Closing down and securing underground mining works in France. Legal and technical aspects

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CLOSING DOWN AND SECURING UNDERGROUND MINING WORKS IN FRANCE. LEGAL AND TECHNICAL ASPECTS

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Abstract

For many years the French economy was based on a quite developed mining industry (iron, coal, salt, potash...). The French Government priorities were largely modified since the progressive closure of iron and potash mines in the last few years and the planned ending of the coal exploitation in 2005. The main goal consists now of managing the post mining period by ensuring the closing and the securing of old mining works in best conditions.

The French mining regulations changed a lot in the last 10 years. The definitive closing of old exploitations is now subjected to strongly demanding procedures. The authorities decided to apply a policy based on a systematic prevention of risks and annoyance by imposing the owner to take any measures that could ensure a long term safety of goods and people as well as limit annoyance that may affect the environment.

A brief overview of the historical and technical background of the French mining exploitation as well as the main disasters that cast a tragic shadow over its history are firstly exposed. The typical content of a mine works definitive closure application is then presented. The main goals of this kind of procedure consist of defining residual risks resulting from the exploitation and determining the counter measures that are best appropriate to limit them.

INERIS is a French National Institute dealing with risks and industrial safety issues. It achieves this kind of definitive closure applications in close co-operation with the owner and the authority in charge of the instruction.

Key words: Underground Mines, Closure, French Regulations, Securing, Risk, Impact, Stability, Water, Mine gases.

1. General Context and objectives

1.1 Historical context

1.1.1 An Ancient Mining Tradition

Like most other Western European countries, France has an ancient mining tradition. In Gaul, gold, silver, lead, copper, tin, iron and possibly zinc and antimony were mined as early as the Gallo-Roman era. However, due to the decline of the Roman Empire and numerous barbaric invasions, mining activity development came almost to a halt. It is only at the end of the first millennium that mining activity started growing again, notably in Eastern France (XI-XIIIth centuries). Coal exploitation in Southern and Eastern France also started during this period.

Obviously, the Industrial Revolution (XVII-XVIIIth centuries) played a major role in mining activity development. This activity, which was mainly a craft industry, progressively grew into a large scale industry thanks to the great inventions (steam engine, use of blasting powder) and the technological leaps of this period. The prospected and exploited minerals were broadly diversified at the beginning of the XIXth century (petrol, oil shale, tungsten, manganese, aluminium, fluorite, zinc, talc, phosphate, etc.).

Over a century, large mineral fields were built to cope with the growth of the heavy industry essential to the Nation development. Coal (for energy), salt (for chemistry), iron (for the steel industry) and potash (for fertilisers) were intensively exploited throughout France. The mining activity provided sufficient income to entire regions. After the Second World War, the French mining industry was at its peak due to the national effort in rebuilding the country and reducing France energy dependency.

1.1.2 Problems Persist Although Mining Activity Ceases

International competition, slumps in prices and the exhaustion of mineral supplies affected the French mining activity and caused its progressive decline. This decline started in the 1980s and became sharper at the beginning of the 1990s. The last iron mine in France closed down in 1997. The exploitation of coal mines is planned to come to an end in 2005 and this of potash mines in 2003. Today, most metal mines have disappeared and the exploitation of uranium is insignificant.

Many lethal accidents have marked the French mining industry (Loire 1899 : 207 people died after a firedamp explosion, Courrières 1906 : 1,099 people died after a coal dust explosion). The hazards of mine operation were strongly reduced thanks to scientific progress, the development of preventive measures and the gradual reduction of the mining activity. However, mining works remain one of the industrial activities most liable to have a long term impact on the environment and human activity. Therefore, although the mining activity is bound to cease, hazards remain. Indeed, it would be senseless to believe that it is possible to fully rehabilitate the land and return to the pre-mining state. In the long term the environment will inevitably bear the scares of this activity [1].

1.2 Legal Scope

1.2.1 French Mining Regulations

At the beginning of the XIXth century, Napoleon Ist ordered a full reform of the French Laws pertaining to mining. The current French Mining Regulations are based on this reform. Therefore, in French Law, the difference between mines and quarries directly results from a fundamental Act dated 1810, which has undergone few changes since then. In France, the difference between mines and quarries is made according to the type of extracted material as opposed to many other countries, which define the difference according to the implemented technique (strip mining, underground mining). Under French Law, the exploitation of materials defined as "eligible for concession" is ruled by the regulations on mines, and the exploitation of materials defined as "non-eligible for concession" is ruled by the regulations on quarries. The materials "eligible for concession" include mineral substances which were considered as strategic and of prime importance for national sovereignty. These substances are mainly hydrocarbons (oil, gas, coal), salt, potash and metals. On the contrary, quarries are mainly used to extract building material (limestone, chalk, gypsum, slate, etc.).

In France, land owners have no right over the underground minerals or substances eligible for concession. Indeed, mines are subject to the "concession" rule. "Concession" refers to the contract, entered into between the French State and a legal person or corporate body, authorising the exploitation of the substance subject to the contract against a fee. The word "concession" is also used to define the area granted to this person or body to perform his or its activity. Therefore, the concession is the administrative entity of reference in Mining Law.

The present reference of the French Mining Regulations is the French Mining Code drafted in 1955 [2]. It contains all current regulations and laws pertaining to the opening, operation and closure of mine works. It notably mentions that when the mining activity ceases (concession revocation or waiver), the exploited area returns to the concessible domain. If the former operator disappeared or is failing, the State guarantees possible problems which could result from old works.

1.2.2 Closing Down Mine Works

Over the last few years, the growing awareness of safety and environmental issues, as well as the knowledge acquired with the first closures, led the French Government to strengthen the legal procedures pertaining to the closure of mine works. The French Government notably decided to integrate the notion of mine works rehabilitation to the mining laws and regulations in order to secure these sites and limit their impact on the environment.

In accordance with the French Mining Code, modified by an Act in 1994, the Concession-Holder must notify the administration of the steps it plans to implement in observance of the fundamental restrictions and obligations pertaining to:

- public safety and health;
- main characteristics of the environment whether on land or at sea;
- integrity of the public or private buildings;
- public road preservation;
- archaeological interests; agricultural interests;
- National Heritage Preservation and protection of outstanding natural sites;
- protection of water resources (ecosystem preservation, protection against pollution, valorisation of water as an economic resource, etc.).

The envisioned measures must mostly be aimed at preventing hazards associated with subsidence or collapse, at ensuring an efficient and perennial closure of the former works' entries, and at guaranteeing that the surface works and facilities do not jeopardise public safety and health or the main characteristics of the natural surroundings. Furthermore, the procedures to secure a site must be in accordance with stringent requirements concerning environmental protection. To this end, the current, past and future consequences of the closure on the underground and surface water source, flow and quality, as well as mine gas migration, must be studied.

The legal procedure which must be implemented to close down a mining site is twofold :

a / From a technical standpoint, the definitive closure of mine works procedure constitutes the major step. The Concession-Holder, for the definitive works closure to be awarded by the « Préfet » (French regional administrative authority), must assess the foreseeable consequences of the former works on the environment to define and implement counter measures. The Préfet can impose to the operator complementary measures to those that have been proposed.

b / Once the definitive closure is awarded, the Concession-Holder must transmit to the Minister in charge of mines a "concession" waiver application. If this waiver is accepted, the Concession-Holder is released from its responsibilities, the mining right is cancelled and the concession goes back to the State and is therefore part of the domain eligible for concession once again.

In the following, we will mainly present the procedure to implement for a definitive closure of mine works application, as the concession waiver procedure is mainly administrative.

1.3 Mine Works Definitive Closure Procedure

1.3.1 Goals of the Procedure

The Concession-Holder must transmit a mine works definitive closure application to the Préfet at least six months before the definitive closure of all or part of the works. An act drafted in 1995 precisely defines the content of this application.

This application must be as complete as possible and lists any pollution liable to affect the surroundings after the closure of the underground mine works. The Concession-Holder, after a general presentation of the sites concerned by the final closure application from the geological, hydrogeological and operational standpoints, must establish a list (in terms of quality and quantity) of the consequences that the underground works have already induced on the environment. The Concession-Holder must then endeavour to assess the long-term consequences of the definitive closure of the works. Finally, he must define the possible counter-measures which he considers most appropriate and which could guarantee a hazard level in compliance with the use which is made of the land above. These measures, based on the Concession-Holder's study, are subject to verification by the French Administration which can either validate or complete them if considered necessary.

All sectors liable to affect the surroundings must be included in these steps. Therefore, the application completed by the Concession-Holder must deal with the following topics:

- impact on water resources (hydrology, hydrogeology, underground water regime modification, quality, etc.);
- land stability (embankment stability, subsidence, collapse, etc.);
- hazards associated to mine gas (hazardous gas emission or accumulation);
- treatment of mine works openings (shafts, tunnels, adits, etc.);
- problem with the dumps, dams and waste tips;
- rehabilitation of the sites and management of the surface facilities (buildings, head frames, etc.)
- possible measures that have to be taken in order to protect the rare animal species living in the old works (especially chiroptera) and those intended to preserve the archaeological interests.

1.3.2 Investigation of the Application

The final closure application must be examined by the various concerned administrative services and local councils during its investigation in accordance with the French Laws and Regulations. Therefore, a sufficiently detailed and precise document must be established so that experts can give their opinion on the quality of the performed studies and relevance of the suggested counter-measures. However, this document must also be understandable by non-specialists (mayors, members of non-profit corporations, etc.).

It is advised to draft a synthetic memo, within the reach of a non-technician, but which nevertheless contains the major elements of the application [2]. It is also advised to enclose a glossary of technical terms essential for a good understanding of the document. The definitive file must obviously contain the essential documents and plans (mining method descriptions, limits of the several exploited panels, thickness of layers, height and characteristics of recovery, major geological accidents, etc.).

Once he has acknowledged the content of the application, the Préfet can either validate the technical proposals or prescribe further measures which were not planned by the Concession-Holder but which could prove to be necessary. If the Concession-Holder fails to complete the prescribed works, the Prefect designates somebody to perform the plans and works required to secure the site at the Concession-Holder's expenses. The Préfet notifies the final works closure by decree following report confirming that the measures implemented by the Concession-Holder are in compliance with the application or the additional provisions.

1.3.3 Studies Performance

The performance of a definitive closure application is generally a difficult and stringent task. The examined topics are both numerous and varied. Furthermore, they often influence one another. For example, a rise in the water level, following the mine draining pumps shutdown, can influence the land stability. In the same sense, the selection of the procedure to secure former shafts or adits depends on whether mine gas is reported or not.

It is important to rationalise the work schedule in order to cut back the delays and costs for the various studies. The typical schedule of studies to be performed is the following [4]:

a / General synthesis of the mining activity

Generally, the analysis starts with the basin geological synthesis and with the mining works synthesis (summary plan drafting for the underground works). As these documents are essential to all studies which will be performed consequently, they must be launched as soon as possible.

b / Analysis of the mining activity consequences

Typically, the hydrological and hydrogeological specific studies are often performed first (indeed, the results of these studies influence most of the other studies to be performed). The surface stability study and the analysis of the hazards associated to the presence of gas can start as soon as the hydrogeological study is well underway. The conclusion of the surface stability and hazardous gas studies are useful to secure former shafts and adits. The other specific studies (waste tips, surface facilities, etc.) are generally independent from the previous studies. Therefore, it is not essential to integrate them to a specific stage of the schedule.

2. Technical Content of a Definitive Works Closure Application

2.1 Environmental Impact on Underground and Surface Water

The impact of a mining activity on underground and surface water is twofold: impact in terms of quantity (modification of the run-off water routes, rise of the ground water sheets, re-emergence of water, etc.) and impact in terms of quality (modification of underground and surface water quality).

2.1.1 Impact of Underground Works on the Surrounding Networks in Terms of Quantity

For the Concession-Holder, the main goal is to limit the impact of the final closure on the surrounding water basin regime. Typically, the procedure implemented to assess the mining works impact or possible impact in terms of quantity consists of five major steps:

1. assessment of the residual unfilled mining voids resulting from the activity;
2. identification of underground reservoirs (location and connection);
3. assessment of the underground reservoirs fill up speed (hydraulic assessment);
4. location of the re-emergence points;
5. assessment of the impact on the surrounding hydrogeological and hydrological networks.

The impact evaluation on the surrounding hydrogeological networks generally requires an advanced hydrogeological study in order to determine the water level after stabilisation. It is necessary to take into account the 50 years return period precipitations on the short term (the month) and the longest term (the year). It is also necessary to take into account the capacities of evacuation of the discharge system, the water level being able to be temporary located higher than the levels of emergence points and thus to flood particular sectors or cellars located even higher than the discharge system.

If applicable, the most appropriate counter measures can be defined by the Concession-Holder once the impact of the former works has been assessed. Typically, the following measures can be mentioned:

⇒ water flow modification (performance of plugs and stoppings in the former works, creation of artificial re-emergence points);

⇒ possible uphold of the pumping system (to prevent submerging the bordering underground works still in activity or flooding the lower points of the surface topography). This solution must only be selected in very specific cases, when no other solution can be envisioned (such as the achievement of stoppings in order to protect the works still in activity or the creation of artificial emergence points) . For obvious reasons, in a long term prospective, the use of techniques which require regular maintenance must be limited as much as possible. When they must nevertheless be implemented, it must be defined in which it belongs to control the good state of the works and to ensure the finance charges (operator, services of the State, etc.);

⇒ limitation of the surface land use in the direct surroundings of the future re-emergence points, or at the lower points of the topography liable to be flooded by the rise of the water level over time.

2.1.2 Impact of the Underground Works on the Surrounding Networks in Terms of Quality

The closure of mining works can affect the quality of underground and surface water. The acid drainage phenomenon (pH reduction, dilution of the metals contained in the ground) is a major cause for water quality downgrading, in many metal mines and in coal mines which have a high level of pyrite. Large concentrations at re-emergence level can also be caused by the dilution of sulphate ions.

It is essential to know the quality of the water before the works started (zero status) in order to assess the actual impact of the site operation in terms of quality. Water in some regions naturally had a very high mineral content even before the mining activity starts.

Several additional procedures can be envisioned to assess the foreseeable impact:

- comparison with neighbouring mines or areas which are already submerged;
- laboratory analysis and tests to define the type of receiving land (content of pyrite, etc.);
- analytical or empirical approaches (sometimes one considers that the concentrations in minerals are reduced by half each time the water of the underground mine reservoirs is renewed);
- hydrogeochemical modelling taking into account the oxygen content of water. More oxidizing meteoric water generate a scrubbing of the grounds more unfavourable than deep water more reducing.

The mining re-emergence points are analysed in terms of impact on the surroundings rather than in terms of run-off water quality. Therefore, an analysis of the type of receiving environment and of its use must be integrated. If required, the Concession-Holder must define and implement the counter measures most adapted to the site. Typically, three types of water treatment processes are distinguished:

⇒ Preventive measures

The possible modification of the underground water flowsheet can be mentioned among the preventive measures (to help the short circulation networks which are close to the surface in order to limit land leaching). Another preventive measure which can be mentioned is the implementation of alkaline backfilling to neutralise the pH of the water discharged at the surface.

⇒ Physico-chemistry treatments

Many physico-chemistry treatments allow processing of low quality water. The selection of one technique rather than another mainly depends on the type of released water. Among the most commonly used techniques are evaporation, oxygenation, neutralisation, decantation, flocculation, filtration, bioremediation, etc.

⇒ Passive treatments

The purpose of passive treatments is to improve the quality of the released water with natural chemical or biological processes which require neither permanent maintenance nor the sustained addition of chemical products. Limestone drains or lakes and artificial wetlands are among the major passive treatments.

2.2 Environmental Impact and Hazards Associated with Land Stability

The long term behaviour of the land undermined by mining works strongly depends on the mining methods used. Generally, the methods which fully fill up underground mining voids after closure (caving, backfilling, etc.) only give rise to surface subsidence phenomena. To the contrary, works which allow residual empty voids to persist (notably rooms and pillars technique) are liable to give rise to surface land collapse phenomena.

In this last case two types of phenomena are likely to occur: generalized collapses or sinkholes. The less the ratio between the height of the recovery over the thickness of the extracted ore, the greater the amplitude of depressions or collapses.

The assessment of the long term stability of land at the surface is quite often a tricky procedure requiring thorough knowledge of the mining works context. Notably, it is essential to research any available information pertaining to the type and thickness of the covering, the hydrogeology of the area (location of submerged sectors or those that will be submerged in time, and those that will never be submerged), the operation parameters (mining technique, size of the pillars, existence of works with several levels, etc.), and the geotechnic characteristics of the ore and the recovery, in particular the water effect on the rocks if the works have to be flooded.

2.2.1 Method for General Assessment of Subsidence Risks

For sectors solely subject to a surface subsidence risk, the main purpose of a stability study is to establish the zone of influence of the former mining works on the overlying strata. Typically, the zone of influence includes all plots of land directly undermined, as well as a non-undermined strip of land which corresponds to the external border of the works (lateral influence of the works).

Once the location of all underground works is known with a satisfactory precision, the main difficulty of the analysis is to determine the value of γ, the works angle of influence on the covering (i .e. the width of lateral influence). This angle notably depends on the type and thickness of the overlying strata, the slope of the rockbeds, the width of the exploited strip, the presence of faults, the existence of several exploited seams, etc. The value of this angle can be defined with surface subsidence measurements if they exist, or based on a similar study performed for neighbouring works and presenting similar geological and operational contexts.

In the case of methods ensuring the integral disappearance of empty mining spaces after operation, subsidence can occur for a period which is generally quite limited and well known after extraction. Therefore, the long term behaviour study of land at the surface must focus on the assessment of the site sensitivity to the two following parameters:

a / Residual subsidence risk

The residual subsidence corresponds to the subsidence phase which extends after extraction and which is generally very reduced. If the duration of this phase and of the sector's operation is known, it is possible to determine if a sector is sensitive to a residual subsidence, and if so, for how long.

b / Subsidence resurgence risk

The two main exogenous factors liable to trigger a subsidence resurgence are a rise in the water level within the former works, and the application of an excessive burden on the surface (notably as a consequence of surface urbanisation). The sectors which are the more sensitive to a subsidence resurgence are generally the sectors close to the surface and not yet submerged but liable to become submerged in time, as well as the sectors intended to be used at the surface.

2.2.2 Method for General Assessment of Collapse Risks

The identification of the collapse risk is a very tricky appraisal which requires a perfect knowledge of the context of the works and of the breaking mechanisms liable to affect the underground works stability (pillar breakage, breaking down of the roof, etc.). The analysis consists in locating the potentially unstable areas and identifying the types of phenomena which could affect the land at the surface.

a / Type of foreseeable disorders

The identification of the type of disorder liable to affect the surface stability is based on a visual inspection of the underground works (when possible) and on the thorough analysis of the site conditions and mining plans. The appraiser must then identify the various breakage scenarios liable to affect the area. Depending on the covering's nature and thickness, he must determine whether the land at the surface is liable to collapse or not. Generally, a rock covering made of poorly competent rockbeds favours gradual breakage which gives rise to a gradual and smooth collapse of the surface. On the contrary, the breakage of rigid and competent rockbeds in the roof can favour a sudden movement of the land at the surface (spontaneous collapse).

b / Sensitivity of a site to breakage

Generally, the collapse date of former works with abandoned rooms and pillars can in no way be assessed, even approximately. To overcome this difficulty, the sites are studied in terms of predisposition to a type of instability.

To determine if a sector is sensitive to the collapse risk of its surface, the three following parameters must be checked simultaneously:

- sectors of the underground works have not yet caved in when the study is performed;
- certain of these sectors are liable to cave in with time;
- the fall-in of the sectors is liable to cause a collapse of the land at the surface.

The selection of an adapted appraisal procedure to characterise the sensitivity of a site to the risk of collapse of the surface notably depends on the type, extension and context of the mining works as well as on the accuracy and quantity of information available on these former works.

Typically, the analysis is based on a close study of the site (signs of disorder at the surface, back-analyses carried out on old collapses which have occurred in the same exploitation or in bordering exploitations presenting similar characteristics, etc.), an assessment by modelling and a calculation of the works behaviour (pillar stability, behaviour of the roof) and, possibly, on the implementation of the exploration works (well boring, geophysical methods) to define the land and detail the calculation assumptions.

2.2.3 Counter Measures Definition

The filling (by backfilling or caving) or reinforcement of the cavities are solutions which can only be envisioned in few very specific cases for obvious financial and technical reasons. Therefore, generally, only the works which are very close to the surface are secured in such a way. In other cases, the trend consists in defining risk perimeters in which preventive principles are defined in terms of development and urbanisation of the surface area. These provisions can range from a simple control of the urbanisation to a strict building prohibition in this area, which can even be closed down and fenced in certain very specific cases.

Of course, the problem becomes trickier for the management of the existing buildings, notably if they are located in areas of high risk for the safety of people and properties. If no reinforcement of the land or buildings can be implemented and the surface facilities cannot be displaced, the implementation of monitoring devices can be envisioned (traditional geotechnical devices, micro-seismic monitoring). Whatever the type of selected measurement devices, the monitoring does not cancel the risk, it simply allows to manage it and inform the population and authorities in case of abnormal evolution of the underlying cavities.

2.3 Hazards Linked To Gas Within the Former Works

When an underground mine is closed down, all hazards associated to mine gas are not necessarily cancelled. The gas accumulated in the reservoir constituted by the residual empty mining voids can migrate to the surface if the pressure within the tank is higher than the outside atmospheric pressure. Ignition (firedamp), intoxication (carbon dioxide and monoxide, hydrogen sulphide) or asphyxia (lack of oxygen) are among the major hazards for persons or properties neighbouring the site. Only a thoroughly detailed study of the geological and operational configurations can allow the identification of the site main hazards and define the counter measures in compliance with the use of the land.

The hazard pertaining to mine gas undergoes an essential transition when the water level rises. If the gradual submergence of the underground works more or less totally stops desorption of gases contained in the strata and gradually fills the available empty residual voids, it however expels the gases contained in these areas by forcing them to the surface via all existing communication means. The release of gas at the surface mainly takes place via communication links between underground works and the surface (shafts, adits), or in a more diffuse way by the covering if its thickness is low and/or its permeability high, or if it is faulty.

Once the water level is stabilised, the risk of gas being expelled by force no longer exists. However, if some voids have not been flooded, a difference in pressure can persist everytime if the outside barometric pressure goes down. Furthermore, gas discharges at the surface are liable to be caused by exceptional events. Notably, the backfilling collapses in the columns of shafts, the performance of borings which reach former works, or the performance of civil engineering projects uncovering works which are close to the surface. Water pumped to the surface from deep underground can also release large amounts of dissolved gas to the atmosphere.

The general assessment of the risk associated with gas after a site is closed down relies on several criteria.

a / Criterion associated with the underground natural reservoir. It is essential to identify the type of gas and its quantity which is liable to accumulate within the former works and the sensitivity of the strata to the accumulation of gas (persistence of residual voids, existence of geological structures that can trap gas, etc.).

b / Criterion associated with the covering strata. The breakage of the land and/or the existence of faults can favour the migration of gas to the surface. Therefore, the thickness and type of covering, as well as the permeability of the various horizons, must be determined.

c / Criterion associated with the land use. Urbanisation at the surface increases the level of residual risk by favouring mine gas accumulation within non-ventilated empty volumes (cellars, underground networks, etc.).

Counter measures adapted to the various encountered configurations are defined when the studies highlight hazardous areas. Typically, the counter measures implemented to secure the site against any possible mine gas discharge at the surface are:

⇒ adequate closure of the mine openings at the surface (in order to prevent any sudden gas discharge);

⇒ performance of venting wells located adequately to discharge gas from the underground « traps ». These works make possible to check the evolution of the gas reservoir parameters (composition and pressure) as well as to provide a controlled and consequently safe outlet for the gas;

⇒ drainage of gas which consists in using an exploitable gas mixture found in the former works (e.g.: CH_4). This technique implies a depressurisation of the reservoir which prevent non-controlled gas discharge at surface. The exploited gas can then be utilised (boilers, etc.) or simply rented;

⇒ land-use management to prevent an increase in the hazard zones (prevent the building of any underground non-ventilated empty volumes for example).

2.4 Hazards Linked to Former Mine Works with Surface Openings

It is of prime importance to secure former mine openings (shafts, adits, tunnels which are close to the surface) as thousands of them are scattered over the French territory in very different environments (sometimes on urbanised sites) and their location is often not well known. These works were generally partially or integrally backfilled at closure.

However, although they have been backfilled, these former works represent a hazard for the surface land, under certain conditions, and therefore for persons and properties. Indeed, some accidents occurred in France or in neighbouring countries over the past decades. Unfortunately, in certain cases, they even turned out to be lethal. The main problems resulting from former mining openings are the risk of entry in old works, collapse, asphyxia, explosion, etc.

To secure the land above these works in a satisfactory way, it is essential to locate and treat the reported or suspected openings in an efficient and sustainable manner. Furthermore, for a given opening, a more stringent treatment will be required if it is located in an urbanised area than in a remote area to guarantee the same safety level.

One of the major stages of the analysis is the selection of the most adapted technique to secure the opening. A general method aimed at selecting a technique for a given environment and opening was developed by INERIS [5]. It details the major characteristics which must be collected to make sure that no fundamental parameter was forgotten during the study of the various possible breakage scenarios. Among these parameters we can mention the size and status of the works, the geology, the hydrogeology, the presence of gas, the type of use which is made of the land above and around.

The selected technique must allow the works to be in compliance with the various requirements as regards the risks liable to affect persons and properties within the area influenced by the mining works, i.e.:

- ⇒ definitively preventing any entry to the former works and guaranty that the opening cannot be violated by acts of vandalism;
- ⇒ securing the land above and around the works in the long term. The treatment must be perennial and dimensioned to reinforce the surrounding rocks in order to prevent disorders which are not in compliance with the type of land use and which are due to the structure's ageing;
- ⇒ controlling the problems associated with gas, if required, notably by preventing any non-diffuse gas emission and systematically shutting down dead-ends or cavities located close to the opening, where gas could accumulates;
- ⇒ manage the problems associated with drain water in the mines, notably by preventing possible future water releases within urbanised areas which were not designed for this purpose.

If protected animal species elected residence in old mining works (chiroptera in particular), these principles must be adapted to allow the passage of these animals, while preventing the penetration of the people.

2.5 Environmental Impact and Hazards Linked to Waste Dumps and Tailing Dams

The exploitation of underground mines generates the constitution of large barren waste heaps next to the extraction sites, known as waste tips. The materials can consist of excavated matter or waste from a processing or transformation line. The waste is transported with lorries, carriages, etc. The main hazards associated to the presence of such works at the surface once the underground mining works are closed down are threefold: local and general long term instability, combustion of certain coal waste tips and nuisances they are liable to cause to their surroundings (air, water).

2.5.1 Long Term Stability of the Works

The waste tip and tailing dam long term stability is not always guaranteed. Large scale incidents associated to instability can jeopardise sensitive structures neighbouring these tips (Aberfan 1966, Buffalo Creek 1972). The breakage of a dump or of its foundation generally results in an unfavourable evolution of one or several fundamental parameters controlling its stability (geometrical configuration, building mode, type of land on which it is sited, the hydraulic and climatic conditions, excessive burden, modification of the embankment geometry). Many instability phenomena can affect the waste tips. These phenomena are generally listed within the major slope instability categories (gradual slumps, slumps which turn into land slides, surface erosion, etc.).

Typically, the appraisal procedure which is implemented to assess the stability conditions of the tips or dumps comprises four fundamental steps :

1. Study of the geological, hydrogeological and operational contexts (in particular presence or risk of formation of a water table in one or both of the deposit or the supporting soils);
2. Geotechnical study of the work (detection of breakage figures);

3. Geotechnical characterisation of the materials in the waste tips;
4. Study of stability conditions with methods of calculations typically implemented to slope stability [6].

If the stability study highlights a breakage risk of the structure, specific provisions guaranteeing its long term stability must be implemented. These provisions depend on the site configuration and characteristics, and or the type of breakage which is liable to occur. Amongst the most frequently implemented counter measures, one can notice:

⇒ waste tip rehabilitation: flank reshaping, building of banks and benches, performance of rip-rap at the foot of the embankments, management of the surface water, replanting of the slopes. It is necessary to eliminate or at least to bring back to an altitude compatible with the stability of the deposit the water tables located inside the deposits (this measure is particularly essential for tailing dams);

⇒ definition of measures pertaining to the use of the surface to prevent building above unstable areas if the stability can not be guaranteed, in spite of dispositions carried out. This case must however remain exceptional, the general rule being to ensure the stability of the deposits;

⇒ monitoring, visual or with appropriate devices including when it is necessary the presence of piezometers in order to characterise the hydrogeologic conditions in the deposits.

2.5.2 Coal Waste Tip Combustion

The waste tips from coal mining sites sometimes contain a large amount of carbonateous matter liable to ignite under certain conditions. In France, about 700 coal waste tips are reported, almost half of them have already partially or totally burnt down [7]. The coal waste tips can be ignited in two ways: ignition by external causes which is often accidental (forest fire or bush fire) and spontaneous combustion. Spontaneous combustion is a physical phenomenon liable to take place if various parameters pertaining to the type of material (volumes of carbonated matter, granulometry, presence of pyrite, etc.), to the structure of the tip (type of implemented dumping system) as well as to the outside environmental conditions (climatic conditions, water) are combined.

The appraisal procedure to characterise the sensitivity of a waste tip in terms of spontaneous combustion breaks down into 4 fundamental stages.

1. Study of the geological, hydrogeological, climatic and dumping contexts;
2. Study of the tip (presence of cracks, emission of fumaroles or gases, suspicious smells, etc.);
3. Physico-chemical characterisation of the waste tip material (sensitivity to spontaneous combustion);
4. Study of the data and determination of the waste tip sensitivity in terms of spontaneous combustion.

The selection of counter measures is associated with the preventive or curative aspects of the intervention.

⇒ Preventive measures.

The ignition can be prevented by limiting air penetration into the dump, by implementing a covering layer of inert material, by controlling and clearing the flanks, displacing the sensitive structures located near to the site, and by controlling the development and planning of the surface next to the area.

⇒ Curative measures.

When the combustion of a tip has already started and the extension of the fire is hazardous, measures such as the performance of fire barrier trenches, the removal of material in combustion and its spreading on non-sensitive areas, the implementation of a regular site monitoring, the prohibition of public access to the site, and/or control of the surface development and planning neighbouring the area. In the case of spoil heaps in combustion it is advisable in particular to analyse the risks of formation of gas as a result of water presence (particularly during rainy period of time). It is also advisable to prohibit the access by the installation of effective fences able to forbid the penetration of people

2.5.3 Impact of the Waste Tips on the Environment

a / Impact on the landscape

The bigger the waste tip and the flatter the land, the stronger the visual impact on the landscape. The replanting of the tip generally limits this impact.

b / Impact on the air

Generally, the consequences of dust emissions are limited. However, they must be precisely assessed if the tips concern exploitation of substances particularly harmful to the environment and human health (uranium). The coal spoil heaps in combustion, most of the time old, reject into the atmosphere harmful gases (CO, H_2S, etc.) which, however, except racing of the phenomenon do not generate a notable impact on the environment.

b / Impact on water

Sometimes, the materials which make up the tips can downgrade water quality. The meteoric water can percolate through the waste tips or run off along their flanks and pick up mineral elements before being released in the natural environment. The chemical processes which downgrade infiltration water are quite similar to those that downgrade the quality of underground waters in contact with former mine works.

A precise knowledge of the site must be acquired in order to assess the quality downgrading risk for the surrounding ground water tables and rivers. To locate the various rivers or ground water tables surrounding the site and assess their vulnerability, a hydrogeolocial study must be performed. Furthermore, this study also characterises the tip permeability and that of its foundation. If required, the petrographic and mineralogical material study characterises the sensitivity to downgrading water quality. Finally, the examination of events which took place in the past and which affected the site or other neighbouring sites provides interesting information.

With the results of the various studies, it is possible to assess if the foreseeable long term consequences are in compliance with the site's sensitivity or if the implementation of possible counter-measures must be envisioned.

⇒ Tip covering up and flank replanting to limit water infiltration and emission of harmful particles, reduce the impact on the landscape and reinforce the stability of its flanks.

⇒ Surface water management to limit the run off and percolation of surface water as well as the risk of water pollution and flank erosion.

⇒ Other techniques, although much more exceptional, can be envisioned: displacement of the tips, addition of alkaline material, bioremediation, creation of sealed barriers, etc.

2.6 Environmental Impact associated with Surface Facilities

Under French Law, the only facilities considered as mining facilities are the infrastructures essential to the mine operation. Therefore, the material processing facilities (chemical treatments in particular) are not considered as such except for the purely physical processing like crushing, sifting, washing, etc. The major environmental impacts of the surface facilities are associated with hazards due to the former facilities instability (headframes, buildings, etc.), to the possible scattering of toxic compounds, and to landscape downgrading.

To evaluate such impacts and define adapted counter measures, a specific analysis exists in French regulations [8]. It is not the aim of this paper to develop this so-called « Simplified Hazard Assessment Procedure ».

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