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Comparative assessment of emergency risks of mining enterprises in the Baikal region

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Abstract. In the article, we carried out a comparative assessment of emergency risks of mining enterprises in the Baikal region. We analyzed the probabilities of major emergencies by means of the incident tree. We also evaluated the consequences of the impact caused by damage effects of emergency situations, and offered key measures to reduce the levels of emergency risks.

1. Introduction

Mining is essentially the only available way to obtain raw materials for meeting the needs of industrial sectors and creating various types of products for human needs. It is no secret that the entire economic power of any country and its position on the geopolitical stage directly depends on raw materials produced by the mining industry.

But despite the uniqueness and the need for mining, as practically with any human activity, the implementation of these types of work makes a negative impact on the environment. Of course, the degree of impact largely depends on the type of mineral being mined, the method of mining and the volume of recoverable raw materials. The impact is made on all geospheres of the earth, namely water bodies, land resources, atmospheric air and the biosphere, the impact on which can be divided into the impact on the natural environment - flora and fauna - as well as the impact on humans themselves.

Although while operating, mining enterprises are capable of causing significant damage during the entire life of the mineral field and even after its exhaustion, the colossal, uncontrolled and most frightening effect occurs as a result of an emergency situation. And it is not for nothing that the Federal Law “On Industrial Safety of Hazardous Production Facilities” of July 21, 1997 No. 116-FZ has a separate category of hazardous production facilities for facilities engaged in mining and mineral processing. Although the probability of emergency situations, provided appropriate measures are implemented, is relatively low, one would rather not give an optimistic forecast. The consequences of an emergency situation themselves can be irreversible and cause catastrophic damage both for humans and their lives and for the natural environment. Damage can be various and depends primarily on the type of a man-made emergency situation. There exists a procedure for assessing emergency risks in order to identify the main causes of an emergency and subsequent consequences of its development in various situations, to determine the probability of an event and assess the possible damage if occurred, followed by the establishment of basic measures to prevent and minimize the consequences. The procedure itself, in



accordance with the Federal Law No. 116-FZ of July 21, 1997 “On Industrial Safety of Hazardous Production Facilities”, is obligatory when working on the development of the industrial safety declaration. As part of this work, we carried out a similar procedure for mining enterprises in the Baikal region.

2. Materials and methods

The emergency risk assessment procedure, as noted earlier, consists of three main steps:

- identification of the main sources and causes of risk as well as possible consequences of its occurrence;
- assessment of the levels of individual risk components and the system as a whole;
- development of risk reduction measures.

In our work, we chose the method of assessing emergency risks by means of building an incident tree as the main method. The incident tree analysis is a structured method of identifying possible causes of an adverse event or hazard. This method allows for selecting and combining all possible causes into categories with the subsequent study of all possible hypotheses. However, the application of this method only makes it possible to identify actual causes, that is, causes are determined only based on empirical data. The structure of the analysis itself is represented in the form of a graphical construction of a diagram with a tree structure. This method involves the analysis performed by a group of experts with relevant knowledge and experience on the situation in question.

The procedure for analyzing with the incident tree method consists of the following steps:

- identification of the effect that must be analyzed, and placing it on top of the corresponding block of the diagram (the main event);
- determination of the main (key) categories of causes and their indication in the corresponding blocks of the diagram. There are usually several categories of causes, such as personnel, equipment, work environment, processes, etc.;
- indication of possible causes for each main (key) category on the branches and subbranches to describe the relationships between them;
- continuation of the study by iteratively asking the questions “why?” or “what caused it?” to identify links between the causes;
- analysis of all branches and subbranches, aimed at checking the consistency and completeness of the identified causes, and their relationship to the main effect;
- identification of the most probable causes of this effect on the basis of the shared opinion of the expert working group and the available objective evidence.

However, when applying this diagram, it is difficult to quantify the result and estimate the probability of the main event, since the reasons are mostly understood as possible factors that can cause the event in question, rather than failures with a known probability of occurrence.

The incident tree method is usually used to determine qualitative assessments. But it is acceptable, by adopting statistical data on the frequency of occurrence of a particular cause, as was done in this paper, to assess the probability of these causes and a negative event as a whole, which puts this method on a quantitative-qualitative level.

Our choice of this method as the preferred one for assessment of emergency risks in this paper was based on the following advantages:

- the method allows for analyzing all possible causes and hypotheses of a negative event;
- a graphical representation of the results in an easy to understand form;
- identification of areas where additional data are required.

But knowing only the probability of the negative event occurrence it is impossible to talk about the risk index value without its second component, that is, the severity of the consequences of the negative event occurrence. For this, we reviewed and identified all possible consequences for each cause of the tree

diagram. Depending on the consequences of the occurrence of a particular cause, we identified the areas exposed to the negative impact, determined the main damage effects, calculated the limits of their impact, and estimated the damage from their destructive impact based on official methods. This procedure gives the possibility to determine the emergency risk value with certainty.

3. The results of the study and their analysis

We chose the mining enterprises in the Baikal region as the objects of research. This territory is united by being adjacent to Lake Baikal, UNESCO World Heritage Site. One of the regions united by such a neighborhood is the Irkutsk region.

The Irkutsk region is not only a region bordering Lake Baikal, with its unique flora, fauna and the largest reserves of fresh water, but also has large deposits of various minerals. The Irkutsk region is a storehouse of mineral resources, including deposits of more than 60 types of minerals, which are represented in the form of such objects as gold, rare metals, black and brown coal, potassium salts, oil, natural gas, gem and ornamental stones, etc. In 2017, 91 subsoil use licenses were issued in the Irkutsk region. But the more mining enterprises in our region, the higher the chance of an emergency at any of them. In this regard, it confirms the need for total control of emergency risks at each of them.

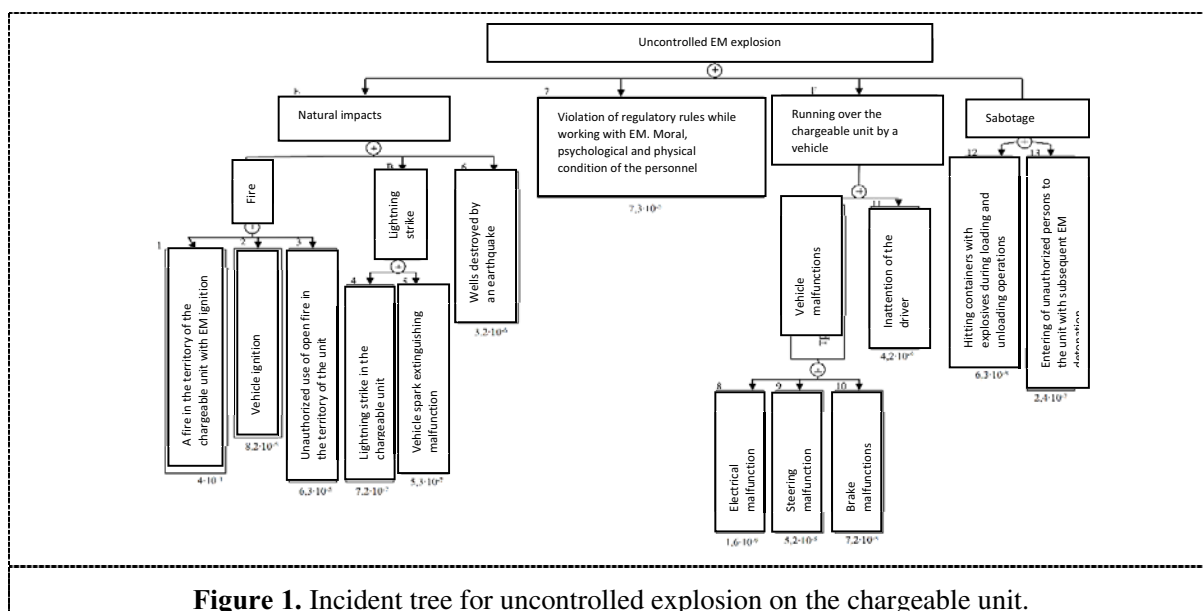
First of all, it is necessary to determine which emergencies are typical for the performance of mining operations. As part of this work, we carried out an emergency risk assessment only during mining operations, without the stages of primary processing of raw materials or auxiliary work. Based on the accepted conditions, we consider the probability of man-made emergencies using their existing classification, that may occur during mining operations.

Emergencies in communal life support systems as well as emergencies with the release of radioactive and biological hazardous substances during mining operations in the Irkutsk region are not typical. Emergencies in electric power systems and transport accidents will not cause particularly noticeable damage and will be local in nature. The sudden collapse of buildings and structures, provided plans for repair and maintenance are followed, is likely to be avoided. Hydrodynamic accidents are more typical for enterprises on the territory of which, as a result of drainage work, the installation of such structures was required. On the territory of the Irkutsk region, there are no structures, the destruction of which will lead to significant damage. Emergencies with the release of chemically hazardous substances are quite likely, but this type of emergency situations is typical for the stage of primary processing of raw materials and not at every enterprise. Emergencies at wastewater treatment plants are another emergency situation type uncharacteristic for mining operations. The formation of wastewater during mining operations is of a minimal amount compared with other stages of the technological process. Emergency situations associated with fires and explosions are the most hazardous and probable, especially if the enterprise extracts combustible minerals, or uses the drilling and blasting method to break down the rock mass.

In this regard, from a multitude of enterprises we selected two for the purpose of conducting a comparative assessment of emergency risks. The first one is the branch of PNK Angasolsky crushed stone plant JSC, which extracts granite using the drilling and blasting method, with the production capacity of about 800 thousand tons per year. The choice of this enterprise is based on its territorial proximity to the settlement of Angasolka, just 800 meters from the borders of the open pit zone. The second enterprise is Irkutsk Oil Company LLC, and in particular the production site of the Yarakta oil and gas condensate field, the main man-made hazard for which is the occurrence of a fire. The main hazard in case of events including a fire at the production site is the subsequent probable ignition of oil and, due to the territorial location of the site in the forest, the passage of flame to nearby trees with the subsequent occurrence of a natural fire. Let us analyze emergency risks at the objects under consideration one by one.

As noted earlier, granite at Angasolsky crushed stone plant is extracted by means of drilling and blasting operations. In this regard, the weakest link in initializing an emergency situation with an

explosion is the process of assembling an explosive network on the chargeable unit. The main causes of an emergency situation on the chargeable unit are: fire, explosion, sabotage, and earthquake. A fire may be caused by: direct lightning strike, unauthorized use of open fire on the chargeable unit, burning containers from explosive materials, smoking, malfunction of a vehicle or its spark-extinguishing system when moving on the unit, accidents of electrical devices. As a result of a fire, EM may ignite with the subsequent transition of burning into explosion. EM explosion can also be caused by: fire, in cases when burning large EM quantities can result in detonation, running over the chargeable unit; bullet-wise EM firing while preventing unauthorized persons from entering the territory of the chargeable unit; violation of the EM handling rules by principals and performers. Figure 1 shows causes of an uncontrolled EM explosion on the chargeable unit in more detail.



For the causes of uncontrolled explosion of explosive materials on the chargeable unit presented in the incident tree, we analyzed statistical information to determine the probability of their occurrence. Based on the information received, we made a calculation of the probability of uncontrolled detonation on the chargeable unit. The probabilities of events were assigned numerical and alphabetic values specified in the incident tree. The calculations allowed us to conclude that the biggest influence on the probability of uncontrolled explosion on the chargeable unit is made by the occurrence of a fire on the chargeable unit.

The main traumatic factors in an emergency situation involving uncontrolled explosion are: injuries by chips and fragments of rock mass and crushable materials as well as the direct impact on a person by an air shock wave and detonation products of explosive charges. We calculated the areas affected by these explosion damage effects based on the Order of the Federal Service for Environmental, Technological and Atomic Supervision No. 605 of December 16, 2013 "On the approval of federal standards and rules in the field of industrial safety "Safety rules for blasting operations" (as amended on November 30, 2017) and the definition of the probit-functions for the explosion pulse of compression and excess pressure.

Based on the results of the calculation, it was found that the zone of glazing destruction from an air shock wave equals to 11,683 m; the zone of average destruction of buildings and structures from an air shock wave is 2,300 m, and the zone of severe destruction is 1,400 m. For a person, the size of the death zone from an air shock wave impact will be 420 m, and 450 m - from hazardous projection of chips and

fragments of rock and rock mass. Taking into account the previously noted distance to the settlement of Angasolka, these zones of impact by damage effects will in most cases lead to the destruction of buildings and structures. Only employees of Angasolsky crushed stone plant will most probably be in the zone hazardous for people.

A completely different emergency situation is found at the oil producing site of the Yarakta field. The most hazardous and difficult to eliminate in terms of technology are accidents with blowouts. An emergency situation that begins in the form of a backflow may turn into a blowout with a fire, destruction of the well and death of people. Emergencies turning into disasters adversely affect the environment and the activities of nearby industrial facilities. Emissions and blowouts in oil and gas fields containing hydrogen sulfide are particularly hazardous. The incident tree for emergency gas flowing from a well is shown in Figure 2.

As the main event we use emergency gas flowing from a well. This critical event is characterized by the failure of the BOP equipment and the unimpeded movement of the gas unit to the wellhead with the subsequent release of oil and gas fluid.

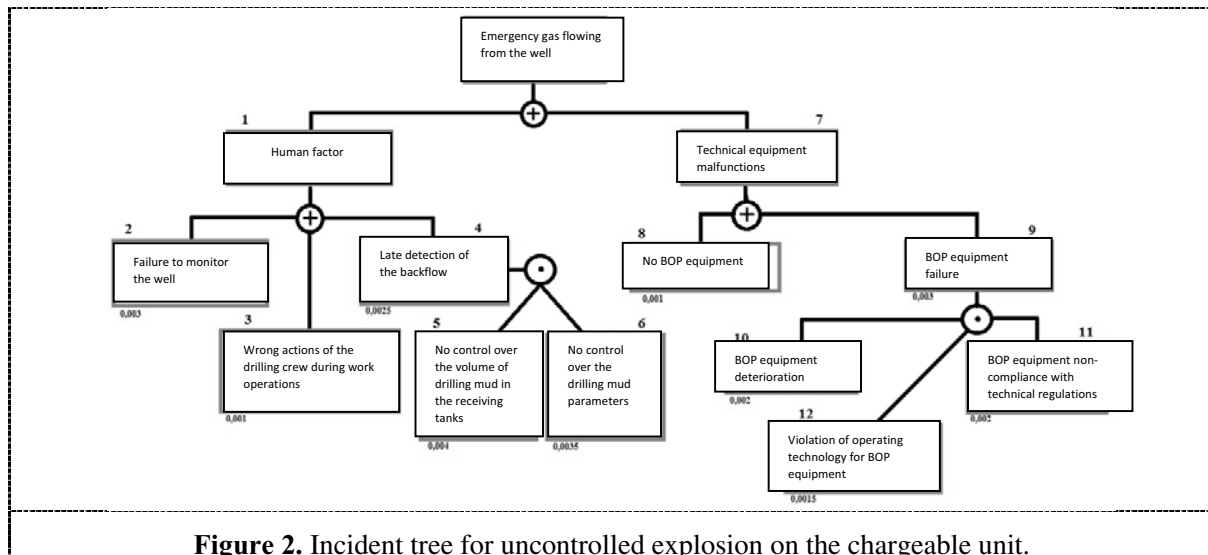


Figure 2. Incident tree for uncontrolled explosion on the chargeable unit.

The formation of scenarios for the development of possible emergencies and the determination of the probability of the occurrence of each scenario is carried out depending on the type of initiating events, the type of equipment on which it occurred, the properties of hazardous substances and the conditions of their containment in equipment.

In the occurrence of this emergency, one will see the impact of the main damage effects of the fire, such as the formation of a fireball from the primary gas cloud, and the subsequent gas combustion with a possible transition to oil burning with a burning intensity sufficient to damage a person. Based on the results of the assessment, it was found that the diameter of the combustion zone will be 546 m, while the primary fireball will have a radius of 149 m, a lifetime of about 11 s, and the intensity of thermal radiation sufficient to cause 2nd degree burns to personnel.

4. Discussion

The results of the emergency risk assessment allowed us to identify significant consequences of their occurrence. Accordingly, to reduce the risk of emergencies, it is proposed to provide for the following measures:

- blasting work personnel should conduct an input quality control of the explosive materials shipped to the unit for charging a mass explosion;
- to organize the study of regulatory documents and information notices on the blasting work by blasting work personnel and specialists of the blasting site;
- to organize a briefing with drivers, loaders and security officers;
- to organize the revision of the “Plan for the elimination of accidents in the open pit” and to conduct personnel familiarization with it;
- to organize the control over the observance by the personnel allowed to perform blasting work of the fire safety rules during the work;
- to introduce an emergency risk management system into the developed safety management system.
- carrying out measures for personnel training, establishing actions in the event of an emergency as well as preparation of plans and instructions for the prevention of emergency situations;
- a barrier that reduces the probability of an ignition source to occur or flame to spread inside the process system;
- carrying out regular maintenance, inspections and timely replacement of worn-out parts and mechanisms according to the datasheet for the relevant equipment.

The implementation of such measures will reduce the probability and damage from the occurrence of the considered emergency situations at these enterprises.

5. Conclusion

The considered procedure for assessing emergency risks will allow for an effective analysis of the deviations of critical elements in the occurrence of emergency situations. The application of the multi-factor risk analysis using the methodology of expert systems in the form of constructing tree diagrams allows for determining measures to reduce the ES risk and the effectiveness of their implementation at the production facility, taking into account data on the technological process under conditions of insufficient volume and uncertainty of the initial information.

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