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Radon Equilibrium Factor and the Assessment of the Annual Effective Dose at Underground Workplaces

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Abstract: The equilibrium factor F is one of the parameters that should be considered when assessing the effective dose based on radon activity concentration. Since the equilibrium factor in various environments ranges theoretically from a value close to 0 to 1, it is expected that dose assessment based on one recommended coefficient value may lead to an underestimation or overestimation of the dose. That is why it is essential to measure this quantity if the basis for dose assessment is the radon concentration and not the concentration of radon decay products. The equilibrium factors were determined based on measurements of radon activity concentration and potential alpha energy concentration and varied from 0.15 to 0.94, with an arithmetic mean of 0.55. The average effective dose calculated for the employee taking into account these values was 31 mSv, assuming an annual working time of 1800 h. In turn, the average effective dose calculated for the equilibrium factor of 0.2 as recommended by the International Commission on Radiological Protection (ICRP) was equal to 13 mSv.

Keywords: radon activity concentration; radon progeny; equilibrium factor; effective dose; touristic mine

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1. Introduction

Radon (^{222}Rn) is a colorless, odorless radioactive gas easily soluble in water. Its presence in the environment is related to the presence of uranium ^{238}U in the soil. Uranium is the progenitor of the uranium series, in which, as a result of radioactive decay, radon is formed, which further decays to the stable lead isotope ^{206}Pb. Radon is considered the second most common cause of lung cancer after cigarette smoking, so it is crucial to assess radon exposure. Although the basis for determining radon exposure is mainly radon activity concentration measurements, according to epidemiological studies and models, the causes of lung cancer induction are short-lived radon decay products. Radon contributes only a tiny amount to the dose: less than 2% and 5% for indoor workplaces and mines, respectively, with the rest being caused by its decay products [1]. As a result of the radioactive decay of radon, progenies are formed that attach to environmental aerosols, creating radioactive aerosols. After inhaling radon and its short-lived progeny, the alpha particles emitted by the radon daughters deposit their energy in the respiratory tract, mainly on the sensitive lung epithelium. Ionizing radiation can cause DNA strand breaks, gene mutations, chromosomal changes, apoptosis, and genetic instability. As a result of the interaction of ionizing radiation with the cell, reactive intermediate oxygen compounds may also be produced, which may cause oxidative damage to DNA. Damaged cells can become cancer cells. Since even a single α-particle can cause multiple damaged cells and spread the "bystander effect", defining a threshold for radon-induced cancer is unlikely [2].

To better understand the following discussion, some essential definitions are explained below.

Equilibrium equivalent activity concentration (EEAC)—the activity concentration of radon in radioactive equilibrium with its decay products, when the corresponding potential alpha energy concentration has the same value as the potential alpha energy concentration of the actual mixture of these isotopes in the gas, which can be described by the following equation [Bq/m^3]:

$$\mathbf{C_{eq}=\frac{\frac{E_1}{\lambda_1}C_1+\frac{E_2}{\lambda_2}C_2+\frac{E_3}{\lambda_3}C_3+\frac{E_4}{\lambda_4}C_4}{\frac{E_1}{\lambda_1}+\frac{E_2}{\lambda_2}+\frac{E_3}{\lambda_3}+\frac{E_4}{\lambda_4}}} \quad (1)$$

where E_i is the potential energy of a single nuclide, λ_i is the decay constant, and C_i is the concentration of radioactive nuclides in the gas, respectively, ^{216}Po, ^{212}Pb, ^{212}Bi, and ^{212}Po.

Potential alpha energy concentration (PAEC)—the sum of the energy of alpha radiation particles emitted by short-lived radon decay products following their complete radioactive decay in a given volume of gas, described by the formula [μJ/m^3]:

$$\mathbf{C_{\alpha}=\frac{E_1}{\lambda_1}C_1+\frac{E_2}{\lambda_2}C_2+\frac{E_3}{\lambda_3}C_3+\frac{E_4}{\lambda_4}C_4} \quad (2)$$

Equilibrium factor F—the quotient of the equilibrium concentration and the concentration of radon in the air, where the equilibrium concentration is equal to the concentration of radon in radioactive equilibrium with its decay products, in a situation where the corresponding potential alpha energy concentration has the same value as the potential alpha energy concentration of the actual mixture of these isotopes in the gas, described by the following equation:

$$\mathbf{F=\frac{C_{eq}}{C_{Rn}}} \quad (3)$$

Therefore, the equilibrium factor depends on the radon concentration and the potential alpha energy. In addition, its value is influenced by the ventilation method used in the excavations. With the increase in the airflow velocity in the excavations, the value of the equilibrium factor decreases.

Effective dose—the sum of equivalent doses from external and internal exposure, considering the weighting factors of tissues and organs. The effective dose determines the degree of exposure of the whole body to ionizing radiation.

Current efforts to assess radon exposure mainly focus on measuring radon activity concentrations. The results of such measurements become the basis for planning mitigation activities. The WHO recommends setting a reference level for radon concentration of 100 Bq/m^3. However, if, for some justified reason, it is too low, it may be increased, but it should not be higher than 300 Bq/m^3 [3]. The EU Council Directive [4] adopts a similar solution. If the radon reference level is exceeded, appropriate measures must be taken to reduce radon occurrence or limit exposure. However, if such treatments do not bring the expected results, EU Member States should ensure that such workplaces are reported to the appropriate offices. In cases where workers' exposure may exceed the effective dose of 6 mSv per year, such situations should be considered as planned exposures, and appropriate dose limits should be applied.

From a technical point of view, measuring the radon activity concentration is simpler than methods that allow determining the activity concentration of their decay products or even the potential alpha energy concentration. However, when only radon concentration is measured, the uncertainty in assessing the effective dose increases due to the need to consider such parameters as the equilibrium factor. For some facilities, such as underground mines, caves, or indoor workplaces, the ICRP (International Commission On Radiological Protection) report indicates that they can be assumed to be 0.2, 0.4, and 0.4 for radon and its decay products, respectively [1]. However, the uncertainty resulting from this approach may be very high. It is enough to point out that the conversion factors mentioned, for example, in the UNSCEAR publication [5], which can be used to assess exposure in the mining and processing industries, are 9 nSv/(Bqhm^{-3}) in relation to equilibrium equivalent concentration and differ from those given in the ICRP report [1].

To sum up, the assessment of doses requires knowledge of such parameters as the equilibrium equivalent activity concentration (EEAC), the dose conversion factor, and the exposure time. If only the radon concentration is known, an equilibrium factor should be assumed between radon and its decay products which can cause significant uncertainty because in some workplaces with particular environmental conditions, the true value of this parameter may differ significantly from the recommended values. The need to measure the equilibrium factor for dose assessment purposes in specific types of workplaces has been identified in some countries, for example, the Czech Republic [6] or the USA, due to NIOSH and MSHA recommendations for mines [7], where limits are expressed in working level months (WLMs). Based on assessing the potential alpha energy concentration, the system is also in force in Polish underground mines [8]. Moreover, the ICRP recommendations [1] also draw attention to the need for a more precise determination of the parameters influencing the dose assessment if the conditions in the tested facilities may differ significantly from typical conditions.

The aim of this study was to draw attention to the wide range of values of the equilibrium factor F that was measured in an underground historic mine. The authors would like to point out that when designing a method for assessing exposure to ionizing radiation in underground facilities, it is necessary to consider the radon concentration and exposure time and the current ventilation system. The process of ventilation (gravitational or mechanical ventilation, ventilation operating hours, and air flow rate) has a huge impact on the concentration of radon and its progeny and, therefore, on the value of the equilibrium factor. This, in turn, determines the value of the effective dose received by staff or tourists. It should be noted that in some cases, the recommended values of F may not be appropriate. Therefore, there is an urgent need for specific recommendations for assessing exposure, underlining the importance of our study's conclusions.

2. Materials and Methods

The measurement site was the Historic Silver Mine in Tarnowskie Góry in Poland. Today, the mine serves only as an underground tourist route, as the last exploitation took place in 1912. The mine is located at a depth of 40 m. The underground mine has approximately 150 km of workings and 20,000 shafts, most of which have been isolated and are not available for tourists. Currently, the part open to the public consists of three galleries with a total length of 1740 m, connected by three mine shafts: the "Żmija" inlet shaft, the "Anioł" outlet shaft, and the closed "Szczęść Boże" shaft. The duration of the mine tour is approximately 1 h [9]. It is worth mentioning that the facility has been included in the UNESCO list. The accessible part of the mine has a specific microclimate characterized by a relatively constant temperature of about 10 °C throughout the year and a relative humidity of 90%. The presence of radon in the former mine is mainly related to the presence of Lower Triassic and Middle Triassic rocks in the area. The mine's substrate is Quaternary sands, lake silts, and silty clays [10]. Figure 1 shows a diagram of the underground tourist route. The direction of airflow is indicated by arrows in this figure, with red indicating fresh air and blue indicating exhausted air. Air in the mine is exchanged naturally (gravity ventilation) and mechanically. For the most part, air exchange in the mine occurs by gravity, with fresh air flowing through the intake shaft ("Żmija" shaft) and used air being removed through the exhaust shaft ("Anioł" shaft). The second way of ventilating the mine is by mechanical ventilation. A fan is installed in the "Anioł" shaft to provide airflow. Mechanical ventilation operates during mine opening hours, ensuring the safety of the visitors. A suction fan, installed in the ventilation duct and removing air from the "Anioł" shaft, enhances the effect of natural depression. Additionally, each time after the start of tourist traffic, for approximately 1.5 h, the underground route is ventilated by forced ventilation (in the direction from the "Żmija" shaft to the "Anioł" shaft) using one of two fans installed in the ventilation station at the "Żmija" shaft.

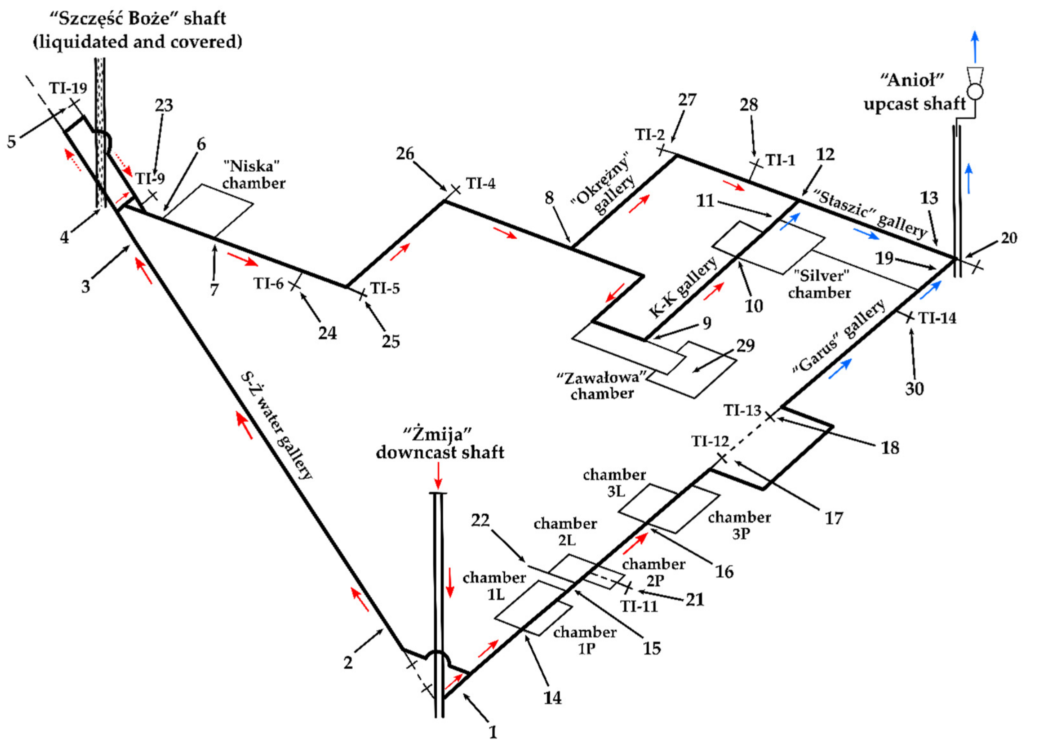

Figure 1. Diagram of the ventilation network of the Historic Silver Mine with marked measurement points at a scale of 1:3000 (red and blue arrows indicate fresh and exhausted air, respectively).

The measurement of radon concentration and potential alpha energy concentration was performed at the same time during one measurement campaign (March 2023—winter season). Measurements were carried out during opening hours (there was tourist traffic in the mine). During this campaign, the mechanical ventilation was turned on. The radon concentration was measured using Lucas cells (based on a ZnS(Ag) detector) and Radon Scout PMT manufactured by SARAD GmbH (Dresden, Germany). The alpha particles were counted using a 3″ photomultiplier tube. Potential alpha energy concentration was measured using an RGR-40 mining radiometer (Institute of Nuclear Chemistry and Technology, Warsaw, Poland). This device is intended for measurements of the potential alpha energy concentration. It is adapted to work in difficult mining conditions. This radiometer uses a silicon detector with a surface barrier, and the measurement cycle used is the Markov method (5 min of sample collection, 10 min of measurement). The flow rate of 2 L/min is controlled with a rotameter, and the filter used is a glass, non-woven fabric [11,12]. Additionally, the measurements of the potential alpha energy concentration were also performed by alpha probes (Two-Met company, Zgierz, Poland), which are equipped with thermoluminescence detectors for the detection of alpha radiation emitted by short-lived radon progeny collected on the filter. This is an integral method that allows researchers to measure the average potential alpha energy concentration up to 8 h [13]. These measurements were made in different periods but always during mine opening hours. The devices used are calibrated (by authorized entities) and regularly checked in a radon chamber in the authors' laboratory.

Knowing the potential alpha energy concentration and the actual concentration of the parent nuclide in the air, it is possible to determine the equilibrium factor F, which is defined as the ratio of equilibrium equivalent concentration to the radon gas activity concentration. Therefore, this factor characterizes the imbalance between the mixture of short-lived radon progeny and the radon gas, and is not the same as the concept of radioactive equilibrium between nuclides. The equilibrium factor F depends mainly on ventilation conditions and the size distribution of radioactive aerosols (plate-out, inertia, and gravitational sedimentation), using Equations 1–3 and decay constants; the F factor can be written as:

$$\mathbf{F}=\frac{\mathbf{C}_{\boldsymbol{\alpha}}}{\mathbf{5.6}\times\mathbf{10}^{-3}\mathbf{C}_{\mathbf{Rn}}} \tag{4}$$

where C_{α} is the potential alpha energy concentration expressed in ($\mu J/m^3$), and C_{Rn} is the radon activity concentration in (Bq/m^3).

3. Results

The equilibrium factor F was determined along the tourist route in the Historic Silver Mine in Tarnowskie Góry. The map of the mine (Figure 1) shows 30 points selected by the mine workers, where routine measurements are carried out. Based on this map and the experience of the mine workers, 15 points were designated, where the equilibrium factor F was measured. The selected points are located strictly on the tourist route, which the guide follows with tourists. The table below (Table 1) shows the calculated F factors. The first column of this table contains the number and description of the measurement point; the numbers from the first column are marked on the spatial diagram of the mine ventilation network (Figure 1). The determined equilibrium factor varies within a wide range from 0.15 to 0.94. The highest values were measured in poorly ventilated places (0.94 in insulating dam XIX), and the lowest values were measured right next to the exhaust shaft, where the air is discharged outside the mine ("Anioł" Shaft—0.23 and the outlet from the "Garus" gallery—0.15). The average value of the equilibrium factor was 0.55.

Table 1. Determined equilibrium factors F.

No	Description of the Measurement Points According to Figure 1	C_{α} ($\mu J/m^3$)	C_{Rn} (Bq/m^3)	F
1.	Inlet to the 1L and 1P chambers (point 14)	4.9 ± 0.2	1840 ± 70	0.48
2.	TI-12 insulating dam (point 17)	6.6 ± 0.2	2720 ± 110	0.44
3.	Outlet from the "Garus" gallery (point 19)	4.6 ± 0.2	5640 ± 170	0.15
4.	TI-5 insulating dam (point 25)	7.1 ± 0.3	1700 ± 90	0.75
5.	TI-2 insulating dam (point 27)	12.6 ± 1.3	3360 ± 100	0.67
6.	Outlet from the water gallery (point 3)	2.2 ± 0.3	830 ± 60	0.47
7.	TI-19 insulating dam (point 5)	5.4 ± 0.2	1020 ± 60	0.94
8.	Outlet from the "A-K" gallery (point 13)	11.5 ± 0.9	3870 ± 120	0.53
9.	"Anioł" upcast shaft (point 20)	4.0 ± 0.3	3040 ± 90	0.23
10.	Inlet to the "K-K" gallery (point 9)	3.3 ± 0.2	810 ± 60	0.73
11.	Inlet to the "Okrężny" gallery (point 8)	2.0 ± 0.1	940 ± 60	0.38
12.	Abandoned "Szczęść Boże" shaft (point 4)	2.9 ± 0.2	770 ± 50	0.66
13.	"Niska" chamber (between points 6 and 7)	4.6 ± 0.2	1240 ± 50	0.67
14.	"Srebrna" chamber (between points 10 and 11)	7.5 ± 0.4	2010 ± 60	0.67
15.	TI-11 insulating dam (point 21)	2.9 ± 0.1	1040 ± 40	0.50
	Average	5.5	2060	0.55

Based on the measurements, the annual effective doses were estimated assuming an annual exposure time of 1800 h [14] and the dose conversion factor of 3.1 mSv/(mJhm^{-3}) recommended for mines by the ICRP [1]. For comparison, calculations were made assuming the measured and recommended equilibrium factor for mines (Table 2), using the following formula

$$\mathbf{E}=\mathbf{DCF}\cdot\mathbf{C}_{\mathbf{Rn}}\cdot\mathbf{F}\cdot\mathbf{5.6}\cdot\mathbf{10}^{-6}\cdot\mathbf{t} \tag{5}$$

where DCF is the dose conversion factor expressed in mSv/(mJhm^{-3}), C_{Rn} is the radon concentration expressed in Bq/m^3, and t is the annual exposure time expressed in hours. The coefficients recommended by the ICRP for mines (F = 0.2; DCF = 3.1) were adopted for the calculations because the tested facility is a mine with mechanical ventilation. According to ICRP recommendations, the unattached fraction in mines is 0.01, which is already considered in the conversions recommended by this commission. A higher contribution of the unattached fraction may increase the conversion value. However, a sporadic study carried out near the "Anioł" shaft, which covered all particles containing short-lived radon progeny from 0.6 nm to about 3 μm, showed that the resultant conversion factor was 2.5 mSv/(mJ/m^3 h) for mouth breathing at an average breathing rate of 1.2 m^3/h as recommended for a reference worker, which, in this case, is lower than the value recommended by the ICRP for underground mines.

Table 2. Comparison of effective doses for the equilibrium factors measured or recommended for mines by ICRP 137 and dose conversion factor of 3.1 mSv/(mJhm^{-3}).

No	Description of the Measurement Points According to Figure 1	F Measured	F = 0.2 ICRP [1]
		Effective Dose (mSv)	
1.	Inlet to the 1L and 1P chambers (point 14)	28	12
2.	TI-12 insulating dam (point 17)	37	17
3.	Outlet from the "Garus" gallery (point 19)	26	35
4.	TI-5 insulating dam (point 25)	39	11
5.	TI-2 insulating dam (point 27)	70	21
6.	Outlet from the water gallery (point 3)	12	5
7.	TI-19 insulating dam (point 5)	30	6
8.	Outlet from the "A-K" gallery (point 13)	64	24
9.	"Anioł" upcast shaft (point 20)	22	19
10.	Inlet to the "K-K" gallery (point 9)	19	5
11.	Inlet to the "Okrężny" gallery (point 8)	11	6
12.	Abandoned "Szczęść Boże" shaft (point 4)	16	5
13.	"Niska" chamber (between points 6 and 7)	26	8
14.	"Srebrna" chamber (between points 10 and 11)	42	13
15.	TI-11 insulating dam (point 21)	16	7
	Average	31	13
	Weighted average	30	12

As the table above shows, the calculated doses vary depending on the equilibrium factor used. The average dose calculated using the measured equilibrium factor was 31 mSv, and using the recommended by the ICRP, 13 mSv. The weighted average dose was also calculated, considering the total time of the tourist route (approximately 1 h) and the times of stops at some points. At 3 out of 15 points where measurements were taken, the guide stops for a few minutes. It was estimated that the stop time at points 2, 10, and 14 is 7 min, 10 min, and 7 min, respectively. At the remaining points, the guide continues briefly but walks from point to point along the route. Therefore, the following weights were adopted: 0.17 for point 10, 0.12 for points 2 and 14, and 0.05 for the remaining points. The calculated weighted average dose was 30 mSv based on the actual balance factors and 12 mSv, assuming the recommended value of 0.2 for calculations. It can therefore be seen that the significant difference in doses results from the fact that the actual equilibrium factor in the mine was from 0.15 up to 0.94, with an average of 0.55, and not 0.2 as recommended.

Table 3 presents the results of potential alpha energy concentration (PAEC) measurements using alpha probes. As can be seen, the results vary widely, from 2.2 to 11.8 μJ/m^3. The average PAEC was 6.9 μJ/m^3. This table also shows the calculated effective doses based on the measured PAEC values. The time and dose conversion factor used in the calculations were the same as those above (1800 h and 3.1 mSv/(mJhm^{-3})).

Table 3. The results of measuring the potential alpha energy concentration during the 2 h passage of the entire tourist route, along with the calculated effective doses.

No	Measurement Date	C_α (μJ/m^3)	Effective Dose (mSv)
1.	May 2021	7.3 ± 1.4	41
2.	November 2021	8.5 ± 0.9	47
3.	March 2022	6.8 ± 1.3	38
4.	June 2022	11.8 ± 1.2	66
5.	September 2022	3.1 ± 0.4	18
6.	December 2022	3.7 ± 0.5	20
7.	March 2023	6.7 ± 0.6	38
8.	July 2023	9.2 ± 1.0	51
9.	August 2023	5.2 ± 0.5	29
10.	September 2023	7.1 ± 0.7	39
11.	October 2023	8.0 ± 0.8	44
12.	November 2023	2.2 ± 0.4	12
13.	December 2023	10.9 ± 1.3	61
	Average	6.9	39

The graph (Figure 2) shows the doses calculated under different assumptions. In variant one, the dose was calculated based on the measured radon concentration and the determined equilibrium factor F. Variant 2 assumed a measured radon concentration and an equilibrium factor of 0.2. In variant 3, the calculation of the dose was based on the results of measurements of the potential alpha energy concentration made with alpha probes. In all cases, an annual exposure time equal to 1800 h and a dose conversion factor of 3.1 mSv/(mJhm^{-3}) were assumed. Since the PAEC measurements were carried out moving along the tourist route (the doses in variant 3 were calculated on this basis), only the average radon activity concentrations measured along the tourist route were considered in variants 1, 2, and 3 of the dose determination (points lying deep in the mine were eliminated). In Figure 2, the cross indicates the arithmetic mean and the horizontal line indicates the median. The arithmetic means are 30.15 mSv, 13.27 mSv, and 38.73 mSv, respectively. In contrast, the medians are 26.44 mSv, 10.65 mSv, and 39.28 mSv.

It should be noted that this work aimed to draw attention to the large variability of the equilibrium factor F within a single object and its effect on the value of the effective dose. For this article, it was assumed that the radon concentration was constant throughout the year. However, the dose determined this way is burdened with large measurement uncertainty. Since the radon concentration can change with the seasons, long-term radon concentration measurements should be carried out for a more accurate dose determination.

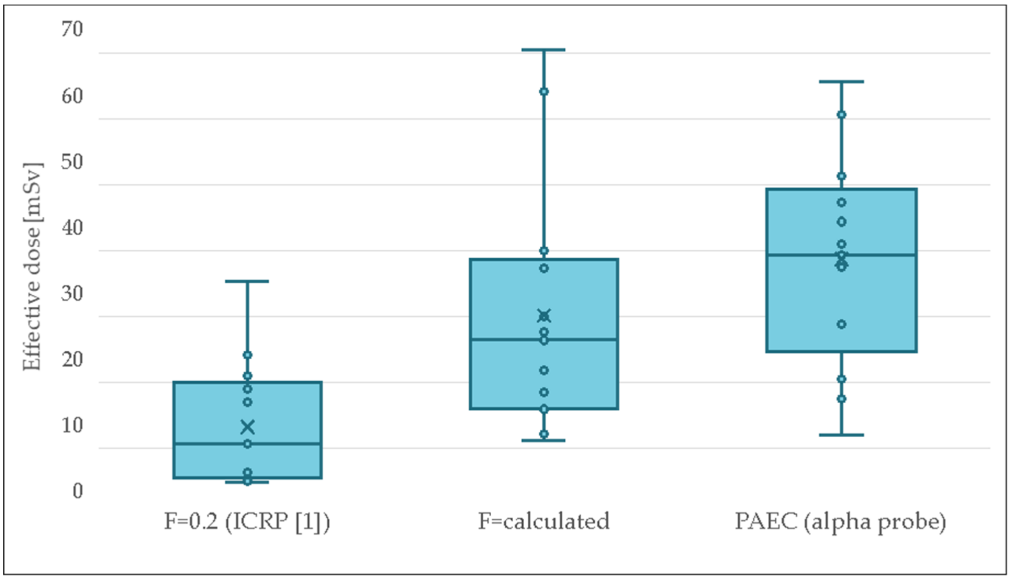

Figure 2. Comparison of effective doses calculated for different equilibrium factors.

4. Discussion

The International Commission On Radiological Protection (ICRP), in publication 137 (part 3), recommends a radon equilibrium factor of 0.2 for mines. As can be seen from the data presented in the table above (Table 1), this value is only sometimes appropriate for a given situation, and adopting it for dose calculations can lead to an overestimation or underestimation of the effective dose. A comprehensive study of the equilibrium factors in underground mines, show caves, tourist mines, and thermal baths was conducted by Chen and Harley [15]. The study included 173 underground mines in 18 countries and 136 underground show caves, tourist mines, and thermal spas in 17 countries. Average radon activity concentrations ranged from 29 to 24,260 Bq/m^3, and the equilibrium coefficients for all active mines included in the study ranged from 0.08 to 0.72 (average 0.38). These depend heavily on particle concentration, size distribution, and ventilation rate. Values for other facilities, such as show caves, tourist mines, and thermal baths, varied in a reasonably similar range from 0.10 to 0.85 (average 0.39). Still, the range of radon concentrations was much more significant: from 5 to 495,800 Bq/m^3. In Polish underground mines, the equilibrium factor can range from less than 0.1 to 0.9 [16]. Skubacz et al. measured equilibrium factors in four demonstration mines and one tourist cave, varying from 0.2 to 0.8 [17]. Similar uncertainties in dose assessment can also occur in other workplaces, such as schools, radium spas, swimming pools, water treatment plants, caves, and abandoned mines. Measurements of the equilibrium coefficient in a tourist cave in Okinawa showed an average F value of 0.55 in winter (January) and 0.24 in summer (July) [18]. Studies conducted in Postojna cave showed a significant variation in the equilibrium factor, ranging from 0.42 to 0.69 in winter and 0.33 to 0.86 in summer [19]. Ntwaeaborwa et al. measured the equilibrium factor in a gold mine in Carltonville (South Africa) at three levels. They showed that the equilibrium factors vary with the level in the mine. The measured values ranged from 0.4 to 0.8 [20]. Chen [21] analyzed hundreds of studies of the equilibrium factor in non-uranium mines. They found that the equilibrium factor in coal mines ranged from 0.02 to 0.9, with an average of 0.35. In the case of metal mines, the equilibrium factor ranged from 0.1 to 0.9 (average 0.4), and in the case of non-metallic mines, the measured factors ranged from 0.05 to 0.7 (average 0.26). In other non-uranium mines without a specified ore type, the average equilibrium factor was 0.42. The equilibrium factors measured in mines in Brazil ranged from 0.2 to 0.7 [22].

Analyzing the results in Table 2, it can be seen that for some measurement points, the dose estimated in different ways may vary several times. Dose values calculated based on the recommended equilibrium factor (0.2) vary from 5 mSv to 35 mSv, averaging 13 mSv. Doses calculated based on the measured F vary between 11 mSv and 70 mSv, averaging 31 mSv. It can, therefore, be seen that depending on the adopted equilibrium factor, doses may differ several times. Hence, adopting an appropriate factor for the calculation is extremely important to avoid an over- or underestimation of dose. Similar measurements of radon and radon progeny concentrations at workplaces (schools, radium spas, swimming pools, water treatment plants, caves, and former mines) were carried out by Otahal et al. [23]. They estimated effective doses based on measured equilibrium factors and using a default equilibrium factor value of 0.4 (recommended by the International Commission on Radiological Protection). Their calculations also showed a dose difference of about 5–95% over a wide range. It can be seen from Figure 2 that the minor differences in estimated doses were obtained when they were determined based on the actual equilibrium factor or based on direct measurements of the potential alpha energy concentration. Dose calculations based on an equilibrium factor of 0.2 (recommended for mines) lead to an underestimation of the effective doses in the investigated mine.

5. Conclusions

Radon activity concentration and potential alpha energy were measured at 15 points of the Historic Silver Mine, and the equilibrium factor F was determined. The calculated factor F varied in the range of 0.15–0.94. Higher values were recorded in places with poor airflow, and lower values were recorded near the fresh air inlet to the mine. The annual effective dose was estimated based on the calculated equilibrium factor, those recommended by ICRP 137 [1], and directly based on measurement of the potential alpha energy concentration. In some cases, significant discrepancies were observed between the doses determined based on the measured equilibrium factor and those recommended by the ICRP. This underscores the need for accurate dose assessment methods. Therefore, it is recommended that the dose assessment be based on measurements of the potential alpha energy concentration of radon decay products or the measurement of radon concentration, considering the actual equilibrium factor. The recommended values may sometimes lead to an overestimation or underestimation of the effective dose. The focus should also be on finding and recommending a new value of the equilibrium factor for mines, taking into account the facility's ventilation method. For example, the current recommended factor of 0.2 can be successfully used in facilities with good mechanical ventilation. However, a higher factor F should be used in facilities such as tourist mines, where air exchange occurs mainly by gravity or mechanically but with low efficiency. Based on the results obtained, one can lean towards a value of the equilibrium factor closer to 0.5 than 0.2 for such facilities.

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