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Scientific and Practical Foundations of Ensuring Safety In Oil and Gas Extraction

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Abstract:

The analysis of accidents occurring in oil and gas extraction and the key factors contributing to their emergence have been examined in this article. Investigation results of the causes of accidents indicate that in 11% of cases, incidents are associated with internal hazardous factors, such as equipment malfunction and lack of sealing, while in 89% of cases, violations of safety regulations, inadequate organization of repair works, failure to meet technical requirements for providing technical services to facilities, and personnel errors are identified as the main causes. Additionally, the refinement of the management organization model in exceptional situations has been elucidated.

Keywords: *emergency situations, accidents, critical incidents, oil and gas industry, drilling.*

Introduction

The successful development of the oil and gas industry worldwide and the significant growth of hydrocarbon deposits have a considerable impact on enhancing the quality of oil and gas extraction operations and safety technologies. As a result of the technological advancement in the industry, the achievements of companies represent an average of 65% in Germany, 50% in Sweden, 40% in Great Britain and Portugal, and 8-10% in Russia. With the aim to increase industrial sustainability, efforts are made to reduce expenses by 14% through an average 18% growth and a 2.9% annual income increase to foster development. Consequently, the complex systematic resolution of issues arising from exceptional situations in oil and gas extraction considering geological and climatic conditions is receiving particular attention.

In our Republic, strengthening and expanding the mineral-resource and energy bases, as well as the advancement of the oil and gas extraction complex, are closely related to the improvement of geological exploration techniques for oil and gas. Additionally, in regions with complex terrain, challenging geological and natural-climatic conditions, underdeveloped infrastructure, and a lack of material-technical resources, technical breakdowns in oil and gas extraction lead to accidents and critical situations. In accordance with the decree of the President of the Republic of Uzbekistan on the strategy for the development of the New Uzbekistan, significant new tasks have been set to establish an effective system for alerting and preventing critical situations. Given these tasks, it becomes crucial to enhance the quality and sustainability of geological exploration works in promising areas and address the challenges in preventing critical situations in oil and gas extraction.

Today, oil and gas extraction is one of the essential natural resources vital for humanity's well-being. Oil plays a distinct role in the energy balance; it's used in the production of motor fuels, lubricants, plastics, synthetic fibers, and various other products. Gas, primarily used for heating, cooking, as fuel for machinery, and producing various organic materials, holds a significant position in energy resources. Therefore, these resources are crucial to the primary industry worldwide. The drilling of oil and gas wells requires oil and gas rigs located underground.

Accidents in oil and gas extraction occur in several ways: accidents involving wellheads and tubing; accidents related to well pumps, measurement devices (samplers), packers, and lower sections of cementing and drilling lines; accidents involving cables, tubing, and wiring.

The first type of accidents involves casing wellheads ranging from 90 to 480 mm in diameter, experiencing issues with drilling, casing, and pump-compressor wellheads.

The second type involves turbo couplings, electrical couplings, submersible electric pumps from water bottom centers, couplings, the lower part of cementing and drilling lines, chokes, equipment for organizing production, and drilling rigs. Additionally, mishaps occur due to pump actuators left on pumps (on or above) or in critical areas; corrosion of pipes, crackers, and other metal fittings. Analyzing and understanding all information, particularly about wellheads, to neutralize accidents, and specifying the corrective actions are crucial in establishing a response regimen and selecting necessary equipment.

The response time for averting accidents is critical, correlating with an increase in depth. Therefore, one of the primary causes of neglecting the equipment for drilling stems from the violation of technological rules by operators (due to staff errors).

During the installation of exploration and evaluation wells for oil and gas, accidents (ruptures) occurred, estimated at approximately 26% due to the lowering of well pressure (Type I according to A.K. Samotoy's classification), 32% due to equipment failure (Type II), and 42% due to borehole collapse, mud inflow, fluid leakage, and heavy material (Type III) causing wellbore obstruction (Figure 1.1).

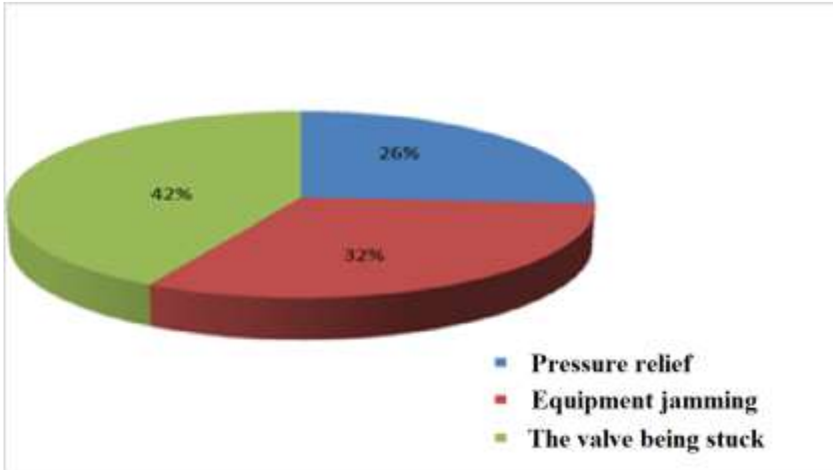

Figure 1.1. Number of accidents during drilling

In terms of accident severity, equipment ruptures accounted for 52.8%, oil and gas water incidents for 21.1%, accidents involving drilling mud elements for 5.2%, and other anomalies constituted 20.9%. These details are illustrated in Figure 1.2.

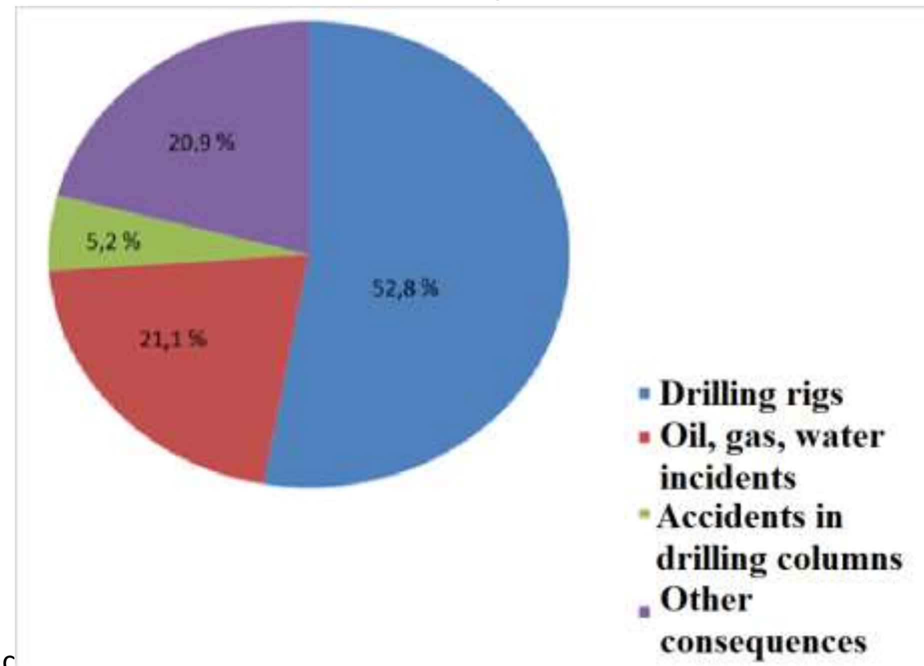

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Figure 1.2. Causes of Accidents

Analysis of Accidents in Oil and Gas Extraction Facilities in the Russian Federation.

In 2022, the Federal State Supervision in the field of safety during oil and gas extraction was carried out concerning 8687 oil and gas extraction facilities.

Among them were the following:

Drill sites – 225;

Oil, gas, and gas condensate extraction – 1315;

Well funds – 2184;

Drilling structures (including drilling platforms, among them drilling rigs) – 17.

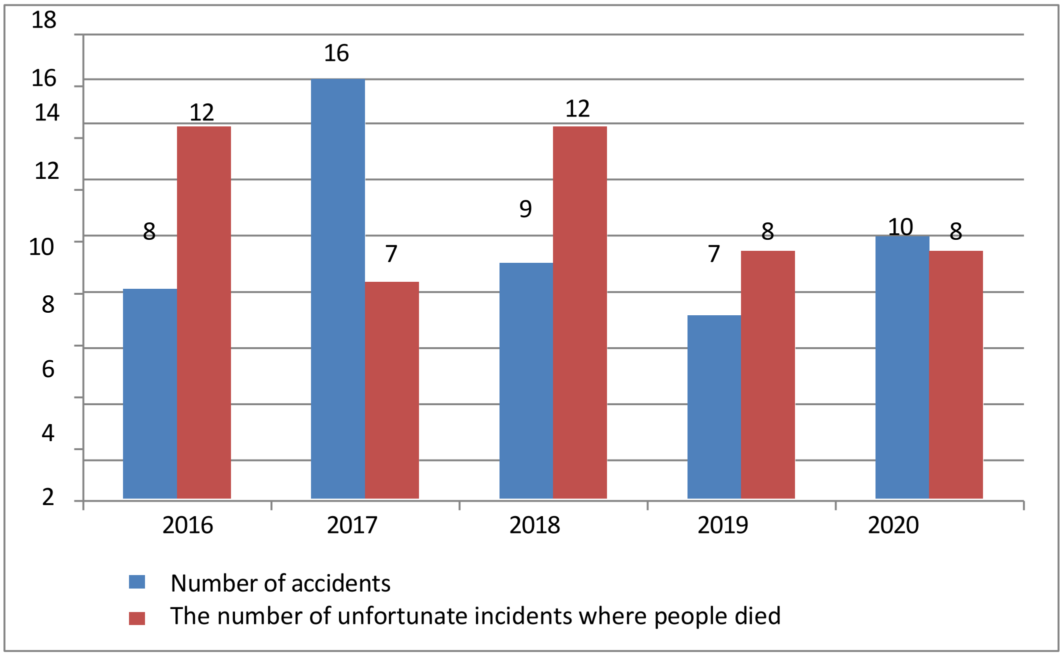

Figure 1.3. Dynamics of accidents and fatal Incidents at oil and gas extraction facilities in Russia from 2018 to 2022

Between 2018 and 2022, a total of 50 accidents occurred at oil and gas extraction facilities (Tables 1.1 and 1.2).

As a result of these accidents, 21 individuals were injured, and 63 people lost their lives. The total economic damage amounted to 1 billion 752 million 466 thousand rubles, including environmental damage totaling 8 million 202 thousand rubles.

Table 1.1

Information on accidents in industrial sectors

Field direction	**Number of accidents**					
	2018	2019	2020	2021	2022	**Total**
In oil extraction facilities	8	16	9	6	10	**49**
In gas extraction facilities	0	0	0	1	0	**1**
Total:	8	16	9	7	10	**50**

Table 1.2

Information on the types of accidents occurred in oil and gas extraction from 2018 to 2022

Type of accidents	**Number of accidents**						
	2018	2019	2020	2021	2022	**Total**	%

Open fountains	2	9	3	2	2	18	36
Fires and explosions at objects	2	3	1	2	6	14	28
Collapse of drilling rigs and breakdown of parts in them	1	0	1	0	0	2	4
Others (malfunction of technical equipment, spillage of oil products)	3	4	4	3	2	16	32
Total:	**8**	**16**	**9**	**7**	**10**	**50**	**100**

The main causes of accidents identified in the conducted research and investigation processes are as follows:

A total of 18 accidents occurred in open flames, constituting 36% of the overall accident count.

Fire and explosion-related incidents totaled 14, representing 28% of the total accidents.

2 incidents were related to collapses of drilling structures and parts, accounting for 4% of the total accidents.

16 accidents were associated with malfunctions of technical equipment and spillage of oil products, making up 32% of the total accidents.

The analysis of investigation results into the causes of accidents indicates that in 11% of cases, accidents occurred due to internal hazards related to the malfunction and lack of sealing of technical constructions, while in 89% of cases, incidents happened due to gas-related hazards, organizing and conducting repair work, and neglecting technical requirements for providing technical services, attributed to the errors of personnel.

On April 20, 2010, at the Macondo well in the Gulf of Mexico (operated by British Petroleum), one of the largest catastrophes in the world occurred due to the release, ignition, and explosion of the oil and gas mixture. The modern water-depth drilling rig "Deepwater Horizon" sank after burning for 36 hours, resulting in the loss of 11 lives. According to British Petroleum's information, an estimated 0.7 million tons (4.9 million barrels) of oil leaked into the Gulf, spreading across an area of up to 75 thousand square kilometers. The wellhead was only capped after 86 days of continuous spewing.

The catastrophe on the “Deepwater Horizon” was caused by the uncontrolled release and ignition of the oil and gas mixture, primarily due to numerous technical failures and equipment deficiencies resulting from inadequate monitoring. It was compounded by the crew's apparent errors in their actions (human error), including not detecting the flaws in the cementing of the wellhead. The immediate cause of the natural disaster, directly or indirectly declared, intensified due to anomalies such as abnormally high underground pressure in this area and attempts to stop the hydrocarbon flow into the water, which triggered the formation of gas hydrates near the deep water. The

Figure 1.4 Fire on the Deepwater Horizon platform of the Macondo field

financial damage from this disaster amounted to $40 billion. It ranks among the most severe disasters, both in terms of the amount of oil spilled into the sea and its global impact. Previously, the most significant incident related to oil spills and fire occurred in 1979 on the "Sedco 135F" platform in the Mexican Shelf. In that accident, approximately 0.5 million tons of oil leaked into the sea, resulting in human casualties and the complete destruction of the platform. It took 294 days to stop the gushing. If such catastrophes were to occur in the Arctic, their consequences could be global.

The advancement of technologies and technical means for extracting hydrocarbons from the seabed and underground has led to the discovery of anomalous high-pressure formations in several regions worldwide: Lakeview Gusher and Dos Cuadras in California, German Bight in the North Sea, Ekofisk Bravo B-14 and Elgin, Ixtoc, and Macondo in the Gulf of Mexico, Bulla-Deniz in the Caspian Sea, Luninskaya-1 in the Barents Sea, former Soviet Union's Tazovskaya-1 and Tazovskaya-52, Purpeyskaya-101, Bovanenkovskaya-67, and Bovanenkovskaya-118, Kumzhinskaya-9, Tengiz-37 wells. These incidents involve uncontrolled hydrocarbon emissions into the environment and have caused severe situations. It has been determined that such events could be the cause of severe conditions.

According to the U.S. Department of the Interior, between 2001 and 2010, 858 various oil spills and fires were recorded on offshore platforms (an average of one incident every four days). Based on the analysis of accidents, it is possible to draw conclusions about various risky situations, different unfortunate incidents, and measures taken to combat risks and dangers. The interpretation of observed accidents is primarily attributed to natural factors, human factors, equipment aging, and the need to reduce their impact.

The complex development of measures to address issues related to ensuring safety in the technological process of oil and gas extraction is considered to have crucial importance in preventing situations that may arise in the oil and gas industry.

The comprehensive technological system for planning and implementing measures and programs to prevent and neutralize the consequences of critical situations is based on a systematic approach aimed at achieving clear activities and tasks that ensure the accomplishment of these goals and their effective implementation.

A system for managing critical situations has its own unique features and work schedules, typically comprising three preventive strategic plans:

1)A plan used for managing complexes of measures in the daily operational plan;

2)A high readiness regime established based on short-term predictive information about the likelihood of the emergence and development of critical situations, employed within the system for managing situations in critical circumstances;

3)A quick notification-based plan utilized for creating a situational plan in the area, providing rapid clarity to the management actions plan of relevant authorities during critical situations, explained and formulated in detail, and used in establishing the situation plan in the area based on prompt notifications.

These plans were formulated as purposeful plans or programs and included tasks, implementation timelines, responsible organizations (ministries and agencies), as well as resources allocated at the national, regional, and organizational levels.

The typical classifications of purposeful plans are as follows:

1) Plans for the enhancement of the security of potential hazardous objects, relocation and construction of industrial and civic objects, improving their seismic stability, conducting scientific research, and experimental design work on other issues.

2) Plans for monitoring and forecasting the emergence and development of natural and man-made hazardous events, as well as creating and improving the monitoring system.

3) Plans for implementing preventive measures complexes in technogenic hazardous objects of public importance.

4) Plans for creating capabilities and means for executing rescue and other non-delayable operations, organizing readiness, and equipment.

5) Plans for developing tools and equipment for rescue and other non-delayable operations.

6) Plans for creating and placing material and technical resources for executing rescue and eliminating the consequences of hazardous situations.

7) Plans for the execution of educational and practical measures for the forces, means, and resources of emergency situations bodies in the examples of scenarios of the development of hazardous situations and the population.

Let's denote the collection of programs aimed at anticipating and ensuring the safety of hazardous situations in a certain area as R = $\{ p_j, \ i = 1, I \}$ If there is an association of independent entities and their authorized representatives participate in relevant programs for their own benefit. Most representatives P= $\{ p_j, j = 1, J\}$ express their interests through budget allocations necessary for financing the programs they require. Each proposed program, subject to discussion (or proposed), is allocated necessary expenses S_i, $i = 1, I$ for its implementation. Within the allocated budget amounts, the representative might allocate the amount Mij for the i-th program of interest to them. Moreover, assuming that programs are executed under the conditions where all the budget allocations are exhausted, the selection of programs has been estimated. It is essential to identify a collection of programs that consider all parties' interests and allow for effective and fair discussions in legislative bodies.

Let's define the variable of the problem:

$$X_i = \begin{cases} 1, \text{агар давлат дастури кўриб чиқиш учун тўпламга киритиладиган бўлса,}, \\ 0, \text{otherwise.} \end{cases}$$

Let’s consider the “benefits” from all sides.

$$Y_i = \begin{cases} 1, \ \text{if } S_i X_i - \sum_{j=1}^{J} M_{ij} X_i \leq 0, \\ 0, \ \text{if } S_i X_i - \sum_{j=1}^{J} M_{ij} X_i > 0, \end{cases} \qquad (1.2)$$

$Y_i = 1$ i indicates the availability of funds for the state program or $Y_i = 0$ indicates the lack of funds for the implementation of the state program.

It's clear that there is a total deficit for all selected programs in the debates.

$$f\{X_i\} = \sum_{i=1}^{I} \left(S_i X_i - \sum_{j=1}^{j} M_{ij} X_i \right) \qquad (1.3)$$

In this case

$f\{X_i\} = \sum_{i=1}^{I} \alpha_i X_i$- The function of the budget shortfall,

(Y_i the function of funding programs with financial resources. ($i = 1, I$).

Opportunities for alignment and temporary approval of the targeted program package increased significantly in the following cases.

$$max \sum_{i=1}^{I} Y_i, \qquad (1.4)$$

$$\min \sum_{i=1}^{I} \alpha_i X_i \quad (1.5)$$

We will define the matrix of participation in financing the programs by representatives of separate organizations as follows:

$$A = \|\alpha_{ij}\|, i = \overline{1,I},\ j = \overline{1,J}, \quad (1.6)$$

Here

$$\alpha_{ij} = \begin{cases} 1, & \text{if, } Mij>0, \quad \textit{The } j^{th} \text{ organization participated in financing the } i^{th} \text{ state program.} \\ 0, & \text{if } Mij = 0. \end{cases}$$

In this case

$$\varphi_j(X) = \sum_{i=1}^{I} \alpha_{ij} Y_i \quad (1.7)$$

the j^{th} representative program financed by finance determines the number, meaning it reflects the "benefits" (rights) of each representative. Each representative invests financial resources to ensure.

$$\max \sum_{i=1}^{I} \alpha_{ij} Y_i, \quad j = \overline{1,J}. \quad (1.8)$$

After reviewing (1.3) and (1.6), it becomes clear that the objective functions are distinct, meaning the total benefits correspond to the benefits of each representative. The increase in the number of programs financed by the j^{th} representative, which are beneficial, is noticeable

$\underset{\{Y_i\}}{max} \sum_{j=1}^{J} \sum_{i=1}^{I} \alpha_{ij} Y_i$ was performed in the context of the function (1.9)

This approach is beneficial from the perspective of each representative as well as from the standpoint of overall benefits in the field of security. Hence, it's possible to shape the task of selecting programs as follows:

$$\min \sum_{i=1}^{I} \alpha_i X_i \quad (1.10)$$

in the case of the budget allocated to each representative

$$\sum_{i=1}^{I} M_{ij} X_i \le b_j,\ j = \overline{1,J}, \quad (1.11)$$

regarding the overall costs of implementing all the programs allocated for discussion

$$\sum_{i=1}^{I} S_i X_i \le R. \quad (1.12)$$

In defining (1.8)-(1.10), the programs under consideration were estimated to be of significant importance. If there is an organizing body (center) and it possesses allocated funds for supporting and empowering these programs, officially, a designated representative, say P_j, j = 1, J, may participate as a specific representative alongside other representatives of P_o with equal rights.

In addition, having a centralized body involved with its own strategic programs and evaluating the most effective execution of these programs within the specified regions becomes essential. In such a scenario, when possessing its financial resources, confirming the initial decision to adopt these strategic programs (under the aegis of the Center) may be enhanced through subsequent selection.

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