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Disposal of the Abandoned Mine Workings of Uranium Mines – Case Study of Rožná I Mine, Czech Republic

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Abstract
Having abandoned mine workings, the closure strategy of mine working openings is important in terms of maintaining long-term stability. The paper describes the process of closing the mine workings in the uranium deposit Rožná using unconsolidated backfill. Before backfilling, it is vital to carry out preparatory work underground for ecological, technological or economic reasons. The mine workings backfilling using unconsolidated backfill is preceded by calculations to determine the quantity of the backfill. The stability of the mine workings opening is achieved using a closing sinking platform made of reinforced concrete. The abandonment procedure is framed within the legislation of the Czech Republic, grounded in the handbook by the National Coal Board of Great Britain (NCB, 1982), and has been gradually amended according to the experience with disused mine workings. The Czech legislation dealing with mine abandonment is very advanced and may be applied to modify foreign legislation. The abandonment procedure based on Decree 52 (1997) proposed in this paper is complemented by safety features such as micropilots in the sinking platform or shaft lining check-up before the backfill. The proposed method is applicable in mines with analogous specific conditions, such as mines free of gas hazards and coal dust. The paper concludes with an analysis of risks likely to occur due to incorrect mine closures.

Keywords
closure; abandonment; Rožná I; uranium mine; unsolidified backfill; closing sinking platform

Introduction

The exhaustion of the reserves of the minerals of deep mines leads to the cessation of mining activities. The cessation of mining activities at each site can only be implemented after all entrances to the underground spaces have been secured by geotechnical disposal of the main mine workings coming to the surface. These mine workings are traditionally liquidated using solidified or unsolidified backfill. Their pit mouths are then secured with a closing sinking platform to stabilise the shaft of the mine workings. The method and parameters for liquidating these inlets must always be adapted to the local mining and geological conditions.

The number of closing mines is relatively large. In China, nearly 30,000 illegal small coal mines have been closed due to the radical reform policy introduced in 1999 (Shen & Andrews-Speed, 2001). Between 1975 and 2000, copper mines worldwide fell from 250 to 59 (Crowson, 2003). In the United Kingdom, up to 100,000 mine workings have been recorded as having been used to enter underground mine spaces (NCB, 1982). However, Entec UK (2007) reports that the number of ore mine entries alone exceeds 50,000 due to the extensive mining history. With the reunification of Germany in 1990, active uranium ore mining was terminated after more than 40 years, and liquidation began at all sites (Paul et al., 2006). The change of political regime in Czechoslovakia in the 1990s also began a massive decline in mining, especially ore and uranium mining, with only one mine operating in the new millennium, the Rožná I uranium deposit. With the change in Germany's energy policy, the last active coal mines were closed at the end of 2018 (Appunn, 2018). Nowadays, when the global trend is to reduce the use of traditional fossil fuels for electricity and heat generation based on The European Green Deal (Ec.europa, 2021), the issue of the liquidation of major mining operations will be a hot topic. By 2022, 16 coal mines had been closed in Poland (Kuśmirek-Zegadło, 2019). In the Czech Republic, the coal mines in Ostrava-Karviná Coal District are also gradually declining. Hard coal mining was supposed to end in 2022, but due to the energy crisis, mining has been extended until 2025 (Weiss, 2022).

A mine can be abandoned in a mining locality having terminated the closure work on the major mine workings (Act 44, 1988). From a safety point of view, the mine openings must be closed using consolidated or unconsolidated backfill and secured with a closing sinking platform to prevent the mine workings pit shaft disintegration and degradation in the future. Mine closure in the world is always adapted to local mining and geological conditions, but the general information on this topic is given in many publications (DMIRS, 2020; MERN, 2017; Sanchez et al., 2014; de la Vergne, 2008). All technical instructions are adapted to the relevant applicable legislation.

In the Czech Republic, the mine closure works have been incorporated into Decree 52 (1997), which has been amended several times. The decree was prepared from the professional experience of its authors, but the model was the handbook of the National Coal Council of Great Britain (1982). In the years 2005-2007, a national project (Aldorf & Hrubesova, 2011; Aldolf, 2007) was solved on this topic, which supplemented Decree 52 (1997) on suitable safety elements.

However, there are currently several safety features and procedures that are not required by legislation or closely specified. Therefore, the paper deals with a combination of legal requirements and extra safety measures for a more reliable, safer and sustainable mine closure. The method was proposed within the framework of Czech legislation, but thanks to the proposed strict safety limits, the method is applicable for analogous mines worldwide.

The described procedures for the closure of non-gaseous mines in the Czech Republic were applied to the Rožná I mine case study. The Rožná I mine is the last accessible mine of the Czechoslovak uranium industry, where active uranium mining took place until 2017.

Legislation framework for underground mine abandonment in the Czech Republic

Mine closure is governed by only a small number of acts and decrees in the Czech legislation. Mining Act 44 (1988) deals with the development work and exploitation of exclusive deposits and mine and quarry operation and closure plans in § 32. Article (2) states that the plans for the development and exploitation must include an estimate of mine damage settlement costs incurred in connection with the planned mining and post-mining remediation of the affected land, including the provision of required financial funds. Article (4) stipulates that the organisation must prepare plans for mine conservation or closure before the termination of operation in the mine workings or quarries. The last article also mentions the legally binding decree for such activities by the Czech Mining Authority.

Act 61 on mining, explosives and state mining authority (1988) defines mining in § 2. Letters c) and g) state that the establishment, protection and closure of mines and quarries, as well as the protection and closure of old mine workings, are considered mining activities. Such a classification is important for further authorisation decrees and supervision by state mining authority, whose other permit-granting authorities are defined in § 10 of the same act.

Decree 104 on granting mining permits (1988) by Czech Mining Authority stipulates the permit for mining activities in § 5, letter b) in order to protect and close major mine workings and quarries. The permit-granting procedure includes a provision of mine and quarry protection and closure plans as of Annex 6 of the same decree. The main points of the plan are:

- reasons for protection and closure,
- results of the geological-exploratory work, development, and extraction, including dressing and beneficiation of the extracted minerals,
- results of mineral reserve management,
- method of mine and quarry protection or closure,
- schedule for protection and closure work,
- mine water management,
- post-mining remediation and land reclamation plan.

This plan is complemented by relevant map documentation, but the legislation does not specify this plan processing in more detail.

The technical requirements for mine closure are stipulated in Decree 52 (1997) of the Czech Mining Authority. It stipulates the requirements to ensure labour and mine operation safety during major mine workings closure. These two decrees include:

- mine closure principles,
- requirements for backfill,
- ensuring the backfill stability,
- reinforcing dams,
- closing sinking platform,
- safety measures,
- checks in the course of and post-mine closure.

Characteristics of Rožná uranium deposit

The Rožná uranium deposit is located at the edge of Bohemian-Moravian Highlands in the region of Žďár nad Sázavou, approximately 55 km north-west off Brno – see Fig. 1. In the allotment of 8.76 km^2 (it was reduced in 1996) mining activities are carried out by a DIAMO subsidiary, GEAM Dolni Rožínka in Stráž pod Ralskem. Before 27 April 2017, the core of mining activity was the underground mining of uranium ore (Vokurka, 2018) and its subsequent dressing into uranium concentrate – ammonium diuranate $(NH_4)_2U_2O_7$. At present, the underground space of the Rožná I mine is maintained in operation and is used as a radioactive waste repository by the state enterprise Radioactive Waste Repository Authority.

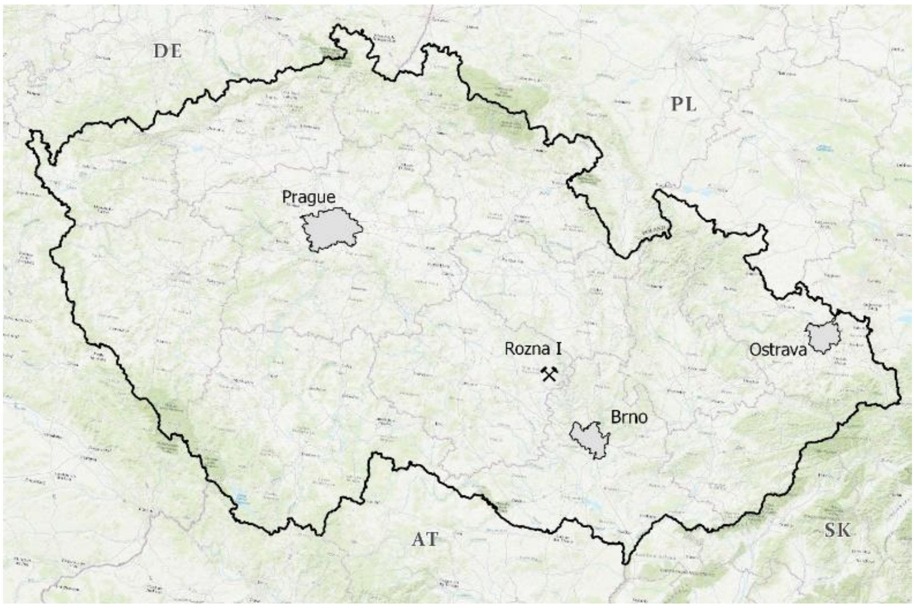

Fig. 1. Location of Rožná I mine in the Czech Republic

Geology of the Rožná deposit

The Rožná deposit makes part of the Bohemian-Moravian Highlands. These represent remains of Variscan chain denudation levelled off by long-term evolution all the way to the worn-down plain, which was revived in the Miocene by young tectonics due to Western Carpathians being over-trusted onto the eastern slopes of the Bohemian Massif (Kribek & Hajek, 2008). The deposit lies at an altitude of 460 to 560 m a.s.l. (Grmela, 2012). There is a rolling surface above the deposit; it is partially afforested and partly farmed (agricultural land and pastures). The surface deposits are made of 0.2 to 1.0 m thick layers of soil (top soil, forest soil and meadow soil), alluvial soil and slope loam 1.0 to 1.5 m thick, with loess loam on the eastern slopes. Next, 3 to 5 m below the surface, there is residual soil – sandy-clayey loam with fragments of weathered rocks.

The Rožná deposit is found in the complex of metamorphic, sedimentary-effusive rocks of the MesoProterozoic Era, which was complicated by fault tectonics in the more recent tectonic periods (Kribek & Hajek, 2005). The complex of the surrounding rocks in the Rožná deposit includes a varied group of the Moldanubian Zone with plagioclase-biotitic to amphibolitic paragneisses of varying degrees of migmatization with amphiboles. To a smaller extent, there are marbles, lime silicate rocks and mica schist, small particles of serpentinite and pyroxene (Kribek & Hajek, 2008).

The Rožná deposit has several hollow impoundments bound onto the Quaternary cover, the erosion zone and near-surface aquifers (Ricka et al., 2010). The most intense circulation of groundwater occurs on the boundary of the eluvium, i.e. in the fractured bedrock rocks. The groundwater level is phreatic or slightly confined.

Current conditions in Rožná I mine in Dolní Rožínka

Since 27 April 2017, when uranium ore extraction was terminated, Rožná I mine has been used for activities of non-mining character. The state enterprise Radioactive Waste Repository Authority decided to use the cavities in Rožná I mine to run a generic underground research laboratory for radioactive waste repository research. The research lab was established on the 12th level. The underground space is maintained as operable, while unused space and structures are gradually disposed of and closed. The major workings openings will be backfilled with unconsolidated backfill before complete mine flooding. Currently, only partial closure works of unused workings are underway; surface infrastructure of these workings are disposed of or closing sinking platforms are built (e.g. in shafts R2, R4 see Table 1).

Tab. 1. Parameters of major mine workings openings in Rožná deposit

Mine working	Section m^2	Clearance m^2	Support type	Depth m	Closure state
R1	10.95	6.83	wood	667.87	in operation
R2	10.95	6.83	wood	541.70	sinking platform (2018)
R3	20.43	14.52	concrete	1 200.40	not in operation
R4	10.95	6.83	wood	313.00	sinking platform (2011)
R5	13.20	9.62	wood	317.30	backfill (1992)
R6	25.52	20.36	concrete	784.20	in operation
B1	10.95	6.83	wood	651.20	in operation
B2	20.43	15.90	concrete	541.80	in operation
Š11	7.68	4.56	wood	134.46	total closure (2020)
Š13	6.68	4.36	wood	59.60	opening protection (1983)
Š37	7.06	4.27	wood	351.10	partial closure (2001)
VK-4/0-1	7.95	7.95	none	200.30	total closure (2023)
VKS 7/0	13.20	9.62	concrete	305.50	in operation

At present, only 4 shafts and 1 ventilation tunnels (marked VK) are maintained in operation as for the major workings openings in the Rožná deposit - see Tab. 1.

Proposal of major mine workings abandonment

The closure of mine workings openings is understood as backfilling the pit shaft with the certified type of backfill and follow-up surface protection of its mouth. The stability of the pit shaft is important as it directly affects the surroundings of the mine workings. The backfill may also be used in combination with binders – consolidated backfill, or without binders – unconsolidated backfill. According to Aldorf & Hrubesova (2011), the reliability of unconsolidated backfill use may be defined as below:

1. Checking the mine workings stability before closure for:
   - disruption and deformation of shaft supports and their susceptibility to falls,
   - structural stability of unsupported shafts,
   - stability of shaft mouth,
   - shaft inundation and need to backfill into an inundated shaft,

2. Minimising the subsidence (compression) of backfill by well considering the following:
   - the backfill properties (compactness, grain-size, compressibility, etc.),
   - the backfill technology (backfill material quantity, its transport into the shaft, etc.),
   - the method of mine workings preparation for backfill (disassembly of equipment in the shaft),
   - the hydrogeological conditions in the mine workings during and after closure (dewatering, inundation),
   - the method to dispose of the levels, shaft stations and other contacts with the shaft (reinforcing dams, disassembly of equipment in the shaft stations),
   - the quality control method for mine workings backfilling,
3. Ensuring the stability of mine workings concerns:
   - the construction of the closing sinking platform,
   - the stability of closing the sinking platform,
   - the disposal method of shaft channels, drill holes and other workings below the shaft mouth,
   - the calculation of load-bearing capacity,
   - determination of the size and shape of the safety zone and space around the shaft,
   - potential implementation of a shaft plug,
4. Readiness to take measures leading to fast elimination of increased backfill subsidence includes:
   - monitoring of backfill subsidence,
   - implementation of checkpoints (control apertures, piping, etc.).

All the factors mentioned above determine the reliability of mine closure both in the stage of its design as well as during its implementation. Compliance with the project documentation must be checked and supervised.

Preparatory work underground before mine abandonment

Mining activities have direct environmental impacts, but they should be minimised. When abandoning a mine, it is not possible to re-establish the original conditions, but environmental or economic risks may be reduced. As for the ecological factors, all materials and equipment with negative environmental impacts should be removed, such as all explosives, lubricants, oils, fuels or other oil products used during mine operation. Considering the economic aspects of mining phase-out, re-using the technology and equipment in other workplaces or selling these is possible.

A mine-technology aspect of development work is the risk minimisation of backfilling the vertical workings openings (NCB, 1982). This concerns the disassembly and removal of steel constructions in the shaft stations that could prevent or complicate filling the shaft stations with unconsolidated backfill. Before abandoning the levels, it is convenient to dismantle bottom frames, i.e. barriers and shaft compartment doors, cover drill holes with sheet metal, and dismantle easily removable parts of tiltable bridges, i.e. fallers and caging devices. It is recommended to use the dismantled constructions and equipment to fill the reinforcing dam on the given level.

According to Aldorf & Hrubesova (2011), disassembly work in vertical mine workings is carried out based on safety assessment. Removing these parts of shaft lining that could prevent or jeopardise the introduction of backfill, particularly wooden landings, is vital. It is possible to leave wooden shaft guides, piping, cables or ducts in the shaft.

An important element in shaft backfilling are reinforcing dams (Aldorf & Hrubesova, 2011; NCB, 1982). Reinforcing dams are steel constructions built to prevent the movement of unconsolidated backfill in the horizontal mine workings. Movement occurs due to the horizontal stress caused by the backfill column in the pit shaft. In case of backfill movement along the horizontal workings, backfill may travel several tens of metres, and the backfill stabilisation would become intense in cost and time. Ideal places to build reinforcing dams are at the sites where:

- profiles of mine workings are changing – i.e. the transition to a smaller profile, change in shape,
- the direction of the mine workings is changing,
- the construction of the lining allows its incorporation into the reinforcing dam.

The construction of reinforcing dams has the character of a welded steel cage construction (Grygarek, 2002). The advantage of the construction is the re-use of the materials found in the abandoned levels. The dam front's roof, floor and walls are fitted with two steel profiles I 240, anchored into the rock using bolts and shackles placed each metre on the profile I 240. The frame from the profiles is welded at all contacts, and an I 240 profile cross is welded in. Next, K 93 rails are welded to make a cage-like steel construction as long as 5 m to support the dam front. The dam is closed by a back frame from I 240 profiles. The dam body is filled with available metal material of a maximum size of 1 m or with stone. Finally, a grid with a step of 0.25 m made of K 93 rails is welded onto the dam front – see Fig. 2.

Fig. 2. Welded steel construction of a reinforcing dam on the 5th level of B1 shaft (photo by Vokurka, 2018)

Backfilling the mine workings with unconsolidated rock material

To close the uranium mine Rožná I, we will use the mine waste generated in connection with the long-term mining activities and was dumped on the Rožná I waste tip. To re-use the material, it is important to comply with legal requirements for safety and environmental protection (Bukowski & Niedbalska, 2013). Unconsolidated backfill from Rožná I waste tip to backfill the major mine workings of Rožná I mine must comply with Act 22 (1997), Government Regulation 163 (2002) and also Act 263 (2016) as it is waste from uranium ore extraction. Apart from these decrees, the backfill must meet both Czech and European standards.

The mine waste from Rožná I tip was assessed as inflammable, insoluble, unslacking and non-expansive. It does not have negative environmental impacts and does not comprise metal objects (TZÚS, 2005a; TZÚS, 2005b). This is because predominantly fine-grained to medium-coarse biotitic paragneiss, locally migmatised, and amphibolites were dumped on the tip. Only a small proportion is made up of crushed rocks from the vein filling and clay. The lumpiness of the dumped materials was assessed as favourable for mine backfill – see Tab. 2.

Tab. 2. Lumpiness of the dumped material on the Rožná I mine waste tip

Grain-size mm	Percentage %
> 250	1 – 2
150 – 250	5 – 10
30 – 150	45
< 30	40 – 45
clay	3

The small number of fractions over 250 mm will help to comply with Decree 52 (1997), according to which the backfill grain size must fit the mesh size of 250 x 250 mm. A backfill grain size below 30 mm is suitable to fill gaps between larger fractions. The percentage of clay is negligible.

Considering the average bulk density of mother rock of 2 700 kg.m^{-3}, the weight of 1 m^3 of backfill in this grain size distribution was determined as 2 000 kg with a coefficient of transient bulk increase of 1.35. After its compaction caused by the fall into the vertical mine workings, the transient bulking changes into permanent bulking of 1.2. The weight of 1 m^3 of backfill is thus 2 250 kg. As a result of the gradual inundation of the deposit, grains will erode into vacant gaps, and the weight of 1 m3 of backfill will increase to 2 300 kg.

Most importantly, the backfill material must be stable for the given conditions. Therefore, it is vital to consider its compressibility. In this case, the mine waste compressibility was determined in the laboratory using an oedometer test (CSN 17892-5, 2017). The mean compressibility was 15 %.

There is the so-called natural angle of discharge for loose aggregates, in which the slope of loose discharged rocks forms with the horizontal plane. The size of the natural angle of discharge depends on the shape and character of grains, their moisture content, bulk density, grain-size distribution and other factors. For the backfill from Rožná I waste tip, the natural angle of discharge is almost identical to the angle of internal friction. The angle differs whether backfilling is implemented in dry or inundated shafts. In the case of a dry shaft, the angle of internal friction is 35°; in backfilling an inundated shaft, it is 25° (Aldorf & Hrubesova, 2011).

The process of backfilling the major mine workings openings must comply with all safety conditions stipulated in Decree 52 (1997). Prior to backfilling, all preparatory work must be completed, i.e. landings must be prepared. Mine workings with headframes, pit-head building and near-surface infrastructure should be modified to facilitate trucks' passage to the filling station of the shaft. In other cases, when the surface infrastructure was removed, the preparatory work lies in ground shaping, i.e. building an access road for trucks – see Fig. 3.

Fig. 3. Example of cyclic backfill of the exploration pit Š11 (photo by Vokurka, 2020)

In the implementation of backfilling, the pit head must be fitted with a grid of 250 x 250 mm mesh size and a feeding hopper to direct the backfill – see Fig. 3b. The pit head should also be fitted with a stop to prevent the trucks from falling into the shaft profile. The backfill can continuously be transported into the mine workings using a belt or drag conveyors or cyclically dumped from trucks' bodies or loaders – see Figure 3a.

To ensure the required stability of backfilled mine workings, it is recommended to use a backfill grain size below 250 mm. The contact of the pit shaft and the levels should be filled with sorted aggregate lumps of 63 – 125 mm (Aldorf & Hrubesova, 2011). The mine waste from the Rožná I waste tip (as of 1 January 2019, there were 508 760 m3 of mine waste) can also be used as backfill. To obtain the required fraction of 63 – 125 mm, a mobile screen can be used. Another option is to use sharp penning of a maximum size of 250 mm from a contractor (Salmon et al., 2015). At the contacts of the pit shaft and levels, the backfill material will fill the stations, and using sorted aggregates, even backfill distribution will be achieved.

In the course of backfilling 50 m of the mine workings, checks should be carried out for the approved technology. In case of a difference in the measured backfill quantity over 20 % of the calculated value, the backfilling work should be interrupted, and further procedures should be determined.

An illustration of the usability of checks may be the closure of exploration pit Š11 in 2020. Backfilling was terminated as soon as only one-third of the mine workings were backfilled because the pit-shaft lining collapsed. It was an old mine working, terminated in 1985, and thus an intervention of mine rescue service was planned along. The rescue team examined the exploration pit before the backfill and discovered an obstacle in the upper half. Backfill was carried out, knowing the exploration pit will never be filled completely.

Proportioning the backfill quantity for mine workings openings

Before closure, a technical closure plan must be prepared according to Decree 104 (1988). This plan must be made based on all available information and parameters of the major mine workings openings. Finally, the plan must be approved by the mine manager. The technical closure plan details the given major mine workings openings and includes a calculation of the theoretical backfill volume.

In each mine workings, the situation is specific in dependence on the mining-geological conditions (Hustrulid & Bullock, 2001; Lecomte & Niharra, 2013). In all the cases, though, the following parameters are considered:

- field length,
- workings clearance,
- current conditions of the mine workings lining,
- number and total volume of stations,
- backfill compressibility.

Based on the input parameters, we calculate the backfill quantity for the major mine workings openings (Vokurka, 2018) and decide the technology for the given closure. Overall, 55 106 m^3 of backfill will be required – see Tab. 3.

Tab. 3. Required backfill quantities (Vokurka, 2019)

Mine workings	Section m^2	Clearance m^2	Depth m	Contacts	Station m^3	Pit shaft m^3	Extra backfill m^3	Total backfill m^3
R1	10.95	6.83	667.87	14	3 981	3 683	383	8 047
R2	10.95	6.83	541.70	9	2 559	2 988	277	5 824
R3*	20.43	14.52	1 200.40	20	-	-	-	-
R4	10.95	6.83	313.00	5	1 280	1 726	150	3 156
R6	25.52	20.36	784.20	9	2 559	13 571	807	16 937
B1	10.95	6.83	651.20	9	2 559	3 592	308	6 459
B2	20.43	15.90	541.80	2	368	7 323	385	8 076
Š13	6.68	4.36	59.60	1	207	216	21	444
Š37**	7.06	4.27	351.10	3	414	1 126	77	1 617
VK-4/0-1	7.95	7.95	200.30	1	142	1 327	74	1 543
VKS 7/0	13.20	9.62	305.50	1	362	2 498	143	3 003
In total				77	14 431	38 050	2 625	55 106

* R3 shaft will be closed with a plug only to serve as a water shaft of the Rožná deposit
** in 2001, only partial closure was implemented; the quantity is given for extra backfill

Mine working surface measures

The aim of surface measures is to reduce or eliminate the risks related to the mine workings subsidence and, thus, environmental hazards (Wojtkowiak & Didier, 1999). As soon as the mine workings are backfilled with unconsolidated rock material, the mouth of the mine workings must be ensured in line with Decree 52 (1997) using a closing sinking platform. Its minimum dimensions may be determined according to equation (1) for shafts backfilled with unconsolidated material. Equation (2) may be used for shafts with wooden or concrete supports, where the concrete shaft mouth collar does not bear upon the solid rocks with all its area.

$$D_{min\_1} = 1,5 \cdot (d + 2 \cdot t) \quad [m]. \tag{1}$$

where *d* is the top clear dimension of the mine working *[m]*,
t is the thickness of the shaft walling *[m]*.

$$D_{min\_2} \geq 1,5 \cdot (d + 2 \cdot p) \quad [m]. \tag{2}$$

where *d* is the top driven dimension of the mine workings *[m]*,
p is the zone of possible rock failure, which falls along the circumference of the mine working when supports collapse *[m]*.

The construction should be designed for a uniformly distributed load of at least 33 $kN.m^{-2}$. In dependence on the used unconsolidated backfill in the mine workings, the sinking platform should be sized with respect to additional unexpected load due to suction forces of 80 $kN.m^{-2}$.

The closing sinking platform should be built at the mine working shaft mouth as a reinforced concrete square platform made of C30/37 concrete and reinforced with continuous bidirectional concrete reinforcement Ø 22, B500A. This reinforced concrete square platform should be placed on the hard floor or possibly a foundation belt made of C30/37 concrete. The dimensions of the foundation belt should be at least 1.0 x 1.0 m, and it should be anchored into the solid rock mass in the bedrock using micropilots – see Fig. 4.

Fig. 4. Micropilots in a foundation belt of R2 shaft in the former Rožná II mine (photo by Vokurka, 2018)

The proposed micropilots of minimum Ø 156 - 200 mm are made from reinforced tubes of minimum Ø 102/10 mm and an expected length of 9.5 m. The length of micropilots depends on the local geological conditions (Zeng & Xiao, 2020). Micropilots ensure the long-term stability of the closing sinking platform. The length of the micropilots pitched into the solid rock mass must be at least 1.5 m. The suitable cementation is a mixture of cement:water = 2.5:1 at the estimated consumption of 20 - 30 l of the mixture per 0.5 m of the injection.

The micropilots are joined to the foundation belt by leading the reinforcing micropilot tubes into the lower part of the foundation belt. Next, via welding steel plates of 0.2 x 0.2 m, a thickness of 20 mm, a foundation for the steel construction of the sinking platform is made. It is advisable to leave a lockable aperture of minimum dimensions of 0.6 x 0.6 m in the closing sinking platform to be able to check the inundation of the shaft and possible extra backfilling.

Fig. 5. Closing sinking platform of R2 shaft in the former Rožná II mine (photo by Vokurka, 2020)

Important protection for closed mine workings openings are safety zones and safety areas. According to Decree 52 (1997), the safety zone is the vicinity of the closed mine workings on the surface endangered by ground and rock movements in case of possible spontaneous destruction of the mine workings under closure. Its minimum dimensions are determined in dependence on the closure method and considering the mining-geological, hydrogeological and geotechnical conditions in its vicinity. Before amendment 237 (2015), it was determined that the smallest dimensions must exceed the outer perimeter of the shaft by at least 20 m. Equation (3) used to be applied to determine the dimensions in practice. According to Decree 52 (1997), the safety area is the immediate surroundings of the mine workings shaft mouth, in which the discharged mine air may endanger human life or health. Each mine workings under closure must have a determined safety zone and be marked in the relevant maps. In the Rožná deposit, there is no mine with harmful gas leaks or coal dust explosion hazards; thus, the safety zone is identical to the safety area.

$$R_{min} \geq d/2 + t + 20 \quad [m]. \tag{3}$$

where d is the largest cross-section of the mine workings opening on the surface $[m]$,
t is the shaft walling thickness $[m]$.

The immediate protection of the closed mine workings openings is a fence along the closing sinking platform perimeter. It is advised to build the fence using fence posts of Ø 51/4 mm combined with reinforced corner and gate posts of Ø 89/5 mm. All the posts should be fitted into the concrete platform of 0.9 m, and protect the posts with welded lids from rainwater. The corner and gate posts should be stabilised by diagonal members of Ø 51/4 mm. Zinc-coated fencing of Ø 4 mm should be drawn between the posts using three anchoring wires. In sites with the potential passage of people, it is advisable to increase the posts and stretch barbed wire. The 2.4-metre-high fence should be equipped with warnings "No Entry – Undermined Area". The closing sinking platform should be marked permanently by a concrete monument where the parameters of the closed mine workings are stated – see Fig. 5.

Safety risks of poor mine abandonment

The mine closure and own backfilling of mine workings using unconsolidated material need not always be a sufficient solution to prevent further undesirable deformations of the rock massif (Aldorf & Hrubesova, 2011; Aldorf, 2007; Didier et al., 2008). It always depends on the tectonic situations in the vicinity of the shaft of the mine working, which may not always show up in the previous survey, or the survey is economically unbearable. In order to eliminate possible deformation of the surroundings of the mine working, the application of micropilot strips anchored to a solid rock massif has been verified to increase the provision of long-term stability (Zeng & Xiao, 2020).

Backfilling can never restore the original properties of the rock massif in the surroundings of the mine workings. In case of post-mining changes in the rock properties and undesirable phenomena after mine closure, it is important to take extra measures during backfilling of the mine workings.

A possible hazard occurring in connection with incorrect closure is the post-mining disruption of groundwater regimes (Wojtkowiak et al., 2000). For this reason, the mine closure method (e.g. use of consolidated backfill) must always be selected based on the knowledge of natural and technical conditions. Possible groundwater contamination could jeopardise human health and lives.

Another risk in connection with incorrect closure is gas leaks on the surface (Skubacz et al., 2019) or into nearby sewers or structures due to the disruption of the overlaying strata of the given deposit. In such a case, knowing whether the gas contains hazardous components is important.

The conclusions drawn in the work (Bajerova, 2016) imply that the radon content in the surroundings of Rožná I does not pose risks to citizens post-closure. The equivalent radon volume activity is likely to increase in the municipalities of Bukov and Rodkov as a result of natural radon airing from underground. In other municipalities of the interest locality, the radon values should decrease.

Conclusions

Uranium ore was extracted in Rožná I mine for almost 60 years and was terminated in 2017. The termination of mining in the given locality is conditioned by the correct and reliable closure of the mine workings and their openings. Closure work must be implemented based on a previously approved plan to ensure a safe methodology during implementation.

The paper describes the closure of ten major mine workings openings using unconsolidated backfill, for which 55 106 m^2 of backfill of a fraction below 250 mm from the Rožná I mine waste tip will be needed. At the contacts of the shaft and levels, sorted aggregates of 63 – 125 mm will be used. Preparatory work underground prior to mine abandonment will ensure backfill reliability and stability of the backfilled pit shaft. A closing sinking platform will be built at the shaft mouth, which will be anchored into the rock massif using micropilots. This way, construction is built to eliminate the formation of subsidence in the surroundings and ensures long-term stability and safety of the closed mine workings.

With the use of four haulage trucks for backfilling and their five transport cycles per shift, the total backfilling time of 10 main mine workings can be assumed to be approximately 11 years. The total time, including the construction of the closing sinking platform, will be approximately 13 years.

The mine closure in the Czech Republic is realised in accordance with valid regulations and is, in most cases, sufficient. However, to ensure long-term stability, it is appropriate to supplement the liquidation work with other safety elements such as micropiles, using aggregate fraction 63-125 mm on all floors, constructing dams wherever possible, etc.

The proposed method for closure works in the locality will be used as background for closure technology. The implementation of the method will be analysed and tested for its functionality. The stated method may be applied in mines of an analogous character, both in the Czech Republic and abroad.

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