Accidents in Coal Mining from Perspective of Risk Theory

E A Khamidullina, S S Timofeeva, G I Smirnov

Department of Industrial Ecology and Life Safety, National Research Irkutsk State Technical University, 83, Lermontov street, Irkutsk 664074, The Russian Federation

E-mail: timofeeva@istu.edu

Abstract. Introduction. The indicators of the safety system quality in the technosphere include risk indicators. The purpose of this work is to assess the social risk of coal mining since coal mining is associated with specific working conditions, and any emergency situation immediately jeopardizes thelives of many people at the same time. Methods. The work is based on the analysis of statistical information. Results and discussion. The F/N curve of coal mining for the 70-year period (1943-2012) was constructed, and the normative values of the social risk of Russia and other industrialized countries were discussed. Judging by the F/N diagram, only the frequency of accidents with a large number of deaths can correspond to the normative level indicating an exceptionally high level of coal mining risk.

1. Introduction

The indicators of the quality of the safety system in the technosphere include risk indicators. In the extractive industries one of these indicators is the specific risk, i.e. the ratio of the number of mortally injured people to a unit of extracted raw materials. The analysis of the literature [1-4] allows to find the indicators of specific mortality of miners during coal mining and trace their changes at different time periods.

So, if before the collapse of the Soviet Union, the specific miner mortality was 1 person per million tons, then since the beginning of the 1990s this figure began to grow, reaching 2 million ppmt in 1995, and in 1997 - its maximum - 2.6 ppmt. For the 2000s, the decline of the indicator in question was characterized by a decline to 1.5-1 ppmt with jump-offs in 2007 and 2010 (major accidents at the Ulyanovskaya and Raspadskaya mines "). In the period from 2011-2013, the specific indicator of fatal injuries of miners reached the historical minimum of 0.5-0.7 ppmt of coal obtained by the mining technology [2].

Other indicators of risk are indicators of individual and social risk. Individual risk is the probability for a person to suffer from the effects of unfavorable, dangerous factors. Social risk characterizes the same threats for a group of people simultaneously. Since the concept of a group of people cannot be expressed in a single number, social risk is expressed graphically as a dependence of the frequency of undesirable events in which at least a certain number of N people suffered from this N number. This graphic expression of social risk is called an F/N diagram.

Coal mining is one of the most traumatic and harmful industries. The proportion of workers in coal mines working in conditions that do not meet government regulatory requirements is one of the highest, just as the coefficient of injury rate in coal mines [5]. All this form high individual and social risks, leading to large human losses and a decline in labor efficiency.

The purpose of this work is to assess the social risk of coal mining. Since coal mining is associated with specific working conditions (such as underground work), any emergency situation immediately jeopardizes the lives of many people at the same time. Thus, it is appropriate to assess the social risk.

2. Methods
This paper assesses the social risk in coal mining in Russia over the 70-year period (1943-2012). We used the data on the accident rate in coal mining for 70 years from 1943 to 2012, according to MiningWiki - a free mining encyclopedia [6]. In addition, the initial data served as Bulletins of the Federal Service for Environmental, Technological and Nuclear Supervision, presented in the information resources of the site www.safety.ru [7] and the materials of the article [3]. At the same time, the authors realize that statistical information for remote periods of time may not be complete and, consequently, the implemented risk assessments can be considered as approximate to some degree.

For the analysis, we selected information about accidents accompanied by group deaths of people in mines, and accidents not related to accidents were not considered. Thus, the performed evaluations reflect the social risk of g-whitening and do not affect traumatization of people in the course of work.

3. Results and discussion
Table 1 summarizes the statistical data on mortality in coal mining during the period under review. As can be seen from this table the total number of emergency situations with the death of people amounted to 146 cases, that is, about two accidents per year with an average number of deaths of 25 people per year and, therefore, 12 (13) deaths in each situation.

Table 1. Initial statistical data on the accident rate in coal mining.

Indicator	Quantity
Total number of accidents with loss of life	146
Total number of deaths in considered accidents	1751
Average number of accidents with deaths of people per year	2.09
Average number of dead accidents per year	25.01
Average number of fatalities per 1 accident	11.99
Number of accidents with at least 10 dead	46
Number of deaths in the worst case	120

Table 2 shows that the majority of accidents with loss of life were with the number of deaths in the range of 2-9 people. The share of major accidents (with the deaths of 10 or more people) was 31.5% or 1 major accident for 3 accidents. These are the average figures over the period under review. It should be noted that similar information can be found in [2] for different time intervals. Thus, it is noted that in the RSFSR in the 1980s, one major accident ac-counted for an average of 313 registered accidents, in the RF in the 1990s - one for 86, and in the 2000s - one for 33. The worst accident occurred on 16.02.1944 at the mine "Baidaevskaya", Novokuznetsk, the Kemerovo region, where explosion of methane killed 120 miners. In the history of the new Russia, the worst at the Ulyanovskaya mine, where on March 19, 2007, as a result of a series of methane-air mixture explosions, 110 miners were killed and 8 people were injured, and on May 8-9, 2010 at the Raspadskaya mine, where as a result of gas explosions 91 people were killed, and 138 were injured.

Table 2. Initial statistical data on the accident rate in coal mining.

Death toll	Number of cases	% of the total number
1	13	8.90
2-9	87	59.59
10-49	38	26.03
≥ 50	8	5.48

The initial data necessary for the calculation and construction of the F/N diagram are presented in Table 3, the resulting F/N diagram is shown in Figure 1.

There have been no criteria for the admissibility of social risk in Russia until recently, the national standard was adopted in 2016 [8].

It should be said that different countries use different approaches, depending on the types of danger, on the category of recipients, on the voluntariness of accepting risk and on other factors. Thus, in the Netherlands, approximately the upper permissible level of social risk for the population living next to a hazardous object is defined as $10^{-3}/N^2$, that is, for the death of one person, the frequency 10^{-3} 1 per year, and for the death of 10 people the risk is 100 times less [9]. Thus, the criterion curve includes the risk aversion factor and has a slope equal to 2. As it is known, the risk aversion factor reflects the fact that people are more negative unattractive to accidents in which a large number of people are killed/injured simultaneously, in contrast from those where one person is killed/traumatized.

**Table 3.** Initial data for constructing a F/N chart.

Number of deaths, N, people	Amount accidents with the number of deaths N	Number of deaths, N, people	Amount accidents with the number of deaths N	Number of deaths, N, people	Amount accidents with the number of deaths N
1	13	15	1	35	1
2	30	17	1	37	1
3	21	18	1	39	1
4	12	19	3	47	1
5	9	20	1	48	1
6	6	21	1	50	1
7	4	23	1	53	1
8	1	24	1	56	1
9	4	25	3	59	1
10	4	26	2	67	1
11	2	27	2	91	1
12	6	28	2	110	1
13	1	34	1	120	1

The British Council for Health and Safety (Health and Safety Executive, HSE) in the article Reducing Risk Protecting People (R2P2) [10] offered a criterion point instead of criterion line, assuming 50 and more than deaths with frequency 2 x 10^{-4} 1 per year (2001), subsequently brought to the line [11], which has a slope equal to – 1,5.

The All-Russian Risk Society in its Declaration [12] proposed the following criteria for permissible social risk: the maximum permissible level of social risk of death N and more people from the population are recommended to set the level of $10^{-3}/N^2$ per year for new (newly designed) facilities

and at the level of $10^{-2}/N^2$ per year for existing facilities. Thus, the proposed criteria coincide with the admissibility criteria adopted in the Netherlands.

In 2017, the national standard of Russia comes into force, regulating the values of the permissible individual and social risks of emergencies for the population and establishing the significance of social risk, as the death rates are simultaneous 10 people or more, equal to 10^{-5}.
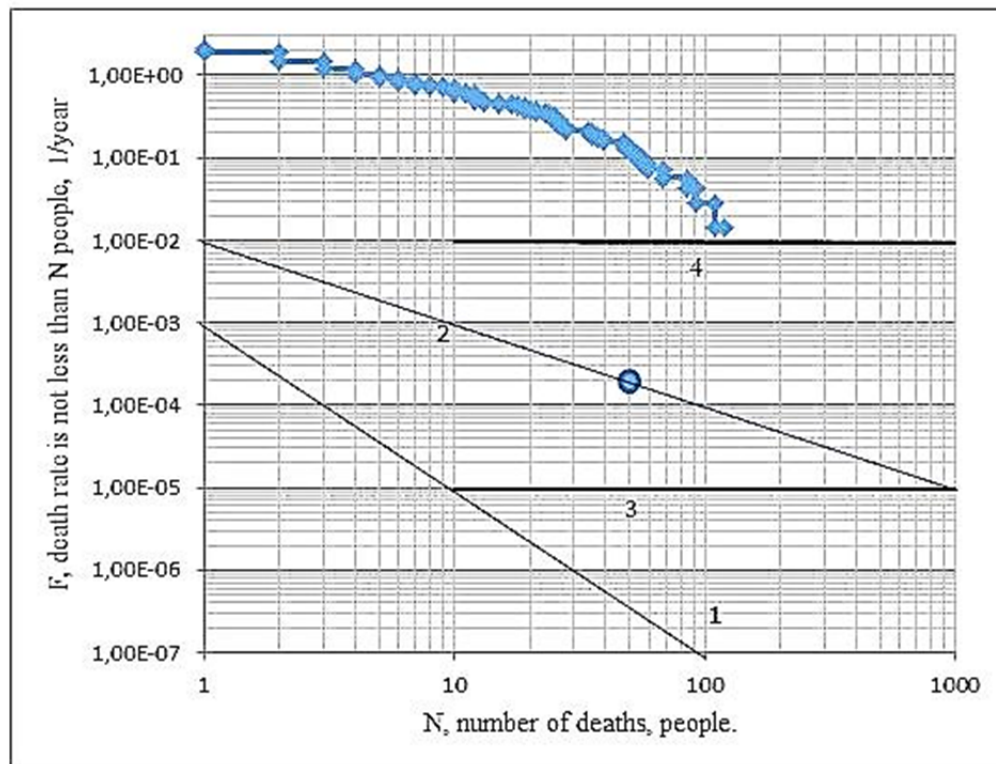
Figure 1. F/N curve for coal mining for 1943-2012 and criteria for the admissibility of social risk: 1. Criterion line of the Netherlands (and the previously proposed level for the population of Russia); 2. Criterion line of Great Britain (R2P2); 3. Admissible social risk for the population in accordance with GOST R 22.10.02-2016; 4. Estimated permissible level for enterprise personnel (Russia)

The social risk for personnel of hazardous production facilities is not regulated even in projects and declarations. In [13], a proposal was made to reduce the requirements for industrial facilities up to 1000 times due to the voluntariness of the risk, the protection of personnel trained in the emergency situation.

Figure 1 shows the criterion lines of permissible social risk in the Netherlands for the population living near hazardous industrial enterprises (line 1), the UK criterion line (line 2) and the permissible level accepted in Russia for the population (GOST) (line 3). Attention is drawn to the fact that the risk aversion factor is not envisaged and an equal relation to situations where 10 people and 100 people die is assumed. Line 4 - is the supposed admissible social risk for the staff, if we accept the above described proposal. Acceptance of this proposal would be quite appropriate, in our view, since despite the voluntariness of occupational risk, any person even at work wants to feel protected.

4. Conclusion
Thus, judging by the F/N diagram, only the frequency of accidents with a large number of deaths can correspond to the normative level, indicating an exceptionally high level of coal mining risk.

Behind each figure given here are real human lives and such a high level of man-made danger should generate adequate social anxiety, contributing to the fulfillment of security du-ties by all parties to the labor process.

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