The present state of accident hazard at work in the Polish mining industry is presented. A comparison is made of the accident indices in relation to other countries. A reference is made to the work safety management system implemented in the mines. Safety management is discussed in terms of risk management. On the basis of the natural death index and that of accidents at work, numerical scales are presented defining the limits of the inadmissable, tolerable, and acceptable risk. The course of variation of risk indices for fatal, serious, and minor accidents is evaluated. The results of the assessment for all kinds of accidents at work in the mining industry are presented.

1. INTRODUCTION

The mining industry is an industry branch with one of the highest rates of accidents at work. Safety in the Polish mining industry is placed in an intermediate position compared to the rest of the world (Studenski, 1995; see Table 1). However, the results are unsatisfactory both for the workers and for government agencies.

Limited space, difficult geological conditions, and work performed under conditions of psychological stress are the reasons why the indices of accidents at work exceed the average values for industry as a whole. For instance, in 1994, the accident at work index in the Polish mining industry as a total was 4.2 times higher than that related to industry overall.

The accident index remaining at a relatively high level and the lack of noticeable changes in this tendency (Figure 1) provoked solutions aimed at improving the level of safety.

In parallel with the changes in the Polish national economy and the directions of restructuring in the mining industry, the philosophy of the changes in the field of safety improvement has been based on the principle of safety management.

2. SAFETY MANAGEMENT

Significant progress in the domain of safety improvement is not possible without concerted actions within the whole enterprise. The roles of the main coordinator and organizer fall to the enterprise’s management, which through its policy engages all personnel in the realization of the specified goals. The new way of thinking is connected with the organizational change at the enterprise, in which the executive managers were responsible for safety, but their responsibility was conveyed to the health and safety departments.

Thus organized safety constitutes an element of the enterprise’s policy and the management is directly responsible for its realization. In most enterprises, yielding a profit is the primary aim of the economic performance. That is why it is not surprising that safety is seen as an element of the cost of the enterprise’s operation. This problem is not well documented in the worldwide literature of the subject (Ridley, 1994).
TABLE 1. Frequency of Fatalities in Underground Hard Coal Mines

<table>
<thead>
<tr>
<th>Country</th>
<th>Fatalities per 1 million tonnes</th>
<th>Fatalities per 1,000 employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>n.d.</td>
<td>0.16</td>
</tr>
<tr>
<td>France</td>
<td>0.40</td>
<td>0.21</td>
</tr>
<tr>
<td>Germany</td>
<td>0.32</td>
<td>0.44</td>
</tr>
<tr>
<td>Great Britain</td>
<td>0.14</td>
<td>0.05</td>
</tr>
<tr>
<td>Poland</td>
<td>0.48</td>
<td>0.39</td>
</tr>
<tr>
<td>Russia</td>
<td>1.37</td>
<td>2.03</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>1.99</td>
<td>1.12</td>
</tr>
<tr>
<td>South Africa</td>
<td>0.19</td>
<td>0.21</td>
</tr>
<tr>
<td>Ukraine</td>
<td>2.32</td>
<td>2.79</td>
</tr>
<tr>
<td>USA</td>
<td>0.12</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Note. n.d.—no data available.

This results from the fact that the cost of ensuring a defined level of safety (fulfillment of the safety requirements) is borne irrespective of the company’s financial result. In extreme cases, it has even been said that human life is priceless, but this has not been reflected in practice. Assessments of the value of human life indicate that it has different value for the family, employer, and society. In spite of the extremely important humanitarian aspect of the protection of human life, for the employer safety has, first of all, an economic dimension. This means safety is frequently interpreted as risk management.

3. RISK

The word risk is of Arabic origin. It comes from the word risqu, which in the Middle Ages was acquired by the Italian language as risico to express the condition of a hazard or uncertainty in undertaken actions. Now, the word risk is defined as the likelihood of suffering a loss or not realizing intentions.

The knowledge of risk and its assessment emerges both from the Polish labor code and the International Labour Organization (1995). In its classic form, risk is expressed as a combination of the probability of the occurrence of an event and its effects or consequences (Figure 2).
Calculating the risk value requires the knowledge of the following parameters:

- "Probability (how often).
- "Loss (how large).
- "Combination of the two (in what conditions).

Because of the possibility of assessing loss with a different probability, this combination is most frequently interpreted as the product of the probability of occurrence of the loss and its size.

\[ R = P \cdot S \]  

where \( R \) is risk, \( P \) is probability of activation of a defined hazard, and \( S \) is size of the expected loss.

Lack of numerical data or difficulty in obtaining them means that calculations of risk according to Equation 1 are made in isolated cases.

Most frequently, risk analysis is limited to identification of the hazards and assignment of an arbitrary scale to the probability and loss; for example, minor, medium, serious, or the like. This leads to the subjectivity of the analyses and the following errors:

- "Occurrences with a high loss and low probability of appearance are overestimated.
- "Occurrences with a high probability of appearance and low loss are underestimated.
- "Risk assessment is limited to quoting the probability of the occurrence of loss.
- "Hazards assessed by the expert are revalued.

Risk, as a general concept, can be connected with any activity of an enterprise: commercial, production, or other. The way of managing both commercial and production risk depends on management’s decision. On the other hand, risk related to the protection of health or life of the employees follows from the State’s policy, reflected in the legal acts concerning safety.

The way of solving this problem differs from country to country (Allen, Garlick, Hayns, & Taig, 1992). Assigning a high rank to risk in safety regulations, it is necessary to define accurately the methods of assessment and quote the limit values.

## 4. RISK LIMITS

In the majority of solutions aimed at keeping the intention of safety improvement, the ALARP (As Low As Reasonably Practicable) principle is being adopted. Such a stipulation in the regulations creates the possibility of an interpretation other than that intended by the legisla-
tor. Figure 3 illustrates that this principle, in relation to the economic performance, can be presented as related to the expenditures for safety.

Because of the conflict of interest between the employers and employees, risk limits should be established in the form of an obligatory document of safety. The question about the extent of acceptable human loss within the labor process is one about risk limits that the society can tolerate.

Taking as a model the solutions accepted in other countries and adjusting them to the domestic situation, the following division of risk is proposed (Niczyporuk, 1996):

- "Inadmissible risk" (after risk has been recorded, the production plant, its division, or another kind of performance must be stopped).
- "Tolerable risk" (it is necessary to aim at lowering the risk to an acceptable level in accordance with the ALARP principle; that is, as low as reasonably practicable).
- "Acceptable risk" (requires no additional actions).

It is the state’s duty to protect society against excessive accidents at work. Therefore, establishing a threshold of fatal accidents is proposed. When such a threshold is exceeded, the risk of working in such conditions would be recognized as inadmissible.

It has been assumed that the index of the death risk caused by accidents at work should be at least 10 times lower than that of the individual risk of natural death, and should reach, no more than $10^{-3}$ deaths per person per year.

The presented proposal results from an assessment of the course of the natural death index and accidents at work in Poland (Table 2).

Adopting the $10^{-3}$ index for fatal accidents means that 1 case per 1,000 employees over a year is admitted as the limit value between inadmissible and tolerable risk. This may seem a very liberal limit. It should be stressed that the values quoted should be related to the number of persons within the hazard zone. Shown in Figure 4 is an example of the accident index according to which the probability of their repeated occurrence is predicted. The accident index differs depending on the area to which it has been related. Confining the area to the

<table>
<thead>
<tr>
<th>TABLE 2. Deaths and Accidents at Work</th>
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<tr>
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<tr>
<td><strong>Number of deaths per 1,000 population</strong></td>
</tr>
<tr>
<td>1990</td>
</tr>
<tr>
<td><strong>Total number of accidents per 1,000 employees</strong></td>
</tr>
<tr>
<td><strong>Number of fatal accidents per 1,000 employees</strong></td>
</tr>
<tr>
<td>1990</td>
</tr>
</tbody>
</table>
hazard zone increases the index. One should aim at accurate identification of the hazard zone in order to specify the number of the person-hours and person-days per one fatal accident.

The value of $10^{-5}$ for fatal accidents has been adopted as a threshold between acceptable and tolerable risks. That is an over hundredfold decrease of the threshold between inadmissible and tolerable risk for fatal accidents. Following Kuhlmann (1981), the threshold value of tolerable risk for minor accidents has been assumed as 100 times higher than that for fatal accidents; that is, $10^{-1}$ accidents per person per year. The threshold for serious accidents has been adopted between the threshold defined for fatal and minor accidents, that is, $10^{-2}$ serious accidents per person per year. The risk index then depends on the expected number of victims.

When assessing risk on the basis of group accidents that have occurred, it is advisable, for legislative reasons, to adopt a constant value. The discussed proposals are presented in Figure 5.

The proposals of risk categories (Figure 5) do not take into account the loss caused by a particular sort of accident. The value of loss caused by accidents at work is differentiated and is evaluated for each kind of accident (fatal, serious, or minor).

![Figure 4. Incident rate—Total number of accidents per 1,000 employees in 1994.](image)

![Figure 5. Propositions for a valuation scale of the inadmissible, tolerable, and acceptable risk categories for fatal, serious, and minor accidents at work, related to the probability of natural death.](image)
In accordance with the assessments made so far, it can be assumed that the loss, in consequence of a fatal accident, is 2.5 times higher than that for a serious accident and 50 times than that for a minor one.

This scale has been based on the risk level index, in which a fatal accident is assigned the number 15 (Steel, 1990). Taking into account the statistics of the accidents and injuries suffered, the following increasing scale has been used for the evaluation of risk; the scale of the loss caused by the accidents at work in Equation 1 for risk assessment:

- "Fatal accident"—15.
- "Serious accident"—6.
- "Minor accident"—0.3.

Risk assessment has been carried out on the basis of accidents in coal mines.

5. RISK ASSESSMENT

All mines and mechanized longwalls in coal mines were assessed. This permitted observations of the risk changes dependent on defining precisely the hazard area—the number of accidents in longwall workings and galleries is highest. Statistical data for the accidents at work in coal mines are presented in Table 3.

The data (Table 3) indicate that the assessment of the state of safety should not be limited to the assessment of fatal accidents. The excessive number of minor accidents can cause a higher loss than that resulting from fatal accidents. The application of the accident loss scales, as discussed here, proves that the loss caused by minor accidents is the highest (Figure 6).

The data presented in Figure 6 show that, when managing safety, it is necessary to pay attention to all sorts of loss so as not to make a mistake in risk assessment. Undertaking proper actions in safety management requires knowing the direct causes of accidents.

As an example, Figure 7 presents the causes of the accidents in mechanized longwall workings of the hard coal mines. The data presented (Figure 7) show that the improvement of safety is a complex problem as the causes of accidents have their origin in geological conditions, technical outfit, and also in human unreliability. The statistics of accidents presented in Figure 8 are astounding.

The presented data point at the necessity for a complex approach to the question of the improvement of safety in mines. Such actions have been undertaken with the aim to create a system of safety management modeled after Total Quality Management (TQM).

### TABLE 3. Accidents in Hard Coal Mines

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of accidents per employee per year</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>fatal accidents</td>
</tr>
<tr>
<td>1991</td>
<td>0.19 · 10^3</td>
</tr>
<tr>
<td>1992</td>
<td>0.15 · 10^3</td>
</tr>
<tr>
<td>1993</td>
<td>0.19 · 10^3</td>
</tr>
<tr>
<td>1994</td>
<td>0.12 · 10^3</td>
</tr>
<tr>
<td>1995</td>
<td>0.13 · 10^3</td>
</tr>
</tbody>
</table>

Inadmissible risk:
- > 10^-1
- > 10^-2
- > 10^-3

Acceptable risk:
- < 10^-5
- < 10^-4
- < 10^-3

See Figure 5.
6. SUMMARY

The presented analysis of safety conditions in coal mines points out the necessity to undertake manifold actions aimed at improving safety. The introduction of the discussed risk categories as a safety standard means there can be administrative intervention when the defined thresholds are exceeded. This safeguards against a free interpretation of the ALARP principle. The presented scale of assessment of the loss caused by accidents permits an assessment consider-

![Figure 6. Distribution of loss caused by the accidents at work in mines in 1995.](image)

![Figure 7. Risk for the most important causes in mechanized longwalls. Note. A—rockburst; B—local operational stress relief; C—geological disturbance; D—protruding rock; E—lack of space; F—material defects (machinery, equipment, etc.); G—failures occurring in the course of operation (machinery, equipment, devices, etc.); H—improper installation of machinery and equipment; I—other material causes; J—lack of or insufficient control of health and safety conditions; K—lack of protection of machinery against its undesirable setting in motion; L—entering forbidden areas; M—lack of suitable team collaboration; N—other faults; O—inad- vertence; P—lack of or inadequate supervision of health and safety.](image)
ing risk as probable loss. In spite of the imperfection of such calculations, they give a represen-
tation of the loss distribution much more accurately than qualitative risk assessment.

The calculations presented relate to the events that have occurred, whereas risk is a prediction of their reoccurrence. Such an assumption is correct if the conditions in which the prediction is made have not changed in relation to those existing at the time of statistical data collection. In the analyzed case this condition was satisfied.

The analysis was carried out for risks of all kinds of accidents, impairing the sense of limiting the examination and statistics only to total accidents. The number and consequences of minor accidents are much more severe than in case of the fatal accidents.

It has been found that difficult working conditions and tiredness are risk-increasing factors (Figure 8).

An improvement of such safety conditions in the mining industry is a complex process in which, in parallel with the improvements of material (technical) working conditions, an increase of the workers' engagement is required. Such an approach is in agreement with the TQM philosophy in which total quality is a highly participative process for improvement.

REFERENCES


