Polish Journal of Occupational Medicine Vol 2, No. 1, 1989

AUTHORIZED LIMITS OF RADON DAUGHTER PRODUCTS IN POLISH UNDERGROUND METAL-ORE MINES IN THE LIGHT OF EXPERIENCE

T. DOMAŃSKI, DSc, PhD, D. KLUSZCZYŃSKI, MSc and W. CHRUŚCIELEWSKI DSc, PhD

Department of Radioactive Contaminations, Nofer's Institute of Occupational Medicine, Lodz, Poland

Key words: Ionizing radiation, Mines, Radon, Limits

Abstract. The paper presents the results of measurements of individual exposures of miners to radioactive radon daughter products, naturally existing in air of metal-ore mines. Results concern the three year period between 1985 and 1987, during which the observed annual average concentrations were stable and have been recognised as values corresponding to the steady state. They are presented and analysed assuming several possible values of the Authorized Limit of the exposure of miners to radon daughter products. The values: 1 WLM, 2.5 WLM, 3.5 WLM (Working Level Month) were considered and compared with the value of 5 WLM, which is currently the basic limit recommended by the International Commission on Radiological Protection (ICRP), and approved by the WHO, ILO and IAEA.

Though the value of 3.5 WLM is presently adopted and officially authorized in Poland as the Authorized Limit of annual individual miners' exposure, the results presented in this paper lead to the conclusion that the value of 2.5 WML could be adopted instead of the current one. This means that the present limit could be decreased by about 30% and without causing any social, technological and economic problems in Polish metal-ore mines.

INTRODUCTION

The annual limit of individual occupational exposure to radon (^{222}Rn) daughter products in air, specified as 5 WLM (17 mJh^{-3}), recommended by the International Commission on Radiological Protection (ICRP) (10) has been adopted and confirmed 'in extenso' by several international organisations and agencies, namely: the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency of the OECD, the World Health Organisation and the International Labour Organisation (6). This limit may be treated as the upper boundary of exposure which must not be exceeded. However, it is recommended that an appropriate competent

Address reprint requests to T. Domański, Department of Radioactive Contaminations, Nofer's Institute of Occupational Medicine, 8 Teresy Street, P.O. Box 199, 90-950 Lodz, Poland

local authority could and should specify and implement the so-called 'authorized limit', which should be generally lower, than the primary limit or its equivalents. Certainly, each authorized limit is and should be a reasonable compromise between the intention of reducing the risk resulting from the exposure and the actual economic costs of the prospective measures.

The Authorized Limit (AL) of the occupational exposure in Polish underground metal-ore mines was adopted as 3.5 WLM (12 $mJhm^{-3}$) (1) more than 10 years ago and this value has been confirmed in recent state regulations (13). Nevertheless, during the last 5 years, the individual annual exposures of miners employed in these mines have never reached this limit; they are usually much less than half of this value. Undoubtedly, the progress which has been observed and reached in reducing miners' exposure, has been possible owing to continual efforts towards improving the ventilation system of mines and in the permanent routine control of air contamination in the work environment.

At present, the situation in Polish nonuranium metal-ore mines seems to be satisfactory and even makes it possible to re-consider the value of the authorized limit.

This paper is aimed at discussing the question to what extent the authorized limit of individual annual exposure to radon daughter products can be decreased at present.

Metal Ore Mines

All of the metal-ore mines actually existing in Poland have been considered. The characteristics of these mines are presented in Table 1. In each of these mines the system of radiation protection is based on the general code of practice prepared and unified for mines.

The principles of the radiation protection system are the following:

1. Employing certified radiation safety officers responsible for measuring or supervising the monitoring of radon daughter concentrations and authorized to order any other necessary technical actions.

2. Routine monitoring of radon daughter product concentrations by a local monitoring service according to principles of the so-called 'Air Sampling System' (ASS).

3. Implementing suitable technical measures and actions in all cases when the monitoring system reveals an unexpected increase in concentrations.

4. Implementing a system of evaluation of individual miners' exposures routinely carried out by the so-called 'Helmet Cassettes System'

TABLE 1. Investigated Metal-Ore Mines

Code of mine	Type of metal-ore	Number of employed miners	Number of miners equipped with individual dosimeters	Year of implementation of the HCS
BOL	Zn-Pb	650	32	1977
TRZ	Zn-Pb	1060	33	1977
OLK	Zn-Pb	520	29	1977
POM	Zn-Pb	1630	58	1977
DAB	Zn-Pb	200	60	1977
MAR	Zn-Pb	85	25	1977
KON	Cu	830	70	1977
LUB	Cu	3880	42	1977
RUD	Cu	5961	50	1977
POL	Cu	3967	30	1977
SIE	Cu	2343	34	1983

(HCS), for appropriately selected representative groups of miners employed in a considered mine.

The principles and other technical details and procedures related to the ASS- and HCS-systems have been described in other papers (3, 4).

It is worth remembering that the HCS-system is based on systematic 1-month routine measurements using individual cassettes worn by selected miners on their helmets. These cassettes contain the passive track-etch detectors sensitive to alpha radiation. Indeed, the detection material used has been properly calibrated in the experimental chamber before its application (2). Usually, the reperesentative group of miners working in helmets with cassettes comprises 20—70 men, depending on the potential radiation hazard existing in a particular mine, i.e. the number of cassettes is related to the average annual concentration of radon daughters observed in a given mine.

The ASS-system is realized by the ventilation staff in each of the considered mines by the use of suitable portable meters and approved methods of measuring.

The results of measurements of the individual exposures of miners constituting the representative groups are the subject of the considerations presented below.

Miners' Individual Exposures

The results of individual miners' exposures collected in a suitable computerised data bank between 1985 and 1987 are the base material for consideration.

In order to establish a possible authorized limit it is necessary to find out what the possible distribution of observed real individual exposures would be if one could assume different predicted values of limits. For this purpose, the following variants of values of possible Authorized Limits are considered: 1 WLM, 2.5 WLM, 3.5 WLM, 5 WLM. The logical justification of such values is as follows:

5 WLM — is the value of the limit of annual equivalent of the exposure of a miner to radon daughters, recommended as the basic limit by the ICRP and other international organizations.

3.5 WLM — is the present value of Authorized Limit adopted in Poland and approved by competent local authorities and confirmed in respective official regulations.

2.5 WLM — is an arbitrary value considered as a possible Authorized Limit which corresponds to one half of the basic ICRP limit.

1 WLM — is the considered value which corresponds to the Authorized Limit recommended in the United States by the National Institute of Occupational Safety and Health (NIOSH) for miners exposed to radon daughters (12).

TABLE 2. The Distribution of Individual Miners' Exposures in Copper and Zinc--lead Ore Mines which Could Be Observed in Particular Years if the Authorized Limit Were Considered as 1 WLM/year

Year	Type of ore	Expected fraction *										
		0 0.1	0.1 0.2	0.2 0.3	0.3 0.4	0.4 0.5	0.5 0.6	0.6 0.7	0.7 0.8	0.8 0.9	0.9 1	1 3
1985	Cu	0.121	0.200	0.112	0.158	0.102	0.093	0.074	0.060	0.033	0.019	0.028
	Zn-Pb	0.140	0.131	0.114	0.123	0.110	0.093	0.081	0.059	0.018	0.034	0.097
1986	Cu	0.138	0.241	0.154	0.159	0.103	0.087	0.056	0.026	0.021		0.015
	Zn-Pb	0.163	0.163	0.198	0.075	0.062	0.106	0.062	0.062	0.022	0.017	0.070
1987	Cu	0.267	0.198	0.188	0.149	0.094	0.069	0.015	0.005			0.015
	Zn-Pb	0.171	0.186	0.129	0.076	0.133	0.090	0.067	0.019	0.023	0.038	0.068
1985—1987	Cu	0.175	0.212	0.150	0.155	0.100	0.083	0.049	0.031	0.018	0.007	0.020
	Zn-Pb	0.158	0.159	0.147	0.091	0.101	0.097	0.070	0.048	0.021	0.030	0.078

* Expected fraction of number of miners, at exposure within given intervals of considered authorized limit, i.e.
$<$ 0—0.1) .... $<$ 1—3) of considered limit.

TABLE 3. The Distribution of Individual Miners' Exposures in Copper and Zinc--lead Ore Mines which Could Be Observed in Particular Years if the Authorized Limit Were Considered as 2.5 WLM/year

Year	Type of ore	Expected fraction *										
		0 0.1	0.1 0.2	0.2 0.3	0.3 0.4	0.4 0.5	0.5 0.6	0.6 0.7	0.7 0.8	0.8 0.9	0.9 1	1 3
1985	Cu	0.367	0.326	0.200	0.079	0.023	0.005					
	Zn-Pb	0.332	0.322	0.201	0.064	0.035	0.028	0.011	0.007			
1986	Cu	0.451	0.344	0.159	0.031	0.010	0.005					
	Zn-Pb	0.414	0.247	0.203	0.066	0.053	0.013	0.004				
1987	Cu	0.589	0.307	0.084	0.005	0.005	0.005	0.005				
	Zn-Pb	0.452	0.243	0.176	0.062	0.038	0.024	0.005				
1985—1987	Cu	0.467	0.325	0.149	0.039	0.013	0.005	0.002				
	Zn-Pb	0.393	0.275	0.194	0.064	0.042	0.022	0.007	0.003			

* Expected fraction of number of miners, at exposure within given intervals of considered authorized limit, i.e.
< 0—0.1) .... < 1—3) of considered limit.

TABLE 4. The Distribution of Individual Miners' Exposures in Copper and Zinc--lead Ore Mines which Could Be Observed in Particular Years if the Authorized Limit Were Considered as 3.5 WLM/year

Year	Type of ore	Expected fraction *										
		0 0.1	0.1 0.2	0.2 0.3	0.3 0.4	0.4 0.5	0.5 0.6	0.6 0.7	0.7 0.8	0.8 0.9	0.9 1	1 3
1985	Cu	0.498	0.363	0.116	0.018	0.005						
	Zn-Pb	0.445	0.347	0.136	0.051	0.013	0.008					
1986	Cu	0.636	0.303	0.046	0.015							
	Zn-Pb	0.568	0.261	0.114	0.044	0.013						
1987	Cu	0.738	0.237	0.015		0.010						
	Zn-Pb	0.533	0.319	0.091	0.052	0.005						
1985—1987	Cu	0.621	0.302	0.061	0.011	0.005						
	Zn-Pb	0.514	0.309	0.115	0.049	0.010	0.003					

* Expected fraction of number of miners, at exposure within given intervals of considered authorized limit, i.e.
< 0—0.1) .... < 1—3) of considered limit.

TABLE 5. The Distribution of Individual Miners' Exposures in Copper and Zinc-lead Ore Mines which Could Be Observed in Particular Years if the Authorized Limit Were Considered as 5 WLM/year

Year	Type of ore	Expected fraction *										
		0 0.1	0.1 0.2	0.2 0.3	0.3 0.4	0.4 0.5	0.5 0.6	0.6 0.7	0.7 0.8	0.8 0.9	0.9 1	1 3
1985	Cu	0.693	0.279	0.028								
	Zn-Pb	0.619	0.284	0.076	0.021							
1986	Cu	0.810	0.175	0.015								
	Zn-Pb	0.661	0.269	0.066	0.004							
1987	Cu	0.898	0.087	0.010	0.005							
	Zn-Pb	0.695	0.238	0.062	0.005							
1985—1987	Cu	0.797	0.183	0.018	0.002							
	Zn-Pb	0.658	0.264	0.068	0.010							

* Expected fraction of number of miners, at exposure within given intervals of considered authorized limit, i.e.
< 0—0.1) .... < 1—3) of considered limit.

The results of individual annual exposures stored in the data bank were processed and expressed as a fraction (or a multiple) of the above presented possible authorized limits. Such data, concerning the particular years 1985, 1986, 1987, are presented in Tables 2, 3, 4, 5 according to the type of mining and concern the assumed limits 1, 2.5, 3.5 and 5 WLM, respectively. Since no significant difference exists in the distribution of results collected for zinc-lead and copper miners and no distinct difference is observed for particular years, the results could be pooled together for both types of mines and for the three year period of observation under consideration. The comparison of pooled results is presented in histograms in Fig. 1.

DISCUSSION

The value 3.5 WLM was adopted in Poland in 1970, since it corresponded to 30 pCi/liter of the radon (^{222}Rn) concentration at full equilibrium with its progeny in air, and assumed the duration of exposure

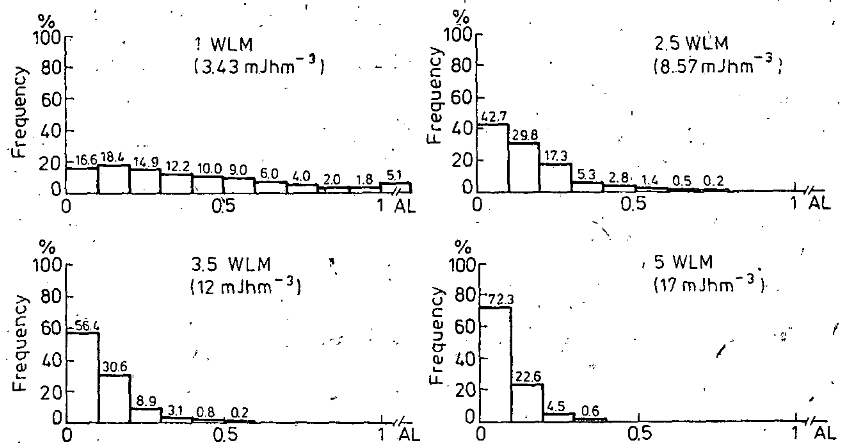

Fig. 1. The distribution of individual exposures of miners of metal-ore mines to radon daughter products, expressed as the fraction of different values of the Authorized Limit (AL).

as 2000 hours per year. So, this limit was in agreement with previous recommendations of the ICRP i.e. Publication No. 2 in 1959 (7) and publication No. 24 in 1976 (8).

When the ICRP recommended the value 5 WLM in Publication No. 32 in 1981, the value 3.5 WLM, previously adopted in Poland, was approved and called the Authorized Limit, since there was no reasonable justification nor any premises to adopt and authorize a limit higher than the previous one. Also, the adoption of the Authorized Limit of 3.5 WLM created a certain safety margin for any unexpected cases in which the exposure to ionising radiation from other sources of radiation hazard would occur in the mine environment. In particular, at this time it was found that abundant fossil waters containing radium-226 can be encountered in many coal-mines and should be considered as the chief potential source of the radiation hazard, except when the hazard could be caused by radon daughters (14).

However, a careful study conducted a few years later (15) revealed that radioactive fossil waters do not exist in zinc-lead and copper mines; neither does their activity reach levels comparable with these observed in coal-mines. Therefore, it is unnecessary to pursue the idea of creating a safety margin.

At present, the results of measurements of individual exposure of representative groups of miners suggest several conclusions.

First of all, it is apparent that the present situation in Polish underground metal-ore mines can be considered to be stable, since no rapid trends of increase in concentrations or exposures are observable.

Moreover, even a slight trend in the decrease of exposures in the period 1988—1987 can be seen in the data presented in Tables 2—5, since the fraction of results in the lowest class, i.e. in the class < 0—0.1 of the considered authorized limit, increases slightly year by year.

Secondly, distributions of exposures of miners in both types of mines (zinc-lead and copper) seem to be very much alike and allow us to draw conclusions which are common for both types of mines.

Our final conclusion is that the value 2.5 WLM can be adopted as the Authorized Limit for the nonuranium underground metal-ore mines in Poland, instead of the currently adopted limit of 3.5 WLM. The justification of such an idea is the fact (see Fig. 1) that no results of individual exposure higher than 80% of this value have been found during the last three years, and only about 2% of results were higher than 50% of this newly proposed limit. The question arises concerning what advantages or disadvantages should be expected regarding this value as compared with the previous one, i.e. 3.5 WLM. The advantages seem to be obvious from the hygienic point of view; namely that the present situation which can be recognised as a steady state at ALARA (As Low As Reasonably Achievable) concentrations — will be guaranteed by introducing relatively low authorized limits of miners' exposure. It is very difficult, or almost impossible, to anticipate which concentrations will be recognised as "reasonably achievable" in the future.

However, even if the lowest relatively achievable concentrations should be higher in the future than the ones existing at present, and if it would cause a certain impact on the possible increase of miners' exposure, then any compromise and possible consent which would be concluded should be considered, since it would involve a decision about changing the authorized limit. In other words, the decreased limit, causing no costs and no other technological complications for the mining industry today, will consolidate the progress reached in respect of relatively very low concentrations of radioactive aerosols which cause low radiation exposure of miners. Therefore, the satisfactory situation which currently exists would not easily be changed for the worse, without any special official reconsideration of the situation preceding a possible decision on increasing the authorized limit. So, the proposal of establishing the value 2.5 WLM as new value of the Authorized Limit seems to be reasonable and justified from the preventative — hygiene point of view. The easy applicablity of this value, in the sense of no-cost and no-technological complications, seems to be a strong argument for the approval of the value proposed.

Also, other problems, closely related with a substantial decrease in the value of the authorized limit, have to be reconsidered, especially the sense, role and numerical values of other reference indexes frequently used in the practice of radiation protection in mining. Several auxiliary indexes are used officially approved for the practice in Poland. They have been characterised and described in detail in previous papers (11, 15), and they correspond to those defined in the ICRP recommendations and the Basic Safety Standards (6, 9), respectively.

What ought to come under consideration are the so-called "derived" limits, sometimes referred to as 'Authorized Derived Limits' (ADL). Generally, the sense of "deriving" is connected with the purpose for which such derived limits are intended. Thus, if they were to be used for the evaluation of a concentration which would guarantee that the exposure of a miner during a period of 2000 working-hours per year would not cause exposure higher than the Authorized Limit, then such an Authorized Derived Limit would have to be calculated as follows:

$$\mathrm{ADL} = \mathrm{AL}/2000 \text{ hours}$$

So, the numerical value of ADL, derived from AL = 2.5 WLM, is 0.21 WL instead of 0.30 WL corresponding to AL equals 3.5 WLM.

The two other reference indexes, namely the so-called 'Investigation Level' (IL) and 'Recording Level' (RL), related to the proposed Authorized Limit of 2.5 WLM, must be changed from the previous ones. According to the definition given in the ICRP recommendation or in the Basic Safety Standards, the recording level "is a level defined by the competent authorities for dose-equivalent or effective dose-equivalent or intake above which the information is of sufficient interest from a radiation point of view to be worth recording and keeping". What can be described "worth recording" is very arbitrary. Previously, the direct suggestion of the ICRP has been adopted, which means, that the RL is usually one twentieth of the Derived Limit corresponding to the Basic Limit of 5 WLM. Therefore, it had a value of 0.02 WL. At present, the authors share the opinion that the boundary value which is "interesting", in the case of a relatively low authorized limit is the annual average value of limit recommended by the ICRP for members of the public in prolonged exposure (many years). Since, in these conditions, the respective limit for annual exposure of members of public to radon progeny is 0.1 WLM, the derived Recording Level would be 0.1 WLM/2000 hours which yields 0.0085 WL. So, the estimated value of the Recording Level is proposed as 0.01 WL.

The investigation level defined by the ICRP as the "value of dose-equivalent or effective dose-equivalent or intake above which the results are considered sufficiently important to justify further investigation" is 1.5 WLM. This value of exposure corresponds to 3/10 ICRP limit 5 WLM, which is recommended as the boundary value distinguishing the so-called "working conditions" of class A and class B (9). So far, the boundary value has been recognised and approved as the investigation level. However, in general, where there are relatively low values of authorized limits (for example 1 WLM in the USA), the value of 3/10 of 5 WLM would sometimes be higher than such limits. Therefore, it seems logical to adopt a different concept for the creation of a possible investigation level. Thus, the general question appears of whether the idea of the existence of an investigation level is useful and sensible. The authors hold the opinion that it does have a certain sense and practical role, especially in the case of the arbitrary level helpful for taking decisions concerning when the individual dosimetry system should be implemented.

So, the authors propose to adopt the criterion of the implementation of the individual dosimetry system above an 'Investigation Level', corresponding to value 0.5 WLM. This value obviously has an arbitrary sense, however, it equals the maximum limit of annual exposure recommended by the ICRP (9) for members of the population.

Summing up, the authors suggest that, at present, for Polish non-uranium, zinc-lead and copper mines the following values of authorized limits and levels can be easily adopted:

	Proposed		Present	
Authorized Limit	2.5	WLM	3.5	WLM
Authorized Derived Limit	0.20	WL	0.30	WL
Investigation Level	0.50	WLM	1.5	WLM
Recording Level	0.010	WL	0.020	WL

ACKNOWLEDGEMENT

This study was performed under the National Cancer Control Programme — "Cancerogenesis of the Working Environment"; Project No. CPBR 11.5.65.2.

REFERENCES

1. Chruścielewski W., and Domański T.: System of personnel dosimetry introduced in Polish nonuranium mines. Proc. Int. Conf. Radiation Hazards in Mining: Control, Measurements, and Medical Aspects. 1981 Oct 4—9, Golden Co (USA). — 2. Chruścielewski W., Orzechowski W., and Domański T.: Calibration of LR-115 (II) Kodak foil for its application as a "passive" track detectors of radon and its progeny. Proc. Radon Specialist Meeting N.E.A. 3—7 March 1980, Rome—Cassacia CNEN, Italy. — 3. Domański T., Chruścielewski W., and Wojda A.: Long-Term measurements of WL-levels in metal mines by using the ASS system and HCS system. Proc Int Conf Occupational Radiation Safety in Mining 1984, Oct. 14—18, Toronto, Canada. — 4. Domański T., and Chruścielewski W.: Radiation exposure

of miners from metal ores and hard coal mines caused by the presence of radon and radioactive aerosols in the air. Stud Mat Monogr, IMP Lodz, 1985 no 19, (in Polish). — 5. Domański T., Chruścielewski W., and Liniecki J.: Project limits for miners' radiation hazard in mines. Stud Mat Monogr, IMP Lodz no 19, 1985 (in Polish). — 6. IAEA, Basic Safety Standards for Radiation Protection, IAEA Safety Series no 9, 1982. — 7. ICRP 2, Permissible dose for internal radiation Publication 2, Pergamon Press, Oxford, 1959. — 8. ICRP 24, Radiation protection in uranium and other mines, Publication 24, Annals of ICRP vol 1 no 1 1977. — 9. ICRP 26 Recommendation of the ICRP. Publication 26, Annals of the ICRP vol 1 no 3 1977. — 10. ICRP 32. Occupational limits for inhalation of radon-222, radon-220 and their short-lived daughters. ICRP Publication 32, Annals of the ICRP vol 6 no 1, 1981.

11. Kluszczyński D., Żórawski A., and Olszewski J.: Radiation exposure of miners and systems of radiation protection in Polish nonuranium mines Pol J Occup Med vol 1 no 1, 1988. — 12. NIOSH, A Recommended Standard for Occupational Exposure to Radon Progeny in Underground Mines DHHS (NIOSH) Publication No 88—101, 1987. — 13. Polish Standard PN-88-270071, 1988. Radiation protection in underground mining plants. Exposure limits for effects of natural radioactive isotopes on miners and methods of monitoring. — 14. Tomza I., and Lebecka J.: Radium-bearing waters in coal mines: occurrence, methods of measurement and radiation hazard. Proc Int Conf on Radiation Hazard in Mining: Control, Measurements and Medical Aspects 1981, Oct. 4—9, Golden Co (USA). — 15. Tomza I.: Private communication.

Received for publication: 03.01.1989
Accepted for publication: 10.01.1989