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Analysis and assessment of the safety level of port facilities using the example of a sulfur storage warehouse

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Introduction. The article deals with the problems of analysis and assessment of the safety level of hazardous production facilities of port facilities that have a negative impact on both the environment and the personnel working at the facility. Objects of this kind are referred to the first class of hazard; therefore, they require a comprehensive assessment of their resistance to emergencies in terms of the likelihood of their occurrence in specific industrial conditions.

Problem Statement. The objective of this study is a comprehensive analysis of the safety level of the most vulnerable areas of the technological process of port activities.

Theoretical Part. The results of a scheduled inspection of the AO "Ust-Donetsk Port" conducted by the Federal Service for Supervision of Natural Resources were used as basic information.

Conclusion. Based on the calculation results, it was found that the probability of an emergency for the most dangerous scenario is 2.4×10-8 and corresponds to the acceptable risk zone.

Keywords: emergency, production factors analysis, safety, event tree, damage, calculation of the emergency probability.

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Introduction. At present, there is a significant progress in the field of port activities. The increase in the volume of cargo transportation and transshipment increases the need to improve the environmental safety of sea and river ports. The problem of the negative impact of cargo handling and storage operations in ports on the environment and industrial safety has not been fully solved to date. The most dangerous factor is dusting and flue dust during storage in open warehouses and transshipment operations of bulk cargo [1, 2]. In addition, dust from combustible materials can create explosive aerosols under certain conditions. It is also known that when unloading and loading both bulk and loose cargo, ship-borne cargo volume losses are often possible, which can have a detrimental effect on the atmospheric air, soil and water body [3].

Ust-Donetsk Port is the largest river port in the south of Russia, which is located on the right bank of the Sukhoy Donets Channel. The total length of the waterfront is more than 1,100 m. The port is assigned a high risk category and a second hazard class. The main production cycles are stevedore operations; open and indoor warehouse storage of cargo; complex logistics; packaging of cargo in big bags, as well as fleet maintenance, which includes the processes of production, repair work and provision of onshore power supply. Cargo transshipment is carried out on floating vehicles board using a crane with a grab, a floating crane with a grab and a motor ship, using the "car-ship" and/or "warehouse-ship" method. The structure is characterized by a predominance of bulk, general and chemical cargo. Most of them are dangerous according to GOST 19 433-88, for example, sulfur, the volume of transshipment of which reaches 1.5 million tons per year. Based on the above, for the organization of storage and transshipment of goods, including those classified as dangerous, the port must be provided with an environmental infrastructure and meet the requirements of industrial safety. In order to recognize the probable danger, it is necessary to determine which key elements, technical systems or processes in the technological scheme of the transshipment significantly need to be analyzed in terms of minimizing the environmental risk of accidents, including the extreme weather conditions [4].

This study is devoted to determining the probability of an emergency in the most dangerous scenario.

Problem Statement. To solve this problem, it is necessary to analyze the technological process in the most dangerous area associated with the acceptance, storage and reloading of a fire-explosive substance — sulfur. The determination of the set of parameters of this type of cargo will allow us to assess the level of industrial safety and the probability of an emergency in the most dangerous scenario.

Theoretical Part. To perform calculations, it is necessary to establish the ecological and toxicological parameters of sulfur dust and the features of its behavior in the environment. Industrial gas sulfur (block, granulated) is a combustible solid crystalline substance that ignites from sparks and open flames. The maximum permissible concentration of sulfur in the working area is 6 mg/m^3, the maximum one-time concentration is 0.03 mg/m^3, and the average daily concentration is 0.005 mg/m^3. According to the degree of influence on the human body, sulfur belongs to the fourth hazard class according to GOST 12.1.005–88. The prolonged inhalation exposure to sulfur in concentrations exceeding the MPC in the air of the working area is likely to cause the development of chronic poisoning, characterized by disorders of the nervous system, gastrointestinal tract, and lung function disorders [5]. This dangerous factor is leveled mainly by the use of PPE.

No less important when assessing the level of safety of a sulfur warehouse is its fire and explosion hazard [6, 7], which determines the need to organize special industrial safety measures in the technology of the port transshipment process [8]. For the scientific development of such measures, it is necessary to assess the risk of an emergency at this facility [9-13].

At the stage of hazard identification at a hazardous production facility, it is necessary to identify the key sources of origin of probable incidents and accidents at a hazardous production facility, as well as general-type scenarios for the development of an accident at the considered hazardous production facility in accordance with Rostechnadzor Order No. 144 of 11.04.2016 On the Approval of the Safety Manual "Methodological bases for conducting hazard analysis and risk assessment of accidents at hazardous production facilities".

Table 1 presents a list of determining factors and possible causes that serve as a tool for the occurrence and development of accidents in the implementation of technological operations with sulfur at ZAO Ust-Donetsk Port.

Table 1

List of determining factors and possible causes that serve as a tool for the occurrence and development of accidents when handling with sulfur

Name of the technological block	Factors contributing to the occurrence and development of emergencies	Possible causes of emergencies
Platform for loading/unloading of sulfur from the railway car	1. A large amount of sulfur unloaded from the railway car creates a risk of formation of an increased amount of explosive sulfur dust. 2. When a large amount of explosive sulfur dust is formed, there may be a risk of explosion, the ignition of sulfur, the involvement of additional masses of fire-hazardous substances in the fire center, the chain development of the accident.	1. Errors of personnel in the conduct of technological operations (loading, unloading). 2. Unauthorized third-party interference. 3. External influence of natural and man-made nature. 4. Terrorist manifestations.
Platform for loading/unloading	1. A large amount of sulfur discharged from the railway car creates a risk of formation of	1. Errors of personnel in the conduct of the technological process (loading,

Name of the technological block	Factors contributing to the occurrence and development of emergencies	Possible causes of emergencies
sulfur from the car to the ship	an increased amount of explosive sulfur dust. 2. When a large amount of explosive sulfur dust is formed, there may be a risk of explosion, the ignition of sulfur, the involvement of additional masses of fire-hazardous substances in the fire center, the chain development of the accident.	unloading). 2. Unauthorized third-party interference. 3. External influence of natural and man-made nature. 4. Terrorist manifestations.
Sulfur storage warehouse	1. A large amount of sulfur stored in the warehouse creates a fire hazard.	1. Errors of personnel during the technological process (loading/unloading), repair and maintenance work. 2. Unauthorized third-party interference. 3. External influence of natural and man-made nature. 4. Terrorist manifestations.

Thus, among the causes of danger during the transshipping process, it is possible to specify the reloaded cargo, reloading equipment, technological process, human factor and meteorological conditions. We would also like to point out that errors in the management of the technological process of loading/unloading at the production facility can be not only the cause of the occurrence and development of emergencies, but also the cause of pollution of environmental components: atmospheric air, soil, the operated water body and lead to environmental damage.

Assessment of the risk of emergencies. The assessment of the probability of implementing the scenario of an accident at a sulfur storage warehouse was carried out on the basis of generalized average statistical data on the failure rates (depressurization) of production equipment, taking into account the number of units of equipment in operation, using the "event tree" analysis method according to RD 03-357-00 "Methodological recommendations for drawing up a declaration of industrial safety of a hazardous production facility" (Fig. 1). The probability of an emergency scenario is calculated by sequentially multiplying the frequency of the initial event by the relative probability of the intermediate stages of the accident development to the final event.

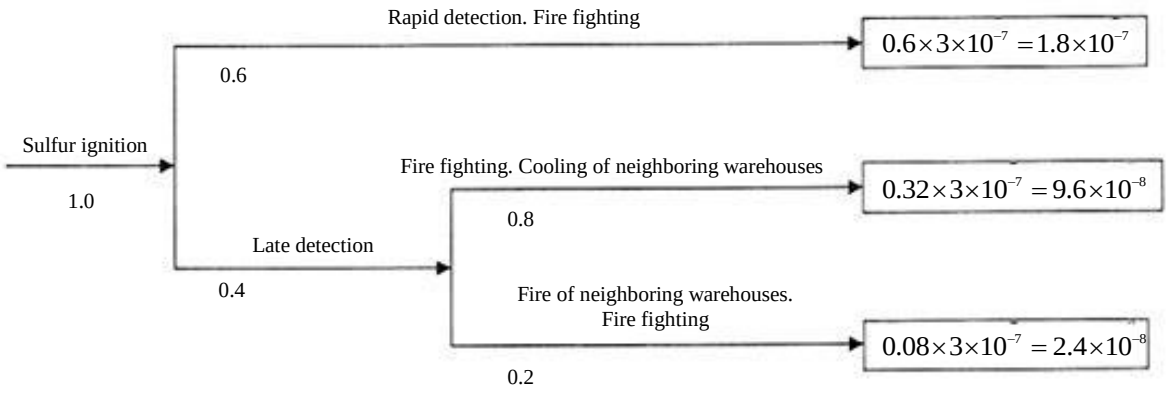

Fig. 1. "Event tree" of possible development of emergencies in case of an accident involving sulfur

Table 2 shows the results of the assessment of the probability of the accident scenario at the sulfur storage warehouse.

Table 2

Value of the frequency that triggers the event

Type of equipment failure	Probability of failure (incident)	Probability of an emergency scenario
Fire probability	3×10^{-7}	2.4×10^{-8}

An assessment of the risk of accidents when handling sulfur at AO Ust-Donetsk Port should be carried out for the most dangerous emergency scenarios, one of which is: the presence of an external heat source in the sulfur storage warehouse — fire — damage to the operating crew.

According to GOST R 12.3.047-2012 "Fire safety of technological processes" in the event of an accident at a production facility, the damaging factor is the dangerous thermal impact of a fire.

The most dangerous scenario of an accident (scenario no. 1) in a sulfur storage warehouse is: ignition of sulfur from an open fire source — late detection of a fire — ignition of adjacent warehouses, extinguishing of adjacent warehouses. The probability of scenario no. 1 in a sulfur storage warehouse is 2.4×10^{-8} year^{-1}.

The most likely scenario of an accident (scenario no. 2) is: the ignition of sulfur from an open fire source — rapid detection of ignition, fire extinguishing. The probability of scenario no. 2 in a sulfur storage warehouse is 1.8×10^{-7} year^{-1}.

The determination of hazard indicators of the object is made for the assumed variant of the implementation of an emergency that develops according to the most unfavorable scenario. It should be noted that, despite the scientific validity of qualitative and quantitative assessments of the risk of emergencies, they are probabilistic in their content and in the real case may not fully correspond to reality, since the methodology considers the generalized version in a simplified form. According to the "Method for determining the design value of the fire risk at production facilities" approved by Order of the Ministry of emergency situations of the Russian Federation No. 404 of 10.07.2009, the value of a potential fire risk P(a) (year^{-1}) at a certain point (a) at the premises of the production facility as well as on adjacent to the object area shall be determined using expression (1):

$$P(a) = \sum_{j=1}^{J} Q_{dj}(a) Q_j, \quad (1)$$

where J is the number of scenarios for the development of fire-hazardous situations (fires) (branches of the logical tree of events; Qdj (a) is the conditional probability of human injury at a certain point on the territory (a) as a result of the implementation of the j-th scenario for the development of fire-hazardous situations that corresponds to a certain event that initiates an accident; Qj is the frequency of the implementation of the j-th scenario for the development of fire-hazardous situations during the year, year-1

The value of the individual risk Rm for the employee m of the object on the territory of the object is determined by formula (2):

$$R_m = \sum_{i=1}^{I} q_{im} P(i), \quad (2)$$

where P(i) — the value of the potential risk in the i-th area of the object's territory, year^{-1}; q_{im} — the probability of the presence of employee m in the i-th area of the object's territory.

Possible total damage in the event of an accident at a hazardous production facility is determined by direct losses, the costs of localization and elimination of the consequences of the accident, socio-economic losses as a result of death and injuries of people and environmental damage according to RD 03-496-02 "Methodological recommendations for assessing damage from an accident at hazardous production facilities" (Fig. 2). As a result of an accident — a fire in

a storage warehouse — the buildings and structures of the warehouse will be damaged, there will be a loss of sulfur, which will cause damage to the atmospheric air as a component of the environment. There may also be material losses associated with injuries to people. The results of the calculations are summarized in Table 3.

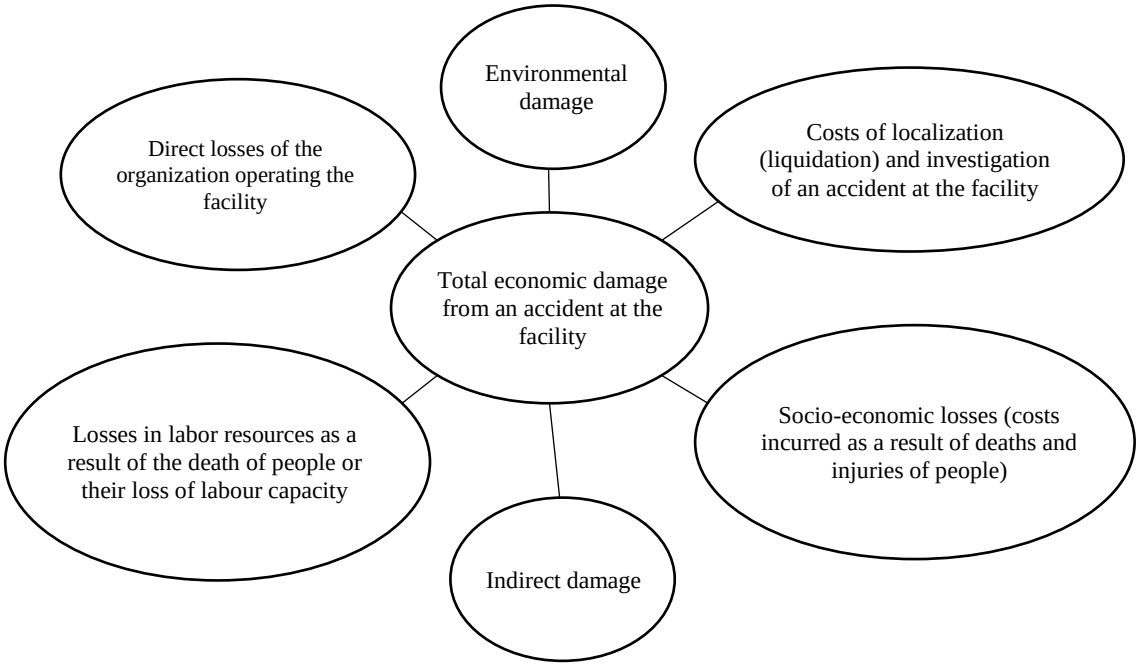

Fig. 2. Scheme for calculating the amount of possible total damage in case of an accident at a hazardous production facility

Table 3

Results of calculating the risk of fire in sulfur storage warehouses

Place of accident occurrence	Probability of failure (incident) year^{-1}	Probability of an accident, year^{-1}	Potential fire risk, year^{-1}	Individual risk of an employee in a sulfur warehouse, year^{-1}	Estimated amount of damage, thousand rubles
Sulfur storage warehouse	3×10^{7}	2.4×10^{-8}	9×10^{7}	2.7×10^{-7}	3100

According to the results of calculations, the probability of an emergency for the most dangerous scenario is 2.4×10-8 year^{-1}, the value of the potential fire risk in the sulfur storage warehouse is 9×10-7 year^{-1}, the value of the individual risk of an employee in the sulfur warehouse is 2.7×10-7 year^{-1}. This, according to the document "Methods for assessing the risks of emergencies and standards of acceptable risk of emergencies", approved by the First Deputy Minister of the Russian Federation for Civil Defense, Emergency Situations and Elimination of the Consequences of Natural Disasters of 09.01.2008 No. 1-4-60-9, corresponds to the zone of acceptable risk. However, to exclude (minimize) the possibility of an emergency in sulfur storage warehouses, it is necessary to introduce modern technical means of production, innovative technologies and additional organizational measures, such as:

— implementation of production control over the implementation of industrial safety requirements in accordance with the approved regulatory and legal acts;

— conducting training sessions and checking the readiness of working shifts for actions to prevent and eliminate emergencies;

— timely cleaning of the territories of the object and its surrounding areas from garbage and grass;

— implementation of recommendations in accordance with the "Information and technical handbook on the best available technologies" of 17.04.2019 No. 46-2019 Reduction of emissions of pollutants, discharges of pollutants during the stocking and storage of goods (cargo).

Conclusion. Thus, the task of minimizing the negative impact of the production activities of AO Ust-Donetsk Port on the environment is possible in the case of developing a set of environmental measures and industrial safety measures necessary for the organization of transit cargo handling, namely, rational methods of cargo handling, as well as improving the technology of their processing. To avoid the possibility of emergencies, it is necessary to introduce modern technical means of production, innovative technologies and additional organizational measures.

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L. E. Pustovaya — scientific supervision, formulation of the main concept, analysis of the research results, revision of the text, formulation of the conclusions; V. A. Chebysheva — collection of the initial data, formulation of the goal and objectives of the study, calculations, preparation of the text, development of the recommendations.