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RADIATION EXPOSURE OF MINERS AND SYSTEMS OF RADIATION PROTECTION IN POLISH NONURANIUM MINES

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Abstract. The authors present an original solution to the problem of radiation protection in Polish mines where miners are exposed to radioactive gas radon and radioactive aerosols. The system refers to hygienic evaluation of the workplace and the individual exposure as well as to technical prevention, the aim of which is to minimize exposure. Hygienic supervision is organized using dosimetric technique which applies track detectors. Principles of the system have been worked out in metal-ore, mines where they have been applied for 10 years, markedly decreasing miners' exposure. The results of the preliminary tests in coal- and chemical elements mines are also presented. The results prove the necessity of practical application of a scientifically described and verified model in these mines. Estimation of radiation risk of miners shows that due to their large population, the problem appears to be especially important and requires permanent supervision and preventive action to keep the exposure as low as reasonably achievable.

INTRODUCTION

The essential source of radiation exposure of miners in Polish nonuranium mines are radioactive aerosols formed by the decay products of radon (^{222}Rn). At present, there are about 100 mines in operation in Poland. They are coal-, zinc-, ore-, lead-ore-, and copper-ore- mines as well as chemical elements and mineral elements mines. In total, they employ 320 thousand miners. Miners are the most numerous population occupationally exposed to ionizing radiation. Therefore, the examination of this exposure was started in Poland in the Institute of Occupational Medicine in Lodz. The examination is accompanied by organization activities, the aim of which is to introduce systems of radiation protection in mines. Analyses carried out in metal-ore-, coal-, and chemical elements

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mines in the '60s (10) proved that the greatest radiation exposure exists in zinc-ore-, lead-ore-, and copper-ore mines. In these mines radiation protection system began to be introduced in the first place. In this paper the authors present the evaluation of radiation hazard in mines along with the principles of systems of radiation protection of miners.

CRITERIA OF EVALUATION OF RADIATION EXPOSURE IN MINES

Regulations concerning radiation protection in Poland are generally based on the International Atomic Energy Agency standards, the so-called Basic Safety Standards (12). Special legal act, the so-called Atomic Law Act, regulates all matters connected with nuclear safety and radiation protection. This Act imposes an obligation of reduction of real radiation

TABLE 1. Limits of Exposure to Radon in Polish Mines

The name of the limit	Symbol	The limit's value
Authorized limit	LA	3.5 WLM
Authorized derived limit	LR	0.3 WL
Investigation level	PD	0.12 WL
Recording level	PI	0.02 WL

1 WL (Working Level) = 21 μJm^{-3} is the commonly used unit of potential energy E_{RnDP} concentration
1 WLM (Working Level Month) = 3.5 $mJhm^{-3}$. Exposure to radon daughters during 1 month (167 h) with E_{RnDP} concentration = 1 WL

doses to a minimum. Therefore, limits of exposure to radon daughters lower even than those recommended by the IAEA Basic Safety Standards have been adopted. The main adopted limit of individual exposure of miners, the so-called Authorized Limit, is equal to 3.5 WLM. Also other auxiliary limits and levels expressed in relevant units were adopted. All the limits and levels are presented in Table 1.

SYSTEM OF RADIATION PROTECTION PRACTICE IN MINING

Up to this time, two systems of radiation protection in zinc-ore-, lead-ore-, and copper-ore mines have been introduced. One of them, called hygienic supervision, is concerned with routine dosimetric measurements in the workplace and the estimation of the individual exposure of miners (2). Dosimetric control of the workplace is performed in those mines where concentrations of potential energy E_{RnDP} exceed the Recording Level. The range and frequency of routine inspection of the workplace depend on the level of radiation hazard. In the mines where the possibility of exposure exceeds 3/10 Basic Limit which equals 5 WLM (17 $mJhm^{-3}$) (14), routine inspection of the individual exposure is introduced. The value of this probability was determined for each of the mines with supervision, using the results of dosimetric measurements in the workplace. The main purpose of hygienic supervision is to provide information about the individual exposure of miners, its changes and trends, and to suggest an optimal measuring range using dosimetric inspection of the workplace. Another simultaneous system is called technical supervision. This kind of supervision is performed by mine's services. They carry out radiometric measurements in order to detect the centres of intensified exhalation of radon from the deposit and to determine intensity changes of concentration of potential energy E_{RnDP} in a given mine. Every time the momentary concentrations exceeding the Authorized Derived Limit LR at miners work-stands are found, ventilation service uses means of technical prevention, the efficiency of which is controlled by radiometric measurements.

METHODS OF ESTIMATION OF RADIATION EXPOSURE OF MINERS AND COMPARISON OF THESE METHODS

Routine monitoring, which is a part of radiation protection, is based on the two methods. The Air Sampling System (ASS) is used for the purpose of technical supervision. In this system the mining radiometer RGR 11 is applied. It utilizes momentary measurements of concentration of

Fig. 1. A dosemeter with track detector.

potential energy E_{RnDP} keeping to the specified measuring methods (7, 17). For the purposes of hygienic supervision, which regulates dosimetric control of the workplace and of the individual exposure, the method of integrating dosemeters with track detectors is used. The dosemeter is presented in Fig. 1. The dosemeter measures exposure, i.e. E_{RnDP} concentrations integrated in time. During dosimetric monitoring of the workplace, the dosemeter is placed at miners' work-stands for 1 month and it is exposed continually. This system of measurement is called the Environ-

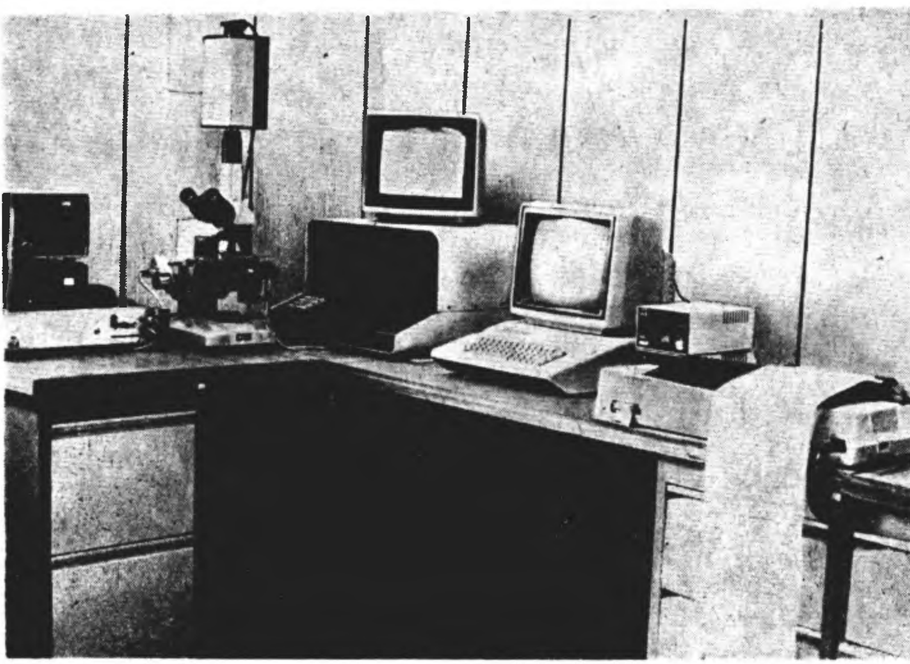

Fig. 2. An automatic system of analysis of track detectors.

mental Casette System (ECS). The result of exposure divided by the time of its duration gives the average E_{RnDP} concentration in which miners worked over the period specified. Routine measurements make it possible to observe changes taking place during this period. The same type of meter can be attached to a mining helmet and serve as an individual dosemeter. This measuring system is called the Helmet Casette System (HCS). Short--term exposure for a given period, instead of the average E_{RnDP} concentration is measured. The track detector of alpha radiation, the nitrocellulose Kodak LR 115 type foil, is used in the dosemeter (3, 20). Calibration in radon chamber (11) makes it possible to determine the exposure of the detector on the basis of the surface track density. Track density on the surface of the detector is calculated using the results of automatic microscopic analysis of the track detector conducted by the RADON measuring system after the necessary chemical treatment. The principal element of the RADON system is the System III type image analyser produced by the Analytical Measuring System Ltd. The automatic read-out system is presented in Fig. 2. One of the elements responsible for the effective functioning of radiation protection is the computer data base of the RADON system in which measurement results are collected. In the ECS- system and HCS- system it is necessary to consider in the calculations the concentrations of potential energy E_{RnDP} or the short-term exposure, depending on the type of mine, value of the coefficient F for dynamic radioactive equilibrium between radon and its decay products (13). Coefficient F values for the particular types of mines have been determined using the results of 430 analyses of radon concentration using the scintillation chamber method (4) and of concentrations of potential energy E_{RnDP} using the filtering method (7). Coefficient F values for zinc--ore, lead-ore, and copper-ore- mines ranged from 0.23 to 0.34 (mean = =0.33), (9), for coal mines — from 0.26 to 0.44 (mean = 0.33) (15), and for chemical elements mines — from 0.19 to 0.83 (mean = 0.42) (25).

The methods of measurement used for systems of radiation protection underwent the test of goodness of fit (24). In a random selected metal-ore mine, measurements of the three systems have been carried out for 1 year. Comparison of the results of these analyses is presented in Fig. 3

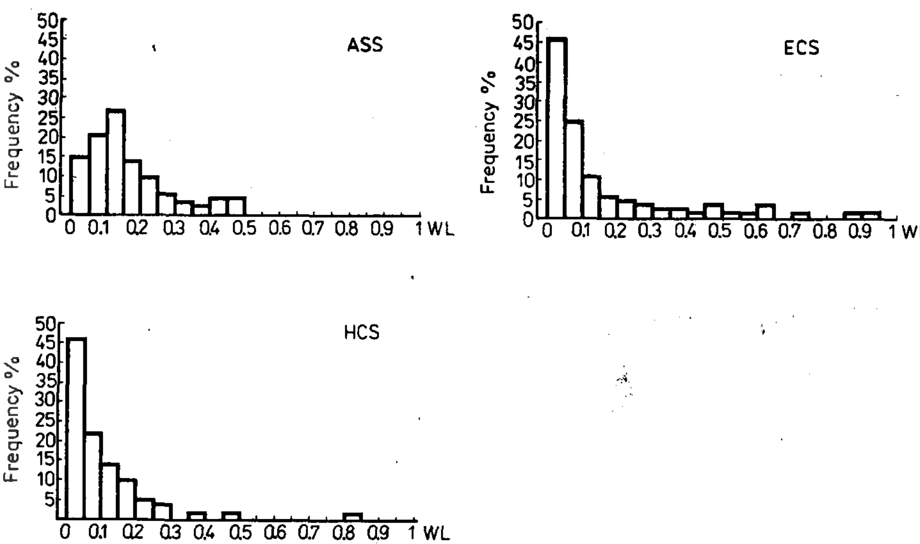

Fig. 3. Distributions of measuring results of concentration of potential energy E_{RnDP} using the ECS-, HCS- and ASS-systems.

in form of histograms of distributions of E_{RnDP} concentrations (1). It has been determined, on the basis of the Kolmogorov test, that the results obtained by using all the three systems have log-normal distribution. This can be explained on the basis of the fact that for each system the test value is lower than the boundary value which amounts to 1.36 at the specified significance level of 0.05 (18). Application of the Kolmogorov--Smirnov test which verifies goodness of fit of empirical distribution of different samples shows that the results collected in the ECS- system and HCS- system do not reveal any statistical differences at significance level 0.05 (the test critical value equals 1.36), which means that they represent

TABLE 2. Statistic Evaluation of Measuring Results of Concentration of Potential Energy E_{RnDP}

Method of measurement of concentrations	Number of measurements	Mean concentrations [WL]	Variances	Mean value error	The Kolmogorov test	The Kolmogorov--Smirnov test
ASS	190	0.147	0.0164	0.0093	0.94	3.61
ECS	610	0.0967	0.0138	0.0047	0.42	3.12
HCS	370	0.0800	0.0108	0.0054	1.08	0.85

the same or very similar population of results. However, distribution of the results collected in the ASS- system differs markedly from the results collected in both the ECS- system and HCS- system. Differences between these distributions may be significant for the interpretation of results and evaluation of the true exposure of miners. In many countries the momentary measurements are still used as the only or main indicator of evaluation of miners' exposure; moreover, the indicators of radiation hazard obtained from the observation of miners in Czechoslovakia, USA, Canada and Sweden (22, 23), have been determined according to measurements of the ASS- system and, therefore, the causes of differences among distributions of the results collected in the ASS- system and the ECS- system are the subject of analyses and studies. The results of the statistical analysis of these distributions are presented in Table 2.

RESULTS OF EVALUATION OF RADIATION EXPOSURE OF MINERS IN POLISH NONURANIUM MINES

Since 1977, an inspection of the individual exposure has been carried out in metal-ore mines for the purpose of hygienic inspection in the HCS- system. Every year about 410 measurements of the 1-year individual exposures of miners were carried out in 11 metal-ore mines. Over the first years of the inspection, a reduction of exposure due to technical operation in mines was noticed. In the following years the situation stabilized and the optimal level has been achieved. No further technical prevention can be used to bring better results. From the point of view of radiation protection it can be assumed that ALARA level (As Low As Reasonable Achievable) has been obtained. Similar situation can be observed in respect to the trend of the mean exposure for year (Fig. 4).

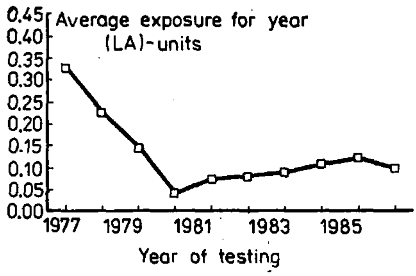

Fig. 4. Trend of 1-year mean exposure to radon daughters in metal-ore mines.

Between 1977 and 1980 a decrease of the mean exposure for year as a consequence of the introduction of dosimetric monitoring was observed, and then, probably as a result of the depression of extracting levels and the extension of ventilation draughts, a slight increase of the exposure has been noticed. The reached mean exposure of c. 0.1 of the Authorized Derived Limit observed in 1986 seems to be satisfactory from the standpoint of radiation protection. The minimum in 1980 was caused by the exchange of the observed group of workers.

In the period 1981—1987 the Institute of Occupational Medicine in Lodz conducted diagnostic examination in all Polish coal-mines in the ECS- system and chemical raw materials mines in the HCS system. The

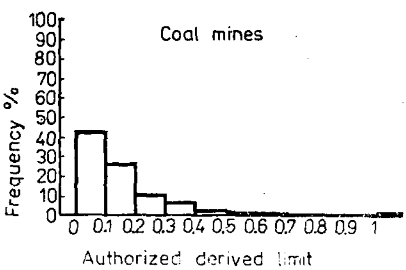

Fig. 5. Distributions of measuring results of concentration of potential energy E_{RnDP} in coal mines. Analyses were conducted using the ECS-system.

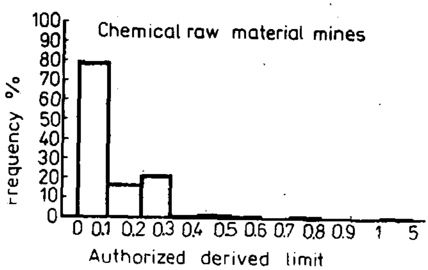

Fig. 6. Distribution of measuring results of concentration of potential energy E_{RnDP} in chemical raw material mines. Analyses were conducted using the HCS-system.

preference of the HCS- system in the latter group of mines has been motivated by the fact of frequent switching off of ventilation systems caused by one- or two-shift work which could bring about the running up of results and misinterpreted evaluation of the workplace while using the ECS- system.

Fig. 5 presents the distribution of the results of concentrations of potential energy E_{RnDP} of alpha radiation of the radon decay products represented in the units of the Authorized Derived Limit (LR) for coal mines, and Fig. 6 — for chemical raw materials mines. In coal mines 861 measurements were conducted; 2.4% of the results exceeded the Authorized Derived Limit (LR), 12% the Investigation Level (PD), and 69% the Recording Level (PI). The mean concentration of potential energy E_{RnDP} equals 0.21 LR. For chemical elements mines 0.3% of results above the Authorized Derived Limit (LR), 2% above the Investigation Level (PD), and 1.5% above the Recording Level (PI) within the overall number of 276 results were recorded. The mean E_{RnDP} concentration equals 0.073 LR. The present study provides an approximation of the true exposure of miners. For the analysis of the results of measurements conducted in coal mines, see Chruścielewski et al (5).

DISCUSSION

On the basis of the results of measurements of miners' exposure in Polish nonuranium mines, the risk of induction of cancer of the upper respiratory tract of all miners' population working under ground and caused by the presence of radon and its radioactive daughters can be estimated. The authors are fully aware of the fact that many para-

TABLE 3. Exposure Evaluation and Risk Assessment of Polish Miners (Based on Experiments Carried out between 1981 and 1987)

Type of mine	Radiation exposed population of miners [thousands]	Average miner's exposure for year [WLM]	Collective exposure [WLM]	Predicted life exposure after 30 years of employment [WLM]	Miners' radiation risk $\cdot 10^{-4}$
Coal mines	300.5	0.75	225375	22.5	34—101
Chemical raw material mines	3.53	0.26	918	7.8	12—35
Zinc-, lead-, and copper-ore mines	17.2	0.29	4988	8.7	13—39

meters of risk assessment, for instance age rate, were not taken into account, and that there exist other methods of risk assessment, eg. the so-called Lost Life Expectancy LLE. However, the results presented in the paper give a general idea of the extent of this risk. The so-called model of the absolute increase of risk was used for the purpose of this analysis. Risk of cancer of the upper respiratory tract equals 5—10 cases by 10^6 person-years by one exposure unit WLM. Assuming that the average exposure period lasts for 30 years and that the level of exposure to radiation in mines over this time remains constant, the overall life risk of cancer induction is $1.5 - 4.5 \cdot 10^{-4}$ by WLM (15). In Table 3 the results of evaluation of radiation exposure in all Polish mines are specified. On this basis, risk of induction of cancer of the upper respiratory tract was estimated for the population of miners exposed for the period of 30 years to the unchanged radiation conditions in mines. This risk averages $33 - 97 \cdot 10^{-4}$. In this point, comparison with the conventional occupational risk in Poland (6) can prove to be quite interesting. Rates of mortality risk for 1 year in different branches of Polish industry are detailed in Table 4. In mining and power industry this risk is $3.06 \cdot 10^{-4}$.

TABLE 4. The Average Risk of Work-Related Fatal Accidents in Different Branches of Polish Economy

Government department	The average risk of work-related fatal accident for 1 year $\cdot 10^{-4}$
Foreign Trade and Water Economics	3.13
Mining and Power Industry	3.06
Transport	2.61
Building	2.00
Agriculture	1.44
Forestry and Wood Industry	1.30
Heavy Industry	1.29
Administration and Environment Protection	1.28
Mean value for Poland	1.20
Central Consumers' Co-operative Union	1.20
Farmers' Mutual Aid	1.19
Chemical Industry	1.06
Telecommunication	0.98
Central Co-operative Union of Work	0.73
Machine-building Industry	0.52
Home Trade and Services	0.49
Food Industry and Purchase	0.48
Light Industry	0.32

With the constancy of mortality risk in time assumed, it can be determined that the rate of risk of a fatal accident in mining during a 30-year period of employment is in Poland $90 \cdot 10^{-4}$. The rate of this risk is comparable with the rate of risk of induction of cancer caused by the presence of radon and its daughters. The overall mining risk during 30 years of employment (the sum of the conventional risk and risk of cancer induction) ranges from $123 \cdot 10^{-4}$ to $187 \cdot 10^{-4}$. It should be realized, however, that this sum can only be an approximation of the overall mining risk. In this estimation different age structures of fatal accidents caused directly by work or induced by cancer were not taken into account. It is worth noticing, that over the same period of employment the average occupational mortality ratio in Poland is $36 \cdot 10^{-4}$.

In Poland, cancer risk for 1 year is $18.3 \cdot 10^{-4}$ (21). As it follows from the calculations, the rise of cancer mortality from the presence of radon and its daughters can be treated as insignificant in comparison with the overall rate of cancers recorded in Poland. Therefore, epidemiological relation between the rate of additionally induced cases of cancer, and radiation exposure in Polish mines can be a difficult task.

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