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The systemic approach, based on the risks analysis and optimization, to research variants for developing hydrocarbon deposits of Arctic regions

Keywords

analysis, Arctic regions, hydrocarbons, model, optimization, probability, quality, resources, risk, technology

Abstract

The original methodological approach based on the risks analysis and optimization is proposed to research variants for developing hydrocarbon deposits of Arctic regions. The basic analytical problems that are due to be solved by probabilistic modelling of processes are formulated. Input and otput allow to research different variants for developing hydrocarbon deposits of Arctic regions. Some effects are demonstrated by example.

1. Introduction

Considerable resources of the hydrocarbons concentrated in Arctic regions, are already confirmed by geophysical research and data of prospecting drilling. Some deposits of resources are already developed (for example on Yamal Peninsula). In this context working out of set of variants of development of deposits of hydrocarbons on various depths of Arctic ocean is expected.
Research in following directions [11] are perspective:
development of technologies of ecologically safe sea investigation and extraction of various kinds of mineral resources in extreme natural-climatic conditions of Arctic regions;
development of technologies of complex safety of works on a continental shelf, including monitoring and forecasting of extreme situations of natural and technogenic character;
the prevention and liquidation of emergency floods of oil, first of all in ice conditions, including creation of technologies for detection of oil under ice;
development of technologies complex hydro-meteorological and ecological monitoring of the dangerous natural phenomena in Arctic regions;
development of technologies of remote sounding of the Earth, including ecological monitoring, an estimation of resources and forecasting of a condition of an environment of the Arctic zone, and also the automated systems of gathering and information processing in remote areas of Arctic regions, etc.
Research in these directions is new.

2. The basic analytical problems that are due to be solved by probabilistic modelling of processes

Presence of various threats generates diverse natural and technogenic risks. In turn realization of threats during the preparatory period and at development of underwater deposits of hydrocarbons can lead to infringement of quality and safety of objects and systems. The analysis of domestic and foreign experience tells about necessity of creating complex approach to risk management in development of deposits of hydrocarbons in the conditions of Arctic regions. It will allow leaving finally on creation of technologies of new generation.
For research and a substantiation of variants of development of hydrocarbons deposits of Arctic

ocean many scientific and technical problems should be solved. Those are, for example, following problems of risk analysis and optimization:
1) for ecologically safe sea investigation, extraction and transportation of various kinds of mineral resources in extreme natural-climatic conditions;
2) for complex safety of works on a continental shelf, including monitoring and forecasting of extreme situations of natural and technogenic character;
3) for prevention and liquidation variants of emergency floods of oil, first of all in ice conditions, including creation of technologies for detection of oil under ice;
4) for development of technologies complex hydrometeorological and ecological monitoring of the dangerous natural phenomena in Arctic regions;
5) for development of technologies of remote sounding of the Earth, including ecological monitoring, an estimation of resources and forecasting of a condition of an environment of the Arctic, and also the automated systems of gathering and information processing in remote areas of Arctic regions.

For research in the specified directions the methodological approach which is based on probabilistic modelling of processes of occurrence, development, the control and neutralization of possible threats of natural and technogenic character is proposed.

3. The proposed methodological approach

3.1 General

This work focuses on using universal metrics in a systems life cycle: probabilities of success or risk to lose integrity during a given period for an element, subsystem, system. The results depend analytically on the time of periodic control, monitoring and recovery of system integrity. Calculation of these metrics allows to predict risks on a uniform probability scale, quantitatively to prove levels of admissible risks. The prediction of risks can use widely monitoring data and statistics. In general case a probabilistic space (Ω, B, P) for estimation of system operation is proposed. Here: Ω - is a limited space of elementary events; B – is a class of all subspace of Ω-space, satisfying the properties of σ-algebra; P – is a probability measure on a space Ω. Because, $\Omega = \{\omega_k\}$ is limited, there is enough to establish a mapping $\omega_k \rightarrow p_k = P(\omega_k)$ such that $p_k \geq 0$ and $\sum_k p_k = 1$. The examples of dozens such models exist [2]-[10] etc..

3.2 Example of risk prediction

Nowadays at system development and utilization an essential part of funds is spent on providing system protection from various dangerous influences on system integrity (these may be natural events, failures or defects events, “human factors” events, terrorist attacks etc). Elementary events for a complex system are “Correct operation” (the main property of system integrity) and “integrity loss” (if system integrity is lost). The term “integrity” should be defined. There are examined two general technologies of providing protection from dangerous influences: periodical diagnostics (controls) of system integrity (technology 1, without monitoring between diagnostics) and additionally monitoring between diagnostics (technology 2) [2]-[4], [6]-[10].

Technology 1 is based on periodical diagnostics of system integrity that are carried out to detect danger threats (for example, danger sources penetration into a system) or consequences of negative influences. The lost system integrity can be detected only as a result of diagnostics, after which system recovery is started. Dangerous influence on a system is acted step-by step: at first a danger threat occurrence and then after activated threat begins to influence. System integrity can’t be lost before a threat (penetrated danger source) is activated. A danger is considered to be realized only after a danger source has influenced on a system.

Note. It is supposed that used diagnostic tools allow providing necessary system integrity recovery after revealing of danger sources penetration into a system or consequences of influences.

Technology 2, unlike the previous one, implies that operators alternating each other trace system integrity between diagnostics (operator may be a man or special devices or their combination or natural analogy of operator). In case of detecting a threats occurrence (danger source penetration) an operator recovers system integrity. The ways of integrity recovering are analogous to the ways of technology 1. Faultless operator’s actions provide a neutralization of a threat (of a danger source trying to penetrate into a system). When operators alternate a complex diagnostic is held. A penetration of a danger source is possible only if an operator makes an error but a dangerous influence occurs if the danger is activated before the next diagnostic (the event “Integrity loss”). Otherwise the threat will be detected and neutralized during the next diagnostic (the event “Correct operation”).

The probability of correct system operation within the given period of prediction (i.e. probability of success) may be estimated as a result of use the probabilistic models [2]-[10] etc. Risk to lose integrity of system during prediction period is an addition to 1 for probability of providing system integrity (correct system operation or "probability of success") $R = 1 - P$. The consequences should be considered.

The inputs for calculations are:

a) for a complex system - given prediction period;

b) for an every element of a complex system:

frequency of dangerous threats occurrence (for example, dangerous sources penetration into a system);

mean activation time of threats;

period between neighboring diagnostics (between system controls) of defined integrity;

the mean diagnostic time (time of system control of defined integrity);

mean time from the last finish of diagnostic (control, recovery) up to the first integrity loss during monitoring (only for technology 2).

3.3 The technology of risk prediction for complex systems

Many models are applicable to a system presented as one element. The main output of modelling is probability of correct system operation or risk to lose system integrity during the given period of time ($T_{req.}$). If probabilities for all points $T_{req.}$ from 0 to ∞ are calculated, it means a trajectory of the PDF depending on threats, periodic control, monitoring and recovery. And the building of PDF is the real base to risk prediction for given time. In analogy with reliability it is important to know a mean time between neighboring losses of integrity (like mean time between neighboring failures in reliability (MTBF), but in application to quality, safety etc. For unrenewable objects this is mean time to the first failure). The PDF allows defining mean time of correct (safe) system operation by traditional methods [2]-[10] etc.

The idea of knowledge mining from probabilistic modelling processes in developing hydrocarbon deposits of Arctic regions consists in the following. Any process represents a set of the acts, which are carried out with defined "success" at limitations for resources and conditions. This amount of acts is characterized by expenses of resources (cost, material, human), accordingly acts can be executed for different time with various quality. And conditions are characterized by a set of random factors influencing processes. From the point of view of probability theory it is possible to suppose formally, that all processes on macro-and micro-levels may be repeated in time line. Time characteristics of processes and frequency characteristics of any events can be used as input. Probabilities of "success" during a given time or risks to lose system integrity are used as final or intermediate result of modelling.

The basic ideas of correct integration of probability metrics are based on a combination and development of models. For a complex estimation of systems with parallel or serial structure existing models can be developed by usual methods of probability theory. The approaches are demonstrated in [2]-[10] etc. Let's consider the elementary structure from two independent parallel or series elements (*Figure 1*).

Let's PDF of time between losses of *i*-th element integrity is $B_i(t) = P(\tau_i \le t)$, then:

1) time between losses of integrity for system combined from series connected independent elements is equal to a minimum from two times τ_i: failure of 1st or 2nd elements (i.e. the system goes into a state of lost integrity when either 1st, or 2nd element integrity is lost). For this case the PDF B(t) of time between losses of system integrity is defined by expression

$$B(t) = P(\min(\tau_1,\tau_2) \le t) = 1 - P(\min(\tau_1,\tau_2) > t)$$

$$=1 - P(\tau_1 > t)P(\tau_2 > t)$$

$$= 1 - [1-B_1(t)]\,[1- B_2(t)]. \quad (1)$$

2) time between losses of integrity for system combined from parallel connected independent elements (hot reservation) is equal to a maximum from two times τ_i: failure of 1st and 2nd elements (i.e. the system goes into a state of lost integrity when both 1st and 2nd elements have lost integrity). For this case the PDF of time between losses of system integrity is defined by expression

$$B(t) = P(\max(\tau_1,\tau_2) \le t) = P(\tau_1 \le t)P(\tau_2 \le t)$$

$$= B_1(t)B_2(t). \quad (2)$$

Applying recurrently expressions (1)–(2), it is possible to build PDF of time between losses of integrity for any complex system with parallel and/or series structure.

Applying recurrently these expressions, it is possible to receive mean recovery time for any complex system with parallel and/or consecutive structure.

All these ideas are implemented in the software technologies of risk prediction for complex systems, for example, the "Complex for evaluating quality of production processes" (patented by Rospatent №2010614145) [6], [9].

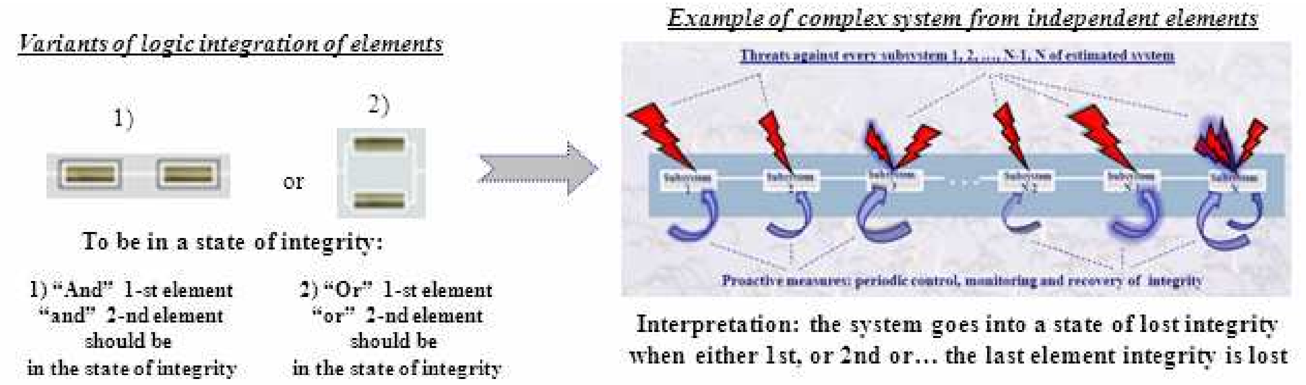

Figure 1. Illustration of system, combined from parallel and series subsystems

4. The input and output to research variants for developing hydrocarbon deposits of Arctic regions

Within the limits of the methodological approach the following metrics that depend on input conditions of problems are proposed.

For solving the problem 1 (analysis and optimization of risks for ecologically safe sea investigation, extraction and transportation of various kinds of mineral resources in extreme natural-climatic conditions):

1.1) efficiency research of various technologies of development of hydrocarbons deposits and other minerals on the Arctic shelf are proposed to be carried out:

by probability of success of problems solving;

by probability to lose integrity (for example, risk to lose safety) of system of deposits development and compound subsystems depending on time characteristics of threats, control and-or monitoring of conditions and comprehensible restoration of broken integrity, and also from characteristics of a possible damage;

1.2) research of influence of hydrometeorological factors on efficiency of resources development taking into account climate changes are proposed to be carried out by risk of critical decrease in efficiency of systems of resources development and compound subsystems depending on time characteristics of threats, control and-or monitoring of conditions and comprehensible restoration of broken integrity (where it is possible and expedient), and also from characteristics of a possible damage;

1.3) the estimation of risks in geological-geophysical investigations and exploitation of hydrocarbonic resources of Arctic ocean is proposed to be carried out by risks of critical decrease in efficiency depending on time characteristics of threats, control and-or monitoring of conditions and comprehensible restoration of broken integrity (where it is possible and expedient), and also from characteristics of a possible damage.

For solving the problem 2 (analysis and optimization of risks for complex safety of works on a continental shelf, including monitoring and forecasting of extreme situations of natural and technogenic character):

2.1) research of occurrence of the extreme dangerous and catastrophic phenomena at Arctic ocean and their influences on sea activity and economic objects of a coastal zone are proposed to be carried out:

- by risk of occurrence of the uncontrollable extreme dangerous and catastrophic phenomena depending on time characteristics of threats, control and-or monitoring of conditions, and also from characteristics of a possible damage;
- by risk of destructive influence of the extreme dangerous and catastrophic phenomena on sea activity and economic objects of a coastal zone depending on time characteristics of threats, control and-or monitoring of conditions and comprehensible restoration of broken integrity, and also from characteristics of a possible damage;

2.2) optimization of sea wildlife management and complex management sea and coastal ecological systems is proposed to carry out by criteria «efficiency – safety – expenses» taking into account risks to lose complex safety of works at Arctic ocean during the given period depending on time characteristics of threats, control and-or monitoring of conditions and comprehensible restoration of broken integrity, and also from characteristics of a possible damage;

2.3) research of quality of hydrometeorological and a geoinformational support of the sea activity, directed on minimization of risks and optimization of sea operations, are proposed to carry out by criteria «efficiency – safety – expenses» taking into account risks to lose quality depending on time characteristics of threats, control and-or monitoring of conditions and comprehensible restoration of broken integrity, and also from characteristics of a possible damage.

For solving the problem 3 (analysis and optimization of risks for prevention and liquidation variants of emergency floods of oil, first of all in ice conditions, including creation of technologies for detection of oil under ice):

3.1) research of efficiency of various variants of technology and the equipment for effective protection of the sea environment against anthropogenous pollution are proposed to be carried out:

by probability of success in problems of protection of the sea environment from anthropogenous pollution;

by risk to lose safety of the sea environment from anthropogenous pollution depending on time characteristics of threats, control and-or monitoring of conditions and comprehensible restoration of broken integrity, including oil detection under ice;

3.2) the estimation of processes of pollution from courts is proposed to be carried out by risk of emergency floods of oil.

For solving the problem 4 (analysis and optimization of risks for development of technologies complex hydrometeorological and ecological monitoring of the dangerous natural phenomena in Arctic regions):

4.1) the estimation of pollution and an ecological damage in the Arctic zone is proposed to be carried out by risk depending on time characteristics of threats, control and-or monitoring of the dangerous natural phenomena and comprehensible restoration of broken integrity;

4.2) the estimation of hydrometeorological and navigating-hydrographic support of sea activity is proposed to be carried out by risks to lose quality depending on time characteristics of threats, control and-or monitoring of conditions and comprehensible restoration of broken integrity, and also from characteristics of expenses and a possible damage;

4.3) research of systems of monitoring of pollution of a surrounding environment are proposed to be carried out by probability of success in problems of monitoring depending on time characteristics of threats, control and-or monitoring of conditions and comprehensible restoration of broken integrity, and also from characteristics of expenses and a possible damage.

For solving the problem 5 (analysis and optimization of risks for development of technologies of remote sounding of the Earth, including ecological monitoring, an estimation of resources and forecasting of a condition of an environment of the Arctic zone, and also the automated systems of gathering and information processing in remote areas of Arctic regions):

5.1) research of system of long-term tool monitoring of key climatic changes of circulation of the World ocean are proposed to be carried out by risk of critical climatic changes depending on time characteristics of destabilizing factors, control of conditions, and also from characteristics of expenses and a possible damage, and also on other metrics of system operation quality, an estimation of resources and forecasting of a condition of an environment;

5.2) research of satellite monitoring and the analysis of seasonal variability of sea ices are proposed to be carried out by risk depending on time characteristics of destabilizing factors, control of conditions, and also from characteristics of expenses and a possible damage, and also on other metrics of quality of the automated systems of gathering and information processing in remote areas of Arctic ocean.

5. The formal statement of problems for system risks analysis and optimization

From system analysis point of view the main function of management is a purposeful change of a condition of process, object or system. Thus the process, object or system considered as managed if among all changes there is available one by means of which the purpose can be achieved. Management is based on a choice of one of set of any alternatives. Rational management is the management leading achievement of the purpose by criterion of an extremum (a minimum or a maximum) the chosen parameter at a set of limitations. Classical examples of rational management generally are maximization of a prize (profit, a degree of quality or safety, etc.) at limitations on expenses or minimization of expenses at limitations on a admissible levels of risks and-or quality and-or safety etc.

For rational management of processes it is necessary to know and predict system behaviour in time line at various influences. For this purpose it is offered to use the mathematical models including presented approach. The metrics entered in these models, or their combination may be used as criteria metrics. Actually they are the quantitative measure (criterion function) describing degree of achievement of a purpose at various stages of system life cycle. The statement of problems for system analysis includes definition of conditions, threats and estimation a level of admissible risk established by precedent principle. Thus the final choice of integrated measures is allocated on a payoff to the customer in view of specificity of created or maintained system. As probability parameters give higher guarantees in estimations of a degree of achieving purposes in comparison with average value at a choice it is recommended to use probability as the cores. And evaluated time characteristics (for example the mean time between violations of admissible system operation quality) are offered as auxiliary.

For example, there are applicable the next general formal statements of problems for system risk optimization:

1) on the stages of system concept, development, production and support:

system parameters, technical and management measures (Q), presented in terms of time characteristics of threats, control and-or monitoring of conditions and comprehensible recovery of lost integrity, are the most rational for the given period if on them the minimum of expenses ($Z_{dev.}$) for creation of system is reached:

$$Z(Q_{rational}) = \min_{Q} Z_{dev.}(Q),$$

at limitations on admissible level of risk to lose integrity $R(Q) \leq R_{adm.}$ and/or probability of an admissible level of quality $P_{quality}(Q) \geq P_{adm}$ and expenses for operation $C_{oper}(Q) \leq C_{adm.}$ and under other development, operation or maintenance conditions;

2) on operation stage :

system parameters, technical and management measures (Q), presented in terms of time characteristics of threats, control and-or monitoring of conditions and comprehensible recovery of lost integrity, are the most rational for the given period of operation if on them the minimum of risk to lose system integrity is reached:

$$R(Q_{rational}) = \min_{Q} R_{oper.}(Q),$$

at limitations on admissible level of risk to lose integrity for i-th subsystem (element) $R_i(Q) \leq R_{adm.\,i}$ and/or probability of an admissible level of quality $P_{quality}(Q) \geq P_{adm.}$ and expenses for operation $C_{oper.}(Q) \leq C_{adm.}$ and under other operation or maintenance conditions.

There may be combination of these formal statements in system life cycle.

The order for use the developed classical formal approach to analyze and optimize system processes is illustrated by *Figure 2*.

The software tools for risks analysis and optimization to research variants for developing hydrocarbon deposits of Arctic region can be based on complex for modelling system life cycle processes "MODELLING OF PROCESSES" [3].

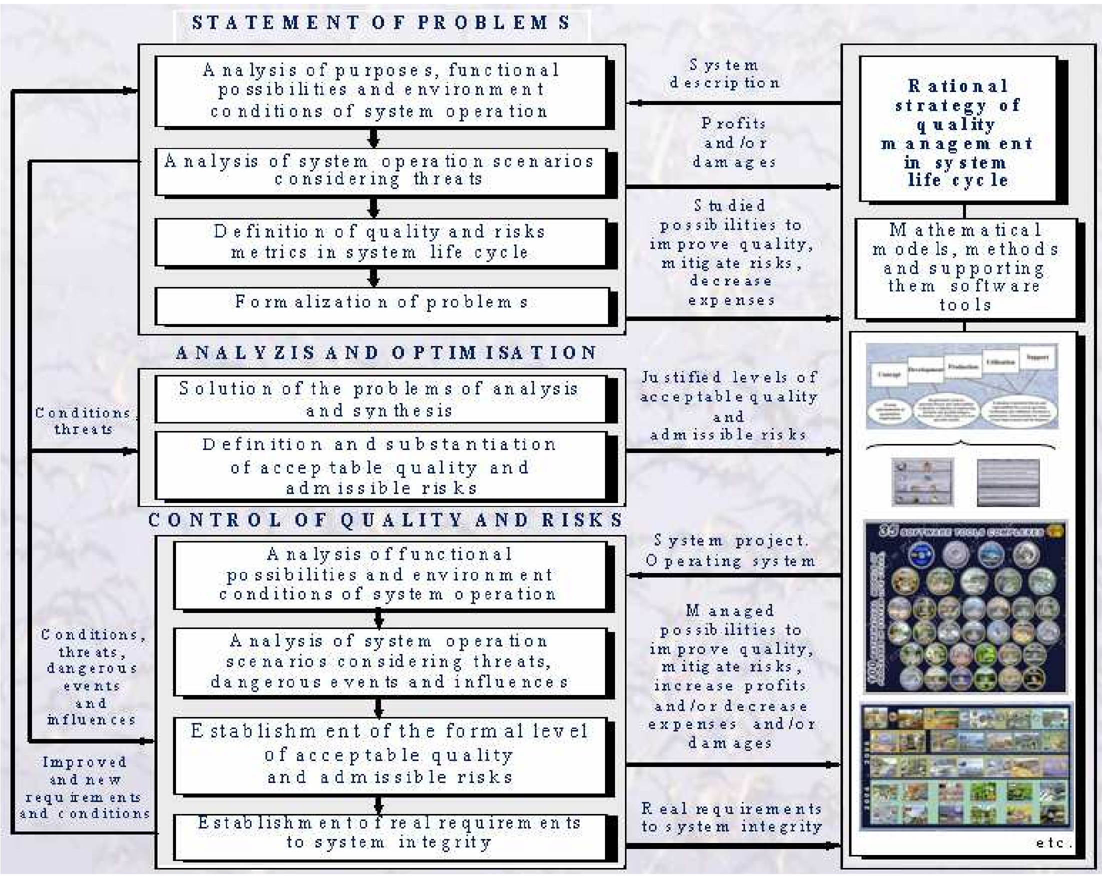

Figure 2. The approach to analyze and optimize system processes

6. Example

Example. Let's analyze a fragment of the main gas pipeline Bovanenkovo-Ukhta (more than 1200 km) by probabilistic modelling of natural and technogenic processes. It constructed over an earth surface. Subfragments between compressor stations (9 stations - Bajdaratsky, Jarynsky, Gagaratsky, Vorkuta, Usinsk, Intinsky, Syninsky, Chikshinsky, Maloperansky) are allocated. There are serial subsystems and every subsystem has parallel structure of elements (pipeline) - see *Figure 3*.

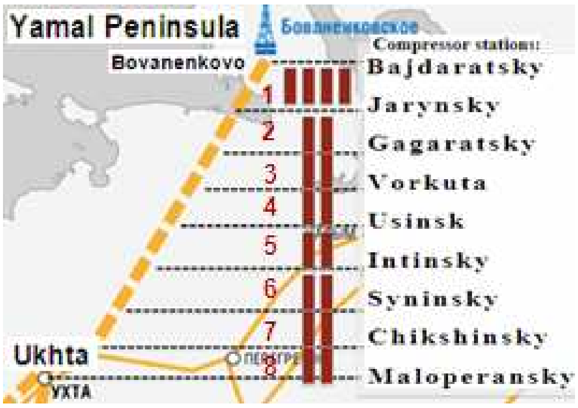

Figure 3. The analyzed fragment of the main gas pipeline

About 75-90% from the pipelines are under natural threats, including ice drift (threats for constructions). It is required to estimate risk to lose integrity (quality of operation) of fragment Bovanenkovo-Ukhta in 2023-2043.

The solving of a problem [1]. According to estimations of experts, in 20-30 years there will be considerable changes of climatic conditions which will cause rise in temperature of frozen thicknesses, increase in depth seasonal thawing and, as consequence, decrease in stability and bearing ability of the bases for a gas pipeline and other engineering constructions.

Technical characteristics of elements between compressor stations are considered as identical, except for the first subfragment (between stations Bajdaratsky and Jarynsky) which is underwater transition (reservation by 4 elements-pipelines) – see *Figure 4*. Initial data for modelling have been generated depending on conditions of concrete sites and specificity of a territorial arrangement of a line.

Figure 4. The structure for modelling processes

Results of modelling processes have shown [1], that risk to lose integrity (quality of operation) for 20 prognostic years during the period 2023-2043 is equal to 0,6-0,8. In comparison with other precedents these figures speak about expediency of undertaking of preventive measures, and also about necessity of working out of the Plan of emergencies liquidation.

If period between system controls will be reduced from 6 to 3 months the risk to lose integrity in 2023-2043 is nearby 0,16-0,44. It is twice more low, rather than for an existing mode of maintenance and repair.

On the basis of these results the following recommendations are scientifically proved:

to establish a risk level to lose integrity (quality of operation) 0,38 within 10 years of operation as admissible (on the base of «precedent principle»);

to pass to the quarterly control of a condition of system after 10 years of operation (i.e. since 2024);

to use annual planning of maintenance measures service on the basis of modelling processes for rational risk management in admissible limits.

7. Conclusion

The presented systemic approach is a real analytical lever to research variants for developing hydrocarbon deposits of Arctic regions from risk point of view. For complex systems the proposed results helps to answer the question «What rational measures should lead to expected effect without waste expenses, when, by which controllable and uncontrollable conditions and costs?». The effect from implementation this approach in system life cycle is commensurable with expenses for system creation. The work has begun.

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