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High radon potential and natural density driven mine air currents through galleries and shafts require effective radiation protection measures for miners during remediation work in old mining.

Radon Exposures of Miners at Small Underground Construction Sites in Old Mining: Recommendations to Improve Radiation Protection Measures by the Saxon Radiation Protection Authority

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Abstract: The Ore Mountains (Erzgebirge) and Vogtland are low-mountain regions in the East German state of Saxony. Here, silver deposits were found in 1168. Mining began shortly after, continues at varying intensity to this day, and has left numerous galleries and shafts. Today, eight companies with about 250 miners carry out maintenance at more than 40 small and frequently changing underground construction sites throughout the year. Miners are protected against high radon exposure by radiation protection measures such as ventilations, stoppings made of wood, foil, and expanding foam, and staff rotations. However, some of them still show high annual exposure levels; for example, in 2015 up to 14.4 mSv measured by passive

radon dosimeters. Reasons for this include the high radon potential in old mining and the natural density driven mine air current through the galleries. Mine air currents can change directions during the day depending on outdoor temperatures. This paper presents the experiences of the Saxon Radiation Protection Authority in monitoring miners in old mining. For this purpose, the paper looks at seven examples of miners' critical exposures based on measurement curves of radon activity concentration and derives respective radiation protection measures. These encompass, for example, to activate mine fans, erect stoppings, extend ventilation pipes, and change the locations of mine fans. Conclusions are drawn for the operative and strategic radiation protection in old mining. *Health Phys.* 118(00):000–000; 2020

Key words: operational topics; radiation protection; radon; ventilation

INTRODUCTION

THE ORE Mountains (Erzgebirge) and Vogtland are low-mountain ranges in Saxony. They consist of up to 570-million-years-old gneisses and mica slate, into which numerous and partly vast granites have penetrated. Mining for silver began in the 12th century. Throughout the centuries, silver, tin, cobalt, fluor-spar, lime, and uranium were mined. Today, explorations for lithium, tungsten, and tin take place. Mining has left numerous galleries and shafts, which lead to damages to buildings and roads and make necessary repair work. Furthermore, several galleries have to be maintained permanently for water discharge. One of the latter is the Markus Semmler gallery in Schneeberg, constructed between 1503 and 1841. The gallery is 29.4 km (18.3 miles) long. The system of galleries extends to more than 220 km (136 miles) and carries water from the Schneeberg mining

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FIG. 1. Construction site of remediation work in the Markus Semmler gallery in Schneeberg.

district near Niederschlema to the river Mulde (Fig. 1). Another example is the Rothsönberg gallery. It was constructed from 1844 to 1882. The main gallery's length is 28.9 km (18 miles), in addition to side galleries with a length of 22 km (13.7 miles). The gallery carries water from the Brand mining district and the Freiberg mining district near Rothsönberg to the river Triebisch.

Today, eight companies with about 250 miners carry out maintenance and repair work at more than 40 small and frequently changing underground construction sites throughout the year. The radon potential in the Ore Mountains (Erzgebirge) and the Vogtland is high. Radon activity concentration peaks with up to 1 MBq m^{-3} can occur. Therefore, extensive radiation protection measures are necessary for miners. The most important measures are mine ventilation with mine fans and pipes, the erection of stoppings, and the rotation of staff. Details on repair work and maintenance in old mining as well as on radiation protection for miners can be found in Dehnert et al.² There, one can also find measurements for radon potential, information on the effective annual doses of miners, and the distribution of those doses. Moreover, an enhanced radon dosimetry system

for miners was described, which uses radonproof boxes with activated carbon cartridges instead of reference dosimeters.

Companies take great effort to protect their employees working in abandoned mines against radon. Nearly all miners are monitored with radon personal dosimetry. Despite great personal commitment, expertise, and high expenditures, the effective annual doses of miners in underground remediation work in Saxony's old mining are comparatively high. In 2015, effective annual doses between 1 mSv and 6 mSv were established for 78 out of all 252 miners (31%). The highest effective annual dose was 14.4 mSv and was relatively near the limit of 20 mSv set by the German Radiation Protection Ordinance (Radiation Protection Ordinance 2001). In comparison, 2,434 people working in the industry were monitored for radiation protection reasons in Saxony in 2015. Among them were only six people with effective annual doses greater than 6 mSv. A further six out of 13,053 monitored people working in medicine exceeded 6 mSv (Dehnert 2017b).

In recent years, the Saxon Radiation Protection Authority inspected more than 60 underground construction sites for radiation protection purposes. These inspections entailed a comprehensive measurement of radon activity concentration with an AlphaGUARD PQ2000 PRO by Saphymo GmbH with a

time resolution of 1 minute. The inspections found construction sites with exposures too high for miners. Most often, the conditions at the construction sites had unnoticeably changed over time. Hence, originally effective radiation protection measures had become ineffective. After discussions with the respective head miners, radiation protection measures were optimized at the construction sites.

Although most of the time the legal limit of 20 mSv per year is adhered to in remediation work in old mining, the comparatively high exposure of miners should be motivation for head miners, company managers, and the Saxon Radiation Protection Authority to jointly work to decrease this exposure. Here, important is the exchange of know-how in handling difficult radiologic situations in galleries and shafts. In this paper, the experience the Saxon State Office of Radiation Protection has in monitoring miners in old mining is presented in order to share it with a wider public and relevant authorities. For this purpose, the paper looks at seven examples of miners' critical exposures based on measurement curves of radon activity concentration and derives respective radiation protection measures.

In the following, the isotope ^{222}Rn and the ^{222}Rn activity concentration are simplified with radon and radon activity concentration, respectively. Some figures include parts of original measurement protocols taken by the Saxon Radiation Protection Authority. Protocols have been anonymized for data protection reasons.

Mine air currents in old mining

If the system contains mine openings at varying heights, air flows naturally through a system of interconnected galleries and shafts. In the process, density-driven air currents might accumulate radon and thus show very high radon activity concentrations. Active mines

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operate for a long time. Therefore, stationary high-performance ventilation is installed that provides fresh air in great amounts and suspends the natural throughflow in galleries and shafts. For repair and maintenance work at small and frequently changing construction sites in abandoned mines, mobile fans are used. These mine fans are generator-powered and are of lower performance. They blow in lower amounts of air and only partially change the natural throughflow in galleries and shafts.

A sufficient understanding of the natural throughflow in galleries and shafts, which depends on the outside temperature, is an important foundation for radiation protection in old mining. The equation for hydrostatic pressure is

$$p(h) = \rho g \Delta h + p_0 \quad (1)$$

with p representing hydrostatic pressure, ρ representing density, g representing gravitational acceleration, and Δh representing the difference in height between two points. Including temperature t , eqn (1) can be amended to:

$$p(h, t) = \rho(t) g \Delta h + p_0. \quad (2)$$

The air temperature in galleries and shafts is about 10 degrees Celsius. If the outside temperature is higher than the inside temperature (e.g., 20 degrees Celsius), the air density in the valleys is lower than in the galleries. According to eqn (2), overpressure

develops in the galleries. The colder and heavier air streams from the galleries into the valleys. The warmer outside air flows into the shafts from above. Inside the galleries and shafts, the inflowing outside air rather quickly cools down to 10 degrees Celsius. With this, a density-driven mine air current emerges inside the galleries and shafts. This air current only comes to a halt when the outside temperature drops to 10 degrees Celsius and there is no longer a temperature difference between the outside and inside (Fig. 2, left).

If the outside temperature drops further down to, for example, 5 degrees Celsius, the process reverses. Now the air density inside the valleys is higher than inside the galleries. Because of the overpressure in the valley, colder and heavier outside air streams into the galleries and rather quickly warms up to 10 degrees Celsius. Flowing into the galleries, the outside air causes overpressure in the shafts, pushing air out of the shafts. This density-driven mine air current also persists until the outside temperature reaches 10 degrees Celsius again, and there is no longer a temperature difference between the outside and inside air (Fig. 2, right).

The velocity of the mine air current inside the galleries and shafts depends on the difference in height Δh between both the mine openings to the outside and the outside temperature. The scope

of velocity reaches from “not-noticeable” to “strong wind.”

Within the system of interconnected galleries and shafts, the principle of the communicating vessels applies. There is an air current in all galleries and shafts that are connected at a minimum of two places, even if they are beneath the deepest and above the highest mine openings. For miners, this implies that radon-containing mine air might reach construction sites from unexpected directions.

The air current inside the galleries and shafts is characterized by variable velocities and frequent changes of direction. Furthermore, through the change of seasons, unexpected developments might take place; for instance, strong radon containing mine air currents might occur that stream through construction sites after a longer period of time with weak radon-containing mine air currents, or the other way around.

Fig. 3 shows the natural density-driven mine air currents in galleries and shafts for a construction site in old mining protected by artificial ventilation for high outside temperature (left) and low outside temperature (right). For the mobile ventilator with its lower performance to be more effective, the gallery was additionally sealed with a stopping.

Due to the frequently changing mine air currents, it is important that miners can interpret radon activity

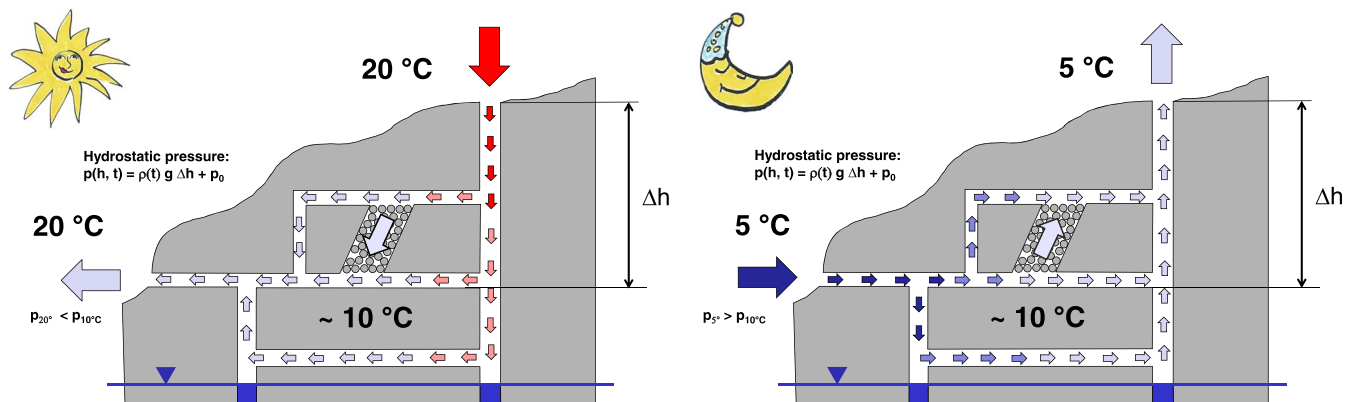


FIG. 2. Natural density-driven mine air current in old mining during higher outdoor temperatures (left) and lower outdoor temperatures (right).

concentration readings themselves without deeper knowledge of radiation protection. To do so, miners can turn to two rules of thumb that apply for an equilibrium factor between radon and its short-lived decay products of 0.4:

1. A radon activity concentration of $1,000 \text{ Bq m}^{-3}$ leads to an effective annual dose of 6 mSv (value of necessary reporting) with an annual total of 2,000 working hours; and
2. A radon activity concentration of $3,000 \text{ Bq m}^{-3}$ leads to an effective annual dose of 20 mSv (limit value) with an annual total of 2,000 working hours.

These rules of thumb are derived from the German Radiation Protection Ordinance. The radon activity concentration measured by miners and multiplied with the working hours leads to the resulting radon exposure. The effective annual dose is calculated from the radon exposure using the official conversion factor from the German Radiation Protection Ordinance (Radiation Protection Ordinance 2001). It is assumed that an exposure of $0.32 \text{ MBq h m}^{-3}$ corresponds to an effective dose of 1 mSv when the equilibrium factor between radon and its short-lived decay products is 0.4. With this, the according radon activity concentrations can be calculated for the two effective annual doses of 6 mSv and 20

mSv. According to the German Radiation Protection Ordinance, companies must report effective doses of more than 6 mSv to the State Offices for Radiation Protection, and companies have to take additional radiation protection measures for their miners. According to the German Radiation Protection Ordinance, the annual limit value is 20 mSv and must not be exceeded.

For mine ventilation with ventilators, equilibrium factors smaller than 0.4 between radon and its short-lived decay products are more common. In terms of the aforementioned rules of thumb, lower equilibrium factors are not a problem, as they make estimated doses appear too high, which is conservative. For calculating effective doses of radon dosimeters, other equilibrium factors listed in a table in the 2003 Guideline Work are used if the equilibrium factor deviates significantly from 0.4 (Guideline Work 2003).

It is to be noted that the dose coefficients stated in the German Radiation Protection Ordinance are largely based on ICRP 65 (1993). The ICRP suggested new radon dose coefficients particularly in the recommendations ICRP 115 (2010) and ICRP 126 (2014) leading to higher effective doses. The German Commission on Radiological Protection's discussion and recommendation for the future use of the new coefficients can be found in Strahlenschutzkommission (2017).

INSPECTIONS

Inspection (1): Mine fan turned off

When miners feel that mine air currents stream in naturally and that fresh, low-radon air flows to workplaces, they tend to turn off existing mine ventilation provided by fans and pipes. This is understandable, as mine ventilation is noisy, might cause colds due to strong air draft, and requires a high amount of energy. Turned-off ventilation systems become problematic when outside temperatures change and a reversal of mine air currents takes place before being noticed in time.

Fig. 4 depicts an example. At a construction site, mine air currents streamed in naturally in the morning. Hence, the miners had turned off the mine fan. At an inspection by the Saxon Radiation Protection Authority at high outside temperatures at noon, inspector measured a radon activity concentration of 27 kBq m^{-3} at the workplace. The mine fan was turned on immediately. The radon activity concentration dropped to 3 kBq m^{-3} within 15 min and to less than 1 kBq m^{-3} 20 min later (Dehnert 2017a).

Inspection (2): Missing stoppings

Stoppings are used to screen off galleries and parts of galleries with strong radon-containing mine air currents from construction sites during remediation work. Some

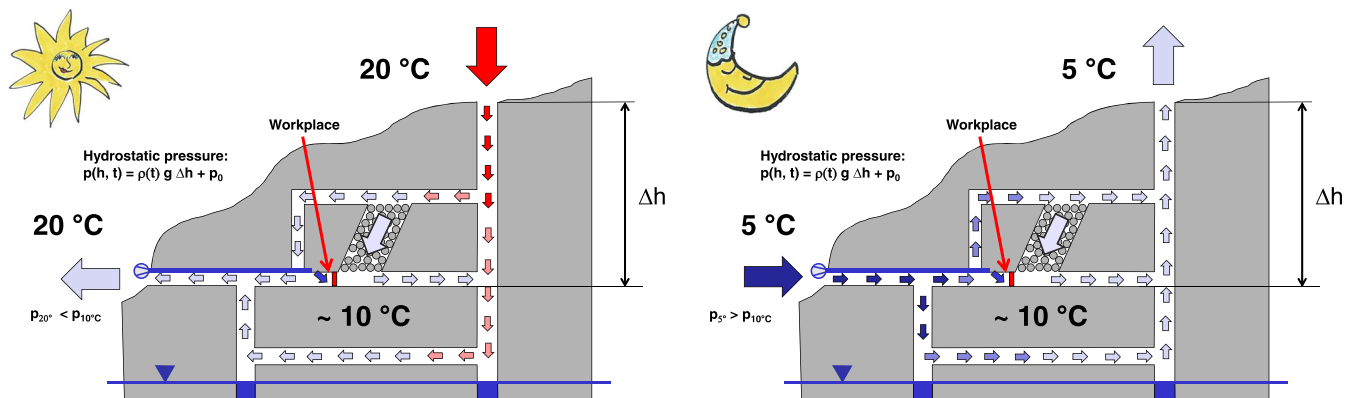


FIG. 3. Natural density-driven mine air current in old mining during higher outdoor temperatures (left) and lower outdoor temperatures (right) including a construction site for remediation work protected by ventilation and stopping.

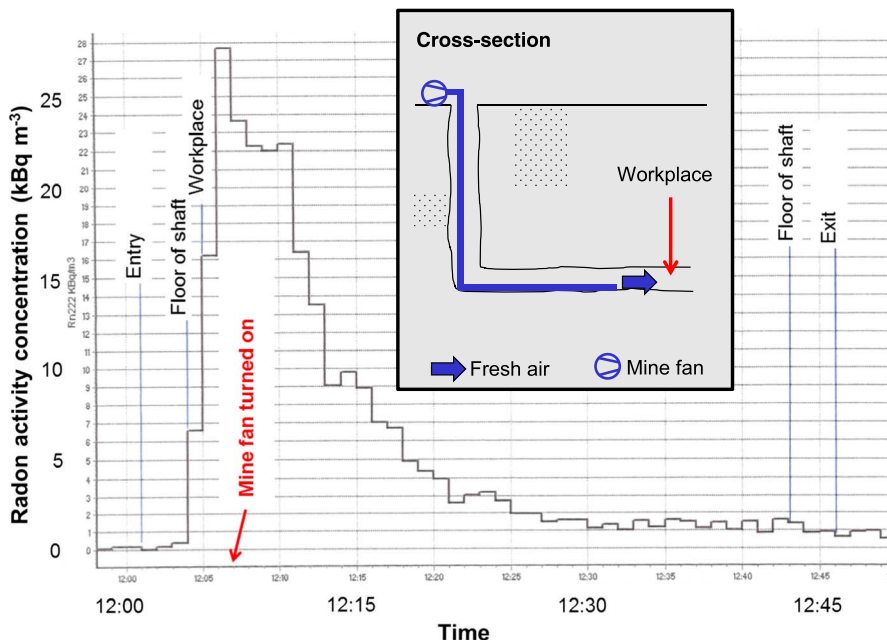


FIG. 4. Course of the radon activity concentration measured by a transportable radon monitor during an inspection of an underground workplace in old mining where the mine fan was turned on too late (Dehnert 2017a).

galleries do not contain radon-containing air currents for a longer period of time. This can change suddenly, and strong radon-containing mine air currents can reach construction areas. Other galleries contain radon-containing mine air currents only for limited periods of time, depending on the daily direction of the mine air currents, which can easily be overlooked. Erecting stoppings made of wood, foil, and expanding foam is resource- and time-consuming. Additionally, stoppings must be dismantled before every blasting and re-erected afterwards. The head miner at the respective construction site decides in which gallery stoppings need to be erected at what time.

During an inspection of a construction site by the Saxon Radiation Protection Authority, a radon activity concentration of 4 kBq m⁻³ was measured, although mine ventilation by a mine fan and a pipe was used at the workplace. During the inspection, the radon activity concentration increased heavily and reached 9 kBq m⁻³ after only 30 min (Fig. 5). Looking for the

sources, a gallery halfway between shaft and workplace and a second gallery directly at the shaft were found, both funneling in radon-containing mine air currents with an activity concentration of 38 kBq m⁻³ and 23 kBq m⁻³, respectively. The old strong radon-containing mine air currents blended with fresh low radon-containing mine air currents and rendered the mine

ventilation ineffective. For radiation protection measures, stoppings were used to seal off both galleries from the construction site. After that, the radon activity concentration dropped permanently from about 10 kBq m⁻³ to 300 Bq m⁻³. The effectiveness of mine ventilation was restored (Dehnert 2017a).

Inspection (3): Missing stopping

At an inspection by the Saxon Radiation Protection Authority of another construction site ventilated by a mine fan and a pipe, a radon activity concentration of 500 Bq m⁻³ was measured at around 11 am. At a repeated measurement at the same place 30 min later, the radon activity concentration had jumped to 8 kBq m⁻³ despite the mine ventilation (Fig. 6). The mine ventilation had rapidly become inefficient. Looking for the causes, it was found that strong radon-containing mine air currents in the gallery in front of the construction area were under high pressure due to high outside temperatures and were largely hindered by the mine ventilation. Rising outside temperatures increased pressure, which led to a breach after a short amount of time. Between 11 am and 11:30 am, natural density-driven mine air

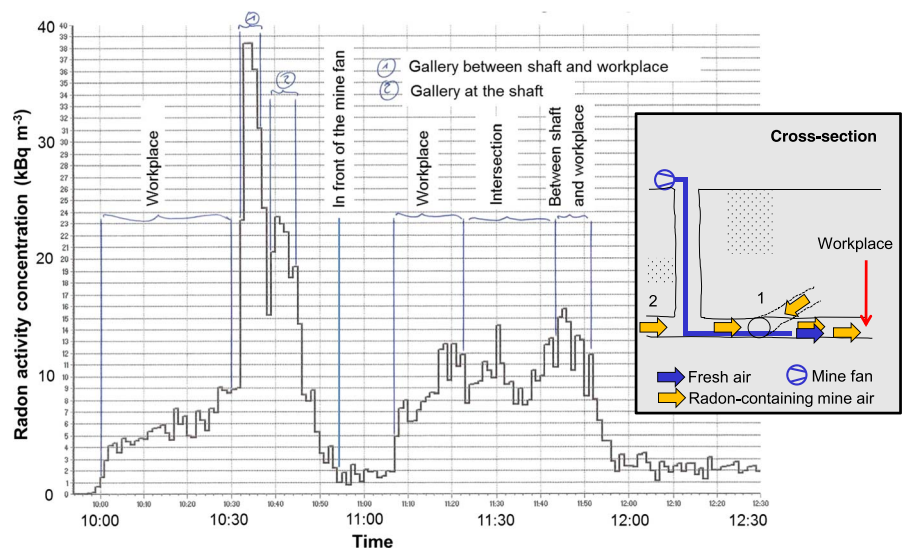


FIG. 5. Course of the radon activity concentration measured by a transportable radon monitor during an inspection of an underground workplace in old mining where stoppings were missing (Dehnert 2017a).

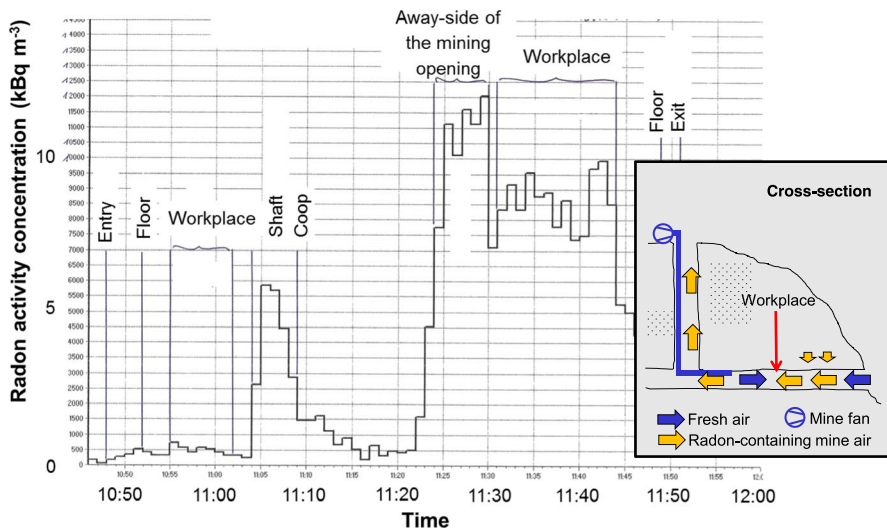


FIG. 6. Course of the radon activity concentration measured by a transportable radon monitor during an inspection of an underground workplace in old mining where a stopping was missing.

currents emerged and led to strong radon-containing mine air currents flooding the construction site. Fresh air currents from the pipe could not reach the workplace anymore and were taken by the natural density-driven mine air currents and carried away through the shaft. As radiation protection measures, a stopping was erected in the gallery in front of the construction site. The stopping disrupted the natural density-driven mine air currents. The mine ventilation by mine fan and pipe was efficient again, and the natural radon activity concentration remained permanently in the region of a few hundred Bq m^{-3} .

Inspection (4): Pipe too short for mine ventilation

There are mobile construction sites that move slowly horizontally in galleries or vertically in shafts. Typically, workplaces and working platforms move daily or weekly for a few meters. Mine ventilation at the construction sites needs to be moved as well. Therefore, the pipes for the mine ventilation are extended.

At an inspection by the Saxon Radiation Protection Authority of a mobile construction site in a shaft, a radon activity concentration of 13 kBq m^{-3} was measured at the working platform despite mine

ventilation by a mine fan and a pipe (Fig. 7). The mine ventilation was ineffective. Looking for the causes, strong outgoing mine air currents were found in the shaft. The distance between the end of the pipe and the working platform was too high. The fresh mine air currents could not reach the working platform. They were entrained by the outgoing mine air currents and were carried away through the shaft. The cause for this was the construction of the pipe system made up of pipes of 10 m length. Hence, the mine ventilation at the working platform was originally effective but weakened with increasing distance from the end of the pipe until it ceased entirely before another pipe could be installed (Dehnert 2017a). For radiation protection measures, a pipe of 5 m length was installed at the end of the pipe system and carried with the working platform. Hence, the maximum distance between the end of the pipeline and the working platform was halved from 10 m to 5 m, and effective mine ventilation was permanently restored.

Inspection (5): Outgoing mine air currents in coops

In remediation work, wooden coops are built above shafts to

protect them and miners from rain, snow, and wind and dismantled once the work is completed. At least one miner in the coops has to secure the underground work of his colleagues. Furthermore, he needs to supply them with construction materials down the shaft as well as receive and empty buckets filled with rocks. It is understandable that miners keep the coops' windows and doors closed, especially during low temperatures outside.

The miners are monitored with radon personal dosimetry. The radon dosimeters are worn for three months. For miner A, an effective dose of 7.8 mSv was measured for a quarter. However, the miner transported material in a coop for only 5 days. The remaining 11 weeks, he worked at another construction site outdoors at a support wall for a road. Miners B and C worked for 12 weeks at a construction site in a gallery. The construction site was ventilated by a mine fan and a pipeline. For them, effective doses of 2.2 mSv and 3.0 mSv were measured (Fig. 8). The miners' company mistook miner's A effective dose of 7.8 mSv for a measuring error. The company requested the Saxon Radiation Protection Authority to set a replacement dose of 0 mSv.

At an inspection, the Saxon Radiation Protection Authority was able to show that no measuring error occurred (Dehnert 2017b). Miner A in the coop worked in the outgoing strong radon-containing mine air currents of many, long, and branched galleries. His colleagues B and C at the construction site in the gallery were protected well enough by the mine ventilation. The extraordinarily high exposure of 7.8 mSv in the coop occurred within only 5 days. For radiation protection measures of future work, coops are to be aired with open windows and doors and the miners' retention time in outgoing mine air currents is to be minimized.

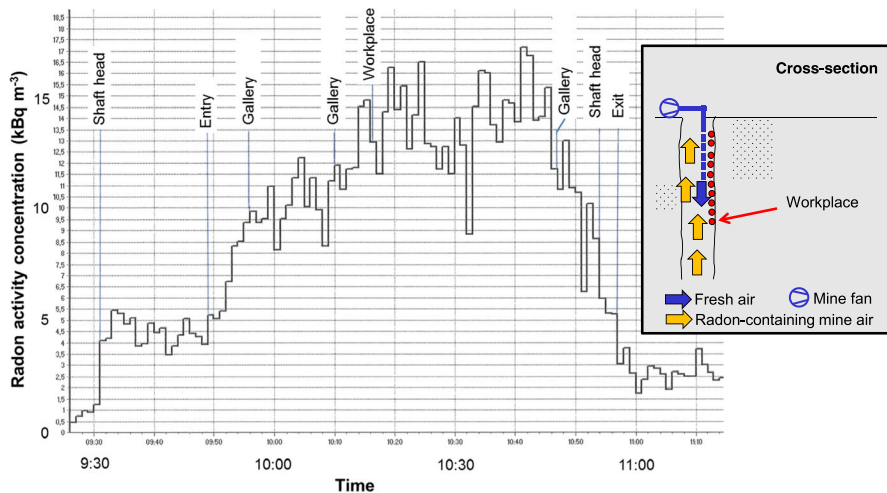


FIG. 7. Course of the radon activity concentration measured by a transportable radon monitor during an inspection of a mobile underground workplace in old mining where the distance between the air-ducting system and the working platform was too big (Dehnert 2017a).

Inspection (6): A mine fan pushes outgoing mine air currents back into the mountain

For mine ventilation, mine fans, and in most cases generators too, need to be set up overground. In this regard, some construction sites are difficult in terms of terrain and development. They might be cramped and right in the middle of buildings and narrow roads in a centuries-old town in the Ore Mountains (Erzgebirge). Hence, the question arises of how to set up mine fans and generators so that the inconvenience for residents by noise and exhaust gas can be minimized.

At an inspection by the Saxon Radiation Protection Authority, a construction site was found where the air leaving the mine ventilation at the end of a pipe in a gallery had a radon activity concentration of 1 kBq m^{-3} (Fig. 9). At this construction site, the mine fan was placed above the mine opening between two buildings next to a hill due to reasons of space. The colder mine air currents leaving the gallery were supposed to stream downhill with higher outside temperatures due to their higher density. Actually, though, a distinct thermal lift out of the valley emerged on hot summer days and carried with it the outgoing cold

mine air currents up hill. Because of this and despite their higher density, mine air currents were partially sucked in by the mine fan and pushed back into the gallery with warm outside temperatures. For radiation protection measures, a piece of brattice cloth was put up overground to channel the outgoing mine air currents away from the mine fan (Dehnert 2017b).

Inspection (7): Mine fan activates radon-containing mine air currents by sucking them in.

Sometimes, mine fans are set up in a gallery without a pipeline between mine opening and fan. By producing low pressure where they suck in air, such fans might not only suck in fresh low radon-containing air through the mine opening but also strong radon-containing air through the walls of galleries.

At an inspection of a construction site with a mine fan set up loosely in the gallery, the Saxon Radiation Protection Authority found that the fresh incoming mine air currents interspersed with strong radon-containing mine air right after the mine opening through gaps in the wall due to the low pressure produced by the fan. Currents had a radon activity concentration of 3 kBq m^{-3} only a few feet after the mine opening that rose to up to 5 kBq m^{-3} at the mine fan (Fig. 10). The mine fan did not improve radiation protection in the gallery. For radiation protection measures, a pipe could either be laid from the

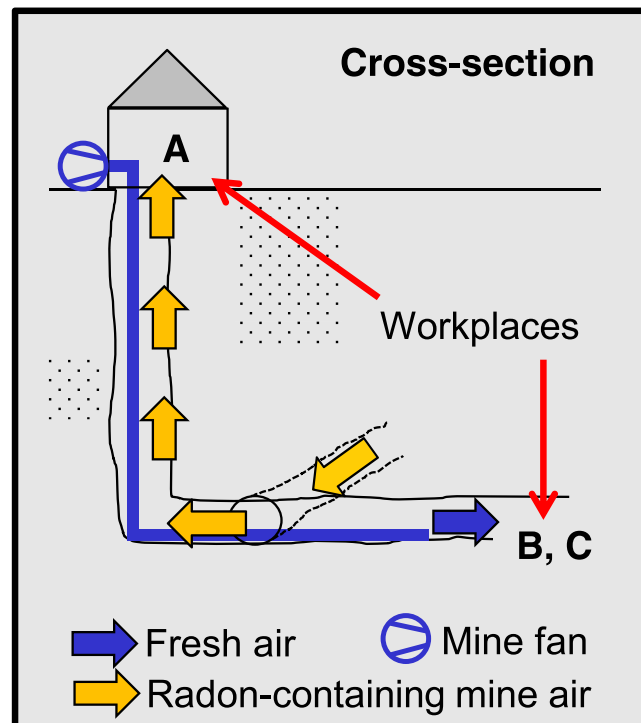


FIG. 8. View of a construction site in old mining with outgoing strong radon-containing mine air currents in the coop (workplace miner A) and mine ventilation underground (workplace miners B and C) (Dehnert 2017b).

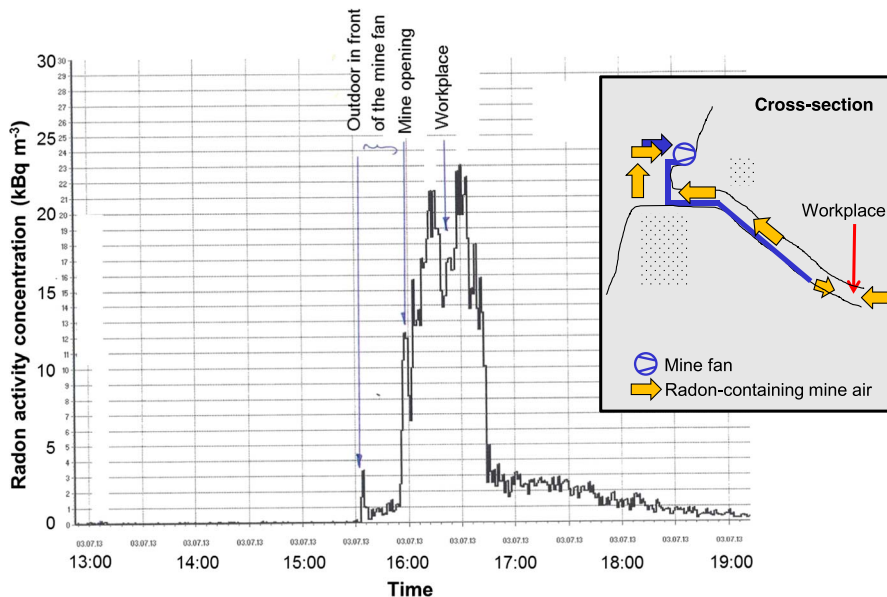


FIG. 9. Course of the radon activity concentration measured by a transportable radon monitor during an inspection of an underground workplace in old mining where outgoing mine air currents are sucked in by the mine fan and pushed back into the gallery (Dehnert 2017b).

mine opening to the fan or the fan could be set up at the mine opening to push low radon-containing air into the gallery (Dehnert 2017b).

CONCLUSION

Operative radiation protection

The following recommendations for operative radiation protection during remediation work in old mining have been derived from more than 60 inspections by the Saxon Radiation Protection Authority:

1. Even with natural density-driven mine air currents, mine fans may only be turned off, if the radon activity concentration at the workplaces is monitored by radon monitors so that fans can be turned on in time;
2. Galleries with strong radon-containing mine air currents need to be screened off from construction sites with the help of stoppings;
3. Pipes for mine ventilation need to be placed close enough to workplaces and mobile working places alike. Therefore, sufficiently short pipes need to be used and be at hand;
4. Overground work on top of shafts and in front of entries

of galleries are equally important as underground work and require meticulously planned radiation protection measures. Coops, for example, are to be aired with open windows and doors, and miners' retention time minimized in outgoing mine air currents;

5. Mine fans set up overground need to be set up in a way so that outgoing radon-containing mine air currents are not sucked

in and pushed back into the gallery or shaft; and

6. It must be ensured that fresh mine air currents do not load up with radon on the way from the mine opening to the mine fan, if fans without pipes are set up. If this is the case, a ventilation pipe could either be laid at the side of the mine fan where it sucks in air, or the mine fan could be set up at the mine opening pushing in air.

Strategic radiation protection

The recommendations for the operative radiation protection were derived from individual cases of high exposures of miners and required fast radiation protection measures. Radiation protection measures were sufficient at most of the inspected construction sites. However, the level of exposure in Saxon old mining is high. To reduce the level of exposure, strategic recommendations have also been derived from the more than 60 inspections by the Saxon Radiation Protection Authority:

- (1) Following the precautionary principle, stoppings should be erected in all adjacent galleries

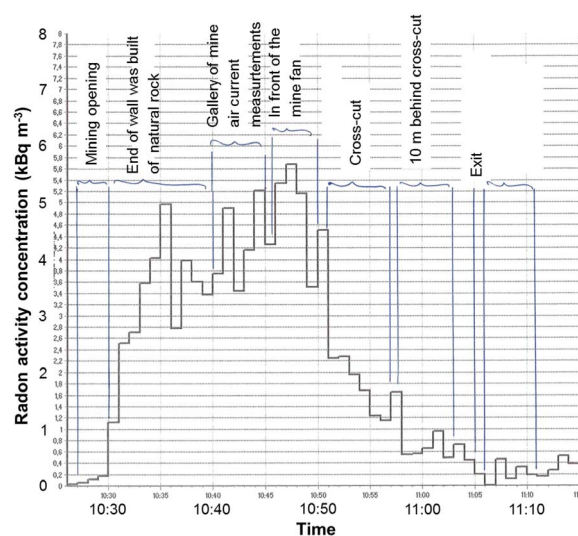


FIG. 10. Course of the radon activity concentration measured by a transportable radon monitor during an inspection of an underground workplace in old mining where fresh air is loading up with radon where the mine fan sucks in air (Dehnert 2017b).



FIG. 11. The “Quick-Erect Stopping System” (QESS) set up in the Querschlag 60 gallery in Schneeberg to shut off the radon rich Querschlag 60 from the Markus Semmler gallery to prevent the miners from radon exposures.

when establishing construction sites; and

- (2) As a rapid alert system, active radon monitors at all construction sites should shorten the time until radiation protection measures are initiated.

Erecting stoppings as described in (1) is time-consuming and thus costly. Stoppings are usually only erected if galleries contain strong radon-containing mine air currents and if the stoppings are necessary for the acute radiation protection of a construction site. Some galleries do not contain radon-containing mine air currents for a long time, but they can suddenly funnel strong radon-containing mine air currents to the construction site. Other galleries contain radon-containing

mine air currents only short-term, depending on the direction of the mine air currents, which can easily be overlooked. It often takes some time until this is recognized by the head miner and counter-measures are initiated. This leads to higher exposures of miners over the year and over all construction sites. These exposures can be avoided if stoppings are erected in all adjacent galleries independent of the radon activity concentration when construction sites are established, following the precautionary principle. To address this increased demand, the reusable “Quick-Erect Stopping System” (QESS) was designed (Dehnert 2016; Dehnert et al. 2016) and produced by the Aluminiumbau und Verwaltungs GmbH Stopp.

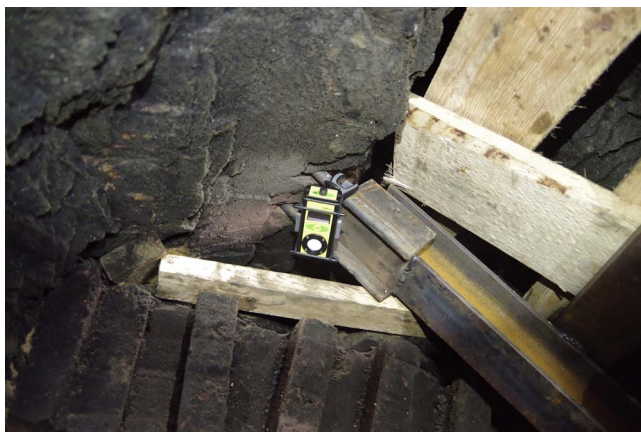


FIG. 12. Radon monitor DOSEman Mining Edition fixed at the ceiling of the Persival Morgengang gallery in Schneeberg to display possible sudden increases of radon activity concentration to prevent miners from radon exposures (Dehnert 2017b).

Galleries with any type of cross-section can be screened within minutes using this radon-proof quick-erect stopping in form of a modular design (Fig. 11).

Up to now, the stationary monitoring of galleries with active radon monitors as described in (2) was reserved for active mining due to financial reasons. Today, new radon measurement technology that is suitable for mining and inexpensive allows the systematic equipping of all underground remediation work with simple radon monitors. The radon monitor “DOSEman Mining Edition” by Sarad GmbH was designed to withstand the tough conditions in old mining and tested at various construction sites (Fig. 12). It has alpha-spectroscopy, is robust, splash-proof as described in protective class IP67, can be handled by only one button, and can remain underground for 1 week until its battery needs to be recharged. With those features, the radon monitor could become the “radon thermometer” of the miner (Dehnert et al. 2017). By using it, the miner is able to recognize a worsening of exposure at work “in passing,” and can report it to his head miner shortly after. The head miner can then initiate radiation protection measures without delay.

One can anticipate that erecting stoppings following the precautionary principle and using radon monitors as a rapid alert system at all construction sites will lower miners’ levels of exposure during remediation work in old mining. Both are feasible without a noteworthy increase in costs for companies.

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