TECHNICAL, ECONOMIC AND SOCIAL RISKS ENCOUNTERED IN THE MINE CLOSURE ACTIVITY IN THE JIU VALLEY

RISCURI TEHNICE, ECONOMICE ȘI SOCIALE ÎNTÂLNITE ÎN ACTIVITATEA DE ÎNCHIDERE A MINELOR DIN VALEA JIULUI

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Abstract: *Closure of a coal mine is based on a series of specific phased works over periods of time in which it is necessary to take into account a number of technical risk factors to which underground workers are exposed, as well as the open ore body. On top of this is need to add the negative impact of the political and social risk factors, the consequences of which are economic underdevelopment and population poverty.*

Managing these risks by analyzing their causes, assessment and their evaluation, eventual measures to mitigate or anticipate them, to achieve progress or regress, is part of the subject of this paper.

Keywords: mine, coal, risk, exploitation, closure.

Rezumat: *Închiderea exploatării unei mine de cărbune impune o serie de lucrări specifice etapizate în perioade de timp în care trebuie să se țină seama de o serie de factori de risc tehnic la care sunt expuși lucrătorii din subteran cât și zăcământul deschis. La aceștia se adaugă la suprafață, impactul negativ al seriei de factori de risc politic și social, ale căror consecințe sunt subdezvoltarea economică și pauperizarea populației.*

Gestionarea acestor riscuri, prin analiza asupra identificării, evaluării şi aprecierii lor, eventual a unor măsuri de atenuare sau anticipare a acestora, obținerea unui progres sau regres, face parte din obiectul prezentei lucrări.

Cuvinte cheie: mină, cărbune, risc, exploatare, închidere.

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1. Introduction

In the context of Romania's energy strategy, coal is the primary energy resource, being a strategic fuel in supporting national and regional energy security. In extreme weather, coal is the basis for the resilience of power supply and proper functioning of the National Energy System (SEN), covering one third of the electricity demand.

Jiu Valley pit coal, with an average caloric power of 3650 kcal / kg, is being used at the two thermal power plants in Hunedoara County, which have an installed capacity of 865 MW, in 5 energy groups - Mintia and 150 MW - in one energy group - Paroseni, with a market share of 5% of Romania's electricity production. If production would be at its maximum capacity, it would provide the system with about 20% of its installed power on coal [7].

Coal exploitation in Jiu Valley started in 1840, when outcrops of coal deposits were discovered and surface exploitation of existing deposit in the mining fields at Vulcan, Petrosani and Petrila began. Over time, the area developed economically and other underground mining units opened, covering from eastern to western coalfield border. Everything until 1997 when the first restructuring started, amid the abandonment of projects for financing investments in coal exploitation by Romanian Government and the national economy decentralization policy [2].

Major stages of mining restructuring were also imposed by adherence to EU conditions and by IMF. Government strategies to close unprofitable mines and increase theefficiency of mines with potential have been adopted. At present, in Jiu Valley there are two production units, Livezeni and Vulcan and Lonea and Lupeni mines are included in the accelerated closure program with state aid.

The Hunedoara Energetic Complex made an appeal to European Commission to continue production in safety conditions, both for workers and for the deposit, until reserves are exhausted. The request was based on risks arising from underground coal exploitation from the two mining operations.

The analysis of these risks has been the subject of two research studies by two institutes, INCD-INSEMEX Petrosani - Romania and Central Mining Institute (GIG), Katowice – Poland [3], [6].

2. Geological resources – description

The Jiu Valley (Valea Jiului)/Petroşani basin is an asymmetrical synclinal structure formed during the Alpine orogeny and sliced by transverse faults. The Jiu Valley basin, with an SW–NE orientation, is 48-km long and 10-km wide on the eastern side and 2-km wide on the western side; the coal mines are distributed along the centre of the valley, following the western and eastern tributaries of the Jiu River. The tectonic structure of the deposit is quite complicated thus, the action of faults influences the appearance of water and gases hazard [1].

The thickness of these deposits ranges from 270-m to west to 350-m to east. Up to twenty-two seams of coal have been identified in the Chattian-age rocks, numbered as seam 0 to seam 21, from the bottom to the top. Coal seams 3, 4, 5, 7, 8/9, 12, 13, 14, 15, and 17/18 are economically feasible for extraction, coal seam 3 being the most productive. The thickness of these beds varies from several meters up to several tens of meters. In the mining field Lupeni, seam no. 3 has a thickness of 25-28 m presenting barren intercalations with 0.2-1 m thickness.

In Figure 1. the section through the Petroșani Basin is presented. In the Lupeni mine deposit (central part of Jiu Valley) coal seams are practically horizontally, on the other hand in the Lonea mine deposit (east part of the Jiu Valley) coal seams are almost vertically.

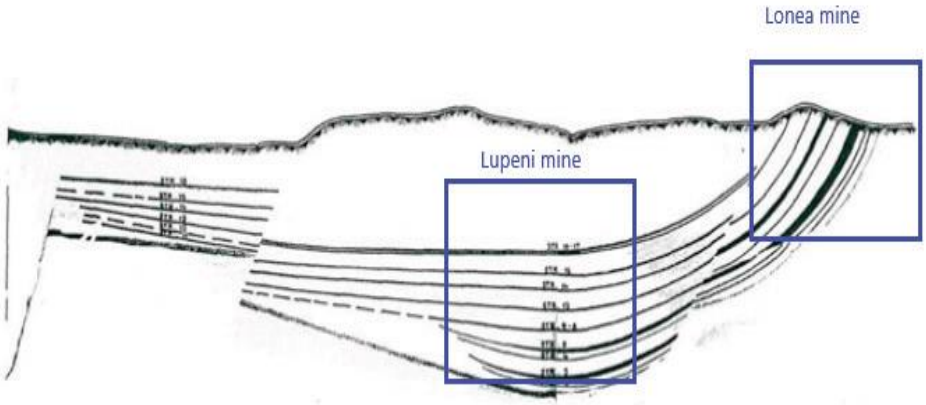

Figure 1. Section through Petroșani Basin

Because of difficult geological conditions, the Lonea and Lupeni mines use a special system of exploitation – sublevel caving with individual support or short wall with individual hydraulic props and metal beams. Currently, there are active panels as follows:

- Mine Lonea: panel (wall) 34B, seam 3, layer XXXVI, and panel (wall) 39, seam 3, layer IX
- Mine Lupeni: panel (wall) 9, seam 3, and panel (wall) 7c, seam 3.

The known coal resources in Romania are 232 million tons (85 million Tep) of which 83 million tons (30 million Tep) are chartered areas. At an average consumption of reserves of 0.3 million Tep/year, coal resources will last for 104 years, but the exploitation of this primary energy resource is conditioned by economic feasibility of exploitations [8].

3. Identifying, analysing and assessing risks

For underground coal exploitation, because of the complexity of deposit and extraction conditions, a number of specific risks are identified, in which, maintenance of safety conditions requires great efforts and a long time to prevent and combat those risks.

Specific risks include, in particular, the risk of coal self-ignition, the risk of explosion, the risks of gases in the underground atmosphere and the risk of flooding. The current paper will not deal with the last listed risk.

For closure of the two mines, Lonea and Lupeni, the studies contain risk scenarios developed for various mine closure conditions, which take into account the tectonics of deposits for each mining unit. Measures to address and reduce risk generating situations have been developed.

Risk analysis consisted in establishing their consequences and probabilities for identified risk events. The consequences and probabilities are then combined to measure a level of risk and its evaluation. For this analysis, the portfolio of events recorded at these two mining units for a period of 20 years (1997-2017) was used, the focus being on the causes of their occurrence [7].

3.1. Lonea mine

Lonea mining perimeter is located at the eastern boundary of Petrosani Coal Basin. Exploitation of coal in Lonea mining perimeter is over 145 years old. The beginning of opening activities for Lonea mine was decided in 1869. In 2010, according to EU decision 787/2010, assumed by the Romanian state, it is decided to cease mining operations at 31.12.2018.

3.1.1. Risk of coal self-ignition

Laboratory measurements, according to INCD-INSEMEX Petroşani methodology, on samples of coal extracted from productive capacities of Lonea mine, have been classified as high risk self-ignition coal (group IV - corresponding to behaviour of coal in gaseous oxygen environments) and coals with a pronounced risk of self-ignition (group III - corresponding to behaviour of coal in liquid oxygen environments) [6].

GIG Katowice measurements, according to Polish standards, ranked coal in Group V (the highest) of the spontaneous combustion predisposition and Group IV (the highest) in terms of spontaneous combustion tendencies based on results of the adiabatic test [3].

The causes for the occurrence of 35 spontaneous combustion phenomena (endogenous flames) were analysed, among which:

- non-observance of work technology;
- air circulation through exploited space;

- non-implementation of measures to prevent self-heating phenomena;
- increasing depression on exploited space favouring air circulation;
- uncontrolled air circulation through solid cracks in the fault area;
- reactivation of heated areas in upper sublayers.

Measures to prevent and confute the risk of self-ignition consist in application of two methods, the classical method (sludge, anti-pyrogenic treatment, chemical foams, waterproofing and flooding) and modern method (nitrogen inertization, measuring self-ignition risk, self- monitoring of underground atmospheres through fire indices or thermal imaging cameras) for a period of 4 years.

The first risk scenario was developed for mine closure on 31.12.2018 and results of the risk analysis confirmed a very high risk and the outcome of risk assessment is unacceptable.

The second risk scenario was developed for mine closure on 31.12.2022, following implementation of risk mitigation measures. Analysis results confirmed an average risk and the outcome of the risk assessment is acceptable.

Residual hazards: Effective enforcement of prevention/ mitigation measures, sludge, additional sealing (stoppings), nitrogen inertization, total coal extraction, and flooding to a certain level can significantly reduce the risk of spontaneous combustion.

3.1.2. The risk of mine gases occurrence

Circulating through mining operations, atmospheric air undergoes a series of transformations, changing both its physical characteristics and its chemical composition. Thus underground two categories of air can be found: fresh air with a composition close to that of atmospheric air and foul air whose composition differs from that of atmospheric air because of gas content increase as well as decrease of oxygen content.

Thus, constituents that may occur in the composition of foul air can be grouped into four categories:

• Toxic - nitrogen oxides (NO, NO_2, N_2O_3, N_2O_5), hydrogen sulphide (H_2S), sulphur dioxide (SO_2), carbon monoxide (CO); hydrogen (H_2);

• Explosives - methane (CH_4), hydrogen (H_2), hydrogen sulphide (H_2S), carbon oxide (CO), acetylene (C_2H_2);

• Asphyxiating elements (suffocating) - methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2), acetylene (C_2H_2);

• Radioactive - radon (Rn) and thoron (Tn).

The imminent danger is represented by methane emissions present in the coal beds and surrounding rocks, and in underground spaces not adequately ventilated combined with air, leads to explosive mixtures, which in certain concentrations (5-15% vol.) in the presence of an efficient ignition source produces an explosion with destructive effects for workers, works and mining facilities.

At Lonea mine, mining accident statistics over the past two decades tell of two methane ignitions caused by gas accumulation, triggered by shooting or

mechanical friction. If mining works in the closure phase are not ventilated according to the ventilation project, the risk of explosion is imminent.

In the first risk scenario for mine closure on 31.12.2018, according to GIG Katowice's forecasts, the total estimate of methane emissions in mining voids after the completion of works in 2019, over a period of 15 years, amounts to 8 036 003,52 m^3 [3], [4], [5].

Because of favouring effects, cracks, faults, permeability, temperature and pressure, methane from voids can migrate to surface, penetrating into households, causing a risk to residents and civilian constructions.

Also from the estimation calculation according to the algorithm, the end of methane emission will occur in 2034. Risk analysis result of the first scenario indicates a very high risk and the risk assessment indicates an unacceptable risk.

Measures to mitigate the risk of gas accumulation consist of full exploitation of the open reserve in accordance with exploitation methods in the program. The assessment of methane emissions for a period of 15 years in the existing voids, at mine and other aeration galleries closure in 2023, is estimated at a volume of 5 684 153.76 m^3.

Consideration is also given to increase in groundwater levels that can force migration of methane to surface on minimal strength lines caused by cracks, fissures, faults, etc. The methane emissions, according to the adopted calculation scheme, will end in 2038.

For the second mine closure scenario, on 31.12.2022, the estimated residual risks consist of a reduction in methane migration to surface due to extension of operation and ventilation time, as well as to identification of migration paths and implementation of protection measures.

Total methane emissions, calculated for 15 years, in mining voids is 29% lower than in the first scenario. The outcome of the risk scenario analysis for the second scenario indicates an average risk and the risk assessment indicates an acceptable risk.

3.2. Lupeni Mine

Lupeni Mine perimeter is located in the western central area of the Petroşani Mining Basin, mine exploitation activities started here in 1892. At present Lupeni mine is the largest operating mine in Jiu Valley. In 2010, the same EU Decision impels to cease operations on 31.12.2018.

3.2.1. Risk of coal self-ignition

Coal from the Lupeni mines' exploitable strata are classified as high self-ignition risk coal (group IV - corresponding to behaviour of coal in gaseous oxygen environments) and coals with a pronounced risk of self-ignition (group III - corresponding to behaviour of coal in liquid oxygen environments).

GIG Katowice ranked coal in Group V (the highest) of the spontaneous combustion predisposition and Group IV (the highest) in terms of spontaneous combustion tendencies based on results of the adiabatic test.

Analysis of 35 spontaneous combustion phenomena showed the following causes [7]:

- low penetration speed;
- air circulation through exploited space;
- inadequate air management;
- non-observance of work technology;
- non-implementation of measures to prevent self-heating phenomena;
- increasing depression on exploited space favouring air circulation.

As with the Lonea mine, the same risk mitigation measures are referred to, respectively the two methods described above. Results of risk analysis for the first scenario have confirmed a very high risk and outcome of the risk assessment is unacceptable. For the second risk scenario, results of the analysis confirmed an average risk and outcome of the risk assessment is acceptable.

Residual risks: are similar to those of the Lonea mine, and effective enforcement of prevention/ mitigation measures reduces the risk of spontaneous combustion.

3.2.2. *The risk of mine gases occurrence*

To define the risk, methane concentrations were measured in underground mining works in Lupeni mine, on ventilation circuits and in the area closed by means of insulation dams. Thus, in the mine working profiled methane concentration was 0.43% vol., which at an air flow rate of 180 m^3 / min, allows the calculation of the absolute methane flow, which is 0.77 m^3 CH_4 / min. In the area closed by means of insulation dams, methane concentrations ranged from CH_4 = 12-43% vol., which, under conditions of poor ventilation and poor sealing of methane isolation constructions, can migrate into mining operations in explosive concentrations [3].

In the last 20 years, Lupeni mine has recorded two hazardous incidents of methane ignition.

Estimation of total methane emissions from mining voids over a period of 15 years after the closure of works and other ventilation connections (2019) is estimated at 23 551 669,27 m^3.

According to the adopted calculation model, methane emissions will end in 2034. For the first scenario, outcome of risk analysis indicates a very high risk and the risk assessment indicates an unacceptable risk.

To mitigate the risk of methane gas accumulation, the effective measure consists in fully exploiting the coal reserves in open works. Estimation of total methane emissions at mining voids over a period of 15 years after closure of coal pits and other ventilation connections (2023) is estimated at 19 508 600,59 m^3. According to the adopted model, methane emissions will end in 2038.

Residual risk: reducing negative effects of methane migration to surface by identifying migration paths and introducing protection measures.

In the second scenario, projected total methane emission in mining voids over 15 years after mine closure is 17% lower than in the first scenario. For the second risk scenario, results of analysis confirmed an average risk and outcome of the risk assessment is acceptable.

4. Conclusions

Restructuring of coal mining industry in Romania, imposed by EU Decision 787/2010 and assumed by the Romanian state resulted in closure of two productive capacities in Jiu Valley, respectively Lonea and Lupeni mines, at the end of 2018.

After more than 150 years of coal mining in Jiu Valley, the existing coal-mining resources offer the possibility to provide the necessary coal for another century of extractive industry, provided that the extraction can be cost-effective.

At Lonea and Lupeni mines, the most important risks identified are: the risk of coal self-ignition, the risk of explosion, the risks arising from the presence of gases in the underground atmosphere and the risk of flooding. An analysis of all risks is vital to ensure a safe mine closure process. The study consisted of the analysis of two risk scenarios.

In the first scenario, the initial conditions were assessed and the mine closure was assumed to begin on 31th December 2018. The risk assessment process for the first scenario showed that from the perspective of spontaneous combustion and mine gases, the result is "unacceptable" and therefore is necessary to implement risk reduction strategies.

The second scenario under consideration assumes that, over a period of about 4 years, the mining operator will undertake risk reduction actions. The repeated risk assessment has shown a lower risk level, the result being "acceptable".

Analysis of underground coal mining risks at Lonea and Lupeni mining exploitations was dealt with in two research studies by two institutes, INCD-INSEMEX Petrosani - Romania and the Central Mining Institute (GIG), Katowice - Poland, the two reaching the same conclusion: to continue safe production activities, both for workers and for the deposit, until reserves are exhausted, for another 4 years (2022).

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