

RADIATION HAZARD IN POLISH SPAS — TEN YEARS' EXPERIENCE AND STUDIES

TOMISŁAW DOMAŃSKI, DSc, JACEK DONIEC, MSc
and WOJCIECH CHRUSCIELEWSKI, DSc

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

Key words: Ionizing radiation, Radiation hazard, Radon daughters, Spas

Abstract. This paper deals with radiation hazard of the personnel of Polish spas exposed to radon ^{222}Rn and the radioactive products of its decay in the air of the rooms in which they work. The results of individual measurements of the exposure of personnel in three spas — Ładek Zdrój, Świeradów and Kowary during the last 10 years are presented. The results of measurements of the concentration of radon decay products carried out between 1985 and 1988 in all other of Polish spas where radon can occur, are also described. In the discussion, an outline of a system of radiation protection in Polish spas is presented, along with the criteria of classification of work-stands where personnel can be exposed to radiation. In addition, the requirements needed to facilitate the implementation of this outline are given some attention.

INTRODUCTION

In numerous Polish spas, mineral waters can be found which contain the radioactive gas radon (^{222}Rn). These waters are, either bottled or used during balneotherapeutical procedures (baths, water procedures, inhalations). During all these procedures, radon which is a noble gas, can easily penetrate the surroundings by natural diffusion. During radioactive disintegration ($T_{1/2}=3.8$ days), radon emits alpha radiation and forms other, also short-lived decay products, of which ^{218}Po (RaA) $T_{1/2}=3.05$ min., ^{214}Pb (RaB) $T_{1/2}=26.8$ min., ^{214}Bi (RaC) $T_{1/2}=19.9$ min., ^{214}Po (RaC') $T_{1/2}=1.6 \cdot 10^{-4}$ sec. are the most important.

All these products form so-called alpha radioactive aerosols. Their presence in the air which people inhale results in irradiation of the respiratory tract. This situation may cause an ionizing radiation hazard to the personnel of balneotherapy rooms or in mineral water bottling

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



plants. The most seriously exposed cells are the basal cells of the bronchus epithelium. The ionizing radiation dose derives from radiation of both radon and aerosols which are inhaled at the same time. However, the contribution of aerosol radiation is much higher (96%) than that of radon. Chronic exposure to radon and radioactive aerosols characterized by concentrations much higher than natural concentrations in ambient atmospheric air may lead to the admission of large doses of radiation to the respiratory tract, which, in turn, can bring about malignant neoplasms of the irradiated bronchus epithelium. The neoplasm's long period of latency (20—30 years), as well as the absence of any early symptoms of this disease in its initial stages, right after or still during exposure, lie behind the lack of attention paid to the problem of radiation exposure of personnel.

The present paper is concerned with measurements of the exposure of personnel in Polish spas and examines the principles which apply in balneotherapy rooms and mineral waters utilization plants throughout our country.

METHODS OF MEASURING AND ESTIMATION OF HAZARD

Concentrations of radioactive aerosols are measured using the potential energy of alpha radiation of radon decay products as a parameter. This is the energy of all alpha particles which are to be emitted as a consequence of the total decay of all radon daughter products at the full equilibrium and concentration of 100 pCi/l. The accepted traditional unit is 1 WL (Working Level). Human exposure to radioactive aerosols is expressed in exposure units which are obtained by multiplying the concentration and exposure duration. A conventional unit is 1 WLM (Working Level Month). The relationship between these two units and their equivalents expressed by the International System of Units is presented in Table 1.

TABLE 1. Relationship between Concentration Units and Units of Exposure to Radioactive Aerosols of Radon (^{222}Rn) Decay Products

Term	Symbol	Value expressed in traditional units	Value expressed in SI units
Concentration of radioactive aerosols	1 WL	$1.3 \cdot 10^5 \frac{\text{MeV}}{\text{liter}}$	$2.1 \cdot 10^{-5} \frac{\text{J}}{\text{m}^3}$
Exposure	1 WLM	$2.2 \cdot 10^7 \frac{\text{MeVh}}{\text{liter}}$	$3.5 \cdot 10^{-3} \frac{\text{Jh}}{\text{m}^3}$

$$1 \text{ WLM} = 1 \text{ WL} \cdot 170 \text{ hours} = 170 \text{ WL hours}$$



Both the concentration and the exposure can be expressed in different measuring systems and using different techniques, as necessary. In the examination described below, three measuring systems were used.

a) a measuring system based on filtering particular air samples and analyzing the activity of a given filter (the so-called 'Air Sampling System'),

b) a measuring system based on the use of cassettes placed in a considered environment with passive integrating detectors of alpha radiation of radon decay products (the so-called 'Environmental Cassettes System'),

c) a measuring system based on the use of cassettes, as in the case of the ECS-system, but attached to and worn on the personnels' working clothes (the so-called 'Individual Cassettes System').

Technical details concerning the above mentioned measuring systems have already been described and discussed, since all of them have been employed many times (with certain small variations) in order to evaluate the radiation exposure of miners in Polish underground mines (1).

Sensitivity¹ and precision² of measuring methods used for the examination of concentrations and exposure of personnel in spas were as follows:

the ASS-system	sensitivity = 2 nJ/m ³	precision = 20%
the ECS-system	sensitivity = 100 nJ/m ³	precision = 30%
the ICS-system	sensitivity = 0.07 nJh/m ³	precision = 30%

The principal measuring device used in the ASS-system is the mining radiometer RGR-11 and RGR-12 with a semiconductor detector of alpha particles manufactured by POLON (Poland). In measuring cassettes used in the ECS- and ICS- system, the so-called 'solid state nuclear track detectors' LR-115 produced by Kodak (USA) are used. Measurements carried out using the ASS-, ECS- and ICS-systems are presented in Figures 1, 2 and 3, respectively.

LEVELS AND LIMITS

The following control levels and limits of exposure to ionizing radiation have been adopted:

— Annual Limit of Exposure (ALE): the annual individual exposure to radioactive aerosols which must not be exceeded, except in an emergency or rescue action. This limit has been established and defined by the International Commission on Radiological Protection (ICRP) (7), with

¹ the lowest measurable concentration or exposure at the confidence level = 95%

² variability of measurements in a series defined as the value of standard deviation and expressed as a percentage of the mean value



Fig. 1

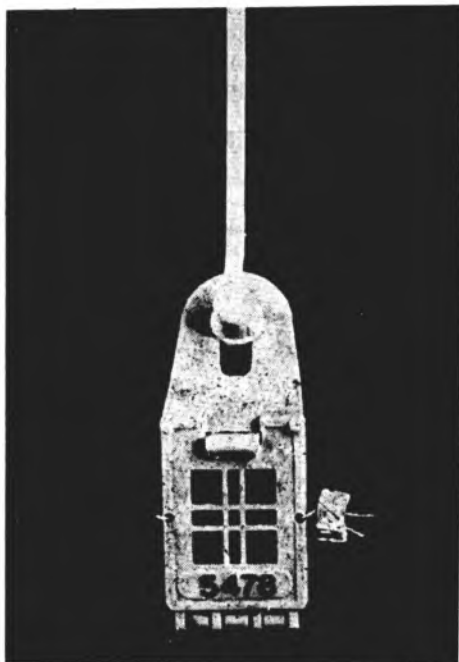


Fig. 2



Fig. 1. Measurements of potential energy concentrations of alpha radiation of radon decay products in air using the ASS-system.

Fig. 2. A cassette with a detector used for environmental measurements of potential energy concentrations of alpha radiation of radon decay products in air using the ECS-system.

Fig. 3. Measurements of worker's individual exposure to radioactive aerosols — radon decay products — at work using the ICS-system.



the recommendation to accept the lower value as the so-called Authorized Limit, should this be possible and practicable.

— Authorized Limit: the adopted practicable value of an annual exposure, which must not be exceeded except in an emergency.

— Derived Air Concentration Limit (DAC): the value of concentration of potential energy of alpha radiation of radon decay products in air, at which, during 2000 working hours a year, the ALE will not be exceeded,

TABLE 2. Accepted Limits and Levels

Name	Symbol	SI		Traditional system	
		Value	Units	Value	Units
Annual Limit of Exposure	LG_a	$17 \cdot 10^{-3}$	$J \cdot h \cdot m^{-3}$	5	WLM
Derived Air Concentration Limit	LP_a	$8.4 \cdot 10^{-6}$	$J \cdot m^{-3}$	0.4	WL
Authorized Limit	LA_a	$12 \cdot 10^{-3}$	$J \cdot h \cdot m^{-3}$	3.5	WLM
Authorized Derived Limit	LR_a	$6.2 \cdot 10^{-6}$	$J \cdot m^3$	0.3	WL
Recording Level	PI_a	$0.4 \cdot 10^{-6}$	$J \cdot m^{-3}$	0.02	WL
Investigation Level	PD_a	$5 \cdot 10^{-3}$	$J \cdot h \cdot m^{-3}$	1.5	WLM

— Authorized Derived Limit: the value of potential energy concentration of alpha radiation of radon decay products in air, at which, during 2000 working hours per year the Authorized Limit will not be exceeded,

— Recording Level: the value of potential energy concentration of alpha radiation of radon decay products in air. If it occurs, a detailed examination of exposure conditions is necessary.

— Investigation Level: the value of mean annual exposure of a worker. If it occurs, it is necessary to implement individual dosimetry for the exposed personnel.

Numerical values of limits and levels are presented in Table 2. The justification of accepted numerical values is discussed separately (2).



CHARACTERIZATION OF SPAS

The characteristics of surveyed Polish spas are presented in Table 3. The approximate geographical position of particular spas mentioned above is presented in Fig. 4. Table 4 displays the mean annual concen-

TABLE 3. Surveyed Spas in which Radiation Exposure of Personnel to ^{222}Rn and its Daughters Can Occur

Spa	The way of utilizing a medium containing ^{222}Rn and mineral waters ¹	Number of personnel
Busko Zdroj	ih, pk, km, bu	60
Ciechocinek	ih, pk, km, ig, bu	38
Cieplce Zdroj	pk, km, bu	59
Duszniki Zdroj	ih, pk, km, kk	13
Horyniec Zdroj	ih, pk, km, kk	6
Iwonicz Zdroj	ih, pk, km, kk	24
Kamien Pomorski	ih, ks	23
Kolobrzeg	ih, pk, km, kk, bu	24
Kowary	ir ²	28
Krynica Zdroj	pk, km, kk, kp, kg, bu	66
Kudowa Zdroj	ih, pk, km, kk, kg, bu	47
Ladek Zdroj	pk, km, kk, kp, kr, kb, ir ³	34
Naleczow	ih, pk, km, kk, bu	60
Polanica Zdroj	ih, pk, kk, bu	38
Polczyn Zdroj	ih, km, kk, bu	92
Przerzeczyn Zdroj	ih, kk, kg ³	15
Rabka Zdroj	ih, pk, km, kk	18
Rymanow Zdroj	ih, pk, km, kk, bu	45
Swoszowice	km, pp	25
Szczawnica	ih, pk, km, pp, bu	23
Szczawno Zdroj	ih, pk, km, kk, bu ³	12
Swieradow Zdroj	pk, km, kr, ir ³	18
Swinoujscie	ih, km, kk	33
Ustron	km, kk	152
Wieniec Zdroj	km, kk	18
Total		971

¹ Explanation to abbreviations — (number of spas performing a given activity are given in brackets):

bu	— bottling (12)	ih	— inhalations (17)
ig	— gynecological irrigations (1)	kb	— baths in a pool (1)
ir	— radon inhalations (3)	km	— mineral water baths (21)
kg	— gas baths (2)	kp	— pearly baths (3)
kk	— carbonic acid baths (17)	ks	— saline baths (1)
kr	— radon baths (2)	pp	— paradontium rinsing washing (2)
pk	— drinking cure (17)		

² inhalations are performed in worked-out uranium mines

³ mineral water containing more than 74 Bq $^{222}\text{Rn}/\text{l}$ (2 nCi/l)



tration of potential energy of radon decay products in air in particular Polish spas. The data have been obtained on the basis of a whole year of measurements carried out using the ECS-system. Twelve one-month measuring cycles, consisting of 10 single measurements each, were performed at different work-stands (4). Only in Kowary, where concentra-

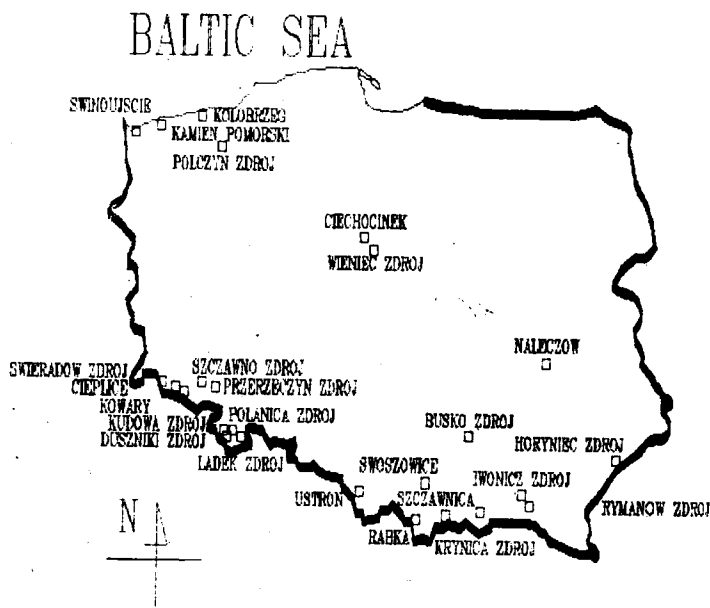


Fig. 4. Geographical location of surveyed spas in Poland.

tions are much higher than in other spas, was it possible to carry out measurements using the ASS-system. One hundred and nine single measurements were made in different periods of the therapeutic season in the spas (5). In total, 2336 measurements were performed in 25 spas.

Table 5 presents data on the seasonal variability of concentrations in particular Polish spas (4), where the values of mean arithmetic concentrations observed in respective months of the year are expressed as fractions or a multiplication of the mean annual value. The data imply the lack of a relationship between concentrations observed and seasons of the year.

RADIATION HAZARD OF PERSONNEL IN SPAS

Personnel of spas in which natural mineral waters are used consist of medical personnel, i.e. physicians, physiotherapists and nurses and engineering staff attending machinery. Additionally, in some spas, special

TABLE 4. Mean and Maximum Concentrations of Potential Energy of Radon ^{222}Rn Decay Products in Air of Work Rooms in Surveyed Spas, Expressed in nJ/m^3 and mWL

Spa	Arithmetic mean	SD* [%]	Number of measurements	Maximum value
Busko Zdroj	61.2 (2.9)	21	104	291.0 (14.0)
Ciechocinek	80.9 (3.9)	25	52	434.0 (20.9)
Cieplce Zdroj	170.0 (8.2)	29	79	1330.0 (63.9)
Duszniki Zdroj	101.0 (4.9)	18	84	524.0 (25.2)
Horyniec Zdroj	62.0 (3.0)	15	107	192.0 (9.2)
Iwonicz Zdroj	74.3 (3.6)	25	120	371.0 (17.8)
Kamien Pomorski	123.0 (5.9)	15	83	320.0 (15.4)
Kolobrzeg	49.4 (2.4)	41	98	533.0 (25.6)
Kowary	226000.0 (10900.0)	64	119	678000.0 (32600.0)
Krynica Zdroj	86.6 (4.2)	27	84	535.0 (25.7)
Kudowa Zdroj	78.8 (3.8)	26	101	484.0 (23.3)
Ladek Zdroj	574.0 (27.6)	61	98	7200.0 (346.0)
Naleczow	60.6 (2.9)	24	110	465.0 (22.4)
Polanica Zdroj	79.6 (3.8)	52	32	414.0 (20.0)
Polczyn Zdroj	69.6 (3.3)	24	129	268.0 (12.9)
Przerzeczyn Zdroj	294.0 (14.1)	52	105	4170.0 (200.0)
Rabka Zdroj	44.4 (2.1)	22	109	148.0 (7.1)
Rymanow Zdroj	190.0 (9.1)	31	116	1300.0 (62.5)
Swoszowice	73.3 (3.5)	24	110	239.0 (11.5)
Szczawnica	125.0 (6.0)	25	105	505.0 (24.3)
Szczawno Zdroj	79.9 (3.8)	21	88	450.0 (21.6)
Swieradow Zdroj	292.0 (14.0)	18	74	1700.0 (81.7)
Swinoujscie	25.9 (1.2)	51	53	145.0 (7.0)
Ustron	37.8 (1.8)	33	99	168.0 (8.1)
Wieniec Zdroj	52.6 (2.5)	32	87	244.0 (11.7)

* SD — standard deviation expressed as a percentage of the mean value

groups of workers who bottle mineral waters are employed. Systematic measurements of individual exposures of personnel have been carried out in three spas: Kowary, Ladek Zdroj and Swieradow Zdroj. Table 6 displays mean and maximal annual individual exposures in the above mentioned spas between 1977 and 1987. In 1977 the Institute of Occupational Medicine in Lodz (IOM) initiated measurements of individual exposures of personnel. In 1978, preliminary suggestions concerning a radiation protection system for these three spas were proposed and then brought into practice (1979). Unchanged, the system has existed until now. The principal features of the system were as follows:

— reduction of time spent by medical personnel and engineering staff in an area of air contamination,



TABLE 5. Variability of Concentrations of Potential Energy in Particular Spas Calculated in Comparison with the Mean Annual Concentration of Radioactive Aerosols and the Ratio between the Highest and the Lowest Concentrations Observed

Spa	I	II	III	IV	V	VI	VII	Months				X	XI	XII	Year	max	
								VIII	IX	X	XI					min	min
Busko Zdroj	0.71	1.95	1.05	0.47	0.95	0.63	0.82	—	1.14	1.15	1.35	0.84	1.0	1.0	4.2		
Ciechocinek	2.20	2.23	0.92	—	0.80	—	—	—	0.64	0.73	0.46	1.02	1.0	1.0	4.9		
Cieplisz Zdroj	0.28	0.21	2.84	0.68	0.87	—	0.30	1.01	1.05	1.33	—	2.89	1.0	1.0	13.6		
Duszniki Zdroj	1.14	0.75	0.32	0.20	0.64	—	1.08	—	0.81	—	3.60	0.57	1.0	1.0	18.1		
Horyniec Zdroj	1.38	0.83	0.33	0.88	0.35	1.16	0.71	0.89	1.06	0.84	1.40	1.99	1.0	1.0	6.1		
Iwonicz Zdroj	1.63	0.31	0.48	0.79	0.88	1.54	1.39	0.82	1.71	1.04	0.66	0.81	1.0	1.0	5.5		
Kamien Pomorski	1.53	1.24	1.16	1.01	0.58	0.49	0.96	1.54	0.69	0.35	1.24	1.14	1.0	1.0	4.4		
Kolobrzeg	0.52	1.92	0.97	1.04	0.74	0.18	0.72	1.78	0.14	0.84	0.99	1.63	1.0	1.0	14.0		
Krynica Zdroj	0.35	0.41	1.17	0.89	—	0.85	0.48	1.88	0.83	1.40	1.55	—	1.0	1.0	5.4		
Kudowa Zdroj	0.57	0.46	0.73	1.31	0.92	0.84	—	3.34	1.96	0.39	1.17	0.97	1.0	1.0	8.6		
Ladek Zdroj	1.25	0.64	0.49	0.76	0.46	1.09	0.80	2.12	0.17	1.18	2.00	0.87	1.0	1.0	12.2		
Naleczow	0.80	0.64	0.13	0.93	1.97	0.60	1.02	0.75	0.97	0.87	2.23	0.89	1.0	1.0	17.8		
Polanica Zdroj	0.92	—	—	0.91	—	—	—	—	1.80	—	—	0.23	1.0	1.0	7.9		
Polczyn Zdroj	1.39	1.16	1.14	1.11	0.45	2.00	1.32	1.18	0.06	0.70	0.47	0.81	1.0	1.0	30.6		
Przerzeczyn Zdroj	0.32	0.67	0.60	2.13	—	0.51	0.84	1.43	1.00	0.76	1.78	1.40	1.0	1.0	6.7		
Rabka Zdroj	0.97	1.15	0.88	0.31	1.15	1.37	1.11	0.31	—	1.22	2.06	0.45	1.0	1.0	6.6		
Rymanow Zdroj	1.85	0.82	0.77	1.17	1.16	0.78	0.88	1.67	0.51	0.66	0.68	1.04	1.0	1.0	3.7		
Swoszowice	0.53	1.00	1.21	1.21	0.78	0.75	—	—	0.99	1.42	1.06	1.02	1.0	1.0	2.7		
Szczawnica	—	0.59	1.62	0.72	0.84	1.17	0.87	0.99	—	0.74	2.71	1.03	1.0	1.0	4.6		
Szczawnio Zdroj	0.09	—	0.19	0.74	1.13	0.89	—	—	2.06	1.80	—	—	1.0	1.0	22.5		
Swieradow Zdroj	2.15	1.08	0.45	0.78	1.45	0.93	0.65	1.14	1.05	0.69	0.73	0.78	1.0	1.0	4.8		
Swinoujście	1.22	0.41	0.19	0.77	0.84	—	3.05	2.41	0.95	0.63	0.18	0.56	1.0	1.0	17.4		
Ustron	1.65	1.30	—	0.48	0.32	1.03	1.19	0.85	1.01	1.00	1.19	—	1.0	1.0	5.1		
Wieniec Zdroj	1.92	1.28	0.06	0.32	0.67	0.77	0.78	—	—	1.25	2.13	0.35	1.0	1.0	35.3		

TABLE 6. Mean and Maximum Exposures of Personnel Observed between 1977 and 1987, Expressed in mJhm⁻³

Year	Spa								
	Ladek Zdroj			Swieradow Zdroj			Kowary		
	number of per- sons	mean value	max.	number of per- sons	mean value	max.	number of per- sons	mean value	max.
1977	20	72.8	383.9				15	5.0	10.3
1978	15	42.8	592.0	53	3.7	9.8	19	3.7	6.0
1979	26	8.2	65.5	56	2.4	6.1	20	1.7	3.6
1980	21	1.7	9.6	57	1.9	5.2	17	0.8	2.4
1981	17	2.5	8.4	59	1.9	4.9	24	1.6	4.7
1982	28	1.1	10.5	65	1.8	20.9	27	0.8	2.5
1983	33	2.4	21.1	59	1.4	7.9	34	0.7	2.0
1984	26	0.4	1.7	59	1.7	5.5	38	0.7	1.9
1985	28	1.4	22.4	64	1.5	8.3	37	0.7	1.9
1986	22	3.0	27.8	74	0.7	2.1	27	0.7	1.8
1987	39	2.0	8.6						

- employing local radiation safety officers who were supposed to control the radiation hazard of personnel,
- introduction of individual dosimeters for personnel (the ICS-system established by IOM) and environmental monitoring (the ASS-system made use of by local radiation safety officers),
- use of protective face masks by personnel while working in an area of contaminated air (efficiency of the masks used was 73% (6); this value was applied while calculating workers' exposure using the individual dosimeter).

The introduction of the radiation protection system in selected spas resulted in a significant decrease in the exposure of personnel, which, since 1979, has not exceeded the accepted value of the Authorized Limit.

In other spas individual dosimetry has not been introduced so far. However, the results of concentration measurements obtained during the survey rendered it possible to assess the expected mean annual exposures of personnel, assuming 2000 hours as an annual working time. Table 7 shows the calculated mean annual exposures of personnel as well as the collective effective dose equivalent for personnel in particular spas. For calculations of the collective dose, a relationship was agreed which implied that 1 WLM exposure corresponds to 0.010 Sv (7). The value of the calculated collective effective dose equivalent for the whole group at risk, i.e. for personnel of all spas in Poland, amounts to 1378 mSv per year.



TABLE 7. Expected Mean Annual Exposure of a Worker and Expected Mean Collective Effective Equivalent Dose Calculated on the Basis of Concentrations Observed between 1986 and 1988

Spa	Expected mean annual exposure mJh/m ³ (WLM)	Calculated annual collective effective equivalent dose man*mSv
Kowary	1.56 (0.444)	125.0
Ladek Zdroj	1.28 (0.365)	124.0
Cieplice Zdroj	0.34 (0.097)	57.6
Rymanow Zdroj	0.38 (0.108)	49.0
Swieradow Zdroj	0.78 (0.222)	40.1
Polczyn Zdroj	0.14 (0.040)	36.6
Ustron	0.08 (0.023)	32.8
Krynica Zdroj	0.17 (0.048)	32.7
Przerzeczyn Zdroj	0.59 (0.168)	25.2
Kudowa Zdroj	0.16 (0.046)	21.2
Busko Zdroj	0.12 (0.034)	21.0
Naleczow	0.12 (0.034)	20.8
Ciechocinek	0.16 (0.046)	17.6
Kamien Pomorski	0.24 (0.068)	16.1
Polanica Zdroj	0.16 (0.046)	12.7
Swoszowice	0.15 (0.043)	10.5
Szczawno Zdroj	0.16 (0.046)	10.5
Iwonicz Zdroj	0.15 (0.043)	10.2
Szczawnica	0.25 (0.071)	8.6
Duszniki Zdroj	0.20 (0.057)	7.5
Kolobrzeg	0.10 (0.028)	6.8
Wieniec Zdroj	0.11 (0.031)	5.4
Swinoujscie	0.05 (0.014)	4.9
Rabka Zdroj	0.09 (0.026)	4.6
Horyniec Zdroj	0.12 (0.034)	2.1
Total		1378.5

A decrease in workers' exposure brought about a decrease of risk of lung cancer incidence. Assuming that exposure to radon and radioactive aerosols which equals 1 WLM brings about an increase of lung cancer incidence by about 1% on average (8), it can easily be calculated that at present a year's period of work in exposure to radioactive aerosols can result in an increase of risk of lung cancer incidence of about 0.5%. Before the implementation of the radiation protection system, the expected risk, during the same period, amounted to 21% on average, and in some cases even to more than 100%.



These examples indicate the need to maintain the existing discipline of radiation protection in those spas where protection systems have already been introduced, as well as the necessity to implement a comprehensive system of radiation protection in other spas.

Outline of a comprehensive system of radiation protection in spas

Ten years' observations and measurements indicate that in those spas where radon and radioactive aerosols occur, a system of radiation protection should be initiated and made fully operational. The system ought to be conceptionally and methodically uniform but its scope should vary according to the level of potential hazard to the personnel. The radiation protection system should be implemented stage by stage.

Stage one — survey

The first stage should be devoted to a detailed examination of the extent of potential radiation hazard to personnel at particular work-stands in the surveyed spas. It would be advisable to expand the examination over as many spas as possible, or even to cover all spas, and to do that using suitable standardized methods, or — and this would be the best solution — under the supervision of a qualified research institution. As practice shows, the ECS-system in which a monthly cycle of exchange of detectors is necessary is the most useful and economical one. At least one measuring cassette should be placed in a selected technological, social or therapeutical room with a floor area of 30 m², and in the case of rooms of over 30 m² of floor area (pools, production houses in bottling plants of mineral waters, etc.) at least 2—3 cassettes should be used. In addition, it should be assumed that at least 10 cassettes would be used in any one spa. The survey period should be one year. The aim of the survey would be to collect credible data concerning the potential radiation hazard of personnel working at particular work-stands in all spas in which the survey is carried out.

Stage two — classification

The second stage should consist of the classification of work-stands concerning the extent of hazard to personnel, as well as the evaluation of the radiation protection measures which need to be introduced during stage three. Obviously, during the classification of the work-stands in all spas, it would be necessary to adopt unified classification criteria. In Table 8 the proposed criteria are presented.



TABLE 8. Classification Criteria of Work-Stands in Spas as Regards Exposure to Radon Decay Products

Group of work-stands	Definition	Motivation and justification
I	To this group belong the work-stands at which mean annual concentrations are below 0.1 LP_α	Continuous work under these conditions does not result in exceeding $1/10$ of Annual Limit of Exposure (LG_α) Working at these work-stands requires only a periodical environmental control
II	To this group belong the work-stands at which mean annual concentrations range between (0.1 LP_α and 1.0 LR^α)	Continuous work under these conditions does not result in exceeding the Authorized Limit (LA_α) Working at these work-stands requires continuous control of the working environment and perpetual control of individual hazard
III	To this group belong the work-stands at which mean annual concentration of radioactive aerosols-radon daughters-exceed Authorized Derived Limit (LR_α)	Continuous working under these conditions Limit (LA_α) may cause the exceeding of Authorized and excessive hazard at 1 work Working at these work-stands demands a continuous control of the working environment and of individual hazard, a stable system of protection with the use of technical measures, as well as a sound supervision system.

Stage three — steady state of system

The aim of this stage is the permanent existence of a radiation protection system in selected classified spas. Practical implementation of the system requires both the organization of measuring or monitoring systems and the supporting, if need be, of personal protective measures. Requirements for particular work-stand groups are displayed in Table 9.

The motivation and justification behind carrying out the measurements of radioactive aerosol concentration once every three months using the ECS-system at the work-stands from Group I, which are characterized by relatively low concentrations, is the possibility of confirming that the concentration of radioactive aerosols remains permanently at the level determined during the survey stage.

At work-stands from Group II, continuous environmental surveillance using the ECS-system is necessary together with an evaluation of individual hazard using the ICS-system. The coexistence of the two



TABLE 9. Requirements Concerning Work-Stands Classified as Belonging to Different Groups

Groups of work-stands	Proposed technically-organizational activities concerning radiation protection
I	1. Periodical dosimetric control of the working environment (one month's measurements using the ECS-system every term) imposed centrally by an appointed scientific research or measuring center.
II	1. Continuous dosimetric control of the working environment (using the ECS-system) imposed centrally by a selected scientific research or measuring center. 2. Continuous control of individual hazard (using the ICS-system) imposed as above. 3. Providing the possibility of consultations with radiation safety officers, in the case of changes in working technology or observed increase of concentrations in the working environment. 4. Use of technical measures which decrease hazard (eg. ventilation, communication, etc.).
III	1. Continuous dosimetric control of the working environment (using the ECS-system), imposed centrally by a selected scientific research or measuring center. 2. Continuous control of individual hazard (using the ICS-system) imposed as above. 3. Immediate radiometric control of work-stands (using the ACS-system), imposed by own service or radiation safety officer. 4. Employing at least two radiation safety officers. 5. Use of individual security measures (protective face masks). 6. Use of technical measures which decrease hazard, eg. ventilation of work-stands, limiting of work-time of personnel, communication systems, cabins for personnel, etc.

systems can easily be justified. In some spas a frequent rotation or exchange of personnel can be observed. A situation may arise in which individual exposures are not exceeded owing to the rather frequent exchange of personnel, although the working conditions may be improper (high concentration of radioactive aerosols) and could cause an undesired high collective dose. Therefore, the ICS-system provides the control of individual exposure, while the ECS-system, a continuous control of working conditions.

At the work-stands included in Group III, measurement should be made using the ASS-system, as well as the ECS- and ICS-systems: the two latter are useful for the reason given in the case of the work-stands from Group II. The ASS-system, on the other hand, makes it possible to obtain measurement results of the concentration of radioactive aerosols instantaneously after the measurement has been completed. That is



why this system can be used in all unforeseen situations and during emergencies, when a decision must be made immediately whether to evacuate personnel or to reduce their stay in areas of high radioactive concentrations.

Local radiation safety officers should be employed only in those spas or bottling plants of mineral waters where work-stands from Group III can be identified, since at those stands, concentrations of radioactive aerosols can be so high that the Authorized Limit or even the ALE may be exceeded. The task for safety officers is to control the safety of personnel by making relevant measurements of concentrations, and to inspect whether personnel properly use individual dosimeters and personal protective equipment (eg. face protective masks). Two safety officers employed in a spa should provide continuous supervision during the whole of a working season. In those spas or establishments where only the work-stands from Group I or II are found, it is not absolutely necessary to employ radiation safety officers. However, expert consultations concerning radiation protection or techniques of measurements should be performed by local or central institutions which specialize in this subject. Such consultations should, of course, be provided in the case of any changes in working technology, accidents or other unforeseen situations which could cause an increase in concentrations or personnel exposure.

The requirements presented and discussed in this paper are only the minimum required for radiation protection in spas. Any expansion of the scope of safety inspection, extension of the measuring programme, provision of a greater variety of personal protection measures and a more efficient communication system is possible and would both ensure safety at work with radioactive media and stimulate the sense of working security in personnel.

Decisions concerning any of such extensions, however, can be taken only by the administration of a given spa or establishment. For instance, the system of individual dosimetry could be introduced also for persons working at work-stands from Group I, although it is not necessary. In such a case, personal dosimeters could be used only to confirm the fact that exposures of personnel were indeed low and that working conditions were typical for work-stands from this group.

SURVEY AND CLASSIFICATION OF WORK-STANDS IN POLISH SPAS

Results of the survey performed, as well as the number of work-stands divided into three groups in surveyed spas and bottling plants of mineral waters are presented in Table 10.



TABLE 10. Number of Work-Stands Classified in Particular Groups of Surveyed Polish Spas

Spa	Number of work-stands (number of personnel employed at the work-stands included in a given group)		
	Group I	Group II	Group III
Busko Zdroj	11 (60)		
Ciechocinek	11 (38)		
Cieplice Zdroj	15 (59)		
Duszniki Zdroj	11 (13)		
Horyniec Zdroj	12 (6)		
Iwonicz Zdroj	11 (24)		
Kamien Pomorski	8 (23)		
Kolobrzeg	10 (24)		
Kowary			10 (28)
Krynica Zdroj	12 (66)		
Kudowa Zdroj	10 (47)		
Ladek Zdroj	12 (33)	1 (1)	
Naleczow	11 (60)		
Polanica Zdroj	12 (38)		
Polczyn Zdroj	14 (92)		
Przerzeczyn Zdroj	9 (14)	1 (1)	
Rabka Zdroj	11 (18)		
Rymanow Zdroj	16 (45)		
Swoszowice	7 (25)		
Szczawnica	10 (23)		
Szczawno Zdroj	12 (12)		
Swieradow Zdroj	13 (18)		
Swinoujscie	13 (33)		
Ustron	11 (152)		
Wieniec Zdroj	13 (18)		
Total	275 (941)	2 (2)	10 (28)

RESULTS

The measurements of concentrations of radioactive aerosols in air of operative and work rooms and calculations and evaluations of personnel exposure in Polish spas performed in 1978 indicate that it is possible to identify work-stands at which significant exposures of personnel to radon decay products occur in these spas. Should there be no radiation protection system, as was the case before 1977, or no control over the way in which such a system would work, exposures could reach or exceed even the ALE. Therefore, there is a need to implement a system of radiation protection suitable for all spas. Such a system should be introduced stage by stage, and then made operational by spa administra-



tion together with consultative and supervisory institutions, according to the criteria and conceptions presented in this paper.

ACKNOWLEDGEMENT

The results of this paper have been obtained from the project CPBR 11.11.19.

REFERENCES

1. Chruścielewski W. and Domański T.: System of personal dosimetry introduced in Polish non-uranium mines. Proc Conf on Radiation Hazard in Mining. October 4—9, 1981, Colorado School of Mines, Golden, CO (USA), 589, 1981. —
2. Chruścielewski W., Domański T. and Kluszczyński D.: Project of regulations of radiation protection in mines. Report IMP- ZOR-71/87; Institute of Occupational Medicine in Lodz, 1987 (in Polish). —
3. Recommendations of the ICRP (International Commission on Radiological Protection) — ICRP Publication No. 26, Annals of the ICRP, Vol. 1, No. 3, 1976. —
4. Doniec J., Skalski H. and Klucznik W.: Concentrations of ^{222}Rn daughters in rooms of Polish spas (in preparation for publication). —
5. Chruścielewski W., Domański T. and Orzechowski W.: Concentrations of radon and its progeny in the rooms of Polish spas. Health Physics, 45, 2, 421, 1983. —
6. Domański T., Więcek E. and Chruścielewski W.: Results of studies on the efficiency of retention of radioactive aerosols — products of radon decay by some types of anti-dust masks. Med Pracy, 29, 2, 135, 1978 (in Polish). —
7. Limits for inhalation of radon daughters by workers — ICRP Publication No. 32, Annals of the ICRP, Vol. 6, No. 1. —
8. Exposure and lung cancer risk of the general population from inhaled radon daughters — ICRP Publication.

Received for publication: 18.08.1988.

Accepted for publication: 02.12.1988.

