2020

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Radovan Kukutsch
Czech Academy of Sciences

Petr Waclawik
Czech Academy of Sciences

Jan Nemcik
University of Wollongong

Libin Gong
University of Wollongong

SAFETY ASPECTS OF DISPOSAL OF A MINE AND ABANDONED UNDERGROUND WORKINGS AND RISKS RESULTING FROM THE MINE DISPOSAL

Radovan Kukutsch[1], Petr Waclawik[2], Jan Nemcik[3], Libin Gong[4]

ABSTRACT: Since time immemorial, mining has been an inseparable part of human history. Generations of our ancestors drove and excavated mining workings to enable them find and exploit useful minerals from the ground. Shafts, drifts and corridors created in this way, however, had always limited service life; their significance and purpose mostly expired as soon as the available reserves in the deposit were exhausted. Unused workings were then often abandoned without having been disposed and safeguarded properly. For mining companies, namely, these activities represented and still represent spending of substantial financial resources with zero economic effect. This always relied exclusively on the contemporary state of mining legislation at the given place and time as well as executive ability to check and enforce pertinent provisions of the mining law concerning disposal of mining workings. Nevertheless, existence of an insufficiently disposed or unsecured working represents a considerable safety risk for the surroundings, whereas this paper includes reasons for disposal and requirements for proper disposal of the mine.

INTRODUCTION

Decommissioning and disposal of an underground mine is an integral part of the mining capacity implementation cycle, irrespective of the kind of the mineral resource and deposit location (Makarius 1999).

It is caused by natural and technological factors (depletion of usable deposits, technology of mining and treatment of the mineral resource), commercial (loss of strategic characteristic of raw materials) or economic factors related to insufficient level of the production sales or its prices, which does not enable creation of sufficient financial flows to finance the mining entity's business activities.

Technical disposal of permanently terminated operation in mining workings represents a set of works and necessary precautions which must provide for elimination of potential risks for the future in which the underground will not be accessible (Hudeček et al. 2007).

1 Dr/Researcher, The Czech Academy of Sciences, Institute of Geonics. kukutsch@ugn.cas.cz +420 596979242
2 Dr/Researcher, The Czech Academy of Sciences, Institute of Geonics. waclawik@ugn.cas.cz +420 596979701
3 Dr/Honorary Senior Fellow, University of Wollongong. jnemcik@uow.edu.au +61 2 4221 44920
4 Ph.D. Graduate, University of Wollongong. lg283@uowmail.edu.au +61 424387896

Technical disposal of an underground mine after completion of early development, preparatory works and mining involves:

- technical disposal of the mine underground;
- technical disposal or safeguarding of the surface (removal of machinery and equipment, disposal of building objects, operating units) if the surface objects are not to be used for other purposes;
- elimination of consequences of mining activities with regard to restoration of the area for other utilisation, including removal of mining damage, redevelopment and reclamation of plots affected by extraction.

SAFETY ASPECTS OF DISPOSAL OF THE MAIN MINING WORKINGS, MINE AND ABANDONED UNDERGROUND

Potential risks during disposal of main mining workings include (Hudeček et al. 2007):

- impaired stability of the working opening (subsidence of the working opening and its incoherent surroundings into the shaft as a result of the backfill material slide or break of the bulkhead);
- sudden surface subsidence (caused by caving of the drift, for instance)
- ascent of mine gases to the surface (with possible accumulation of gases in objects, with subsequent explosion, inflammation or poisoning).

Impaired underground stability of abandoned workings

Insufficiently disposed underground workings: Impaired stability of the shaft opening means slide of the shaft opening and its incoherent surroundings into free spaces in the shaft or adjacent corridors as a result of insufficient disposal of the shaft in the past. The highest imminent risk includes cases of objects built directly above the shaft or in its immediate vicinity. In practice, several types of insufficiently disposed shafts can be found.

- The shaft is only closed by means of a closing pit bank bulkhead. The stability is impaired by breakthrough of the bulkhead (caused by aging of the material used or exceeding of its bearing capacity) or collapse of incoherent rocks into free spaces.
- In some cases, particularly of very old shafts, only the upper part of the shaft was backfilled to the created bulkhead, mostly wooden, which collapsed with subsequent slide of the backfilling material and breakdown of the shaft opening and its incoherent surroundings.
- Another cause of impaired stability of the shaft is slide of unconsolidated backfilling material into unfilled corridors mouthed into the shaft, as a result of insufficient strength or total absence of closing dams at the shaft entrances.

- One of the possibilities of impaired stability of the shaft is slide of backfilling material into free space in the shaft, which developed at the filling time owing to insufficient fragmentation of the material which fills up the free spaces only partly or creates an arch in the shaft.

- Another possible cause of the backfilling material slide and thus the impaired shaft stability is insufficient removal of the shaft accessories and filling of ducts and ventilation pipes.

- Non-observance of specified precautions and procedures during monitoring of the backfill state and its refilling during disposal of main mining workings is another of the possible risks.

- Non-observance of technological procedures during production of consolidated cement-ash mixture and concrete for the pit bank plug, or consolidated plug in the pit shaft can also add certain risks of impaired stability of the main mining workings disposed.

- Backfilling materials of certain types can also slide if the backfilling material is flooded with water, its properties totally change, and it subsequently pours out into the free spaces. Such cases occur, for instances, after heavy rains or partial flooding of the shaft with mine waters.

Water effect on the backfilling material stability: Impaired stability of unconsolidated backfilling material in the shaft may also be caused by water if any of the following cases occurs (Slivka et al. 2007):

- creation of a water column above the impermeable plug in the shaft;

- watering or hydraulisation of the backfilling material above the impermeable plug;

- flooding of mining spaces including the backfill in the shaft.

Water column above impermeable plug in the shaft

During disposal, a column of water flowing in the shaft may form, either by creation of a watertight plug in the shaft or by filling the shaft with impermeable material. In this case, the water column acts on the backfilling material in the shaft with hydrostatic pressure corresponding to the water column height. This pressure may rise so that the shaft plug cannot resist this pressure or the backfilling material is pushed by the water column out into the free mining spaces.

Watering of the backfilling material above the watertight plug

The shaft is filled up with unconsolidated backfilling material, whereas a watertight plug is created at a certain depth or this plug is created in the backfilling material by sedimentation of its small fraction, in which way the backfill becomes impermeable. The backfilling material above the plug is saturated by the inflowing water. This material, however, is of such a kind as not to behave as a hydraulic liquid (such as dump material) after watering. In this case, pressure is created equal to the sum total of the backfilling material pressure and water pressure.

Hydraulization of the backfilling material above the watertight plug

In the shaft, the same case occurs as with the above-mentioned watering of the backfilling material; in contrast, the shaft is filled up with a material behaving like a hydraulic liquid after being flooded with water. Only materials composed primarily of silts and fine sands (0.002–0.2 mm), which are able to be hydraulised, can behave in this way.

Flooding of mine spaces including the shaft backfill

The shaft is filled up with unconsolidated backfilling material; subsequently, *the mine spaces including the shaft are flooded*, partly or up to the surface. In this case, it depends on the type of the backfilling material whether it can or cannot be washed out or even hydraulised.

In the flooded shaft with *water-saturated backfill material*, pressures caused by the water in the shaft and surrounding free spaces equalize and only pressures induced by the backfill material are acting.

If the backfill material in the shaft behaves like a *hydraulic liquid,* this material induces pressure which is approximately twice as high as the pressure induced by water in the surrounding flooded free spaces. Consequently, the backfilling material may slide into these spaces.

Effect of water on the backfilling material stability in the shaft can be expressed by the degree of risk of the backfilling material slide.

Degree of risk of the backfilling material slide caused by flooding

1) *shafts unaffected by flooding of the backfilling material*

2) shafts with a negligible risk (consolidated backfilling material; flooding in a short shaft length only; flooding only in the case of the full retention tank; unconsolidated backfilling material, but smaller flooding depth and closing dams at the levels).

3) shafts endangered by slide of the backfilling material (unconsolidated backfilling material and higher flooded depth with closing dams at the levels; without any objects in the safety zone (hereinafter SZ); disposal without dams, but with a concrete plug under the pit bank).

4) shafts dangerous for slide of the backfilling material caused by flooding (unconsolidated backfilling material, higher flooded depth, without closing dams at the levels and with objects in SZ).

Surface subsidence spots

Another risk and harmful effect of abandoned underground workings is creation of *surface subsidence* caused by caving of old drifts, air-raid shelters or by subsequent settlement of seam stopes at low depth under the surface, particularly of worked-out areas of seams in steep dips. This is a particular risk of shallow-positioned deposits with seeping surface water, which can cause waterlogging of the ground and influence conditions of surface objects. Here one must try to dispose of them by means of adequate additional backfilling. Subsidence places may form on the surface as a result of the sudden surface descend, which can both endanger the safety on the surface and cause loss of stability at the shaft opening.

Dimensions and design of the safety area of the main mining working, drift and inclined shaft is determined by calculation according to the specified methodology (Makarius 2000).

Ascent of mine gases to the surface

After termination of mining activities and disposal of the mine, mine gases, primarily methane, continue escaping from the carboniferous massif. One speaks of the so-called *residual gas-bearing capacity.* Ascent of mine gases to the surface is influenced by a variety of natural, atmospheric and mining-engineering factors. After termination of controlled ventilation of the mine, the mine gases may uncontrollably ascend to the surface by natural and artificial communications. Various exceptional events give evidence of this fact (Žůrek et al. 2012).

The source of an exceptional event is methane accumulated at explosive concentration in the mining workings disposed. A ventilation plant must be in permanent operation in the spaces.

In term of the extent of the area affected by ascent of mine gases to the surface, the following is distinguished:

- **point ascent** (that is, ascent though abandoned underground parts opened to the surface);
- **areal ascent** (that is, ascent from worked-out areas of seams at places of gas-permeable covering formation or through tectonic zones).

During disposal of main mining workings opened to the surface, ascent of mine gases is one of the risk factors, see Fig 1.

Figure 1: Gas explosion at Hermanice Mine during the liquidation of the He-III shaft

Artificial communication with the surface

Artificial communications cause the so-called point ascent of mine gases to the surface, which is caused by:

- *Mining and underground workings* (shafts and drifts opened to the surface);

- *Geological workings* (older surface test holes of larger diameters).

In connection with every mine disposal, risks related to the ascent of mine gases must already be assessed within processing of project documentation; to prevent them, technical and safety measures must be specified in a plan, particularly on the basis of:

- evaluation of gas-bearing capacity of the mine at the time of its exploitation, prognosis of residual gas-bearing capacity;

- determination of the ventilation system, or degassing in the disposal process;

- design of the monitoring system.

Issues of interconnection with adjacent mines

- work at the boundary of the mining area;

- possible impacts of the disposal on the adjacent mining area;

- changes of ventilation in connection with disposal of some of the interconnected mining areas;

- changes of water pumping in connection with disposal of some of the interconnected mining areas;

- transfer of resources.

Principles of treatment of worked-out underground and stopes of the disposed mine

Disposal of the mine by backfilling its underground spaces is aimed at both long-term safeguarding of the actual mine underground and minimization of impacts of mining activities on the surface as well as, naturally, economic feasibility of the works and environmental friendliness of the entire process of disposal. The basic safety condition of the mine disposal by backfilling is filling up of free spaces of the mine from the deepest level to the surface and from the mining area boundary to the shafts.

The decision on the method and extent of the disposal of the mine or its parts is significantly influenced by these criteria:

- Minimization of subsidence risks and effects on the surface after completion of the mine disposal

- Elimination of potential water migration in the mining area affected by mining after completion of the mine disposal
- Minimization of potential accumulation of mine gases and its effect on the surface after completion of the mine disposal
- Maximum utilization of the available underground yardage (filling coefficient) of the disposed mine
- Maximum utilization of the existing technological equipment of the disposed mine
- Final utilization of the treated territory of the mining area of the disposed mine

Inventory of mining workings to the extent of the mining area of the mine shall delimit mining spaces for implementation of the method of their disposal within the mine disposal. The inventory shall include all accessible and maintained mining workings. Of the closed mining workings, the inventory shall include temporarily closed mining workings, or other workings the disposal of which can be justified by safety or other requirements.

MINIMIZATION OF RISKS OF SUBSIDENCE AND EFFECTS ON THE SURFACE AFTER COMPLETION OF THE MINE DISPOSAL

One of the most significant factors of the decision on the method and extent of disposal of the mine or its part is the task to ensure minimization of subsidence and slumping risks and other effects resulting from free underground spaces after completion of mining activities. In particular, this is an essential requirement on execution of disposal works in densely populated and built-up mining areas. Therefore, the mine disposal documentation must include a detailed description of possible effects on surface objects in terms of undermining, anticipated course of subsidence, slumping as well as possible dynamic effects with regard to underground vibrations after backfilling in seismic mines or mines with mining methods creating large free spaces (long-wall mining in massive seams with firm top, by chamber working).

Identification of risk localities with regard to stability of accompanying rocks, which represent the abandoned underground mining spaces located near the surface and mining workings opened to the surface (in particular, abandoned and old mining workings) is executed by evaluation of map sources of mining-survey documentation.

With regard to the disposal works – disposal of workings from bottom to top – it must be stated whether the risks also impend during the disposal works and how they are to be eliminated.

Elimination of potential water migration in the mining area affected by mining after completion of the mine disposal

Filling of all free underground spaces with suitable backfilling eliminates the possibility of water migration in the area of the disposed mine. In the mining practice, numerous cases have been recorded when flooding of a mine resulted in outflow of contaminated mine waters with subsequent menace to surface waters (Oslavany, Rtyně in Podkrkonoší). Therefore, the mine disposal documentation must include a thorough analysis of the underground water state including its quantity, stability of inflow and chemical status, predicted development and changes, particularly in the chemical status of this water, outflows after prospective flooding of the mine and necessary investments in their cleaning. For mines operated on a long-term basis, it is also necessary to indicate effects of old mining activities in terms of anticipated contamination and outflow of waste waters.

Description of these risks may play a significant role in the phase of deciding on the method of the mine disposal and support of the selected method of disposal by its backfilling, particularly on the part of professional bodies.

Minimization of possible accumulation of mine gases and its effect on the surface after completion of the mine disposal

As mentioned above, after completion of mining activities and artificial ventilation, underground and gaseous mines pose a considerable risk of ascent of explosive mine gases. Again, this must be described in detail in the mine disposal documentation, including the anticipated communication ways, possible amount and concentration of gases as well as the risk of their impossible estimate.

It is also necessary to indicate the time estimate and development of gas ascent, including the risk of accumulation in the flooded underground.

In the built-up area of the disposed mine, this fact may again play a significant role in the phase of decision on the method of disposal and support to the underground disposal by its backfilling. If the mine is to be disposed by backfilling of its free spaces with artificial ventilation for the entire time of disposal works, the risk must be analysed even though it is minimized in this way.

Maximum utilization of the available underground yardage (filling coefficient) of the disposed mine

To fulfil the above-mentioned requirements on this method of disposal during disposal of the mine by backfilling of its underground spaces, it is necessary to achieve the highest possible infilling of the available free yardage, whereas the backfilling properties must ensure that, after decantation of water, its volume does not reduce significantly, it has minimum compressibility, yet maximum elasticity, and, in particular, it can be transported even to the farthermost places and least accessible spaces of the mine. For this, it is necessary to choose both backfilling of a suitable type as well as transport technology in the mine and method of backfilling. In the ideal state, the achieved infilling coefficient of free spaces of the disposed mine would be equal to one.

To carry out a check of infilling, it is first necessary to calculate the free underground yardage as precisely as possible in the documentation so that the check can be carried out simultaneously with the process of the mine disposal. This calculation must also consider backfilling of free top excavations and drifts (in particular, by means of blasting operations, with workings through which gob and disturbed rocks passed) as well as unfilled stopes.

Thus the documentation for the mine disposal by backfilling must contain not only calculation of free spaces by parts, levels and the entire mine, but also calculation of the infilling coefficient of the disposed workings and parts of the mine on the basis of the determined transport technology, backfilling method and procedure and the proposed types of backfilling. The calculation of anticipated yardages is based on mine maps on the scale of 1:1000 and determination of the yardage coefficient, considering the time factor and type of working, properties of accompanying rocks and influence of surrounding mining activities (by action of mining pressures). Its value is determined by expert estimate in the range of 0.25- 0.8. At the same time, control mechanisms must be specified to monitor the real state of infilling.

Final utilization of the treated territory of the mining area of the disposed mine

The documentation shall solve not only the method and actual execution of the disposal of the mine underground, redevelopment and reclamation of the area affected by mining in the disposed mine locality and the entire affected mining space, but also the subsequent utilization of the redeveloped surface. In our case, in contrast to abandoned unfilled underground of the mine, a variant solution of utilization of the mine surface premises can be suggested in the documentation of the disposed mine with underground backfilling, possibly also for other equipment in the mining area, which was formerly used for mining activities. After the underground has been filled up with backfilling of necessary parameters, further utilization of objects can be proposed boldly, for example, for:

- creation of a museum of mining;
- transformation of the premises into an industrial zone;
- combination of the above variants.

REQUIREMENTS FOR TECHNICAL DISPOSAL OF UNDERGROUND MINES

The method of technical disposal of the mine must be based on the mine-geological conditions in the deposit locality, morphology and geology of wider surroundings, hydrogeological and geomechanical relations, situation of the mining capacity in the countryside, particularly in relation to habitation, method of the deposit early development and application of mining methods.

The adopted technical solution of the mine disposal must provide for elimination, or at least minimization, of risks related to abandonment of the locality, particularly those of the safety, health and environmental character, specifically:

a) ascent of mine gases from underground spaces with the risk of their accumulation in surface and underground building objects;

b) impaired stability of openings of main mining workings;

c) sudden surface subsidence through loss of stability of accompanying rocks owing to caving of underground spaces of abandoned mining workings located near the surface;

d) contamination of mine waters migrating through the mine environment, owing to leaching of substances out of this environment or contaminants left in the underground spaces:

During disposal of the mine, the entity must:

- manage economical utilization of the deposit reserves, safeguard the unused part of the mineral deposit;
- safeguard the adjacent deposits;
- take necessary measures to protect mining workings of the adjacent mines;
- take necessary measures to protect the environment and utilize the area after termination of mining activities;
- implement essential measures to provide for labour and operational safety and prevent risks in the locality.

The disposal plan shall include execution of all necessary works for safe disposal of the mine as an operating unit. Particularly, it shall specify the technical method of disposal, use of technologies, technical equipment, means and precautions to ensure safety and environmental protection.

CONCLUSIONS

At the present time, Czech mining faces a period of deep downturn. Essentially, classic mining activities in the underground are taking place in OKD only; even there, they are to be terminated within a few years. In the area of elimination of the consequences of past mining activities, however, there is still a huge task to deal with for the Czech state.

It is necessary to perform gradual reconnaissance of most of the registered mining workings, evaluate the state of their safeguarding, the rate of risk which they pose for their surroundings, and subsequently safeguard the selected workings in a proper manner. All organisational units of the state should reach an agreement on the common procedure of these activities so that the financial resources assigned for the given purpose according to law are spent with maximum efficiency. Proper attention to the issue of past mining activities should also be paid by municipalities and pertinent building authorities within production of land-use plans.

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