplace	Work record significant for OD occurrence* (years)	Contribution made by cooling meteorological factors to risks of somatic and occupational diseases (%)					
			Work record (years)					
			5	10	15	20	25	30
DDU operators	DNS-1 OTPW No. 2 (*n* = 10)	15	18.0	13.3	11.2	22.2	33.6	42.5
	CRP OTDW No. 1 (*n* = 24)	10	13.3	10.0	8.5	17.7	28.3	37.2
PWSB operators	KNS-6 OTPW No. 1 (*n* = 7)	25	37.0	27.0	22.7	39.1	54.4	65.1
	KNS-1E OTPW No. 2 (*n* = 3)	20	24.7	18.0	14.9	28.1	40.0	48.2
CU operators	TAKAT-1,2,3 VCU OTPW No. 1 (*n* = 4)	15	19.8	14.6	12.3	24.0	35.6	44.3
	VKS-28 OTPW No. 2 (*n* = 4)	10	14.7	10.9	9.3	19.1	31.2	42.1
Repairmen	DNS-4 ERW (*n* = 52)	25	29.4	22.7	19.8	35.5	47.2	54.2
	KSP-6 ERW (*n* = 51)	25	29.4	22.7	19.8	35.5	47.2	54.2

Note: * OD means occupational diseases.

The research involved using the health risk assessment procedure. According to it, we applied models for assessing prior group health risk that helped us determine contributions made by specific factors into the total risk. A time study performed at workplaces was a vital stage in hazard identification. This study was performed at workplaces where workers had to deal with various work tasks during their work shift and an amount of time spent working on open grounds was of fundamental importance for health outcomes in a whole number of cases. Thus, it was reported that workers who performed their work tasks on open grounds for 60 % of their working time or even longer had a high risk of a developing chronic pathology [21].

Posterior risk assessment revealed that exposure to harmful occupational factors combined with cooling meteorological factors had a direct correlation with morbidity since RR was higher than 1 for priority categories of diseases, both on average and as per its upper and bottom limits [22].

Since etiological fractions were higher than 50 % as per these categories of diseases, we can conclude there is a strong correlation here. Therefore, diseases of the circulatory system (RR = 2.87, CI: 2.36–3.48, $p < 0.001$), diseases of the ear and mastoid process (RR = 2.49, CI: 1.85–3.36, $p < 0.001$), diseases of the nervous system (RR = 5.12, CI: 3.21–8.16, $p < 0.001$), diseases of the musculoskeletal system (RR = 3.18, CI: 2.46–4.09, $p < 0.001$), diseases of the digestive system (RR = 3.35, CI: 2.04–5.48, $p < 0.001$) and diseases of the respiratory system (RR = 4.9, CI: 2.64–9.25, $p < 0.001$) can be considered occupational and associated with long periods spent by workers on open grounds under exposure to cold (Table 3) [21].

The next stage in our research involved assessing individual peculiarities based on the questioning results as well as the results produced by field and model tests.

Thermal regulation disorders were assessed subjectively and objectively in workers who were exposed to cooling meteorological factors at their workplaces. As a result, we determined what individual peculiarities made for developing local and overall thermal regulation disorders. They were a long period spent working outdoors, for 60 % of the total working time or even longer (RR = 3.0; CI: 1.20–7.45; $p = 0.017$); chronic pathology including diseases of the circulatory system (RR = 1.46; CI: 1.30–1.63; $p < 0.0001$), diseases of the ear and mastoid process (RR = 1.33; CI: 1.20–1.47; $p < 0.0001$), endocrine, nutritional and metabolic

Table 3

Posterior health risks for workers who spend the longest time on open grounds

№	Category of diseases as per ICD-10	Relative risk (RR) (95 % confidence interval (CI))	Sensitivity, %	Specificity, %	Etiological fraction EF, %	Statistic indicators
1	Diseases of the circulatory system	2.87 (2.36–3.48)	67.6	69.6	65.2	χ^2 = 129.56; **p < 0.001**
2	Diseases of the ear and mastoid process	2.49 (1.85–3.36)	64.4	62.0	59.8	χ^2 = 39.52; **p < 0.001**
3	Diseases of the digestive system	3.35 (2.04–5.48)	70.8	60.0	70.1	χ^2 = 26.26; **p < 0.001**
4	Diseases of the nervous system	5.12 (3.21–8.16)	78.8	61.7	80.5	χ^2 = 60.46; **p < 0.001**
5	Diseases of the musculoskeletal system	3.18 (2.46–4.09)	69.7	65.5	68.5	χ^2 = 91.30; **p < 0.001**
6	Diseases of the respiratory system	4.90 (2.64–9.25)	78.2	59.9	79.6	χ^2 = 31.07; **p < 0.001**

Table 4

Risks of developing local and overall thermal regulation disorders for workers with individual peculiarities who have to work on open grounds during the cold season

№	Individual peculiarities	Relative risk (RR), 95 % confidence interval (CI), significance level (p)	
		Local thermal regulation disorders	Overall thermal regulation disorders
1	Tobacco smoking	2.69 (1.23–5.88) $p = 0.007$	1.13 (1.02–1.27) $p = 0.0378$
A	Smoking intensity from 11 to 20 cigarettes a day	4.17 (1.33–13.04) $p = 0.005$	$p > 0.05$
B	Smoking for more than 20 years	$p > 0.05$	1.23 (1.05–1.43) $p = 0.043$
2	Health disorders		
A	Diseases of the circulatory system	1.88 (1.43–2.46) $p < 0.0001$	1.46 (1.30–1.63) $p < 0.0001$
B	Diseases of the ear and mastoid process	$p > 0.05$	1.33 (1.20–1.47) $p < 0.0001$
C	Diseases of the musculoskeletal system and connective tissue	1.61 (1.25–2.13) $p = 0.0008$	1.35 (1.22–1.48) $p < 0.0001$
D	Endocrine, nutritional and metabolic diseases	2.19 (1.62–2.96) $p = 0.0001$	1.31 (1.16–1.48) $p = 0.015$
E	Diseases of the nervous system	1.57 (1.19–2.07) $p = 0.003$	$p > 0.05$
3	24.0–31.0 hours per 40-hour working week spent working outdoors (60 % of the total working time or even longer)	1.92 (1.18–3.14) $p = 0.005$	3.0 (1.20–7.45) $p = 0.017$

diseases (RR = 1.31; CI: 1.16–1.48; $p = 0.015$), diseases of the musculoskeletal system (RR = 1.35; CI: 1.22–1.48; $p < 0.0001$), diseases of the nervous system (RR = 1.57; CI: 1.19–2.07; $p = 0.003$); and tobacco smoking (RR = 1.13; CI: 1.02–1.27; $p = 0.0378$) (Table 4).

All these individual peculiarities were determined for workers employed at the studied enterprise who have to work on open grounds in the cold season.

The results produced by this personified assessment of thermal regulation disorders in workers necessitate considering individual peculiarities within health risk assessment and give an opportunity to develop targeted medical and preventive activities for this category of workers.

The research accomplished successfully, we were able to suggest an integrated model for risk assessment, risk management and information about health risks associated with working on open grounds in the cold season. The model considers the results produced by assessing group occupational risks and individual peculiarities of a worker (Figure).

Conclusions:

1. Quantitative prior risk assessment gave an opportunity to identify workers' groups with a significant risk of developing occupational and non-occupational diseases. It also allowed ranking workplaces as per "health hazards" and developing preventive activities aimed at reducing negative effects produced on workers' health by cooling microclimate on open production grounds, harmful occupational factors as well as factors related to work process.

2. Posterior risk assessment confirmed the results produced by prior risk assessment regarding potentiating negative effects produced by cooling meteorological factors combined

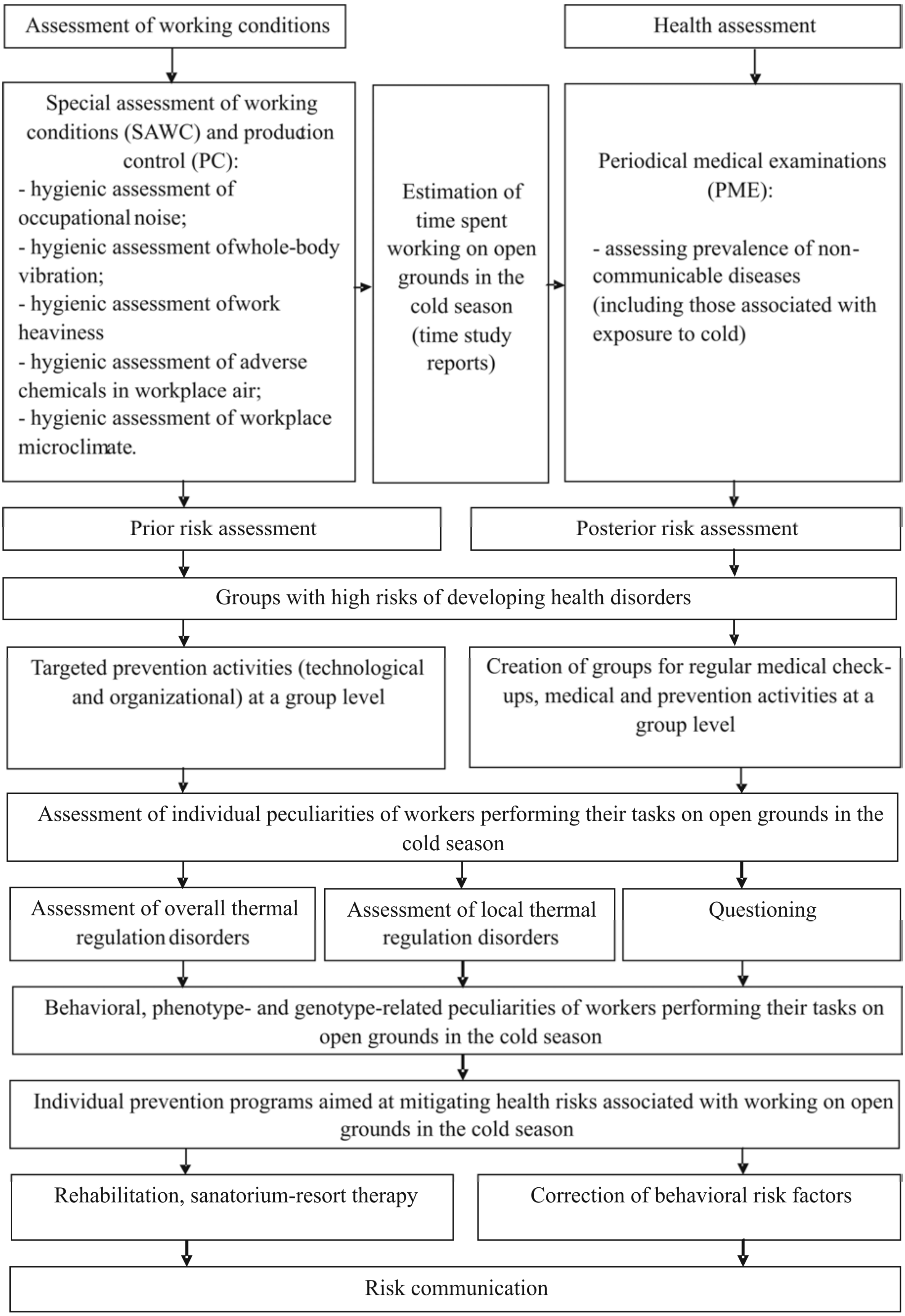

Figure. The model for risk assessment, management and communication regarding health risks associated with working on open grounds during the cold season with harmful occupational factors on health of workers from specific occupational groups who have to spend more than 60 % of their total working time on open grounds.

3. Identified individual peculiarities necessitate considering them within health risk assessment and make it possible to develop targeted personified medical and preventive activities for these occupational groups.

4. We have developed and suggested an integral model for risk assessment, risk management and communication about health risks for workers who have to work on open grounds under exposure to cooling meteorological factors. This model gave grounds for developing targeted (primary and secondary) prevention activities aimed at mitigating risks and communication about them. These activities included technological and administrative measures to reduce risks and to shorten exposure duration; use of personal protective equipment; correction of behavioral risk factors; organization of preliminary and periodical medical examinations, regular medical check-ups and health-improving rehabilitation programs.

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