Occupational exposure to radon progenies in underground coal mines

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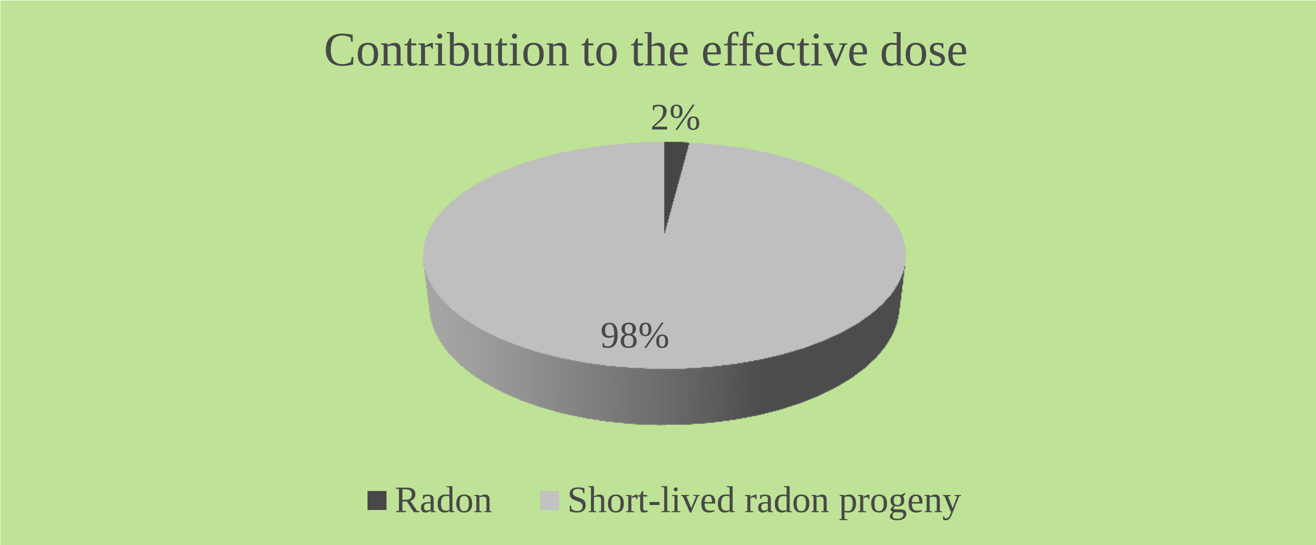
Underground mining in Poland

- 18 underground coal mines,
- 3 underground copper mines,
- 1 zinc and lead underground mine,
- 1 salt underground mine,
- a number of historic mines (gold, uranium, salt and coal mines)

Natural radionuclides in environment and underground mines

Source	Surface	Underground mines
Short-lived radon progeny	Open air, 1 m above the ground: 0.05 μJ/m^3 Dwellings: 0.10 μJ/m^3	up to 15 μJ/m^3 (60 μJ/m^3)*
Waters	Rivers, lakes: 0.004 kBq/m^3	Ra-226: up to 390 kBq/m^3 Ra-228: up to 200 kBq/m^3
Sediments	Soil, Ra-226: 0.025 kBq/kg Soil, Ra-228: 0.025 kBq/kg	up to 500 kBq/kg (Ra-226+Ra-228)
Gamma radiation	Open air: 0.069 μGy/h	up to 100 μGy/h

*) the increase in the potential alpha energy concentration to 60 μJ/m^3 was not a result of usual mining operation but by the uranium deposit accidentally exposed in one of hard coal mines.



According to calculations based on the Jacobi-Eisfeld lung dosimetry model for aerosols of 0.25 μm in size which are deposited in the airways with the least efficiency, radon contributes only 2% to the effective dose, while its short-lived progeny 98% assuming that all these isotopes are in radioactive equilibrium.

Due to the ventilation and mining system the evaluated equilibrium between radon and short-lived radon progeny changes in the range from below 5 % up to 95 %

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Measurement locations: **Short-lived radon progeny**

Short-lived radon progeny

Obligatory measurement locations of potential alpha energy concentration

- Workplaces close to the air outlet from the longwalls,
- Workplaces close to the air outlet from the road head with the separate ventilation,
- Stationary workplaces such as workshops, special mine rooms, and switching stations,
- Temporary or stationary workplaces where air kerma rate is greater than 0.6 μGy/h.

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Calculation of the effective dose

Short-lived radon progeny: $\mathbf{E_{\alpha} = 0.0014 \cdot (C_{\alpha} + \Delta C_{\alpha} - 0.1) \cdot t}$

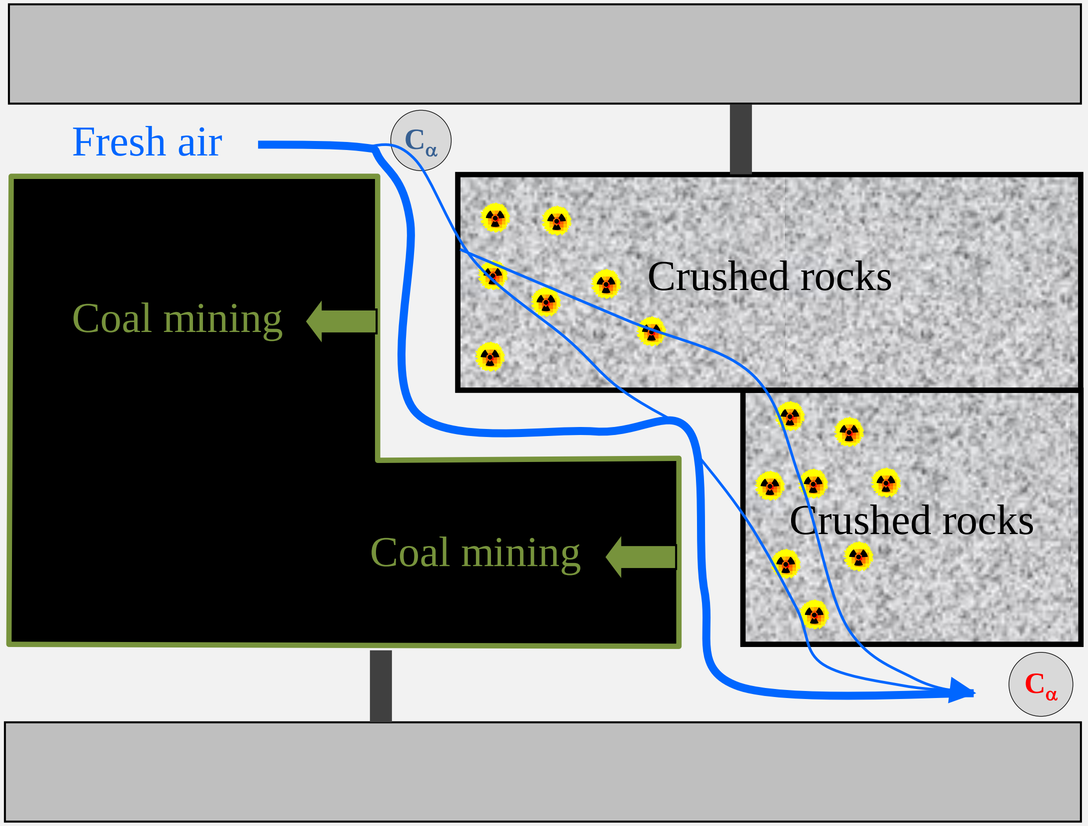
The dose conversion factor 0.0014 corresponds to occupational exposure. The measured value should be increased by an uncertainty evaluated at the confidence level of 95% and decreased by background kerma rate of 0.1 $\mu J/m^3$. The effective dose E_{α} is expressed in (mSv), potential alpha energy concentration in ($\mu J/m^3$) and exposure time in (h).

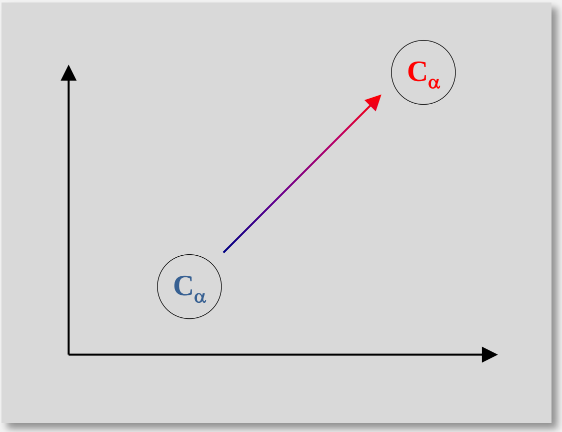
Supervised and restricted areas

- ❑ Access only permitted to classified workers or those entering in accordance with "suitable written arrangements".
- ❑ Restrictive controls on the access by non-radiation workers.
- ❑ Some form of personal monitoring mandatory.

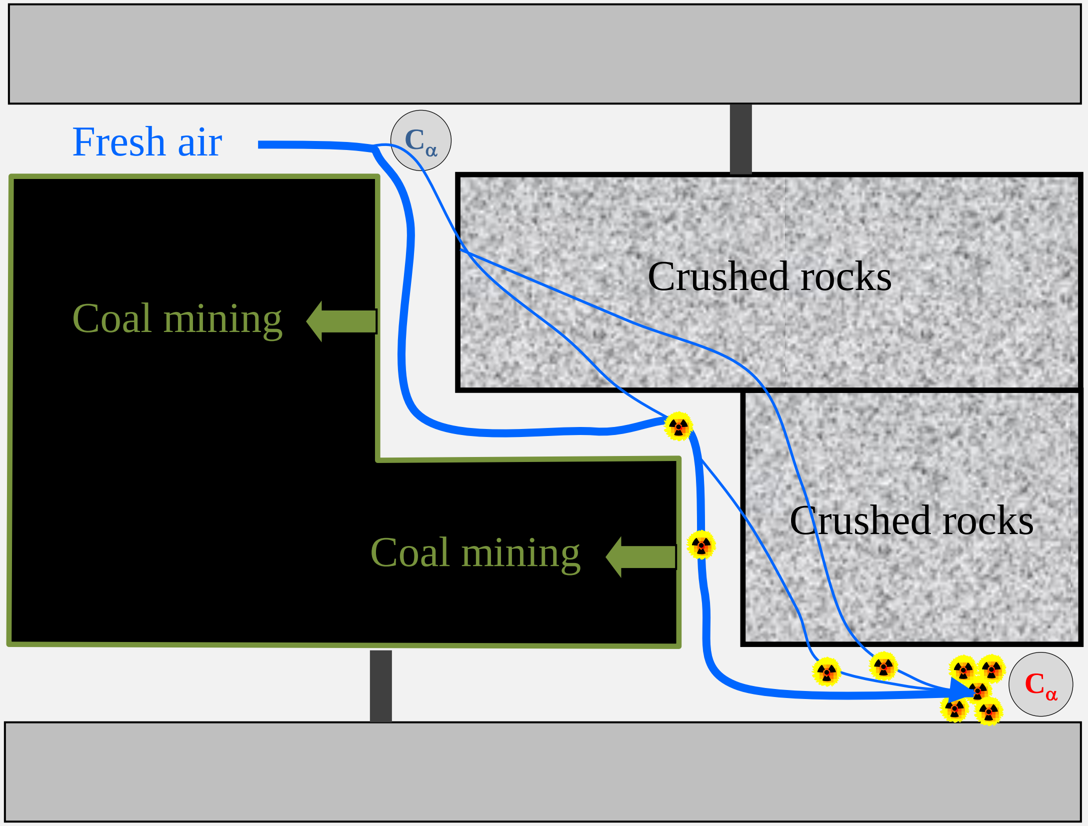
- ❑ Managed access by non-radiation workers permitted.
- ❑ Personal monitoring only required in certain circumstances.
- ❑ Additional information about radiation source not required

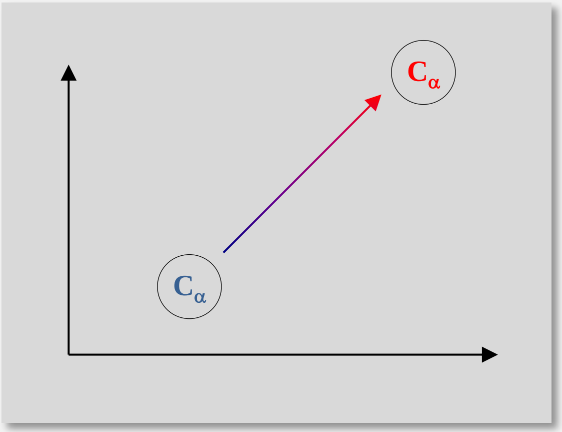
Increase of radon and radon progeny concentration in air as a result of ventilation of mining area (1)





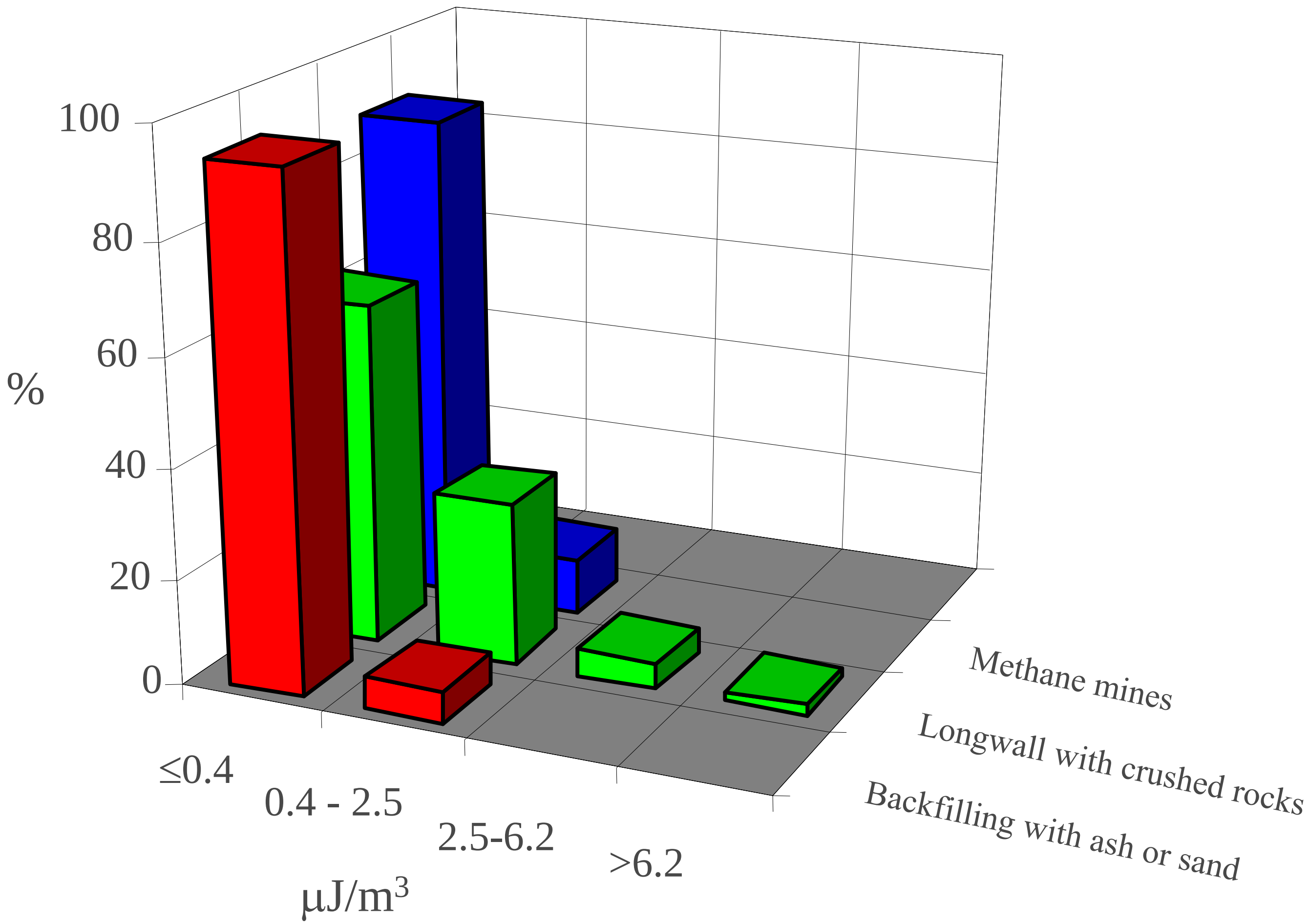
Increase of radon and radon progeny concentration in air as a result of ventilation of mining area (2)





Increase in radon exhalation

Short-lived radon daughter concentration and mining systems



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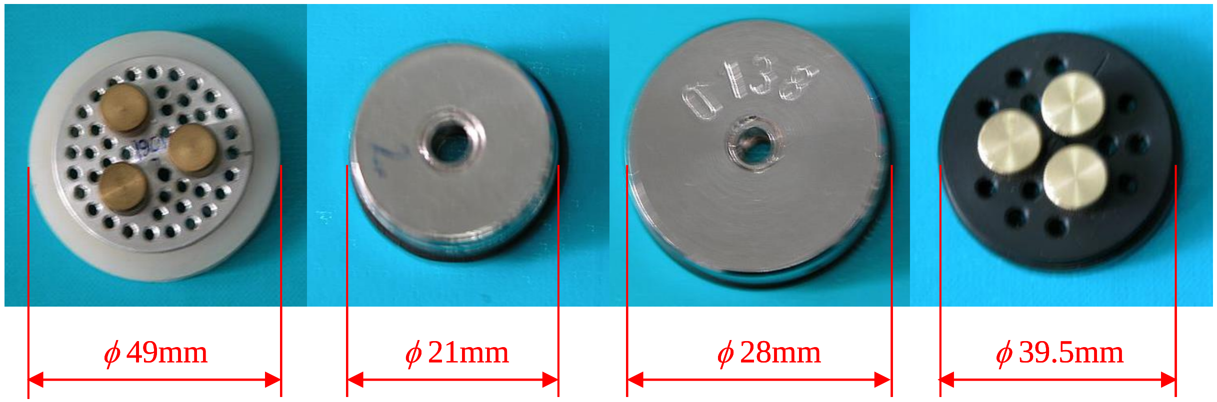
Short-lived radon progeny: integrating measurement devices

Aspirator AP-2000 EX

Aspirator SKC 224-PCEX8

Dust sampler Barbara 3a

Measurement methods: **Short-lived radon progeny**



Alfa-31 probe for Barbara 3A dust sampler | Alfa-2000 probe for SKC dust sampler | Alfa-2000 for TWO-MET dust sampler | Alfa-2004 probe for TWO-MET dust sampler

- Inside the cyclones are so-called alpha probes with thermoluminescent detectors (TLDs): $CaSO_4$:Dy (or $CaSO_4$:Tm). They are located above the filter that intercepts the respirable particles passing through the cyclone. The TLDs are placed in three sockets and record the radiation emitted by short-lived radon progeny.

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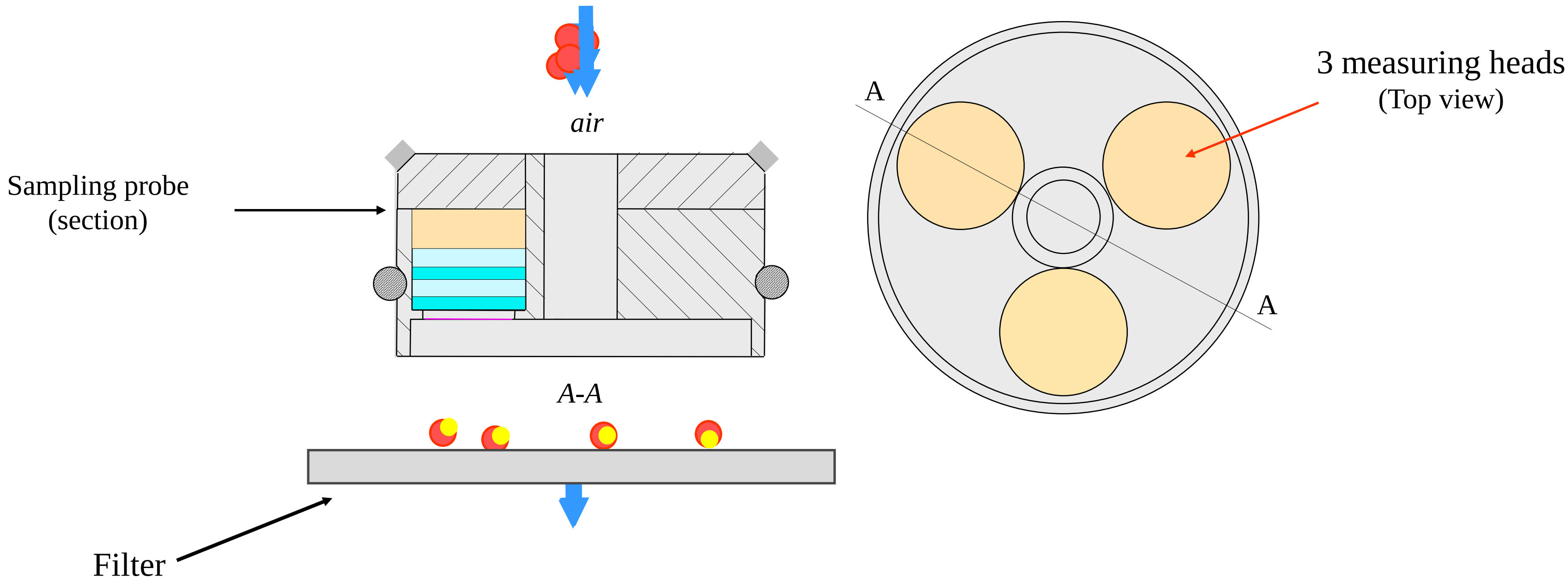
Measurement methods: **Short-lived radon progeny**



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PAEC grab sampling: RGR 40 – working in Markov cycle

Lower limit of detection at 5% significance level

Measuring device	(µJ/m^3)
SKC aspirator with the alpha probe and membrane filters	0.01
Alfa-2000 aspirator with the alpha probe and polypropylene filters	0.02
Barbara-3a dust sampler with the alpha and membrane filters	0.01
RGR-40 radiometer	0.16

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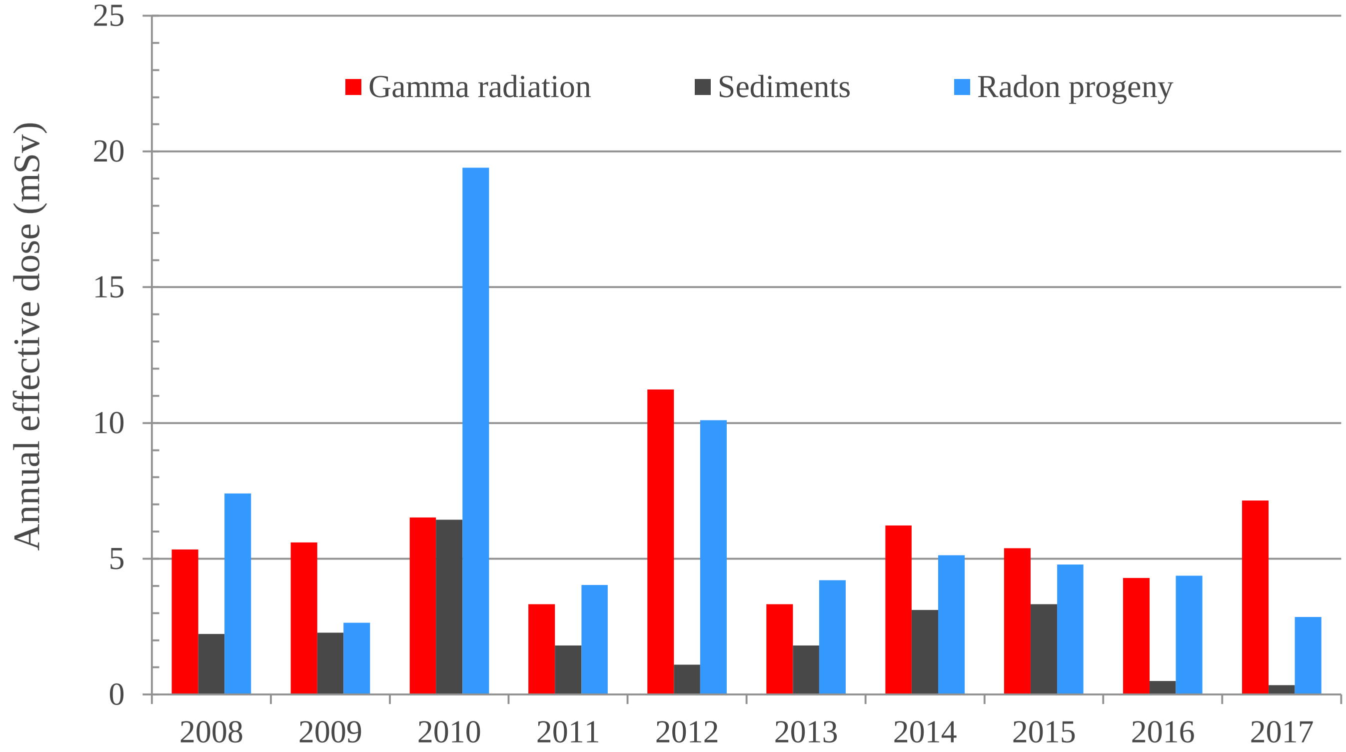
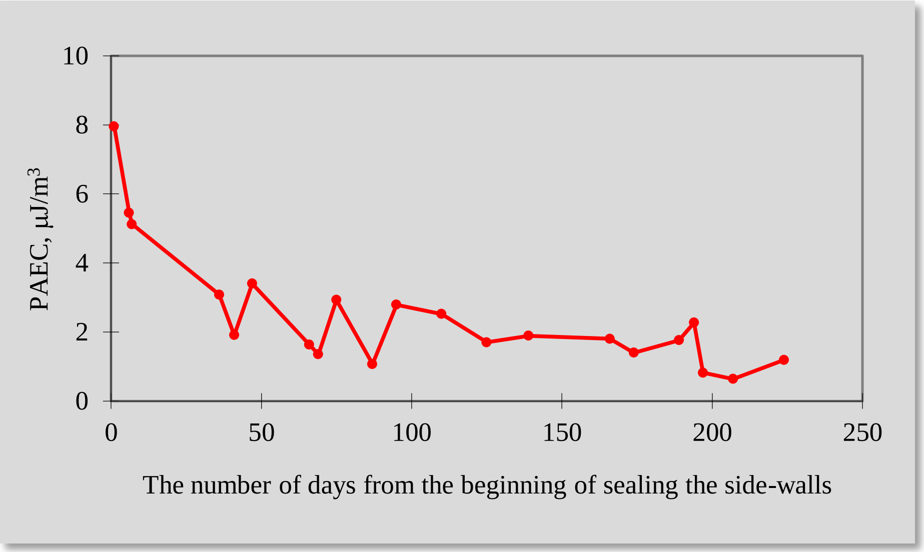
Maximum annual effective doses related to natural sources of radiation hazards in underground hard coal mines



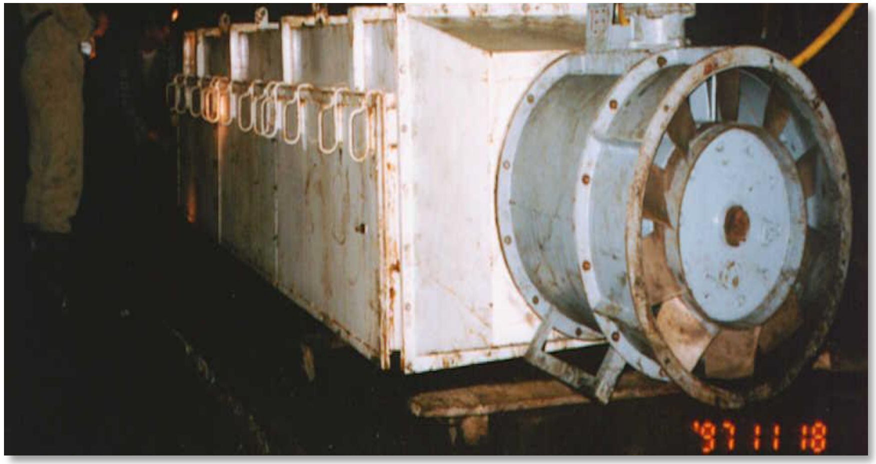
Mitigation: Side-wall sealing.

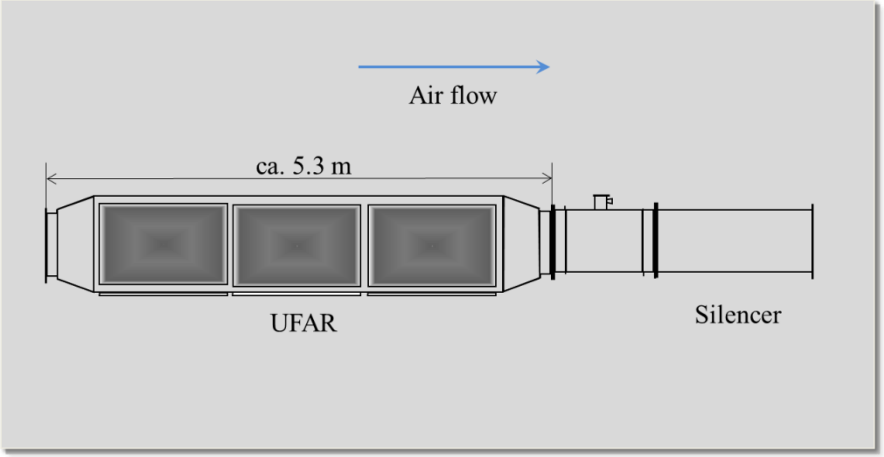


Side-wall covering with sealing compound like phenol-formaldehyde resin + catalyst. However, such activities are usually carried out to reduce the underground fire hazard.

Decreasing of potential alpha energy concentration after sealing of the side-walls. The concentration was reduced by eight times.

Mitigation: Air cleaning with UFAR-300.





Measurement	Before cleaning C_{α}, μJ/m³	After cleaning C_{α}, μJ/m³	Flow rate m³/min
1	3.64	0.48	360
2	3.37	0.79	310
3	2.25	0.56	266

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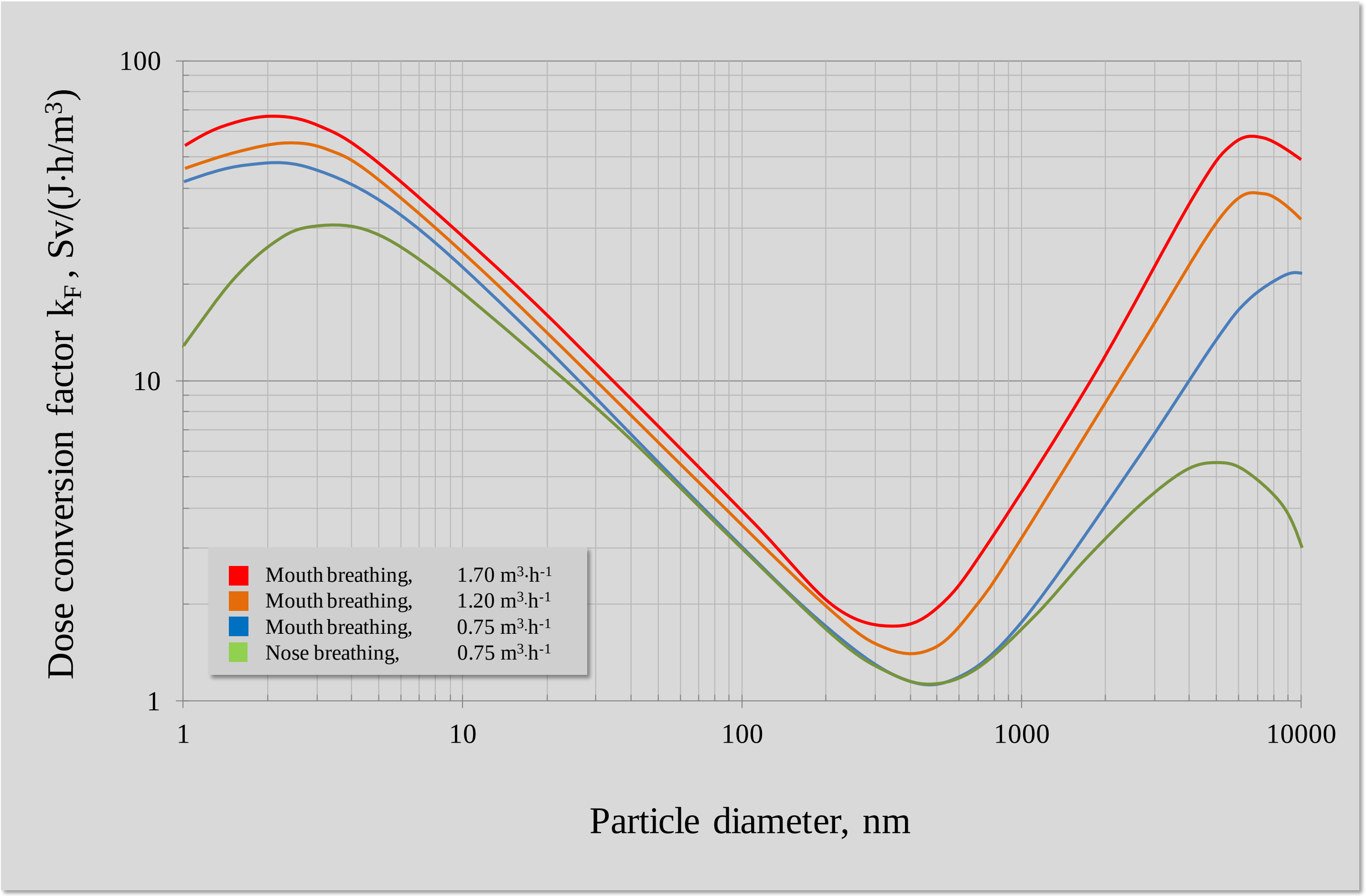
Dose conversion factor as a function of particle diameter



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Underground coal mine. Aerosol size distribution measurements.

SMPS|APS Particle spectrometers
Range: 10 – 20000 nm

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Ambient aerosols in an underground coal mine

Measurement point	Total concentration (particles·cm^{-3})	Class of aerosol particles (μm)			
		LB–0.1 (ultrafine (%)	0.1–2.5 (fine) (%)	2.5–10.0 (coarse) (%)	10.0–UB (supercoarse) (%)
Downcast shaft bottom	56,000	87	13	<0.01	<0.001
Cross–cut	53,000	60	40	0.03	<0.001
Water gallery	24,000	70	30	0.02	<0.001
Road head	20,000	42	57	1.28	0.005
Road head: machine OFF	11,000	45	54	0.23	0.001
Road head: machine ON	58,000	52	47	1.03	0.005
Coal face (30 m away)	25,000	52	47	0.99	0.003
Coal face (30 m away): machine OFF	13,000	20	79	0.18	0.001
Coal face (30 m away): machine ON	59,000	69	30	1.11	0.004
Coal face (80 m away)	47,000	72	28	0.17	<0.001
Coal face (80 m away): machine OFF	15,000	47	53	0.05	<0.001
Coal face (80 m away): machine ON	140,000	82	18	0.10	<0.001
Upcast shaft bottom	35,000	73	27	0.02	<0.001

Note: LB=15.1nm; UB=17.6 μm except for the downcast shaft bottom, where UB=19.8 μm

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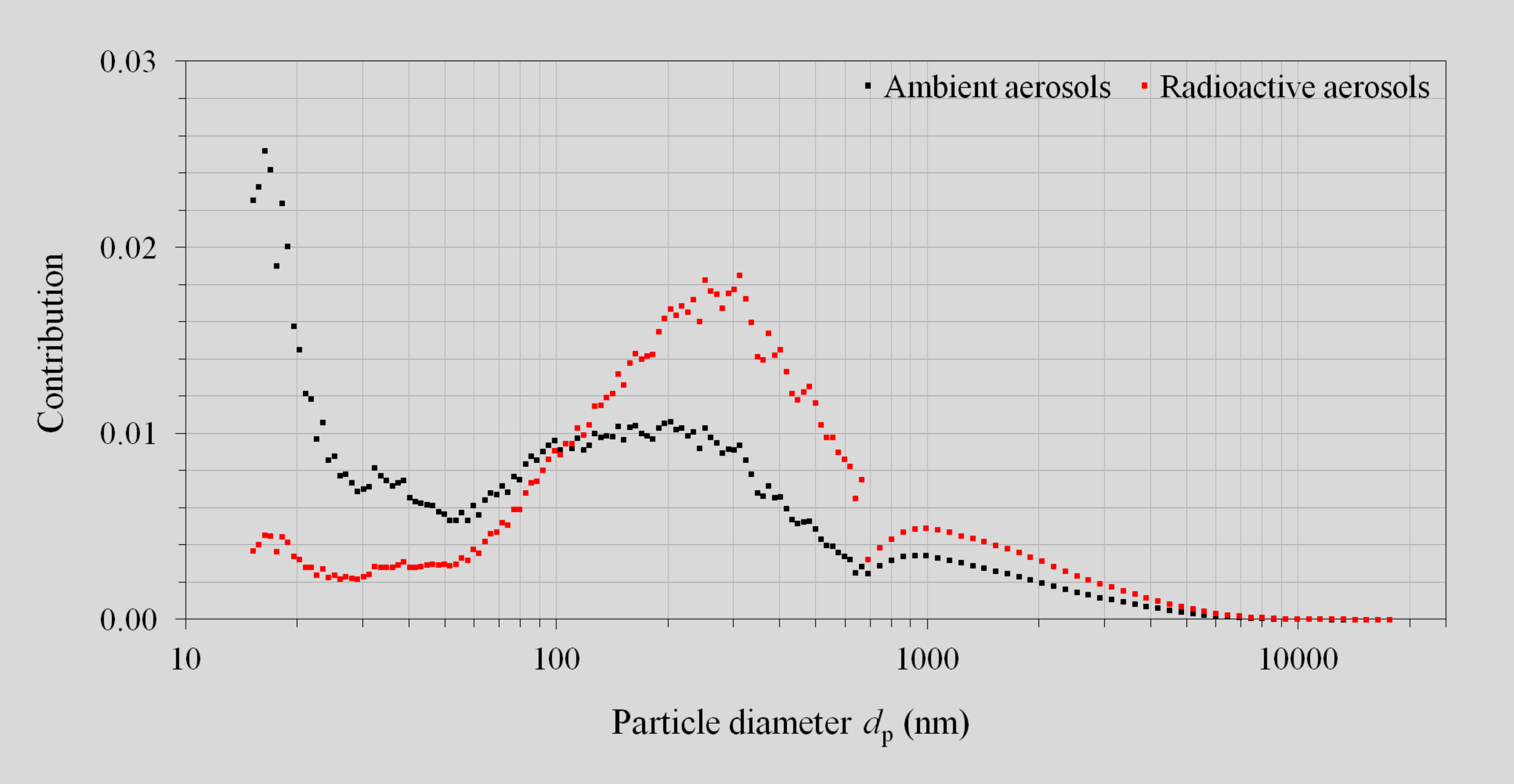

The count and activity contributions of ambient and radioactive aerosols measured close to the road head during heading machine operation (χ =1.1, ρ_p =1.4 g.cm^{-3})

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Dose conversion factor for an underground coal mine

Estimated based on measurement of the ambient aerosol size distribution

Measurement point	Unattached fraction f_p (%)	Dose conversion factor k_F (Sv/(J/m^3·h))	
		Mouth 1.2 m^3/h	Nose 0.75 m^3/h
Downcast shaft bottom	0.7	**6.0**	**4.7**
Cross-cut	0.7	**4.4**	**3.4**
Water gallery	1.7	**4.9**	**3.7**
Road head	2.0	**4.3**	**2.8**
Coal face (30 m away)	1.6	**4.6**	**3.1**
Coal face (80 m away)	0.4	**7.1**	**5.5**
Upcast shaft bottom	1.1	**5.3**	**4.1**

Reference value of the dose conversion factor for occupational exposure k_F = 1.4 Sv/(J/m^3·h)

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Summary

Increasing of short-lived radon progeny concentration in underground workings is mainly due to the ventilation and mining system.

Due to the high variability of the equilibrium factor, monitoring of the alpha energy concentration instead of the concentration of radon is carried out in Polish underground mines.

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Thank you for your attention