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SAFETY RISK MANAGEMENT IN BIH COAL MINES – OBJECTIVE NEED OR A BURDEN

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SUMMARY

Safety risk management in Bosnian-Herzegovinian underground coal mines is not based on a systematic approach and standardized risk management methods. Mostly there is a traditional approach present, i.e. reaction to incidents/accidents that happen. This paper aims to point out the need for proactive approach introduction with an emphasis on importance of ventilation systems failure mechanism simulation analysis in planning of people and property defense and rescue in crisis situations. Based on ventilation parameters measuring results for a given research site (brown coal mine), a model was developed on which a simulation analysis was performed for three characteristic ventilation failure cases: spontaneous oxidation at the longwall exit, collapse at the entrance to the longwall and methane outburst - preparation of a new excavation field. VnetPC and CFD "Fluent" software packages were used to simulate mine ventilation.

Keywords: risk management, brown coal mine, safety, ventilation system, longwall, simulation analysis, VnetPC, Fluent.

INTRODUCTION

The principle of "normative safety" is dominant in Bosnia and Herzegovina's (BiH) coal mines, with frequent and common basic principles and obligations neglection, a routine approach to safety and efforts to meet the law, regulations and technical norms requirements. The scope of consequences and probability of certain dangerous conditions as well as their treatment in accordance with risk management standards is not considered.

The Law on Mining Industry of the FBiH obliges mines to develop a Defense and rescue plan for collective risks and accidents, which must be adjusted to the specific circumstances and specifics of the mine, updated in a timely manner, provide all preventive and operational measures and activities related to potential hazards.

All decisions envisaged by the mine Defense plans mainly depend on the "persons responsible experience" and possible information from the endangered part of the mine, provided that communication with workers is not interrupted and that the gases and ventilation parameters remote control system is not damaged or interrupted.

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The current safety concept and technical solutions for protection in underground coal mines in BiH do not provide adequate protection of human life and health in isolated areas in case of mining accidents, and even during some events that do not last long and after which production can be re-established.

The mine defense plans analysis has shown that crisis management conventional methods in coal mines in case of components or ventilation system as a whole failure do not provide an adequate level of workers life and health safety [6].

In modern risk management theory, adverse events domain extends to so-called "missed opportunities", thus the risk management process goes beyond the traditional safety framework, and practically encompasses the entire decision-making and management process [3] [7]. Everything that has not been done in a favorable and feasible way in given conditions becomes risky.

The new risk management concept is a significant shift from the current system of "normative safety", according to which accidents in mines that are not the result of violating the regulations or non-compliance with prescribed standards are considered "force majeure". Risk management implies the identification of the "risk owner" and his obligation to take all objectively possible measures to maintain risks at the accepted level, i.e. to prevent an adverse event.

2. VENTILATION SYSTEM FUNCTIONING HAZARDS

Underground coal mines are complex systems in technical and technological terms, especially in terms of ventilation. Mine ventilation system reliability during its exploitation period implies the ability to preserve designed ventilation parameters that ensure prescribed ventilation regime and air properties (gas, thermodynamic and climatic relations) in mining premises.

Numerous models for mine ventilation systems risk assessment have been developed in the world, while in our country there are no criteria or methods for risk parameters calculation. Current mining regulations in BiH treat the ventilation systems reliability according to a simplified procedure by determining limit values of the equivalent orifice, fan pressure potential and differences in the potential of the ventilation system that must meet prescribed limit requirements for normative stability of ventilation.

Factors with the greatest impact on mine ventilation system reliability and ventilation risks are [2]:

- aerodynamic resistances of the ventilation system elements,
- fan operation reliability and ventilation facilities functioning,
- network topology (organizational schematics, system organization),
- occurrence of sudden threats such as explosions, mine fires, rock burst, gases and materials outbursts, collapse,
- ventilation facilities maintenance planning and implementation,
- conditions and methods of exploitation,
- initial data in calculations (accuracy) and
- methods of applied ventilation systems calculations.

An adverse event of a mine ventilation system means a state of functioning capacity loss, violation of the designed or prescribed regime, or a state in which the ventilation facility (process) or some part of it partially or completely loses its working capacity.

The ventilation system always works with a certain risk, and the occurrence of ventilation system failures in mines cannot be ruled out even when extensive prevention measures are taken. For efficient protection against unexpected events in coal mine, it is important to predict possible ventilation conditions and the development of individual failures to effectively manage risks. In case of severe failures, key information is usually missing or the reliability of awareness about processes and phenomena is limited. Rescuers enter the mine with unclear picture of the situation. Experience with coal mining accidents shows that the existing communication systems in mines are not reliable enough, and that one of the first challenges is to establish a connection with endangered workers.

In recent years, many published scientific and professional papers have been dealing with numerical simulations of ventilation system failures, and they have also been used for major mining accidents analysis.

Research by Greuer R.E. [5] indicates the physical principles and principles of mine ventilation systems operation as well as the skills of ventilation modeling. The paper then describes several computer programs for modeling the interaction of mine ventilation and fire. Yuan and Smith [10] [11] conducted research on spontaneous heating, by CFD numerical modeling, investigating spontaneous heating in old workings.

Papers [4] and [8] present a case of the practical CFD methods application in mining accidents research, and provide a complete experiences analysis. The paper [1] analyzes local increase in volume flows and flow velocities in a large profile room (longwall) by controlled recirculation, and the impact of this process on explosive and toxic gases concentrations in mine workings.

3. EXPERIMENTAL RESEARCH METHODOLOGY

Underground coal mines are a specific and very complex problem for analyzing the reliability of systems required to ensure working and living conditions due to long distances and depths, long ventilation paths, the presence of methane and other explosive and flammable gases and substances, sudden occurrence of toxic gases, harmful coal dust and a number of other detrimental effects on workers.

The selected research site (mine B) has a pronounced stochastic nature of the process characterized by specific technological and natural conditions related to gas, gases dynamics, tectonics, hydrogeological conditions, etc. that cause unpredictable hazards.

With the aim to develop a technical model for predicting and preventing adverse effects of the ventilation system (or its components) failure, a series of "in-situ" and laboratory measurements were conducted within research, as follows:

- effective fan pressure (depression),
- air flow rates,
- air and rock mass temperatures,
- coal tendency to spontaneous combustion testing,
- testing dust flammable and explosive characteristics.
- volumetric air flow,
- aerodynamic resistance,
- air chemical composition analysis,
- monitoring the occurrence of oxidation processes (analysis of fire indicators)

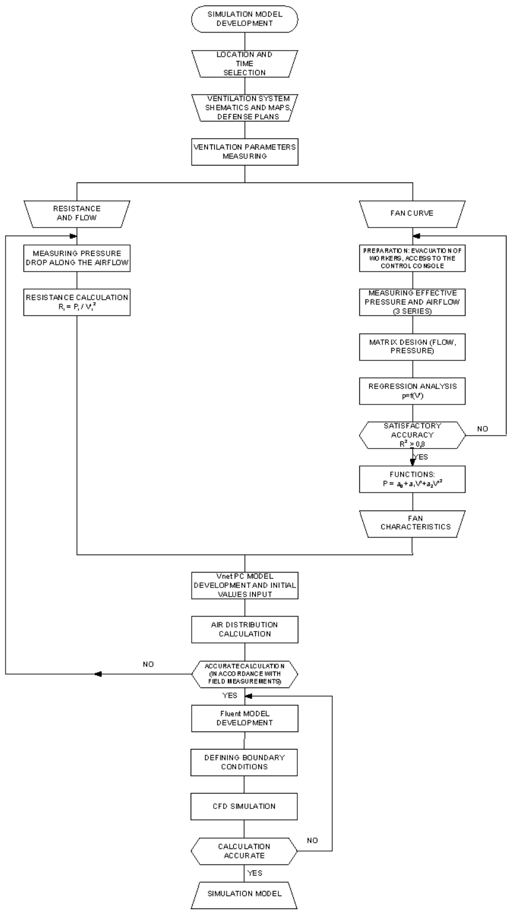

Figure 1. Schematic presentation of "in situ" ventilation parameters measuring plan and simulation models development [6]

Based on the obtained research results, a model was developed for computer simulation of contaminant distribution processes and changes in ventilation parameters with Hardy-Cross method using VnetPC software package and CFD software package „Fluent", which is illustrated by the flow diagram presented in Figure 1.

4. COMPUTER SIMULATION OF VENTILATION SYSTEM FAILURE IN COAL MINE B

Figure 2 shows a linear scheme of underground Mine B ventilation system with two main inlet air flow rooms and one outlet to the main ventilation heading inclined roadway.

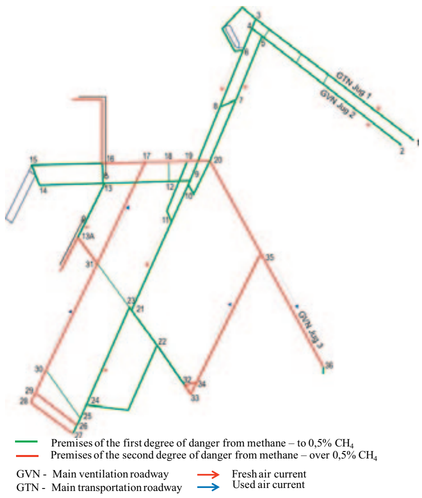

Figure 2. Mine B linear ventilation layout [source: mine documentation]

Working with three active longwalls in a thick coal seam prone to spontaneous oxidation imposes the necessity of analyzing the process within the system itself, which is the "heart" of both the production system and mine ventilation.

For the combined analysis, a ventilation compartment with two longwall excavations was selected, as shown in the normal operating mode in Figure 3.

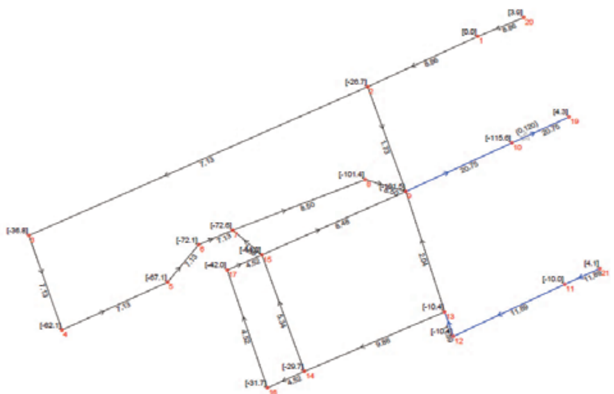

Figure 3. Mine B longwall linear ventilation layout (normal air distribution) [6]

In the normal state of ventilation, and at the time when three longwalls are active, as shown in Figure 3, two ventilation compartments (VO) can be observed: in one of them there is a mechanized longwall excavation, and in the other one there are two classic longwalls. As can be seen from Figure 3, the two VOs have a joint outlet air flow so that the total outlet air flow has a volume flow of 20.75 [m^3/s]. The inlet air current in the northern part of the excavation has a volume flow of 8.86 [m^3/s], and 7.13 [m^3/s] goes towards the longwall itself. Classic longwall excavations are ventilated with a total of 11.89 [m^3/s] of air.

In order to consider potential consequences of characteristic and possible failures on the entire ventilation system functioning, a computer simulations of characteristic cases were performed on a previously calibrated model for ventilation calculation, which is presented in the following subsections:

1. Spontaneous oxidation at the longwall outlet where 300 [ppm] CO is released;
2. Collapse at the inlet to the longwall (inlet air current) where the flow is reduced to 20% of the initial value;
3. Methane outburst - preparation of a new excavation field longwall, simulated methane concentration 25%.

The simulation analysis have determined ventilation branches that failed in case of simulated danger. The assessment of the contaminants distribution and their intensity determined zones where workers and the production process are endangered.

The Mine defense plan analysis for simulated failures have shown that the personal protective equipment provided by the mine to workers is not adequate due to the limited protection level and that it is necessary to plan secondary protection measures for most possible failures, Figure 9.

Simulation analysis have also indicated a high probability of the secondary failures occurrence which are not treated by the Defense plan, and protection measures are not provided for them.

4.1. SPONTANEOUS OXIDATION AT THE LONGWALL EXIT WITH 300 PPM CO RELEASED

The oxidation process at the longwall outlet was simulated, with a concentration of 300 [ppm] of carbon monoxide registered at the oxidation site, as illustrated in Figure 4.

Immediately when the air is connected to the air current from the first classical longwall (point 9), the CO concentration decreases by 60%, and only the rooms of the outlet air current are contaminated.

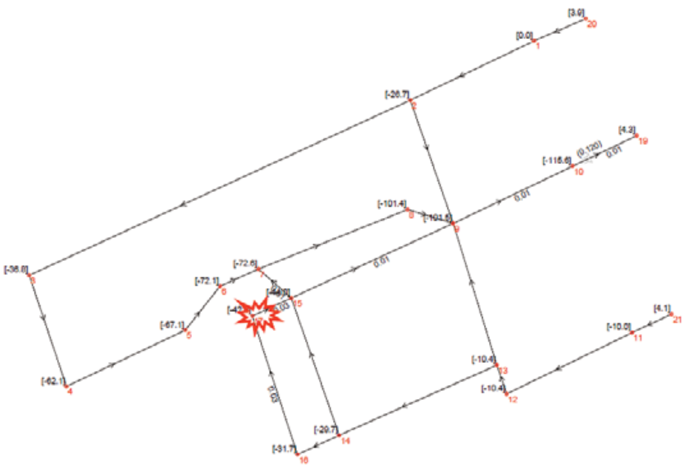

Figure 4. Simulation of spontaneous oxidation [6]

The increase in carbon monoxide concentrations is evident in branches 16-17 and 17-15, i.e. in the longwall rooms where oxidation occurs and the connecting roadway of the exit room from that longwall to the place where it connects with the air flow from the second ventilation compartment longwall.

From the aspect of "failure" and workers endangerment in this phase, we can talk about the endangerment of workers in rooms of the outlet air current. Since the outlet air currents in this mine are used for the materials transport and other types of "auxiliary transport", which is very pronounced in this case, the failure of this type can endanger workers and the process in those rooms. Long ventilation paths, slopes, unfavorable conditions for movement and possible workers disorientation can increase evacuation time out of the scope of protection with personal protective equipment, and it is necessary to consider other protection strategies to reliably save lives from short-term and sudden increases in CO and other oxidation process products.

The defense and rescue plan for collective risks and accidents envisages this danger as part of the group: "plan for protection against fire, explosion and gases" (Figure 5).

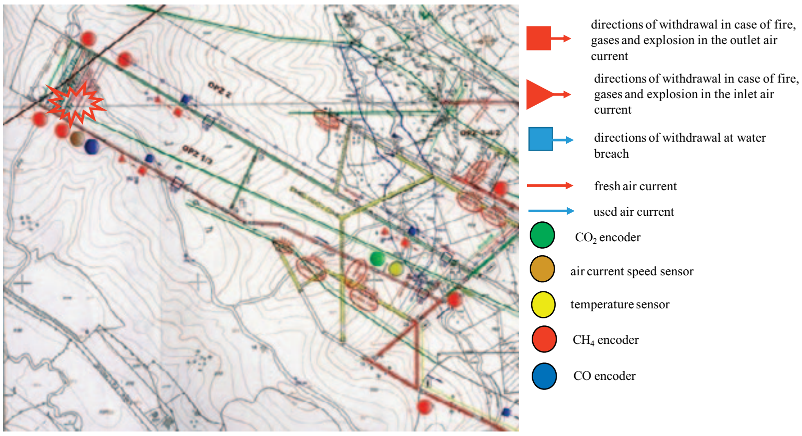

Figure 5. Detail from the Defense plan for simulated hazard [source: mine documentation]

The plan for this group of dangers also predicts the air flow reversion. The decision on reversion is made by the managers based on the situation "experientially". Recommendation for the Defense plan improvement is that such decision-making is preceded by simulating the various possible scenarios and measurements, and detailed, clear and precise prescribing of procedural steps. Air flow reversion can result in contamination of other sites in coal mine and serious endangerment of workers if they are not evacuated in time. This danger cannot be ruled out, given that the Defense plan does not consider such secondary ventilation failures.

4.2. COLLAPSE AT THE LONGWALL ENTRANCE (INLET AIR CURRENT), VOLUMETRIC AIR FLOW REDUCED TO 20% OF INITIAL VALUE

Figure 6 shows simulation of collapse at the longwall entrance.

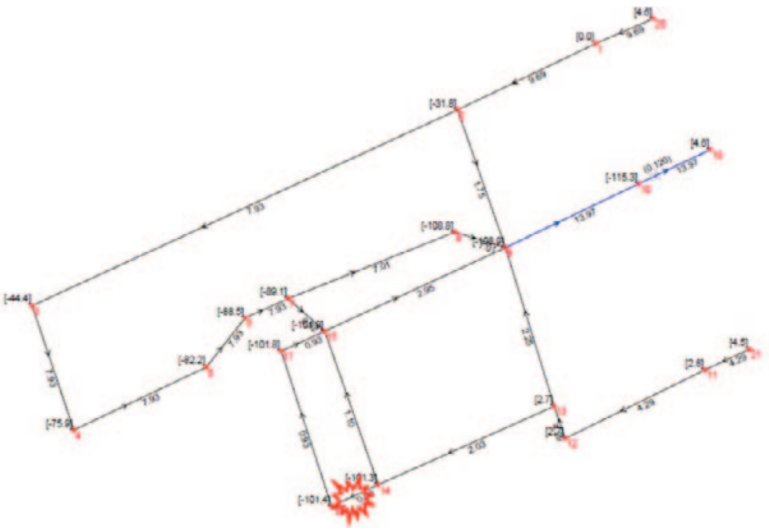

Figure 6. Simulation of collapse at the entrance to the longwall [6]

The collapse or reduction of the effective room profile in any part can have a great impact on ventilation. Even when stacking large quantities of materials or timber, the profile may decrease, resistance may increase and ventilation may be compromised.

Table 1 shows simulation results for the case when the entrance room profile is reduced to 20% of effective compared to the nominal calculated.

The combination of reduced room profile due to pressure or poor maintenance, roof support damage, installation of transport and other equipment and stacking materials in room can, in conditions that seem normal from the aspect of all processes functioning, endanger workers lives. If there is oxidation hotspot in rooms, the situation is further complicated.

Table 1. Changes in airflow by branches during stimulation of collapse at the longwall

From	To	Flow -normal conditions (m^3/s)	Flow during the collapse at longwall (m^3/s)	Flow difference, %
1	2	8,86	9,69	9,37%
2	3	7,13	7,93	11,22%
3	4	7,13	7,93	11,22%
4	5	7,13	7,93	11,22%
5	6	7,13	7,93	11,22%
6	7	7,13	7,93	11,22%
7	8	8,50	7,01	-17,53%
8	9	8,50	7,01	-17,53%
9	10	20,75	13,97	-32,67%
11	12	11,89	4,29	-63,92%
12	13	11,89	4,29	-63,92%
13	14	9,86	2,03	-79,41%
14	15	5,34	1,10	-79,40%
15	9	8,48	2,95	-65,21%
14	16	4,52	0,93	-79,42%
16	17	4,52	0,93	-79,42%
17	15	4,52	0,93	-79,42%
13	9	2,04	2,25	10,29%
9	2	1,73	1,75	1,16%
7	15	1,38	0,92	-33,33%
10	19	20,75	13,97	-32,67%
20	1	8,86	9,69	9,37%
21	11	11,89	4,29	-63,92%

The red color in Table 1 indicates branches where the air flow volume is reduced. In some branches, an increase in volume flow is observed, which is caused by the air reduction in branches marked in red.

As a particularly serious dimension of this problem, it is necessary to investigate the possibility for such a disturbance to occur without being registered by remote control system or not being registered until the moment when a more serious disturbance of gas relations occurs. It is difficult to install and maintain remote control sensors in the rooms immediately around the longwall, and regular measurements and controls at ventilation inspection stations are outside the affected area because standard ventilation inspection stations are installed at the beginning of the excavation fields.

The defense plan envisages measures for this danger, which are reduced to providing the air through perforated pipes, and then removing the rubble.

This type of disturbance needs to be treated more carefully in defense and rescue plans, especially in terms of reliable detection of any changes in resistances and flows in rooms that are most important in the ventilation system: those that make up the production system, always occupied with many workers and which are exposed to the highest heat and gas loads.

4.3. METHANE OUTBURST – PREPARATION OF A NEW EXCAVATION FIELD LONGWALL, SIMULATED METHANE CONCENTRATION 25%

In the case of methane outburst in preparation of a new excavati°n field for a longwall with 1.78 [m^3CH_4/s] (Figure 7), the working space and the return airways are gas filled.

Figure 7. Simulation of methane outburst at the longwall [6]

Flammable or explosive methane concentrations are present throughout the outlet air current, which implies why it is necessary to carefully plan the exclusion of potential ignition sources. The immanent presence of oxidative processes on the open coal seams surface, as well as along the air leakage, results in possibility of methane ignition, in cases where a outburst would occur.

In such accidents, the life danger lasts relatively short, and the potential evacuation directions are not contaminated, so it is necessary to ensure conditions for survival only until the workers evacuation to the surface in usual directions.

Figure 7 shows the part of the mine where the methane outburst at a concentration of 25% was simulated. Table 2 shows methane concentrations for simulated hazard from which it is evident that flammable or explosive concentrations are present in all branches.

Table 2. Methane concentration by branches during the outburst in longwall

Branch	Air flow - normal conditions [m^3/s]	CH_4 concentrations [%]
3-4	7,13	25
4-5	7,13	25
5-6	7,13	25
6-7	7,13	25
7-8	8,50	21,85
8-9	8,50	21,85
9-10	20,75	10,28
10-19	20,75	10,28

Methane outburst is a serious situation that occurs in (methane) gassy mines, and is manifested by mining operations in the area with high methane pressure in the coal seam, roof, floor or by a crack system connected to a remote methane "reservoir" under pressure. It is usually a "point" source of methane, which can create dangerous concentrations in local conditions, even when it comes to small amounts of this gas. In the Defense plan, this danger was treated in the group "plan for fire protection, explosion, and the gases occurrence" with a general approach and measures for protection and rescue.

In the case of methane presence, action strategies must include three dimensions:

1. Early detection of dangerous concentrations and exclusion of possibilities of gas ignition by works termination and workers evacuation. If there is spontaneous oxidation or smoldering, it can be a source of ignition, so the scope of this measure is limited. In the event of a methane explosion, the mechanical effect of the explosion and its consequences can be serious for workers in the immediate vicinity.
2. The methane explosion can create conditions for the propagation of coal dust explosion, which is one of the explosions with the most severe consequences in mining history. It is necessary to pay special attention to this possibility.
3. Explosion products can endanger workers from the place of origin to the mine exit.

4.4. CFD SIMULATION OF RESEARCH POLYGON VENTILATION PARAMETERS

Although previous Hardy-Cross-based simulations did not identify complex cases of ventilation risks, in case of three large-profile longwalls in a relatively small space, a much more extensive and objective view is provided by CFD simulation based on the "finite volume" method.

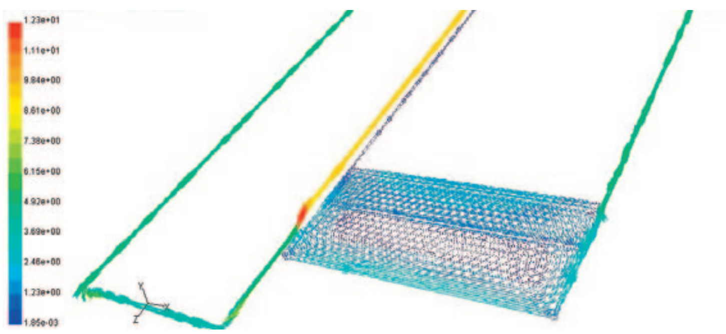

Figure 8. Air velocity vectors [m/s] [6]

Figure 8 shows three analyzed longwalls, where space is discretized on model, as well as the interaction with the old workings and the surrounding rocks. Arrows and different colors show air velocity vectors inside the rooms.

The air flow inside the two classic longwalls on the right side of the image can be seen as particularly complex in terms of ventilation. Velocity vectors indicate air circulation and leak, which is why in the case of increased cracking, the presence of faults or excavations below previously exploited levels, a spontaneous oxidation can be expected.

5. DISCUSSION OF RESEARCH FINDINGS

Figure 9 shows four typical cases of protection and rescue measures, depending on duration of ventilation disorder due to accident, and the safety time provided by each of the 3 levels of workers protection.

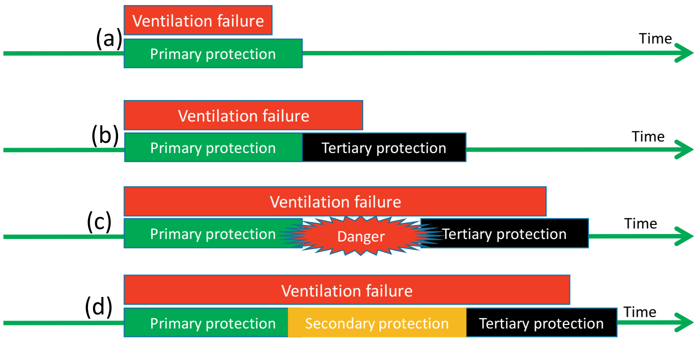

Figure 9. Measures for people protection and rescue from the consequences of ventilation failure

In case (a), primary protection, as it is by regulations in mines in BiH, provides sufficient time to evacuate or otherwise rescue vulnerable workers, when a secondary or tertiary level of protection is not required. When a failure occurs, as in case (b), tertiary protection is necessary, which in combination with primary protection is sufficient and adequate for rescuing endangered miners.

The case under (c) is characterized by a longer period of workers vulnerability, so that primary protection does not provide sufficient time for survival, and tertiary protection cannot provide conditions for evacuation quickly enough. In this case, there is a "time of uncertainty" which is characteristic of cases of trapping and isolation of workers in the mine workings.

Based on experiments and simulations, it has been concluded that in real conditions, probable cases illustrated by the situation "c" from the previous figure are possible.

Primary protection systems are used in coal mines in BiH, and in case of accidents, tertiary protection is applied. The lack of a "second level" - secondary protection - results in frequent "battles with time" and uncertainty about the fate of trapped miners underground. The air needed for survival is not the only thing that needs to be provided in secondary protection measures. It is necessary to solve problem of supplying the drinking water and food, as well as communication and lighting in case of prolonged ventilation interruption.

6. CONCLUDING REMARKS

A detailed review of actual safety concept and technical solutions for protection in underground coal mines in BiH has revealed an objective need to move off the dominant principle of "normative safety" to a proactive approach. In order to create necessary preconditions for successful and efficient safety risks management, it is essential to start with immediate regulation and legislation implementation in accordance with the modern approach and practice of countries with developed mining industry.

Major accidents in mines usually do not occur solely as a result of "force majeure", but result from unwanted and unsafe conditions, and often leads to a numerous induced hazardous conditions. The distinctly stochastic nature of the underground coal mining process, where it is practically impossible to predict all aspects, is a serious problem that must be given more importance and attention. Mining operations take place in environments that are highly heterogeneous and potential sources of danger can