HSE in the Arctic: Forecasting of emergency situations at oil and gas facilities and emergency petroleum products’ spill response in Arctic climatic conditions


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INTRODUCTION

The Arctic contains a huge amount of undeveloped energy resources – oil and gas. At the same time, the extraction of natural resources in the Arctic is extremely difficult and dangerous regarding the environment. In a harsh climate, the probability of accidents increases. The possibility of oil spill response, as well as its performance, are complicated by extremely climatic conditions.

Anticyclonic circulation develops in winter season in the Siberian part of the Arctic. These areas are characterized by very low temperatures, few clouds, small amount of precipitation and weak or moderate winds. Average temperatures of the coldest winter month (January) fall to minus 45–50°C. Minimum temperatures in these areas sometimes push mercury to minus 55–60°C. Because of strong surface cooling, inversions of air temperature are permanent in these areas [2].

For the elements of technical systems operated in the North, the determining external factor is the low air temperatures, which degrade the basic physical and mechanical properties of structural materials, increase their tendency to brittle fracture as a potential source of possible accidents [11]. Uncontrolled development of emergency situations at oil and gas facilities can lead to significant destructions and loss of life.

Methodology of risk analysis

Risk analysis is one of the essential components of safety and is carried out to identify individual sources of hazards and to assess their potential impact on possible damage that can be incurred to the population, the environment and economic facilities [1].

The accident risk analysis procedure consists of the following steps [6]:

1. hazards identification
2. risk assessment
3. development of risk management recommendations.

The hazards identification is a crucial stage of risk analysis, as the hazards not identified at this stage are not subject to further consideration and disappear from the field of view. Here, a preliminary assessment of the hazards shall be performed to select the future direction of activity:

- stop further analysis due to the negligible hazards
- conduct a more detailed risk analysis
- develop recommendations to reduce hazards.

If necessary, after the identification of hazards, the analysis proceeds to the stage of risk assessment. Risk assessment includes frequency analysis, impact analysis and combinations thereof. Risk assessment is the stage at which identified hazards should be assessed based on acceptable risk criteria to identify hazards with unacceptable risk, and this step will serve as the basis for the development of recommendations and measures to mitigate hazards.

Proposals for the implementation of hazards-mitigating measures are aimed at:

- reducing the probability of an accident
- reducing the scale and direction of the physical fields oscillation as a result of the accident impact in the surrounding area
- reducing the disaster scale.

Analysis of accidents with brittle fracture of tanks in the Arctic climate conditions

The Arctic zone of the Russian Federation represents 18% of the country’s territory – 3.1 million km²; it includes entirely or partly the territories of nine constituent entities of the Federation. The Republic of Sakha (Yakutia) demonstrates in the most consistent manner the intrinsic climatic factors of the Arctic areas. Its territory is one fifth of the territory of Russia, with 40% of its area beyond the Arctic circle; and the “cold pole” of the Northern hemisphere is located in the area of Oymyakon – Verkhoyansk, where the winter temperatures push mercury to minus 70°C. At the same time, almost the entire territory of the Republic is in the permafrost zone, the depth of which in places reaches 500 m or more [13].

Based on the analysis of tank failures that occurred at low temperatures in the Republic of Sakha (Yakutia) from 1979 to 2014, the main causes of brittle fracture were identified and a “failure tree” of brittle fracture in tanks was drafted [7] (Fig. 1).

The distribution of the main causes of brittle fracture in tanks at low temperatures is as follows: the use of BCSหลว rimmed steel amounts to 6.25% of the total number of causes of accidents, through cracks – 31.25%, non-uniform subsidence of tanks foundations – 18.75%, embrittlement of the material of the tank due to low temperatures – 31.25%, the external mechanical impacts – 6.25%, the metal ageing – 6.25%.

Analysis of the tanks failures at low temperatures indicates that the brittle fracture occurs only when the following factors are combined: the presence of defects, the occurrence of additional stresses and degradation of fracture toughness of the material.

According to the results of the analysis of statistical data on accidents, the frequency of brittle fracture in tanks at extremely low temperatures is 1.0·10⁻⁴ year⁻¹, at positive temperatures – 5·10⁻⁸ year⁻¹. The results of comparing the frequency of tanks failures that occurred at negative and positive temperatures revealed that the failures frequency at negative temperatures is an order of magnitude higher than at positive temperatures.

This is primarily due to the embrittlement of materials at low temperatures. Also, seasonal freezing and thawing of the soil has a significant impact, which leads to deformation of the tanks structural elements, resulting in additional stresses in the components.

Failures with the brittle fracture of tanks are accompanied
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ABSTRACT

The paper presents the results of the analysis and the risk assessment of the accidents at tanks and gas pipelines operating in the North, and the results of the study of a biological product for oil spills cleanup, produced from indigenous microorganisms – oil degraders recovered from Arctic permafrost soils.

Key words: Arctic zone, low temperatures, temperature inversion, equipment failures, accidents frequency, accidents scenarios, individual fire risk, pollution by petroleum products, petroleum products cleanup, degradation, microorganisms.

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Failures with the brittle fracture of tanks are accompanied

![Figure 1. The "failure tree" of brittle fracture in tanks at low temperatures](image-url)
by the release of a significant amount of petroleum products that pose a serious environmental risk.

**Oil spills cleanup technology in Arctic conditions**

A specific feature of the Arctic regions is the presence of permafrost. During spills, oil penetrates deep into the thawing zone and continues to spread laterally over this zone, undergoing a very slow transformation [5].

Due to natural and climatic conditions, permafrost soils of the Arctic are characterized by weak resistance to oil pollution. Low self-recovery potential in the conditions of short vegetation period and low temperatures necessitates the environmental studies aimed at finding technologies for oil spills cleanup that enable to achieve the maximum possible recovery of natural communities of disturbed lands [13].

The duration of the soil self-recovery at the average level of oil pollution in the North is estimated by various researchers by the period of 10 to 15 years [10].

The solution to the problem of disturbed ecosystems rehabilitation shall be based on an integrated approach with environmental monitoring of pollution of water basins, soils, bottom sediments, the development on its basis of integrated rehabilitation technologies and control of their performance and quality of treatment.

On the territory of one of the tank farms located in the Arctic zone of Yakutia, tests were conducted of a biological method of oil-polluted soil cleanup in the Arctic and one pad – reference (without treatment). The performance of the biological product previously recovered from oil-polluted soils of the study area, zones, two of which were treated with a biological product for this purpose, three experimental pads were arranged in polluted zones, and tests were conducted of a biological product (Fig. 2).

Prior to soils treatment with biological product, three integrated soil samples from different pads and one baseline sample at the boundary of the tank farm were taken. It was found that the level of pollution of the initial samples (before cleanup) was very high. The PP content ranged from 34594 to 81 880 mg/kg (Table 1). All samples are characterized as oil-polluted with various long-standing times that are confirmed by the IR-spectra of oil (1) and extracts of samples with fresh pollution (2), old pollution (3) and baseline soil (4).

During the experiment, the composition of the soil extract from the reference pad (without treatment) has not changed, which can be explained by the slow processes of natural degradation of oil in the Arctic.

During the experiment, the composition of the soil extract after cleanup compared with the initial samples (Fig. 4).

Information on oil pollution transformation as affected by biological product is also carried by the data of the group component composition. It was found that in three months of the experiment after soil treatment, the number of hydrocarbon components in soil extracts decreased and the number of resins and asphaltenes increased (Table 2, Fig. 5).

According to the chromatoo-mass spectrometry, changes in the hydrocarbon composition were found in the process of pollution degradation, accompanied by redistribution of hydrocarbons both within the homologous series and between different series of homologues (Fig. 6, Table 2). Changes are expressed by decrease in the content of alkanes of normal structure and by increase in the content of isokanes (isoprenoids/n-alkanes). Three months after soil treatment with biological product, the proportion of relatively low-molecular weight n-alkanes decreased, and the proportion of high-molecular weight n-alkanes increased. 

The content of hydrocarbon compounds extracts in the soil were conducted.

**Table 1.** PP content in the soils of experimental pads.

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<td>27 880</td>
</tr>
<tr>
<td>Reference</td>
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<td>65 054</td>
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<tr>
<td>Baseline</td>
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It contains a significant number of aromatic hydrocarbons (appearance of 750, 810 and 1600 cm⁻¹ absorption bands in the spectrum), which can be considered as traces of oil pollution (Fig. 3, spectrum 4). Typically, such a composition of baseline samples is found in the territories of man-made facilities, such as tank farms, stockyards of fuels and lubricants, oil storage facilities.

Three months after the soil treatment with the biological product, the samples were re-taken. The reduction of PP residual content for this period was established (Table 1) except for reference pad (without treatment). The degree of oil pollution destruction was 57–65%.

Changes in the chemical structure of the extracts after cleanup indicate the processes of oil pollution degradation. This is evidenced by the increase in the relative absorption coefficient of carbonyl groups R1700 in the samples after cleanup compared with the initial samples (Fig. 4).

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On the territory of one of the tank farms located in the Arctic zone of Yakutia, tests were conducted of a biological method for cleaning oil-polluted lands in natural conditions. For this purpose, three experimental pads were arranged in polluted zones, two of which were treated with a biological product based on indigenous hydrocarbon-oxidizing microorganisms previously recovered from oil-polluted soils of the study area, and one pad – reference (without treatment). The performance of the biological method of oil-polluted soil cleanup in the Arctic will depend on the level and composition of pollution, as well as on the activity of the biological product and its application technology. The processes of oil pollution destruction were studied using the results of a comparative study in the chemical composition of soil samples before and after cleanup. One shall particularly note that only at detecting improvement changes in the composition of pollution, a positive conclusion be made about the biological product performance and the possibility of its use in the Arctic territories.

The study used various R&D methods: chloroform extraction, infrared (IR) Fourier transform spectroscopy to determine the structural-group composition of soil extracts, liquid-adsorption chromatography for the group compositional analysis and chromatography-mass spectrometry for the study of individual composition of saturated hydrocarbons (HC) [15].

The territory of the tank farm is represented mainly by the soils with backfilled gleyic and gravel earth. The traces of fresh spills of petroleum products (PP – diesel fuel, and "old" oxidized oil pollutions are visible in the experimental pads (Fig. 2).

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The assessment of the performance of the developed biological products shall be based on the result of their use – the chemical composition of the extract obtained should be close to the analytical indicators characterizing the baseline situation. All noted changes in the composition of soil extracts indicate the ongoing degradation processes of oil pollution. At the same time, the level of pollution remains high, and the entire picture of individual hydrocarbons distribution, as well as of the structural-group and group composition of extracts components has not yet attained the parameters of baseline soils. This indicates the need for re-treatment of soils with a biological product and further monitoring of the tank farm territory.
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Table 1. PP content in the soils of experimental pads.

![Image](attachment:image1.png)

Figure 2. Oil-polluted pad, where experiments on biological cleanup of the soil were conducted.

![Image](attachment:image2.png)

Figure 3. IR-spectra of oil (1) and extracts of samples with fresh pollution (2), old pollution (3) and baseline soil (4).
The results of the tests show that the biological product produced from indigenous microorganisms – oil destructors recovered from Arctic permafrost soils and grown on special contaminated substrates has a high activity to oil pollution. It can be recommended for use in situ biological treatment (directly on the spot, without moving the soil layer) of soils in the Arctic. This cleanup method is environmentally safe, cost-effective; it can be used for continuous treatment of “chronic” pollutions and use in hard-to-reach places.

Assessment of individual risk of tanks explosion failures in the Arctic

The main hazard of tanks, leading to catastrophic consequences with high material damage and loss of life, is associated with the possibility of explosion and fire. According to the results of analysis and systematization of data on tanks failures with petroleum products at low temperatures, a “tree of events” of tank explosions was drafted (Fig. 7) [8].

Let’s consider the most hazardous scenario 4 (Fig. 7). The conditional probability of this scenario is defined as the product of the conditional probabilities of the following events: explosion in the gas space in the tank, fire, destruction of the tank with a probability \( P_1 \) → formation of the burning dynamic outbreak, dike destruction, spreading of burning petroleum product across the territory of the facility \( P_2 \) → hitting the adjacent tanks \( P_3 \). The frequency of the most hazardous scenario 4 is 1.35·10⁻⁵ year⁻¹.

According to the drafted “tree of events” in the tanks’ explosion, let’s assess the individual risk in the implementation of scenario 4. Individual risk in the area of open flame in case of escalating the most hazardous scenario 4 will be 1.35·10⁻⁷ year⁻¹. The fire risk for personnel is accepted as complete acceptable if the individual risk is less than 10⁻⁶ year⁻¹, and as complete unacceptable if the individual risk is more than 10⁻⁴ year⁻¹. If the individual risk is in the range from 10⁻⁶ to 10⁻⁴ year⁻¹, it is assumed that the fire risk is in the zone of strict risk control [15]. In this zone, the risk is considered acceptable only when measures are taken to reduce it as much as practical.

Risk assessment of gas pipeline accidents in the Arctic climatic zone

Gas pipelines are the facilities of increased hazard due to the presence of many welded and flanged joints, shut-off and control valves. In addition, they operate continuously at high internal pressures and provide the movement of significant amounts of fluids throughout their service life. Even a slight deviation from the design operating conditions can lead to an accident. Therefore, it is very important to analyze the risks of gas pipelines, especially at low air temperatures, which significantly complicate the operation of the gas pipeline both in terms of maintaining the process conditions for gas transportation, and in terms of monitoring the condition of the line part to prevent emergency depressurization of the pipeline.

According to the analysis of gas pipelines accidents at low temperatures, their main causes and occurrence probabilities \( P \) are identified: crack in the pipeline \( P = 0.09 \), corrosion \( P = 0.27 \), wear of the pipe \( P = 0.18 \), deformation of the pipe as a result of metal fatigue and temperature drop \( P = 0.09 \) for each, shut-off valve failure, ball valve failure, depressurization of the joint between the insulating flange connection and the flange of the supply pipeline \( P = 0.14 \), damage to the pipe \( P = 0.14 \) [12].

The accident escalation is determined by the peculiarity of the gas pipeline failure, which is characterized by three stages: the defect nucleation (its propagation to the entire thickness of the pipe wall), the rapid propagation of the through crack along the pipe wall, braking and stopping the fracture (crack). The condition for the beginning of an avalanche-like extended rupture of the pipeline wall at the design pressure (the stress in the pipe body is obviously below the yield strength of the steel used) is the presence of a critical through defect (crack) [16].

The major parameter that determines the development of the main cracks is the impact toughness of the pipe metal, with a decrease in which the mechanism of crack propagation transits from ductile to brittle. The analysis of accidents in gas pipelines at low temperatures has revealed the presence of sudden brittle fracture, i.e. instantaneous propagation of the main crack at maximum equivalent stresses below the yield strength of the material.

The analysis of structural failures at low temperatures and the dependence of impact toughness on temperature has showed that the resistance to brittle fracture at so called critical temperatures decreases sharply (the impact toughness of structural low-carbon steels decreases 2–10 times) [11]. For structural elements, the critical ductile-brittle transition temperature is defined experimentally using standard samples, considering the shift of the first \( T_{cr1} \) and second \( T_{cr2} \) critical temperatures under the effect of design and technological factors (3, 11, 14):

\[
T_{cr1} = T - \Delta T_{cr1},
\]

\[
T_{cr2} = T - \Delta T_{cr2},
\]

where \( T_{cr} \) is the first critical temperature defined using standard samples that characterizes the transition from ductile to quasi-brittle fracture. \( K_{cr1} \) is the shift of the first critical temperature under the effect of design and technological factors, \( K_{cr2} \) is the second critical temperature of the structure. \( T_{cr1} \) is the second critical temperature defined using standard samples that characterizes the transition from ductile to quasi-brittle fracture, \( K_{cr1} \) is the shift of the second critical temperature under the effect of low temperatures, \( K_{cr2} \) is the second critical temperature of the structure at low temperatures. K.

The most difficult issue is the correct calculation of the critical embrittlement temperature shift \( \Delta T_{cr} \) for structural elements, where it is necessary to consider the effect of extremely low ambient temperatures.

The scientists of the Institute of Physical-Technical Problems of the North n.a. V.P.Larionov of the Siberian branch of the Russian Academy of Sciences have developed a database of mechanical properties, inter alia fracture toughness, for a wide range of low-alloy steels used for the manufacture of pipelines operating at low temperatures [3]. To do this, they studied pipe steels: 09G2S (pipelines up to 530 mm diameter with working pressure up to 5 MPa), 16G2S AF (pipelines with average capacity), 18G2EF, 66G2MB and 09G2EF (large diameter pipelines with working pressure 7.5 MPa).

The fracture toughness factor \( K_{cr} \) characterizes the critical intensity of the stress field at the crack tip and links the ultimate stress \( \sigma_u \) with the crack critical size \( C_c \). For an infinite plate with a crack [17] this factor is determined by the formula

\[
K_{cr} = \sigma_u \sqrt{\pi l},
\]

Fig. 8 shows the critical stress intensity factor \( K_{cr} \) of 09G2S steel versus temperature \( T \) for samples with different periods of operation [3]. These dependences and equation (1) were used to determine the critical crack length \( l_c \) versus the air temperature \( T \) and the operation time \( t_o \). The results are presented in Table 3 [4].

The condition for the beginning of an avalanche-like extended rupture of the gas pipeline wall at the design pressure

\[
\frac{\sum \text{HC} \cdot \text{HC}_{\text{n-alkanes}}}{\sum \text{n-alkanes}} = 0.77
\]

\[
\sum \text{HC}_{\text{resins}} = 0.77
\]

Table 2. Comparative characteristics of the soil samples chemical composition during the oil pollution degradation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>Prior to cleanup</td>
</tr>
<tr>
<td>PP content, mg/kg</td>
<td>34 594</td>
</tr>
<tr>
<td>HC content, %</td>
<td>64.90</td>
</tr>
<tr>
<td>Resins content, %</td>
<td>15.84</td>
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<tr>
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<td>19.26</td>
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<tr>
<td>(∑s.b.p.-n)/(∑n+∑s.b.p.-n)</td>
<td>4.25</td>
</tr>
<tr>
<td>Isoprenoids/n-alkanes</td>
<td>0.79</td>
</tr>
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</tr>
<tr>
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\[
K_{cr1} = \frac{\sqrt{\sum \text{HC} \cdot \text{HC}_{\text{n-alkanes}}}}{\sum \text{n-alkanes}}
\]

\[
K_{cr2} = \frac{\sqrt{\sum \text{n-alkanes}}}{\sum \text{n-alkanes}}
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4.25 1.93

0.79 0.95

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1.70 3.76

1.63 4.04

Table 2. Comparative characteristics of the soil samples chemical composition during the oil pollution degradation
The results of the tests show that the biological product produced from indigenous microorganisms – oil destructors recovered from Arctic permafrost soils and grown on special contaminated substrates has a high activity to oil pollution. It can be recommended for use in situ biological treatment (directly on the spot, without moving the soil layer) of soils in the Arctic. This cleanup method is environmentally safe, cost-effective; it can be used for continuous treatment of “chronic” pollutions and use in hard-to-reach places.

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The accident escalation is determined by the peculiarities of the gas pipeline, especially at low air temperatures, which significantly complicate the operation of the gas pipeline both in terms of maintaining the process conditions for gas transportation, and in terms of monitoring the condition of the line part to prevent emergency depressurization of the pipeline.

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The condition for the beginning of an avalanche-like extended pipeline failure, which is characterized by three stages: the defect nucleation (its propagation to the entire thickness of the pipe body), quasi-brittle fracture, i.e. instantaneous propagation of the main crack at maximum stress intensity of the stress field at the crack tip and links the ultimate strength of the steel versus temperature \( T \) for samples with different periods of operation time [3]. To do this, they studied pipe steels: 09G2S (up to 530 mm diameter with working pressure up to 5 MPa), 16G25AF (up to 500 mm diameter with working pressure up to 10 MPa), 18G2FB, 06G2MB and 09G2FB (large diameter pipelines with working pressure 7.5 MPa).

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is the presence of a critical through defect (crack), which leads to a rupture in the entire cross-section of the pipe. At that, the most hazardous damaging factors are heat flow and pressure.

In case of gas pipelines ruptures, damages of releasable joints, malfunctions of shut-off and control valves, explosion- and fire-hazardous substance may be discharged. The volume of discharge depends on the volume of the substance in the equipment, its temperature, pressure and the size of the depressurization opening, as well as on preventive actions.

In the Siberian part of the Arctic, abnormal conditions determined by the formation of strong long-term temperature inversions in combination with windless conditions are considered at low air temperatures. These abnormal conditions make it difficult to disperse the gas in the atmosphere and lead to its accumulation to dangerous concentrations. If there is a source of ignition, the gas-air mixture can ignite, leading to an explosion [9].

The probability of accidents, developing under different scenarios, can be summarised using the “tree of events” method (Fig. 9) [8].

The conditional probability of an initiating event – a gas leak – was assumed to be equal to one. The probability of accident situations escalation was determined using statistical data of accidents in gas pipelines operated at low temperatures.

Let’s consider the most hazardous scenario 1 – a gas leak from the gas pipeline $P_1$, ignition of gas $P_2$, damage to the adjacent facilities $P_3$ and people injured $P_4$.

The frequency of the most hazardous scenario 1 $H(C_{max})$ (Fig. 9) is determined using the formula

$$H(C_{max}) = \lambda PP_{i}PP_{f}$$

where $\lambda$ – frequency of gas leak from gas pipeline at low temperatures, (km·year)$^{-1}$ [8].

Using statistical data on accidents that occurred in gas pipelines at low temperatures from 1974 to 2013, we obtained $\lambda = 3.2 \times 10^{-4}$ (km·year)$^{-1}$ [7]. The “tree of events” of gas leak from the gas pipeline enables estimating the environmental risk of atmospheric pollution with methane in the implementation of scenario 5 as the specific damage $Y$ multiplied by the mass of emergency discharge $M_E$ and the scenario 5 occurrence frequency $HPC_{5}$, [8]:

$$R_E = Y_M H C_{5}$$

In case of accidents at oil and gas facilities, the environmental risk is inevitable, but it should be reduced to a minimum and be economically justified. Any exceedance of the limits of permissible environmental risk is unacceptable.

In this regard, the activities of environmentally hazardous facilities to be suspended or measures taken to reduce the level of environmental risk to “acceptable value”. 

![Figure 6. Mass-chromatograms based on the total ion current of saturated HC. a – initial oil pollution; b – 3 months after cleanup.](image)

<table>
<thead>
<tr>
<th>$T$, K</th>
<th>$K_e$, MPa·mm$^{0.5}$</th>
<th>$l_c$, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>1581/1265</td>
<td>14.7/9.4</td>
</tr>
<tr>
<td>220</td>
<td>1897/1550</td>
<td>21.1/14.1</td>
</tr>
<tr>
<td>230</td>
<td>2550/1759</td>
<td>57.5/17.7</td>
</tr>
<tr>
<td>240</td>
<td>3162/2372</td>
<td>58.7/33.0</td>
</tr>
<tr>
<td>250</td>
<td>3953/3162</td>
<td>91.7/58.7</td>
</tr>
<tr>
<td>260</td>
<td>4743/4111</td>
<td>132/99.1</td>
</tr>
<tr>
<td>270</td>
<td>5060/4427</td>
<td>150.2/115</td>
</tr>
</tbody>
</table>

Table 3. Critical stress intensity factor $K_e$ and critical crack length $l_c$ in the pipeline operated at low temperatures for $t_e < 10$ years (numerator) and $t_e > 10$ years (denominator).
The most hazardous damaging factors are heat flow and pressure. 

Figure 7. “Tree of events” at explosion of tanks with oil products at subzero temperatures.

In case of gas pipelines ruptures, damages of releasable joints, malfunctions of shut-off and control valves, explosion- and fire-hazardous substance may be discharged. The volume of discharge depends on the volume of the substance in the equipment, its temperature, pressure and the size of the depressurization opening, as well as on preventive actions.

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$$R_5 = Y M_e H P C_5$$

In case of accidents at oil and gas facilities, the environmental risk is inevitable, but it should be reduced to a minimum and be economically justified. Any exceedance of the limits of permissible environmental risk is unacceptable. In this regard, the activities of environmentally hazardous facilities to be suspended or measures taken to reduce the level of environmental risk to “acceptable value”.

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Figure 8. “Tree of events” at explosion of tanks with oil products at subzero temperatures.
In the harsh Arctic climate, the pollution of the environment as a result of the release of a significant amount of petroleum products in accidents is a major concern.

**Conclusion**

Improving industrial safety of hazardous production facilities in the Arctic requires a comprehensive account of the impact of climatic factors specific for the area on the risk parameters. Accident risk assessment of hazardous production facilities in the Arctic zone of the Russian Federation based on acceptable risk criteria will make it possible to assess hazards of gas pipelines operation at low temperatures.

**Competing interests**

The authors declare that there is no competing interest regarding the publication of this paper.

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Conclusion

Improving industrial safety of hazardous production facilities in the Arctic requires a comprehensive account of the impact of climatic factors specific for the area on the risk parameters. Accident risk assessment of hazardous production facilities in the Arctic zone of the Russian Federation based on acceptable risk criteria will make it possible to assess hazards with an unacceptable level of risk and will serve as a basis for the development of recommendations and measures to reduce hazards in the harsh Arctic climate.

In addition, one of the environmental problems of the Arctic is the pollution of the environment as a result of the release of a significant amount of petroleum products in accidents.

International experience shows that only 10–15% of spilled oil can be collected and disposed of in the Arctic. Residual oil pollution in the permafrost zone conditions remaining for many years becomes a source of oil hydrocarbons ingress downstream the river flow into the sea and its coastal part.

Results of the tests show that the biological cleanup of soils from oil pollution using the biological products based on indigenous microorganisms – oil destructors recovered from Arctic permafrost soils is an effective, environmentally safe, cost-effective way to eliminate the consequences of accidents and rehabilitation of disturbed lands of the Arctic territories.

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