Health & Safety in Underground Environment

Baltic Sea Underground Innovation Network (BSUIN)

Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
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KGHM CUPRUM Research and Development Centre

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Abstract	Underground laboratories provide a unique environment for various industries and are the perfect place for developing new technologies for mining, geophysical surveys, radiation detection, as well as many other studies and measurements. Unfortunately, working in underground excavations is associated with exposure to many hazards not necessarily encountered in surface laboratories. Water inflow, gas burst, structural collapse, cave-ins, and even seismic hazards, translate into high accident rates in the underground mining industry across the globe. In order to minimise the risk of serious accidents, a lot of research investigations related to development of effective risk assessment procedures are being carried out. One of the initiatives aimed to improving the work safety in underground laboratories is the Baltic Sea Underground Innovation Network project implemented under the Interreg Baltic Sea Region programme. This study presents the process of compiling a database on hazards within underground laboratories. Finally, a proposal for the unification of the procedures for risk assessment, including methods for determining the likelihood and potential impact of unwanted events, has been developed.

List of Abbreviations	
PSMA	Polish State Mining Authority
SMA	State Mining Authority
BSR	Baltic Sea Region
UG	Underground
UL	Underground Laboratory
R&D	Research and Development
SRS	Sensors of Roof Separation
FOS	Factor of stability
SWIFT	Structured What-If Technique
RM	Risk Matrix
PRA	Probabilistic risk assessment
ALARP	As Low As Possible
BN	Bayesian Networks
FTA	Fault Tree Analysis
ETA	Event Tree Analysis
FMECA	Failure Mode Effect and Critical Analysis
FMEA	Failure Mode Effect Analysis
PHA	Preliminary Hazard Analysis
PRA	Probabilistic Risk Assessment
HIRA	Hazard Identification And Risk Analysis
ORA	Optimal risk analysis (
HAZOP	Hazard and Operability Study
MFTA	Modified Fault Tree Analysis
SWeHI	Safety Weighted Hazard Index
FEM	Finite Element Analysis
FEA	Finite Element Method
DEM	Discrete Element Method
BIM	Building Information Modelling
QRA	Quantitative Risk Analysis
HACCP	Hazard Analysis and Critical Control Points System

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1. CONTENT OF PRESENT DOCUMENT

1.1. Document justification

The present document is a part of the project BSUIN work package four (4) outputs related to Health and Safety in laboratories. In the report, the review of potential risk and their minimisation method are presented. Based on the gathered data preliminary risk assessment for Underground Laboratories from BSUIN project were conducted, and some facility improvement solutions were proposed.

1.2. Content description

The issue of the high accident rate in underground environments is one of the biggest challenges for the mining industry. Taking into consideration, that UL's are often located near existing mines, or are established in post-mining areas, it is clear that their operation is in most cases connected with relatively high risk.

Of course, there are several important publications and projects conducted within the risk assessment area, but all of them concern problems encountered of existing mines, and none of them describe how risk assessment should be implemented in new or re-use facilities.

It is important to note, that it was not the authors' intention to create new risk assessment methods when writing this document. The main goal, fitting the project tasks, was the review and description of possible unwanted events in underground environments, allowing for risk identification and mitigation.

Within the frame of this report, data about potential risks was collected with the cooperation of BSUIN UL's, Rock Mechanic Specialists from underground mines, and the Polish State Mining Authority. The list of identified hazards and a proposal of a universal risk assessment procedure is also presented.

2. BSUIN PROJECT

The BSUIN project aims to make the underground laboratories (UL) in the Baltic Sea Region more accessible for innovation, business development, and science by improving the information about the underground facilities, the operation, user experiences and safety.

Baltic Sea Underground Innovation Network (BSUIN) is a collaboration project between 14 partners from 8 Baltic Sea Region (BSR) countries. In addition to the project partners, 17 associated partners contribute to achieving project goals. BSUIN includes five existing underground laboratories around the BSR. Moreover, one UL prototype will be developed within BSUIN activities. During the project, the ULs will be characterized both from infrastructural and operational points of view. As a result, the UL's within the network will be more appealing to potential customers, providing important practical and preliminary information on the location and services. The UL's are looking to attract customers, to develop innovative activities and increase the usage of these underground laboratories.

The main outcome of the project is to create a sustainable network organization, which will collect, describe, and distribute knowledge on designing, building, and maintaining of these kinds of facilities.

Project is funded by Interreg Baltic Sea funding cooperation. Its duration is 36 months, with a total budget of 3.4 M€.

3. RISK IN UNDERGROUND ENVIRONMENT

Efficient operation, in any branch of industry, requires the operators to ensure a high production rate, but also to maintain and implement the highest safety standards in the working environment. It is crucial to continuously identify risks, assess them, and minimize the risks to an acceptable level.

This task is of particular importance in the case of the mining industry, where many risks have the very real possibility of leading to fatal losses. Dangerous working conditions and lack of regulations can lead to a number of accidents resulting in injuries and material losses.

According to a report prepared by the European Commission (EC, 2010), mining is the sector with the most work-related problems in the whole industry. Moreover, health issues resulting from these working environments have been highlighted during the last few years. According to Elgstrand and Vingård (2013), most of the health issues are related to respiratory system diseases, hearing loss, musculoskeletal disorders, all of which, are caused by long-term exposure to adverse working conditions. The working conditions in underground environments include physical, chemical, and ergonomic hazards (Lööw et al. 2019). The total employment linked to the mining industry in selected EU regions is presented in figure 3.1.

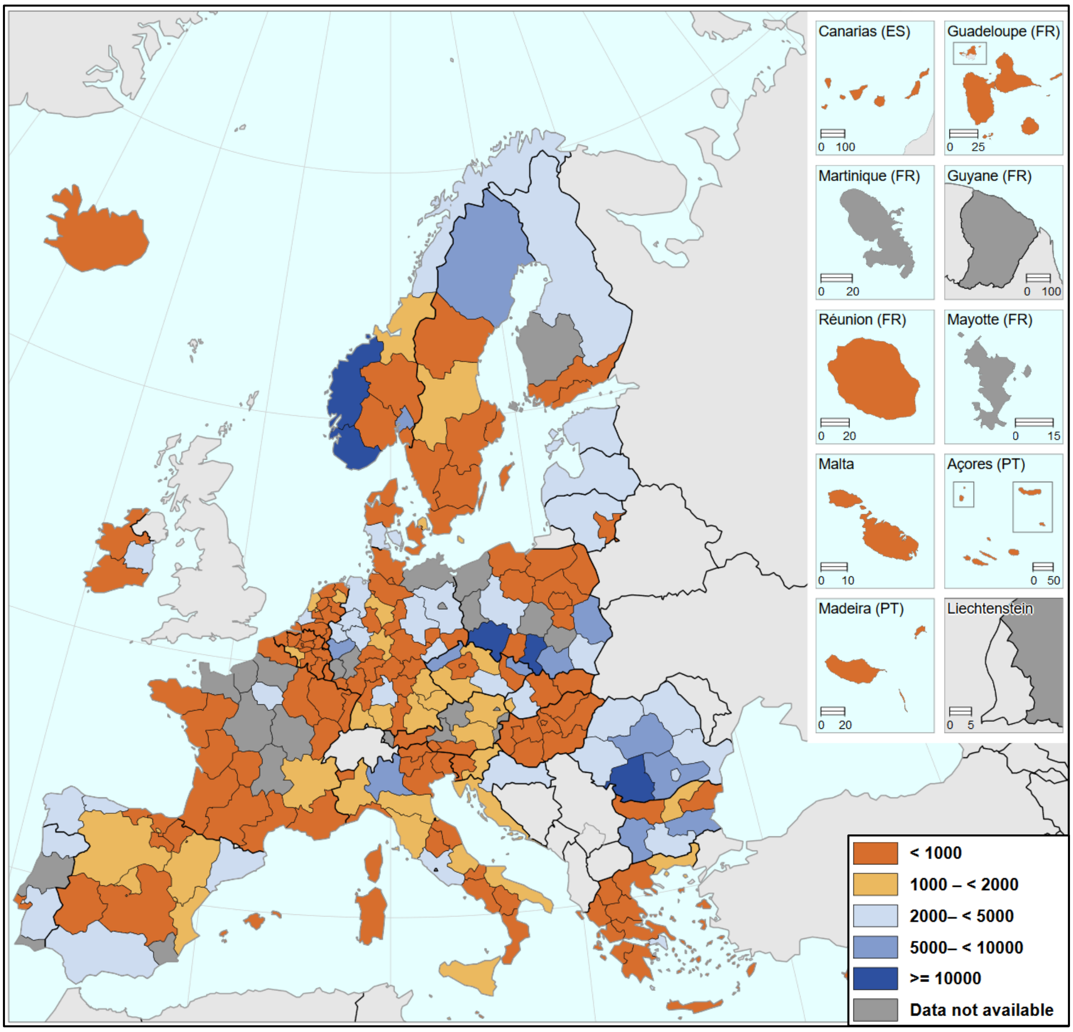


Figure 3.1. Employment in the mining industry in Eu according to Eurostat [Eurostat, 2020]

According to accident reports, the majority of hazards encountered in underground environments are not present in other sectors of industry. These hazards unique to underground facilities include:

- Seismic activity
- Problems with ground control
- Lack of natural ventilation,
- The occurrence of harmful gases
- Radiation
- Flood hazard

Of course, not all of the above-mentioned hazards are encountered at each site, but before planning any underground activity, the probability of their occurrence should be evaluated.

Mining and underground working environments pose problems all around the world. According to a report by The National Institute for Occupational Safety and Health of the US, as many as 726 mining disasters occurred in the United States between the years of 1900-2016. These disasters resulted in more than 12,800 casualties among the miners during the recorded period (CDC, 2018). The situation in underground mines in Asia is also discouraging: since the beginning of the 21st century, dozens of mining accidents have been recorded there, resulting in several hundreds of deaths.

Despite the strong emphasis on the training of mining personnel in occupational safety and the importance of preventive measures, the incident rate in the mining industry remains at a very high level (Sanmiquel et al., 2010; Dhillon, 2010; Komljenovic et al., 2008). This problem concerns almost all underground facilities, as even under good geomechanical conditions, there are still other kinds of hazards related to lighting, watering, ventilation, etc. (Galvin, 2017).

3.1. Accidents in Underground Environment – A case study from underground mining in Poland

To highlight how harsh the working environment may be in underground conditions, brief information about the overall accident rate in Polish mining will be presented in this chapter. According to Polish regulations regarding work safety, there are the following accident groups (Figure 3.2):

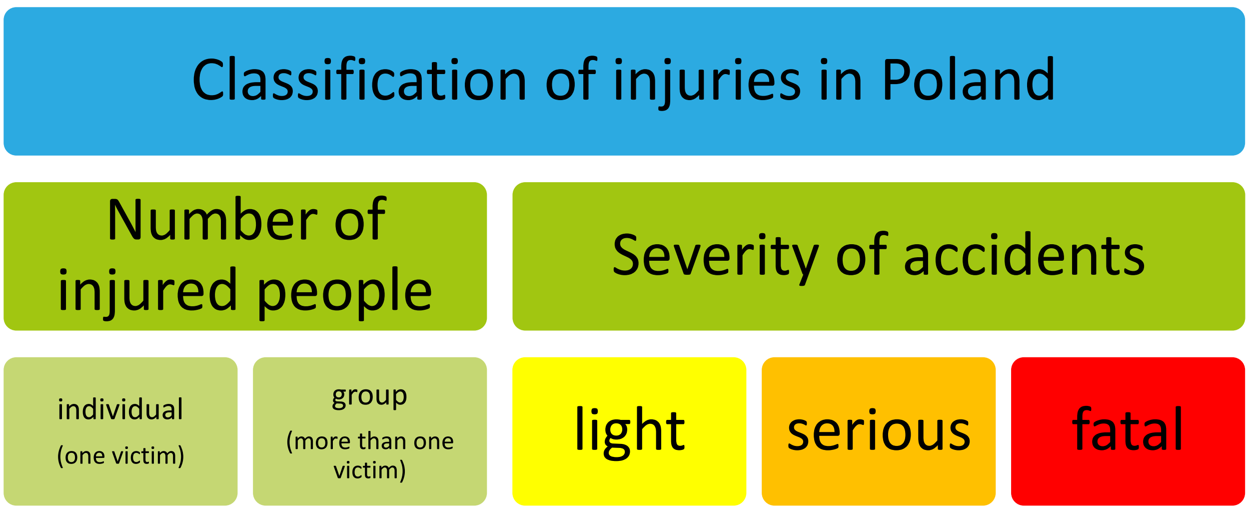


Figure 3.2. Classification of accidents in Poland

Most of the accidents in Polish mining are classified as light, so there are no fatalities or severe bodily damage observed. Accidents where an injury results in serious fracture of bones, loss of sight, or any other sense lacerations, which cause severe haemorrhage, nerve, muscle or tendon damage, injury of an internal organ, severe burn etc. are defined as serious. The last group, in terms of severity, describes fatal accidents i.e. incidents resulting in human death within six months after the accident occurs.

According to the Polish State Mining Authority, data statistic of serious and fatal incidents during the last few years is very disturbing. In Figure 3.3, the number of fatal and serious injuries in two types of Polish underground mines, namely underground black coal mines and underground copper mines, is presented.

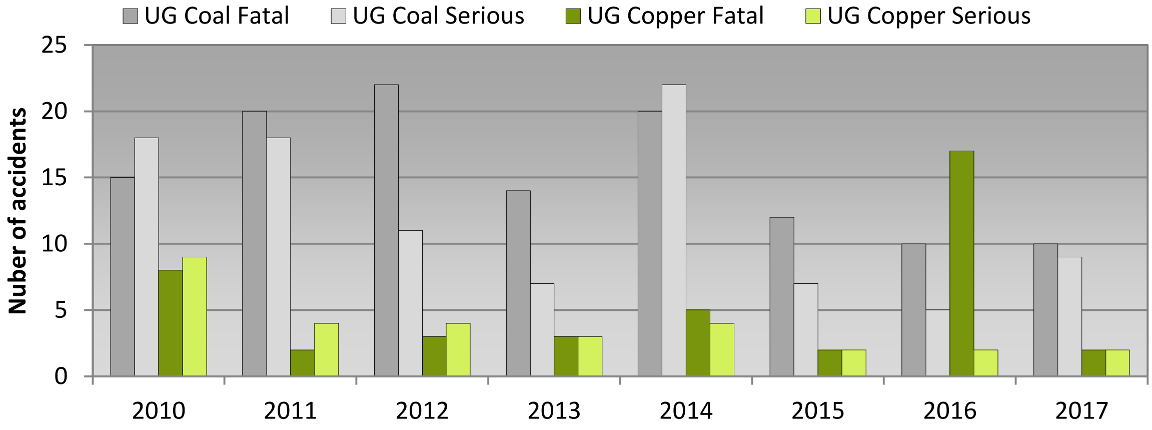


Figure 3.3. Accidents statistics in Polish UG mines from 2010 till 2017 (acc. to PSMA)

Fortunately, there is a downward trend in the total number of accidents in Polish underground mines. According to PSMA reports, the main causes of light accidents are: slipping and falling, hit by rockfall, impacts from tools, machines etc. In turn, serious and fatal injuries are related to rockburst, rock falls, being hit by large mobile equipment, falls from a height, electric shocks, etc.

Presentation of accident rate based directly on quantity can be confusing. A better way to illustrate the problem is to provide analysis of the accident rate according to the rate of extraction or number of employees. In Figure 3.4, number accidents rates per 1000 employees and per one Mg of excavated copper are shown.

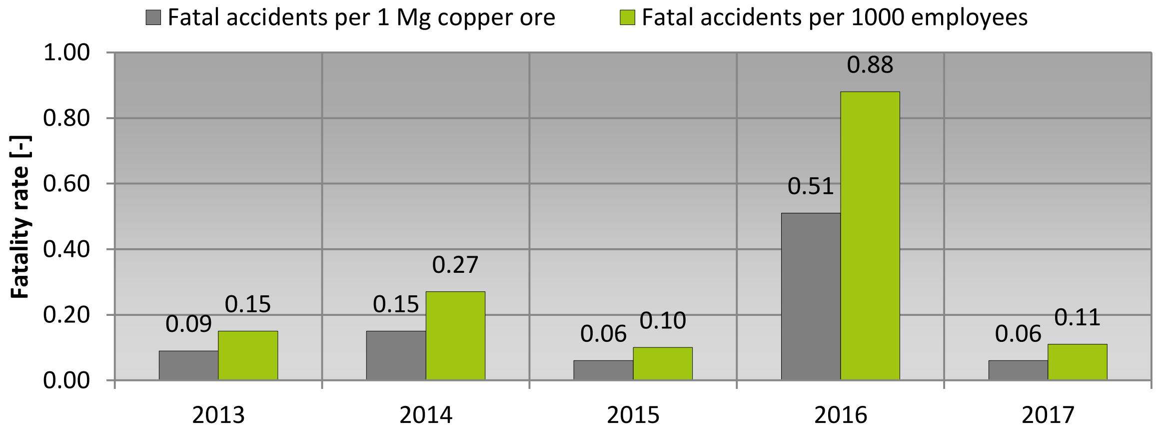


Figure 3.4. Fatal accidents rates in Polish underground

In the 2017, the main causes of fatal injuries were related to natural hazards such as rock falls, methane explosions and rockburst. In total, 45% of accidents were caused by events described as natural ones.

Next group of accidents were caused by machinery (traffic and maintenance), totalling around 30%. Incidents related to electricity and other main reasons in 2017 were shown in figure 3.5.

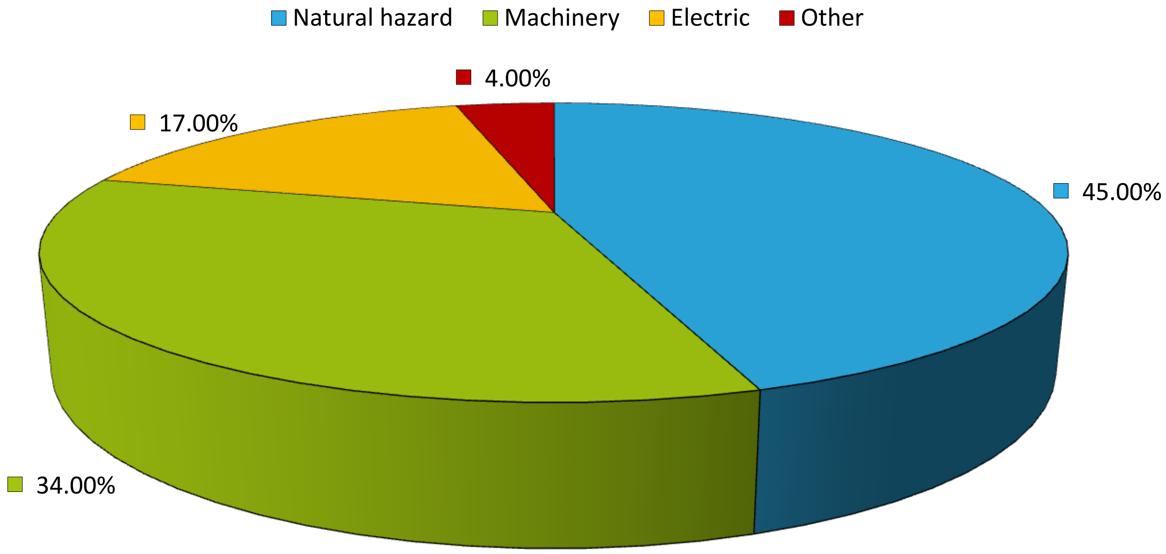


Figure 3.5. Main reasons for the accidents in Polish mines in 2017 (PSMA)

According to PSMA observed categories of unwanted events in years, 2013-2017 are as follows:

- **Methane hazard-** in the analysed period, 22 accidents were related to a methane explosion. As a result, 13 miners died, and 82 workers were injured, and 20 sustained slight injuries. All accidents took place in UG coal mines.

- **Rockburst hazard -** 18 accidents were related to rockburst. As a result, 13 miners died, and 82 workers were injured.

- **Rockfall hazards-** There were 18 accidents related with rockfall, 14 in coal mines and four in copper mines. As a consequence, 22 miners died, and 18 workers were seriously injured. In 2017 there were four rock falls, all of it in UG coal mines.

- **Fire hazards-** There was recorded 49 accidents related to fire hazards, 38 in coal mines and 11 in copper mines. In effect, one miner was slightly injured. In 2017 in UG mines there were 12 fires, 10 in UG coal mines and one in UG copper mines. During the evacuation, 39 miners had to use a self-rescuer.

- **Gas and rock ejection hazards-** There was one accident related to gas and rock ejection in 2015 in a UG copper mine. There were also two events probably related to the dynamic gas eruption. There were no victims. All accidents occurred after blasting works.

- **Mining climate hazards** - There were no accidents related to the mining climate. This kind of hazards has been mitigated by air condition systems or/and reduction of working time.

- **Flood hazards**- There were no accidents related to the flood of the underground workings.

- **Underground traffic accidents-** 57 serious accidents related to machines and mechanical tools were recorded. As a result of these accidents, 35 employees died, and 21 were seriously injured.

- **Hazard related to the utilization of explosives in the extraction process** - 10 accidents related to the use of explosives were recorded. Because of these accidents, one employee died, one was seriously injured and 11 slightly injured. In 2017 there was no accident of this type.

3.2. Safety issues in Underground Laboratories

Underground laboratories may be described as facilities with great research, educational, and touristic potential due to their unique environment. UL's are especially suitable for geo- and astrophysical measurements, and the development of mining technology, including sophisticated support systems, data transmission, and fully automated machines. Of course, working in deeply located laboratories is associated with numerous hazards, such as the ones observed in underground mining. Absence of natural ventilation by diffusion, risk of roof fall or even seismic activity, underline the necessity of conducting very detailed and thorough risk assessment (Martyka, 2015; Groves et al., 2007; Li et al., 2007). The expected level of risk increases in the case of facilities built near active mines and fault-affected zones (Fuławka et al., 2018; Zorychta & Burtan, 2012). In this case, additional preventative measures need to be implemented

Risk in underground laboratories should be appropriately scaled according to the lower possibility of certain hazardous occurrences and lower impact of possible events in comparison to a real, active mining environment. Especially geomechanical hazard should be lower, because the lack of large-scale exploitation, results in a lower disturbance of rockmass stress-strain conditions. According to data obtained in BSUIN project, in most cases, an underground facility such as a UL is built just after the underground exploitation has ended. It allows new users to ensure that geomechanical conditions are relatively stabilised. Still, from the scientific point of view, the building of UL near active mining can work too, providing the opportunity to develop and test new methods and technology in real mining conditions.

Still, regardless of the type of laboratory, the probability of each possible risk should be analyzed and evaluated in a very detailed way. The database containing possible unwanted events was created based on experiences gathered by the management of Underground Laboratories in the Baltic Sea region, supervisors and underground mines as well.

4. UNDERGROUND LABORATORIES IN BALTIC SEA REGION

One of the main objectives of the BSUIN project is to create a unified guideline of risk identification, assessment and mitigation methods, based on the exchange of best practices in the field of Health & Safety. The newly established network includes underground laboratories in the research and development sector (Callio Lab from Finland, Äspö HRL from Sweden, Reiche Zeche from Germany, UL of Khlopin Institute, Russia) and laboratories intended mainly for tourist purposes (Ruskeala, Russia). In addition, the project will be enriched with a guideline based on the conceptual model of an underground laboratory located in a deep mine characterized by high seismic activity developed by KGHM Cuprum, Poland. The location of the underground laboratories involved in the BSUIN project is shown in Figure 4.1.

1- Conceptual lab development co-ordinated by KGHM Cuprum R&D centre, Poland; 2- Callio Lab, Pyhäsalmi mine, Finland; 3-Äspö Hard Rock Laboratory, Oskarshamn, Sweden; 4-Reiche Zeche, TU Freiberg Research and Education mine, Germany; 5- Ruskeala, Russia; 6- Khlopin Institute Underground Laboratory, Russia

Figure 4.1. The new network of Underground Laboratories in the Baltic Sea Region

4.1. Callio Lab, Finland

Callio Lab is a UL situated in the Pyhäsalmi mine in central Finland, 160 km south from Oulu and 180 km north of Jyväskylä (or 350 km from Helsinki). (Figure 4.2)

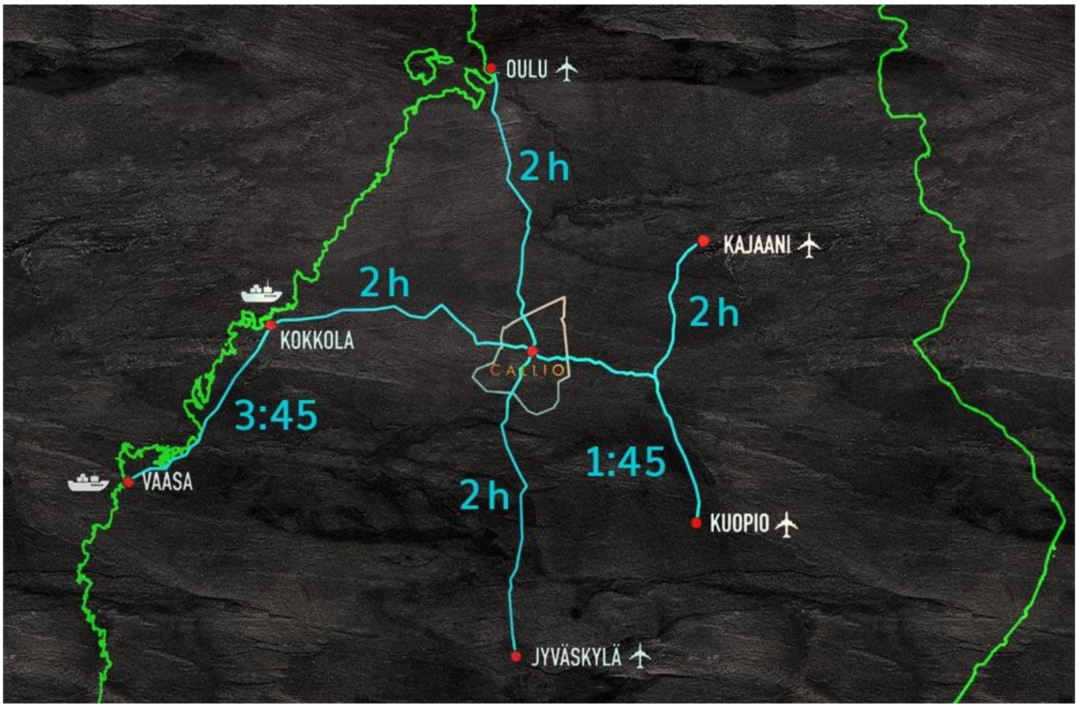


Figure 4.2. Travel time to the whole lab from urban centres

The Callio Lab is part of the Callio – Mine for the Business concept. The Callio is an umbrella organisation for all the re-use activities, whether business, educational or scientific in nature, in the Pyhäsalmi Mine. Callio Lab coordinates the underground science and R & D activities within the Callio. Already six underground labs exist in various levels starting from the depths of 75 down to 1436 metres hosting different activities. The physics experiments can be found at Lab 1, and 5, agriculture in Lab 2 & 4, underground safety Lab 6. Moreover, a well-developed network of underground tunnels is suitable for testing of mining and tunnelling equipment. Examples of underground space usage in Callio Lab is presented in figure 4.3.

Figure 4.3. Current usage of underground workings in Callio lab

All the mine's tunnels are accessible by truck via the 11 km long incline tunnel, extending from the surface to the bottom of the mine, at a depth of 1.44 km depth. The main level (1.4 km underground) is also accessible with the fast elevator (3 min) from the surface. The maximum speed of the elevator is 12 m/s, and it can transport up to 20 people at a time.

4.2. Äspö Hard Rock Laboratory, Sweden

Äspö Hard Rock Laboratory is a research facility where much of the research about the Swedish final repository for spent nuclear fuel is taking place. It is located in the Simpevarp area, in the municipality of Oskarshamn in Sweden. The island of Äspö is located 30 km north of the centre of Oskarshamn and is close to the nuclear power plants. The underground part of the laboratory consists of a main access tunnel from the Simpevarp peninsula, to the southern part of the island Äspö, where the tunnel continues in a spiral down to a depth of 460 m. The depth of Äspö HRL is 0-460 m. Most of the experiments and full-scale demonstration tests are carried out at the 420 and 450 m levels. Examples of underground space usage in Äspö HRL is presented in figure 4.4.

Figure 4.4. One of the chambers in Äspö HRL prepared for research purposes

The Äspö HRL was constructed for the test, design, and construction of a deep geological repository for the final disposal of the Swedish spent nuclear fuel, and it has been in operation since 1995. The current use is devoted to methodological and technical development for final disposal of spent nuclear fuel, in combination with new use in the form of environmental, geotechnical, geo-energy, material science, and various technology development projects. The aim is to turn the facility over to future research and development stakeholders.

4.3. Reiche Zeche, Germany

Research and Education Mine "Reiche Zeche" is located on the edge of the Erzgebirge in the municipality of Freiberg. Freiberg is situated in the centre of Saxony between Dresden and Chemnitz, and close to the Czech border with around 40 km to each side. The expansion of Reiche Zeche mine includes drifts of 129 km, of which 19 km are safely accessible and frequently in use. The mine is accessible up to a level of 230 m, the water level of Rothschönberger Stolln. The level of up to 750 m is flooded. Two shafts realise the access to the mine.

The mine "Himmelfahrt Fundgrube" was founded as a consortium of multiple individual shafts in 1839 to enhance the production of silver in Freiberg. It was first closed in 1913 and handed over to Bergakademie Freiberg in 1919 for teaching purposes. In 1937 the mine was reactivated and once again in operation until 1969. Finally, in 1976 the shafts "Reiche Zeche" and "Alte Elisabeth" were handed over back to the University for research and teaching purposes. Today, multiple research institutions and partners from industry use the mine as a fundament for the development of new technology, production methods, new materials, or to gain reference materials for their databases.

Currently, underground spaces in the Reiche Zeche Lab allow the conducting of research in mining and raw material-related fields. The mine management is capable of establishing underground laboratories, workshops, and office spaces for long-term projects (Figure 4.5).

Figure 4.5. Geophysical measurement in Reiche Zeche Underground Lab

4.4. Ruskeala Mining Park, Russia

The Ruskeala Mining Park can be reached by car from Petrozavodsk (about 250 km), from Sortavala (about 25 km) and Joensuu (Finland) as well – about 130 km. The nearest airport is also located in Joensuu. The "Ruskeala" UL is mostly used for tourism-related purposes (Figure 4.6), but recently, research activities have been conducted too. Currently, these are concerned with the different methodological and technical methods for roof control, and investigation of weak zones.

All data from the Ruskeala Underground Lab is stored at the Institute of Geology KRC RAS. It is possible to organise external projects, including experimental services, ranging from geophysical to tectonophysical study of the area, photogrammetry, and other investigations as well.

Figure 4.6. Touristic part of the Ruskeala Mining Park

4.5. Khlopin Institute Underground Laboratory, Russia,

The laboratory is located in the very centre of St. Petersburg at a depth of about 60 meters. Currently, underground laboratory measurements of tritium on the TriCarb 3100 installation are being conducted. Also, there are three gamma-spectrometer complexes with powerful protection against an external background.

All data and results of research done in the underground laboratory are part of the reports in scientific and commercial contracts. Data is available for customers and contractors. There are several publications available in Russian.

4.6. Conceptual Lab development in deep copper mine condition by KGHM Cuprum, Poland

KGHM Polska Miedź S.A. comprises three of underground copper mines and metallurgic plants in west-southern Poland, close to the towns of Lubin and Polkowice. The company does not have underground laboratories in the classic sense. Instead, it has between depths of 650-1300 m in its disposal hundreds of kilometres of existing excavations, which are accessible and driveable. Each excavation may serve, if necessary, as a temporary trial panel or underground laboratory. The excavations can be utilised for different purposes, e.g. for improvement of excavation, development of blasting or ground support technologies, best matching to the local mining and geological conditions. This is supplemented by a rock KGHM CUPRUM surficial facilities in Wrocław.

The KGHM mines were constructed mainly for the copper ore excavation, processing, and smelting. They have been under constant development for almost 60 years. In selected areas of existing mine workings, UL's may be constructed and built for research and development purposes.

5. BEST PRACTICES IN UL MANAGEMENT

According to Wikipedia, the best practice is determined as „*A best practice is a method or technique that has been generally accepted as superior to any alternatives because it produces results that are superior to those achieved by other means or because it has become a standard way of doing things, e.g., a standard way of complying with legal or ethical requirements*." Each of the UL's was sent a questionnaire with specific best practices they had developed or applied during their operation. Each questionnaire also had an open part where the UL representatives could add their own best practice, that they would like to share with other UL's. The outcome of the best practices' questionnaire has been divided into four subcategories, under which each best practice is briefly described.

5.1. Accessibility and outside visitors

Ruskeala Mining Park in Sortavala, Russia is an old marble quarry which has been natural tourism area. To expand the range of service, an underground part was recently opened to the public. The underground parts are partially filled with water; in order to enable underground visits, floating platforms have been installed. The width and the structure also enable visitors with disabilities to move around in their wheelchairs. Reiche Zeche, TU Freiberg Research and Education mine, is also used for tourism and events. The activities are carried out by a non-profit organization "Förderverein Himmelfahrt Fundgrube Freiberg e.V.". The organization was founded in 1992 to preserve the mining and industrial traditions and transfer mining/industrial history. The non-profit organization bears the costs of its surface facilities and underground gear. The tours range from short and easy trips to up 5 hours long expert tours through mining areas from the 16th to 20th century. Later, meeting and festival rooms have been created to extend the range of services. There is also a route for disabled bodied visitors called a teaching path.

5.2. Controlled parameters and observation points

Underground locations need to be monitored, and the data needs to be comparable with previous and future measurements. At Reiche Zeche, they are using dedicated measuring points indicated by wall-installed info boards, where the location is identified, and the previous value and the conducting engineer is mentioned. This ensures the repeatability of measurements and comparison of values over longer periods with other UL's as well. Enclosed spaces, such as those found in mines and UL's, can cause unfortunate surprises in the form of gas build-up. Both Lab development by KGHM Cuprum R&D centre, Poland and Callio Lab, Pyhäsalmi mine, Finland, are operating inside active mines. In underground workings, the gases released during mining, or the exhausts from diesel power engines can cause significant risks for the employees working underground.

Common toxic gases are hydrogen sulphides, carbon dioxide and carbon monoxide. Monitoring is conducted by infrastructural sensors and in workings by personal gas monitors. Equipment and facilities dedicated to the monitoring and determining the radioactivity of different materials are needed. One such location is located at the UL of Khlopin Radium Institute at the heart of St. Petersburg. In order to measure the gamma-ray spectrum with high precision the spectrometers need to be located underground (shielding from the cosmic rays induced background radiation) and additional shielding is required to shield from gamma-rays emanating from surrounding materials. With careful selection of shielding materials, e.g. aged steel and lead, the background can be suppressed significantly. And by putting emphasis also on the radiopurity of detector materials, the background can be reduced even more. To suppress the contribution of radon into the background, the radon-laden air is displaced by using hollow, sealed liners made of lightweight and low-level material. For their manufacture, 3D printing technology from polymeric materials was used, which had minimal radioactive impurity content. The created unit, yielding to the best European laboratories, is by far the best in Russia. The detector system needs to run under cryostat, operated by scientists at Khlopin using special liquid nitrogen regenerating dewar vessels, thus enabling the continuous operation for several years.

5.3. Personnel training and monitoring

The underground environment can be dangerous and unpleasant for personnel. This is the reason why the training of workers, infrequent operators and visitors on the safety issues is very important. For permanent personnel and infrequent operators, like most of the UL users are, the training is extensive. These trainings include identification of risks, how to move underground, and how to operate in case of an emergency. The CURPUM policy is that all non-staff operators and visitors are accompanied by a staff member as a guide and supervisor. The Callio Lab policy is that after training and gaining experience working underground, one can operate without supervision. Only non-Finnish speaking operators need to be accompanied by an experienced Finnish speaking guide(s), in case of an emergency. In both places, all visitors take introductory training on underground safety and visitors are accompanied by guides. In case of an emergency or getting lost in the underground tunnels, locating the underground personnel is a matter of grave importance. At ÄSPÖ they are using the local area WIFI network relay stations to locate individuals through their facility VOIP phones. At CUPRUM mines, they are using special signals emitted from the helmet lights to locate individuals with a receiver system.

5.4. Environmental and Economical

Wintertime with sub-zero temperatures can be a challenge for UL's due to ice formations. At Callio Lab in the Pyhäsalmi mine, Finland, there is a constant flow of fresh air from the surface to the bottom of the mine. The airflow is at a maximum of 130 m^3/s. With the high flow rates, the air temperature inside the mine needs to be at least +4 degrees to prevent frost from forming. Previously the air was heated with fossil fuels or with natural gas. With the new system, the idea was to achieve cost savings by using the existing heat sources, like wastewater from flue gas scrubber (water temperature up 40°C) and the mine wastewater (water temperature 17°C). In just three years, the investment had paid back. Currently, the system uses only the mine water, but is still producing annual savings. The heat recovery system saves annually 500 tons of fuel oil and reduces CO2 emissions by 1400 tons annually compared to the old system. Another form of adding savings, is to reduce energy consumption and maintenance costs is to change from normal lighting into intelligent lighting. At ÄSPÖ, the lights are dimmed or switched off when no one is at the vicinity of the light sources. For this, they used a commercial supplier who had a fully integrated product available. The change to i-lighting has created savings in energy and has also extended the interval of lamp changes.

5.5. Summary and Conclusions

All of the UL's have unique and practical knowledge and methods they have adapted in their operations. The best practices shown have resulted in improved safety, increased usability and accessibility of the UL's, and savings in maintaining the UL infrastructures. By sharing the best practices among the UL's within the BSUIN network, the UL's organizations can learn from what others have early applied and found practical. This will, in time, reduce the barrier to adopt new practices, as there are working examples available, and which can be developed even further.

6. POSSIBLE UNWANTED EVENTS IN UL'S AND EVALUATION METHODS

Facilities located in these underground environments may be used in different activities, including industrial, tourism-related, and scientific. Scientific fields have use of them as underground laboratories. Underground environments are unique and can provide ideal conditions for a sophisticated type of research in a broad spectrum of industries. These type of facilities are suited for developing new technologies to be used in mining, geophysical surveys, radiation detection, as well as many other studies and measurements.

Unfortunately, working environments in underground excavations are associated with exposure to many hazards not encountered in the facilities located on the surface. Water inflow, gas bursts, roof-fall, rockbursts, and even seismic hazards translate into high accident rates in the underground mining industry. Historically, safety statistics for underground mining and construction show, that the risk of injury is higher underground by a factor of two or even more. Awareness of the threats that are present underground, in connection with proper measures and controls, are crucial to maintaining a safe working environment. This translates into sufficient understanding of hazards, and training of safe operating practices. An integral part of an effective safety system is the monitoring of the environmental parameters that are present, their significance, and hazard level.

6.1. Seismicity

Mining induced seismicity is one of the most dangerous hazards due to its rapid and dynamic nature. Underground exploitation causes the local disturbance in a state of unstable equilibrium, which may result in the sudden release of energy, mainly in the form of mining tremors. The scale and intensity of these types of events depend on a number of factors, of which the most important are (Fulawka et al., 2018-monitoring):

- depth of mining,
- the geometry of the mining drifts,
- distance to the disturbed zones,
- proximity to mined out areas,
- physical and mechanical properties of the surrounding rocks,
- applied type of support,
- presence of tectonic disturbances

A basic solution used to evaluate seismic hazards is the implementation of seismic measurement at areas of induced seismicity. Continuous monitoring of velocity, acceleration, or displacement amplitude of the seismic wave allows the determining of energy and location of the seismic event. Detailed investigation of maximum amplitudes, frequency characteristic, and relative power distribution allows the analysis of how each seismic event affected object stability. Measurements may be carried out with the use of accelographs, geophones, or seismometers, depending on expected maximum amplitudes and frequencies of waves. Generally, at short distances from seismic sources, accelerometers and geophones are suitable options due to their characteristics.

Example of seismic wave analysis in terms of dominant frequency determination and calculation of spectral distribution is presented in figure 6.1.

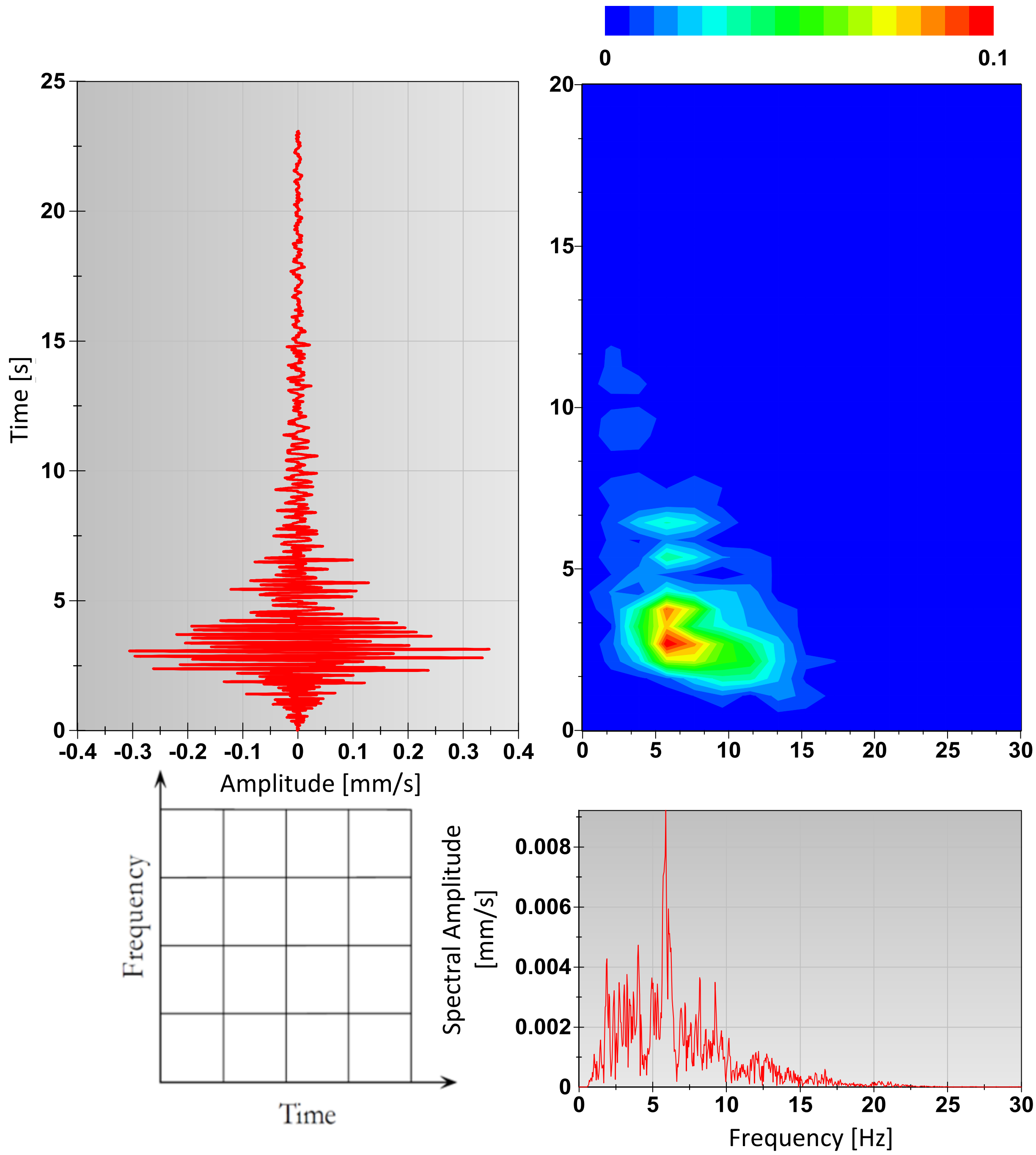


Figure 6.1. Example of seismic data analysis in time-, frequency-, and energy domain

As of now, there is no reliable technical solution which would allow the prediction of tremor occurrences in terms of its time, location, and energy. Still, some statistical methods based on past seismic activity are commonly used.

6.1.1. Prediction with use of Gutenberg – Richter law

Observed mining tremors are characterised as random events regarding their time of occurrence, location, and energy. The magnitude of these phenomena is generally lower than in earthquakes but can have an adverse effect on structures both on the surface (buildings) and underground (drifts, chambers).

In some cases, such events may result in rockbursts or roof falls. It should be emphasised that proper rockburst prevention has to be preceded with hazard assessment.

Due to the stochastic nature of seismic events, the probability of their occurrence may be assessed based on statistical methods. This, in turn, requires collecting a relevant database on the seismic activity within the evaluated panel, including:

- location of each event (x, y, z coordinates),
- energy,
- number and frequency,
- type (provoked by blasting or spontaneous).

Based on the spatial and energetic distribution of seismic events, statistical hazard assessment may be done. For that purpose, the Gutenberg–Richter law may be applied, which expresses the relationship between the magnitude and the total number of earthquakes in any given region, according to the following equation:

$$log_{10}N = a - b \cdot M \tag{6.1}$$

where:
N – number of events having with a magnitude $\geq M$,
a, b – constants (same for all values of N and M).
It is worth mentioning that the Gutenberg–Richter law is a statistical method, so it is affected by a number of uncertainties and limitations. This method does not allow to determine the precise location of a potential seismic event, thus reducing its usefulness for the purposes of active rockburst prevention.

6.1.2. Numerical simulations of rock mass behaviour

Numerical modelling and stress/strain analyses allow the determining of the overall stress/deformation states of the rock mass subjected to static loading. This information is then used for quantitative characterization of the actual level of safety in the vicinity of evaluated panels, using indicators called safety factor or safety margin, in relation to different failure criteria.

The values of safety factor smaller than 1 indicate the likely occurrence of instability in the rock mass (negative value in the case of safety margin). Numerical investigations allow determining the approximate location in the roof strata, which are prone to instability and thus evaluate the rockburst hazard level.

6.1.3. Prediction of tremors intensity developed by KGHM CUPRUM

Appropriate seismic activity forecast involves the following methods (Stolecki et al. 2020):

- a statistical method based on probabilistic analysis of seismic hazard,
- the method based on geologic and mining situation analysis.

The combination of results obtained from the above methods, allows, with high reliability, the estimation of the maximum seismic energy of mining tremors for the considered panels. The statistical method based on probabilistic seismic hazard is used to determine future seismic energy values. This method allows for assessing the energy of expected mining tremors. The result does not indicate the exact energy values, but it suggests the upper limit that should not be exceeded.

In the first stage, zones with a similar level of seismic activity are separated. The analysed data considers both time and spatial distribution of tremors. Then, the distribution of epicentre locations, the frequency of occurrence, and the number of mining tremors are determined for each zone. Probabilistic distributions are characterised for each of the above parameters. As a result, information about past seismicity is used to assess the intensity of future events.

The energy of the seismic event is then logarithmized according to the formula:

$$m = \log E \tag{6.2}$$

The cumulative distribution estimator n for the recorded events of energy $mi \geq mmin$ is determined by the formula:

$$F_A(m) = \begin{cases} 0 & \text{for } m<m_{min} \\ \dfrac{\sum_{i=1}^{n}\left[\Phi\left(\dfrac{m-m_i}{\omega_i h}\right)-\Phi\left(\dfrac{m_{min}-m_i}{\omega_i h}\right)\right]}{\sum_{i=1}^{n}\left[\Phi\left(\dfrac{m_{max}-m_i}{\omega_i h}\right)-\Phi\left(\dfrac{m_{min}-m_i}{\omega_i h}\right)\right]} & \text{for } m_{min}\leq m\leq m_{max} \\ 1 & \text{for } m>mmax \end{cases} \tag{6.3}$$

where:

$\Phi(x) = \frac{1}{\sqrt{2\pi}}\int \exp(\frac{-\xi^2}{2})\,d\xi$ - cumulative distribution of normal distribution,

h - smoothness parameter selected by minimizing the mean total square error

$m_{\min} = \log E_{\min}$, $E_{\min}$ - a lower threshold of completeness of observation,

$m_{\max} = \log E_{\max}$, $E_{\max}$ - upper source limit.

It is known that in given geomechanical conditions, the occurrence of tremors is strictly related to strength parameters of surrounding rocks. Therefore, there is always a value $Emax$, that tremors with energy over the $Emax$ limit are not possible. Estimation of $mmax$ may be determined according to the following formula:

$$m_{max} = m_{max}^{obs} + \int_{m_{min}}^{m_{max}}[F(m)]^{\lambda T}\,dm \tag{6.4}$$

where:

$m_{\max}^{obs} = \log E_{\max}^{obs}$, $E_{\max}^{obs}$ - the energy of the strongest event

$F(m)$ - The cumulative distribution of energy

λ - the average frequency of tremors occurrence with the magnitude of ≥ m_{min},

T - period of activity of the zone

The predicted maximum seismic energy estimator is a parameter for the assessment and prognosis of seismic hazard level. It is assumed, that tremors with the energy greater than $Emax$ will never occur. It should also be noted that the reliability of $Emax$ is strictly related to the quality of archival data used in the forecast, and their appropriate assignment into the individual seismic zones.

When different mining or geologic conditions are present in adjacent mining panels, the observed level of seismic activity may differ significantly between individual panels. The use of one mining panel as a reference for the prediction of seismic activity in adjacent ones is unacceptable and will not reflect the actual level of seismic hazard.

The probabilistic analysis described above, is the first stage of the forecast. The next step, is the examination of geologic and mining conditions, that have a critical impact on the energy level of tremors generated by mining operations. Recent studies conducted by the Mining Seismology Team of KGHM CUPRUM have allowed the creation of a set of geologic and mining factors, that have a significant impact on the level of seismic activity. The following factors should be taken into account when developing forecasts for seismic activity:

a) mining factors:

- size of the mined-out area and closing method of mining activity in neighbouring goafs (adjacent panels),
- size of the mined-out area and closing method of mining activity in analysed mining panel,
- the width and shape of the mining front, the direction of mining,
- depth of mining level and height of the workings,
- the actual progress of mining,
- adopted mining method,

b) geologic factors:

- tectonic dislocation structure,
- deposit lithology,
- boundaries of sandstone stratum with anhydrite binder.

The combination of the above-mentioned methods, i.e. seismic hazard assessment and analysis of the mining- and geology-related situations, creates a reliable tool for the prediction of seismic activity associated with the copper ore mining in the mines belonging to KGHM.

6.2. Geomechanical hazard

The scale of geomechanical hazards depends on many factors. One of the key elements affecting the level of safety in underground laboratories' operation is their depth below the surface, as the geomechanical hazard grows as depth increases (Li et al., 2007). The size of the mined-out area in the vicinity of active underground workings (Fuławka et al., 2018a) and the distance of workings from the fault-affected zones is also significant (Zorychta & Burtan, 2012). As a result, the mining industry, which undoubtedly includes underground research laboratories, is associated with a relatively high incident rate. The most dangerous events related to the geomechanical hazard is rockfall and rockburst. In Polish copper mines, rock falls or rockburst cause on average 15-20% of all accidents. In most cases, these types of events are responsible for most of the very serious injuries or fatalities. Due to this, the measure and control of these kinds of hazards are very important. In light of this, the assessment of the geotechnical hazard has to be based on the evaluation of the stress and strain state in the rock mass. Currently, the most effective method of assessment of the stress and strain field is numerical modelling combined with the in-situ measurement. Local monitoring supplies data to the validation of the model, and what is even more important, can warn directly of an imminent danger situation. Reliable geotechnical data, including mine geology and rock mechanical properties, allows assessing real risk and corrective action to limit risk level. This is the reason why proper and reliable monitoring system is crucial from a safety point of view. Monitoring of rock mass condition and stability is performed utilizing the following elements:

- Extensometers,
- Roof bed separation gauges (SRS),

- Borehole endoscope,
- Inclinometers,
- Convergence indicator,
- Borehole deformation gauge,
- Instrumented rock bolts,
- Hollow inclusion cell,
- Laser scanners,
- Other.

Most of the abovementioned devices are used in the surrounding of underground workings and allow the measuring of stress and deformation. Possible instrumentation of continuous underground stability monitoring is shown in Figure 6.2.

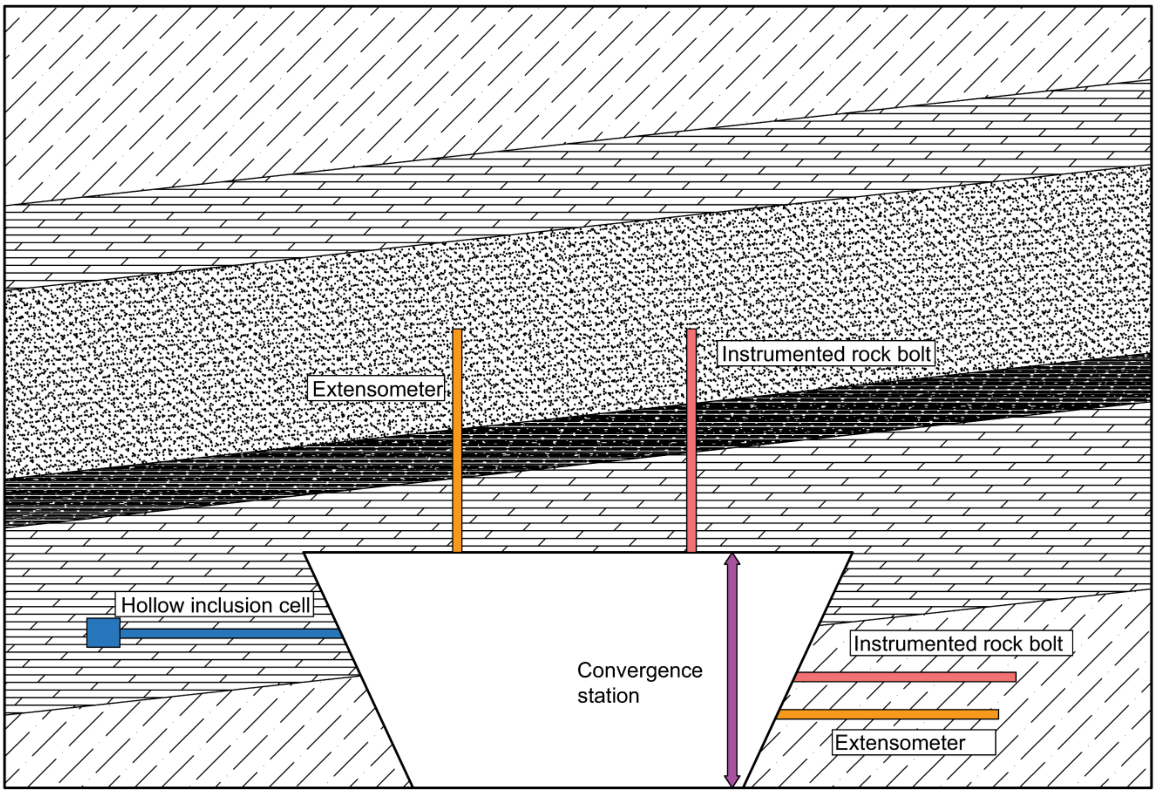


Figure 6.2. Examples of instrumentation that can be used for strata monitoring in mine (Gong et al, 2018)

6.2.1. Extensometers

An extensometer is a tool that measures displacement between two or more points along the single axis. In mining applications, this kind of tool is usually used in the borehole located in the roof strata. Value of recorded deformation and their changing in time indicates that cracks located in the roof strata develop and the stability rock strata is weakened. Operation principle of this kind of device is shown in Figure 6.3. Multi-point extensometers can measure displacements between several points along the single axis. In this case, it is possible to indicate the accurate location of the cracks. Extensometers can be connected to a wide integrated monitoring system.

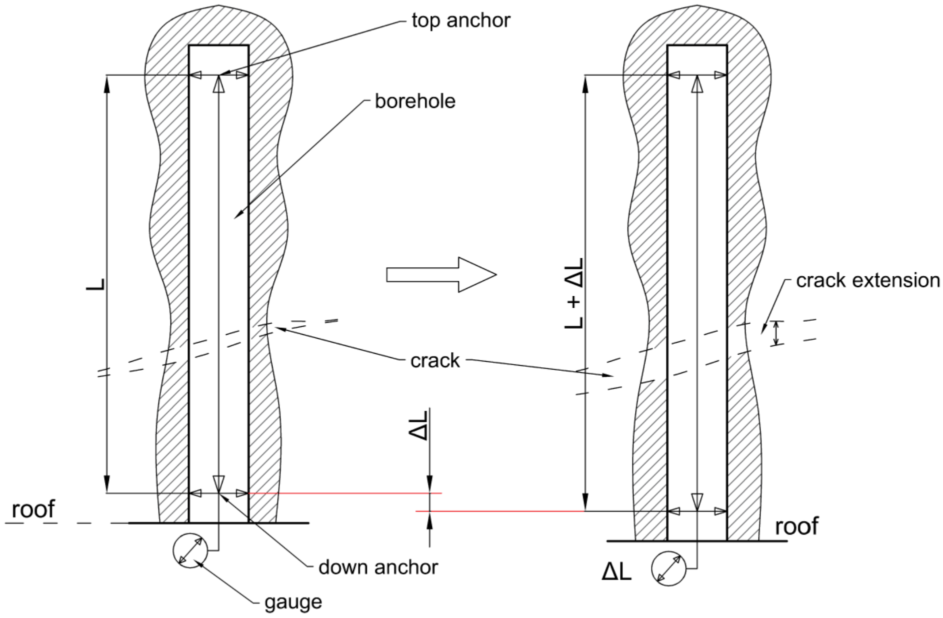


Figure 6.3. Principle of extensometer operation

Extensometers can be mechanical, electrical, or optical. Examples of this type of devices are (Fuławka et al, 2018b):

- CRN type extensometers,
- Multipoint cable extensometer.

The CRN extensometer (Figure 6.4) measures displacement between two anchored points in the roof strata. This system accuracy is 0.03 mm. This type of device is used to determine the displacement of the sliding transducer as a result of the movement of the top and lower anchors.

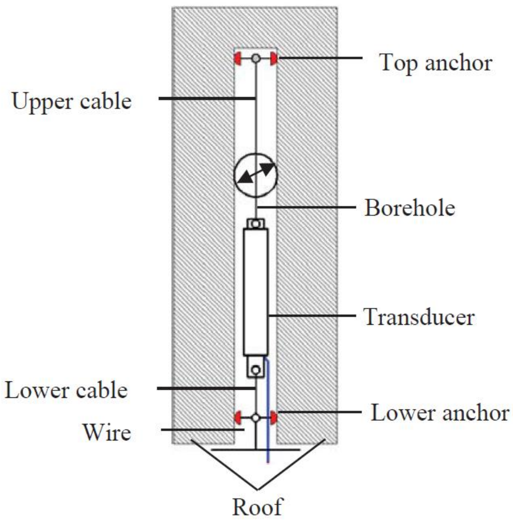


Figure 6.4. Scheme of CRN-60 extensometer (Butra et al, 2011)

On the one hand, using data collected and trend analysis, determination stability of the workings can be estimated. On the other hand, this kind of equipment can also be used as an immediate alarm system in case the limit of the border of displacement is passed. An example of data gathered from extensometer is shown in Figure. 6.5.

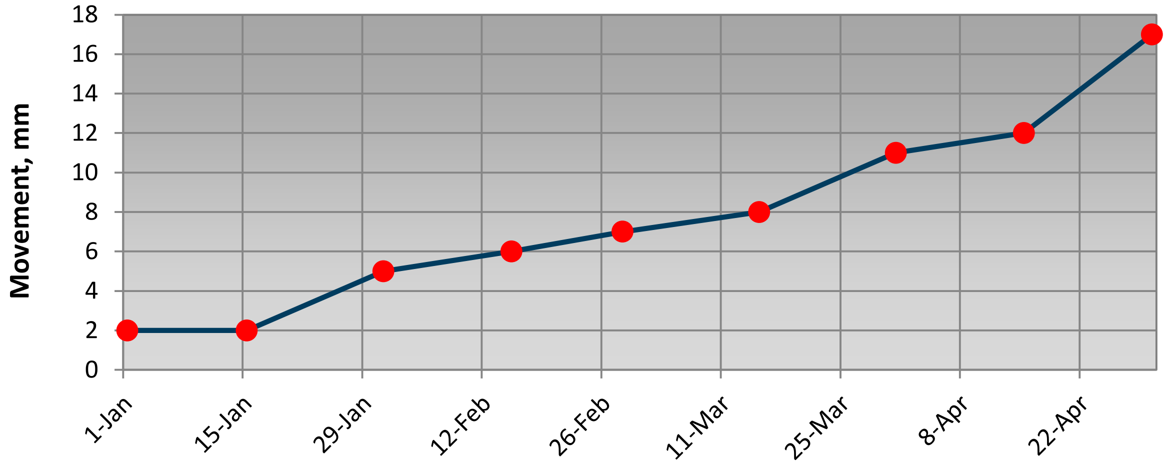


Figure 6.5. An example plot of data recorded by the extensometer

6.2.2. Roof separation gauges

Concerning the roof strata observation, it is worth mentioning a very simple device that is still in use to this day. These devices, called roof bed separation gauges SRS (Sensors of Roof Separation) measure roof delamination. These are installed at all crossings of production excavations in Polish copper mines and are used for the observation of the roof stability in a regular manner. This kind of gauge is very simple to build and install. Its length depends on the height of the opening and the local condition.

In most cases, the length of gauges varies from 3 to over 7 meters. Normally the depth of installation of this type of sensor should be equal to double length of the regular length of the used rock bolts. This ensures that SRS sensors range to cover the weak layers of immediate roof. These sensors are produced in different variants, which differ in the number of signalling plates, their thickness and shape. The most popular version consists of a five-plate indicator and a plate thickness of 5 mm. The most common, however, is a five-plate sensor with a single plate’s thickness of 5 mm, what is presented in Figure 6.6. The disadvantage of this method is the lack of possibilities of the exact location of bed separation (Fuławka et al, 2018).

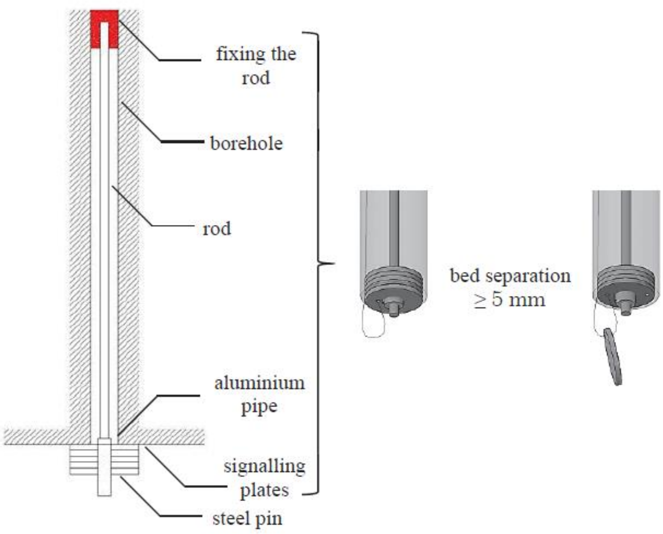


Figure 6.6. Principle of operation of roof separation gauge (KGHM, 2007)

6.2.3. Borehole endoscope

For better recognition of the roof strata, in case of observation of bed separation with roof separation gauges (SRS), there can be a necessity of determination of number and size of the cracks. For this purpose, optical endoscopes are often used. The modern type of endoscope is a special type of camera that permits observing sidewalls of the borehole. It consists of three main elements: the observation head, transmission cable, and screen (Figure 6.7). Visual assessments that can be done utilizing the endoscope provide detailed information of the crack zone and their distribution along the borehole (Małkowski, 2014).

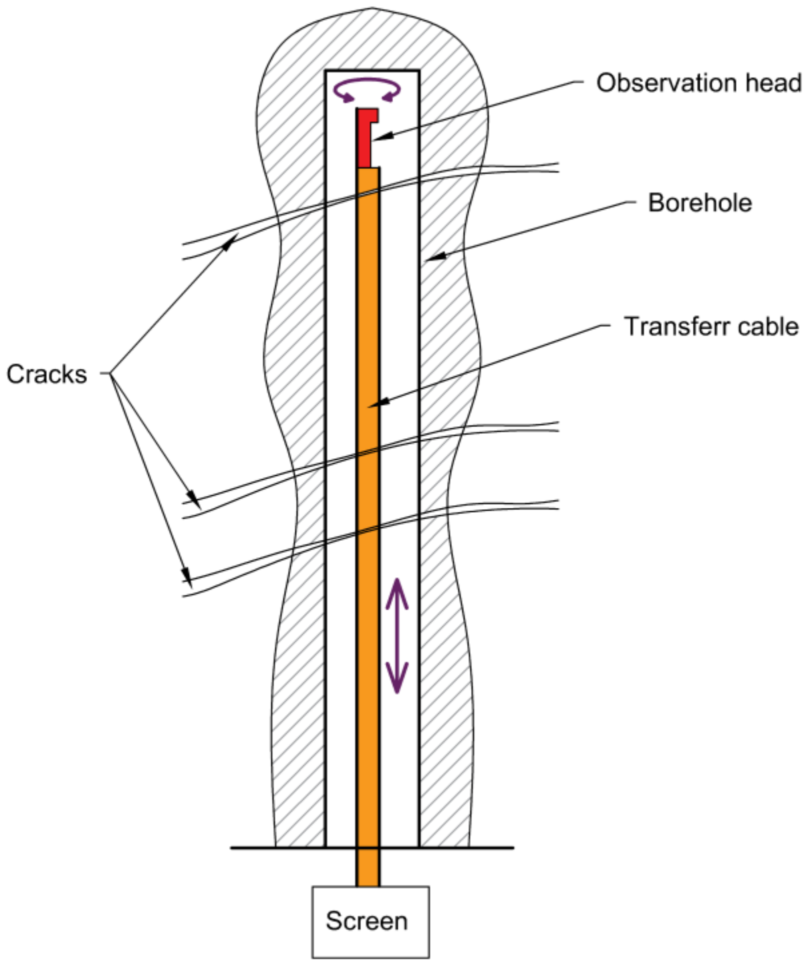


Figure 6.7. Scheme of endoscope

6.2.4. Inclinometers

Other tools that can be used to determine the strain in underground workings are inclinometers. This kind of device can be used to accurately measure the lateral or transverse movement of the elements of underground chambers, such as walls, roofs etc. Inclinometers can be used together with the other instruments to get a wider picture of the behaviour of the rock mass in the analysed area. An inclinometer consists of an inclination sensor, which can measure the angle with one or two perpendicular directions, and a recorder terminal (Figure 6.8). Accuracy of this kind of system is about ± 0.01°. Sensors come in both cabled and wireless models, depending on the system type and configuration (Grzebyk & Stolecki, 2014).

Figure 6.8. Inclinometric measurement system: communication terminal (left) and a CNS sensor (right) (Stolecki & Grzebyk, 2014)

In case of necessity of comprehensive assessment of underground chamber or drift, the inclinometer system can include many sensors installed at different locations of the facility. An example of this kind system is presented in Figure 6.9.

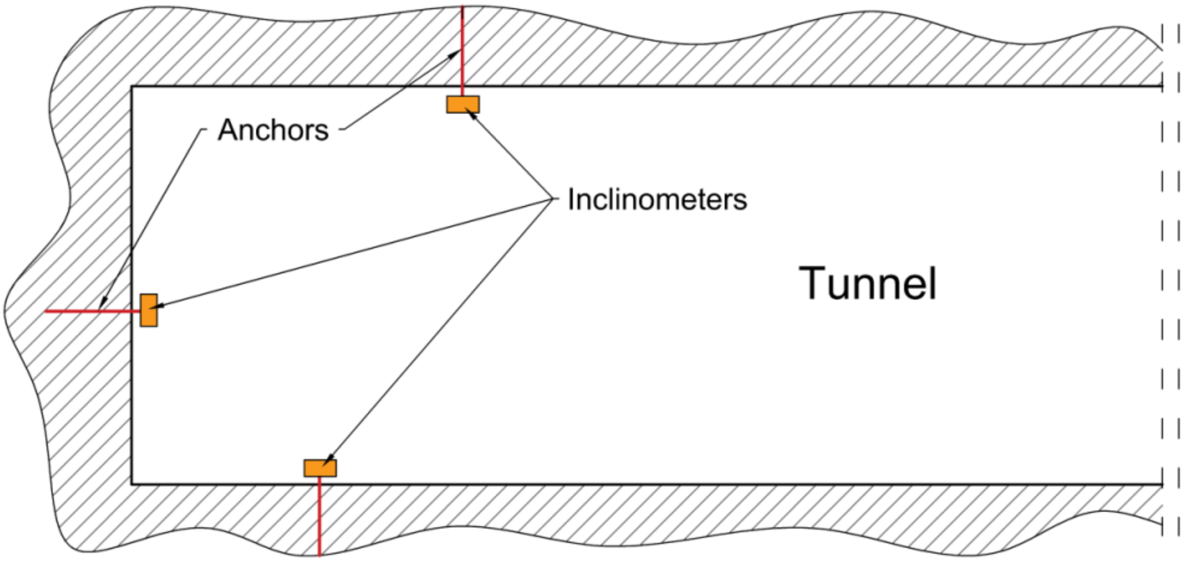


Figure 6.9. Scheme of the measurement system with inclinometers (Grzebyk & Stolecki, 2014)

Changes of angles in time and their values that are recorded during measurement are valuable data that can be used in the assessment of the mining workings stability. Similar to extensometers, there is the possibility to set a limit angle value, and when this value is passed, a warning signal turns on. An example plot of data recorded by inclinometer is shown in Figure 6.10.

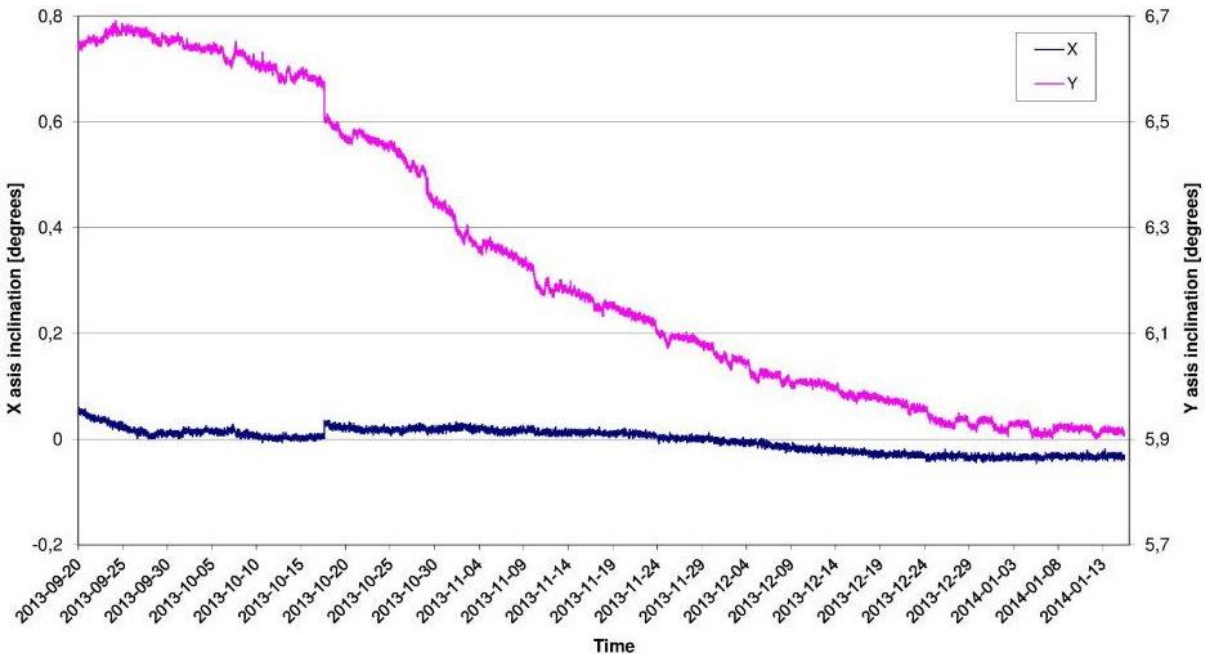


Figure 6.10. An example plot of data recorded by the inclinometer

6.2.5. Convergence indicators

Another type of device that is used for measurement of distance between the roof and floor of underground workings is a convergence indicator. The principle of this measurement is related to the changing of the cross-section dimension. In most cases, the height and width (vertical and horizontal dimension) of the workings is measured. Several types of convergence meters are currently used, but their principle of operation is similar. Depending on environmental conditions, convergence meters can be mechanical, optical (laser rangefinder), etc. In most cases, sensors are permanently fixed between two points: one on the roof and one on the floor. Nowadays, the most popular version is an optical model, where the measurement is carried out by a laser rangefinder. Scheme of this kind of system is presented in Figure 6.11.

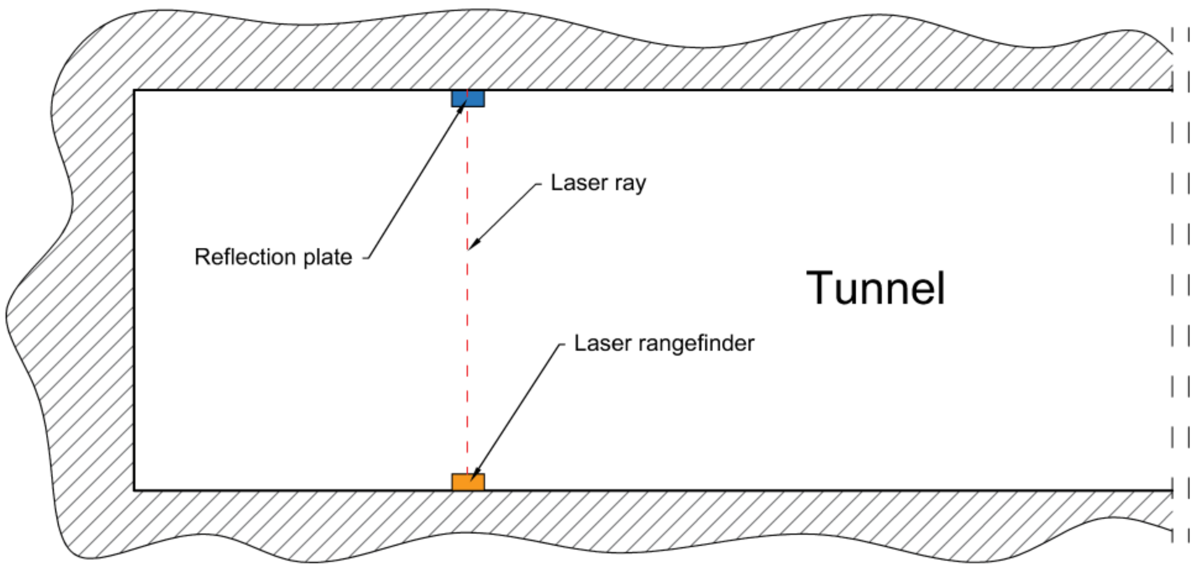


Figure 6.11. Scheme of a laser convergence indicator

The measurement can be done manually or automatically, depending on the local conditions. Currently, there is a tendency to favour automated measurements and integrated systems to obtain data transfer and analysis in real-time, which is very important from a safety point of view.

6.2.6. Borehole deformation gauge

The measurement of borehole deformation can be conducted by means of different types of sensors. For example, the sensors currently used in Polish copper mines are DD (Diameter –Diameter) and DL (Diameter –Length). These devices allow observing the changes of hole diameter and distance between two points anchored in the axis of the borehole. Installation of the sensors horizontally in the pillar ensures the measurement of deformation in the vertical direction, as well as, deformation of the rock mass along the axis of the borehole (Figure 6.12). Observation of the relationship between diameter and length values allows the assessment of the transformation of the pillar into the post-critical state is safe or unsafe. In case the situation is deemed unsafe, de-stress blasting can be carried out to avoid the risk of pillar bump (Orzepowski & Butra, 2011).

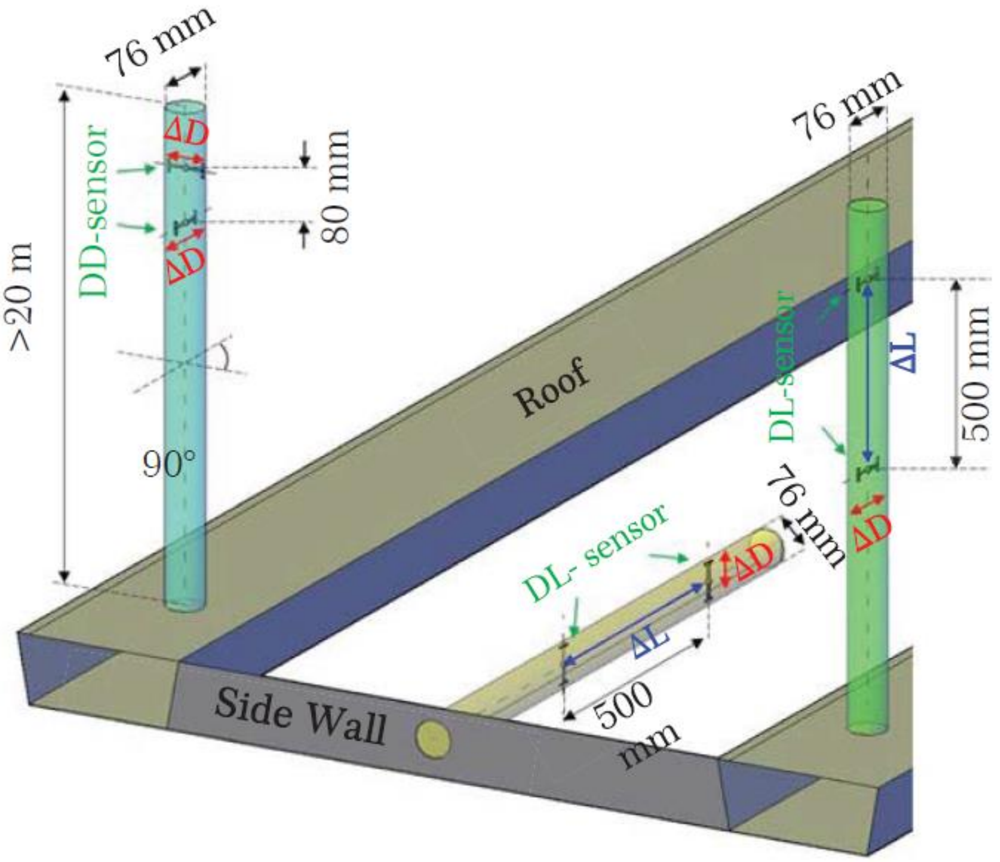


Figure 6.12. Application of borehole deformation sensors (Fuławka et al, 2018b)

6.2.7. Instrumented rock bolts

Observation of the rock strata is also possible using instrumented rock bolts (Figure 6.13). The measurement relies on strain gauges that are installed along with rock bolt. This kind of device enables a measure of axial load and strain (Gong et al, 2018). Popular commercial instrumented rock bolts are equipped with electrical strain gauges. Measurements using electrical strain gauges are based on the changes of the conductor resistance, resulting from an increase or decrease in the cross-sectional area, due to their tension or compression. Length of the rock bolt can be adjusted to the local conditions. Data collected employing this kind of system allows us to determine the following parameters (Pytel et al, 2016):

- displacement,
- bending moments,
- axial stresses,
- share stresses.

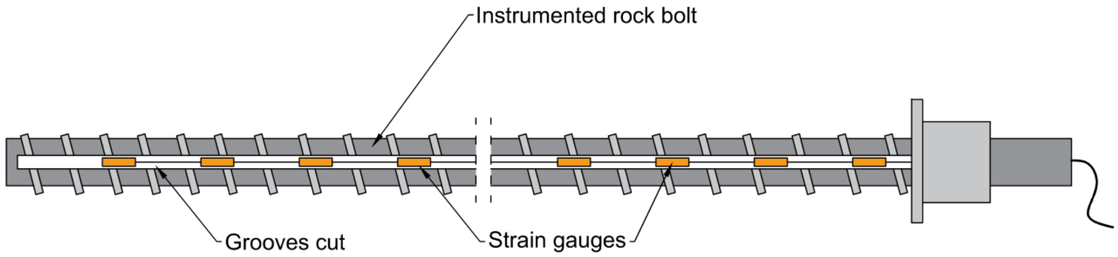


Figure 6.13. Instrumented rock bolt (Gong et al, 2018)

As an example of the application of instrumented rock bolts is a case study conducted in Polish copper mines, where innovative devices for 3D stress mapping were utilised. In this case, a four-groove bolt with a data-gathering system. The applied rock bolt was able to measure stress on five levels, along with four orthogonal directions (Pytel et al, 2016). The system was autonomous (internal battery) and allowed the recording of data with different frequency. Observation of the roof strata using instrumented rock bolts helps understand rock behaviour and avoid accidents. Instrumented rock bolts can also be integrated with other systems used for rock monitoring. An example of data collected by the instrumented rock bolt is shown in Figure 6.14.

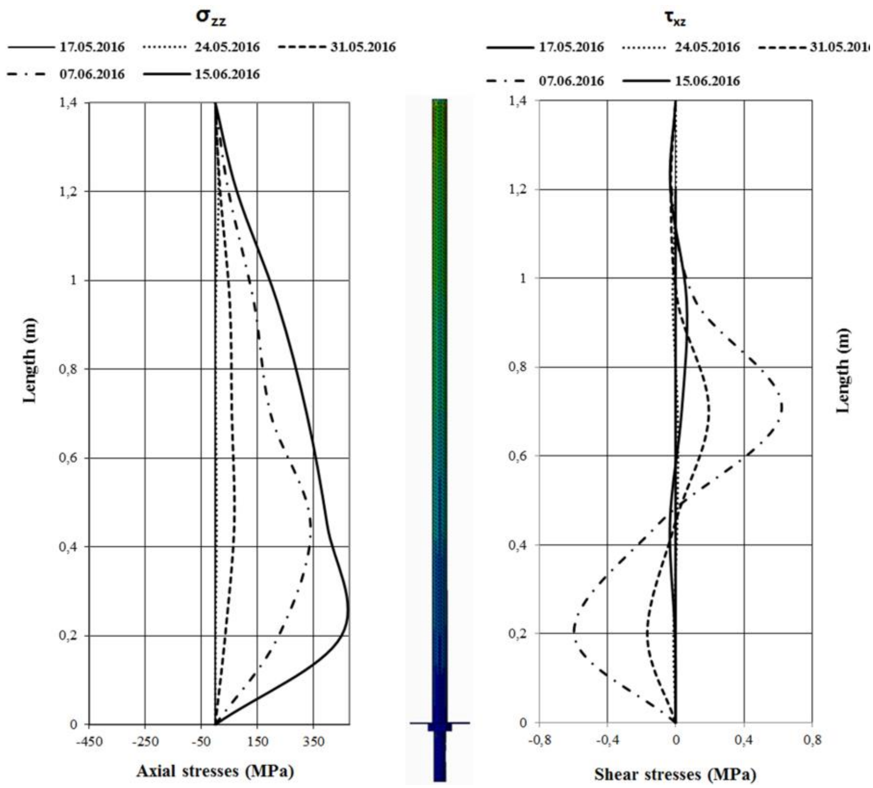


Figure 6.14. Axial stresses (left) and shear stresses (right) distribution

6.2.8. Hollow Inclusion Cell

An instrument purposefully designed for in-situ monitoring of rock stress in 3D is the Hollow Inclusion Cell (HIC). This device is fixed in the borehole located in the analysed area. It contains strain gauges in three directions, which allows continuous measurement of stress changes. Data can be recorded with different frequencies, that can be adjusted to the local conditions. Modern units provide solutions that ensure accurate measurements and limit problems with noise. The HIC consists of an array of strain gauges that are closed in the wall of a pipe with known Elastic Modulus. The cell is mounted into a borehole and monitors relative stress over time. Data transfer is provided by the cable, which can be connected to the recorder. The HIC unit can be used to monitor compressive or tensile stress changes in the long-term. The device can be equipped with up to twelve strain gauges and has applications for measuring both isotropic and anisotropic rock. Example of a HIC unit is shown in Figure 6.15.

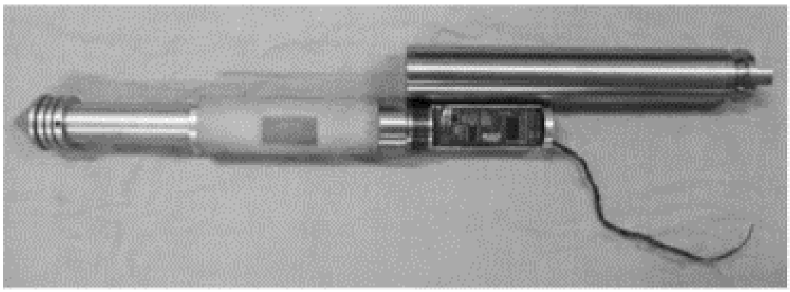


Figure 6.15. The Hollow Inclusion Cell unit (Cai & Peng, 2011)

6.2.9. Laser scanners

Development of laser scanners, especially in relation to their accuracy and speed, has created more possibilities for their use in an underground environment. One such application is the measurement of the deformation of the underground structure. Comparisons of scans conducted at different times of the analysed area can provide detailed information of mine workings or other structures convergence, in 3D in relation to time. Presently, the main problems with this technique are the speed of the scanner and disturbances in the mining process, especial during the scanning process of a large structure. Nevertheless, this method is increasingly used in underground mines for geotechnical purpose. Example of laser scanning of underground working that was done in Polish copper mine is presented in Figure 6.16.

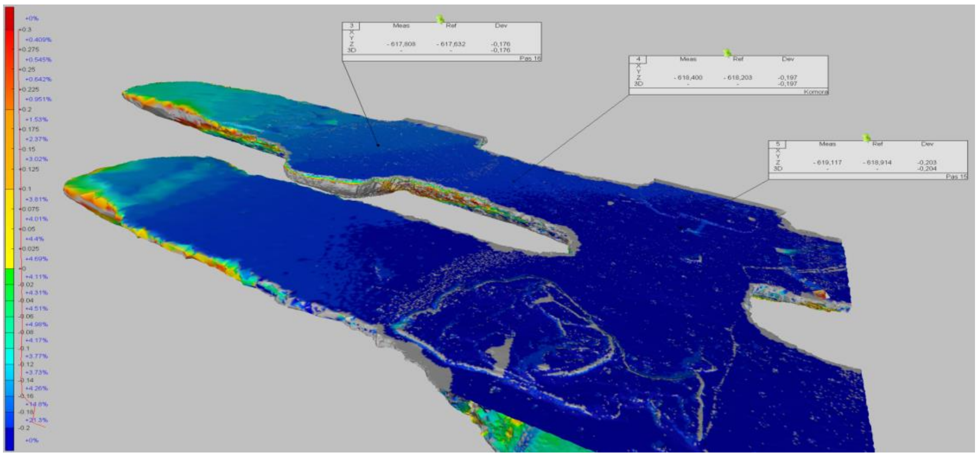


Figure 6.16. Model 3D of the mine workings generated by laser scanning (KGHM, 2016)

6.2.10. Other

Recently, fibre optic sensors (FOS) have been investigated as an alternative to electrical sensors due to advantageous characteristics such as:

- immunity to electromagnetic interference,
- increased safety due to the use of the non-electrical sensor,
- lightweight and compact,
- automated data acquisition,
- a large number of sensing points.

This kind of sensors can be used successfully in structural monitoring for engineering applications in underground tunnels and mines. Modern measurement systems, based on the FOS sensors, allow the measuring of strain at high spatial sampling rate over a large monitoring area. These sensors are also able to simultaneously measure a range of parameters like strain, temperature, and deformation over the same network (Gong et al, 2018).

6.3. Ventilation and cooling

Proper ventilation is a crucial element of a safe workplace in an underground environment. The aim of proper ventilation, on the one hand, is to supply breathable air, and on the other hand, to extract and dilute contaminants. It must be kept in mind, that underground space is limited and confined, meaning that the underground atmosphere can undergo changes very quickly due to natural gases emissions, underground fires and resulting smoke, or fumes from machines.

The underground atmosphere is a mixture of fresh air (supply from the surface) and gases emanating from rock mass, mining operations (e.g. diesel engines, blasting works), and fires. It must be noted that the three principal hazards caused by gases are as follows:

- all gases (except oxygen) are asphyxiating,
- some gases are toxic (e.g. nitrogen oxides (NO_x), carbon monoxide (CO), sulphur dioxide (SO_2), hydrogen sulfide (H_2S))
- some gases are explosive (e.g. methane (CH_4), hydrogen (H_2), carbon monoxide (CO))

It should be noted that some gases are both toxic and explosive, e.g. carbon monoxide (CO), hydrogen sulfide (H_2S). The following gases (excluding normal gases from fresh air) in different concentration can be present in underground spaces (DJ Brake, 2015):

- methane (CH_4),
- nitrogen oxides (NO_x),
- carbon dioxide and monoxide (CO_2, CO),
- sulphur dioxide (SO_2),
- hydrogen sulfide (H_2S),
- ammonia (NH_3).

Therefore, the ventilation system and its' regular control are vital elements of the safety system. The main hazard that relates to the ventilation is unbreathable atmosphere occurrence. It may be caused by:

- low oxygen level,
- occurrence in the working place the atmosphere with gases above acceptable limits,
- natural gases ejection (e.g. methane, carbon dioxide),
- combustive gases explosion or coal dust explosion,

- fires,
- confined space without airflow.

To provide effective control of ventilation, suitable monitoring of air condition must be developed and maintained in the working place. Detailed and actual knowledge of the ventilation system status, along with information on the presence of toxic or flammable gases (e.g. methane) or fumes from fires, is critical for detecting and correcting problems in the underground mine atmosphere. To fulfil these requirements, different kind of sensors can be used in targeted areas of the mine to gather environmental data on levels of gases, temperature, airflow velocity, and direction. Continuous measurement of these parameters helps to control atmosphere status, detects the abnormalities, and implements quick corrective actions. All these activities can improve the safety of the workplace. (CDC, 2020).
For the monitoring of underground atmosphere, the following instruments are used:

- oxygen detector,
- gas detectors,
- anemometer,
- thermometer,
- hygrometer,
- barometer.

6.3.1. Oxygen detector

The main element of the underground atmosphere is oxygen content. Oxygen level must be kept above 19 % in volumetric measure. For this purpose, oxygen detectors are used. The detector can be stationary or portable. In this kind of instrument, electrochemical or paramagnetic sensors are used. An example of an oxygen detector with an electrochemical sensor is portable oxygen detector DRÄGER PAC 6000 (Fig. 6.17)

Figure 6.17. Portable oxygen detector DRÄGER PAC 6000 (www.draeger.com)

This type of detectors can be used by workers, especially in enclosed spaces before entry and during work. The device works continuously and is equipped with sound alarm in case of an emergency. Oxygen detectors can be also stationary and connected into a larger ventilation system.

6.3.2. Gas detectors

Gas detectors measure the content of various gases within an area. They can be a part of a stationary safety system (stationary sensors) or portable as a part of personal protection equipment. In case a gas concentration threshold limit is exceeded, the instrument provides an alarm to workers, and it may activate safety systems and remedial actions, e.g. increasing the ventilation, turning off the power supply. These instruments come in both single or multi-gas monitor models. Modern multi-gas detectors can measure up to five different gases. In some combinations of recent sensors (able to measure two gases), measurement of seven gases is possible, but for a specific set of gases only. It must be noted that the configuration and number of gases that are measured can be changed by the replacement of used sensors. Concerning the type of gases, the following type of sensors can be used (Mandal, 2013; Brake, 2015):

- electrochemical (e.g. carbon monoxide (CO), hydrogen sulfide (H_2S), nitrogen oxides (NO_x)),
- catalytic oxidation (e.g. methane (CH_4), hydrogen (H_2)),
- infrared (e.g. carbon monoxide (CO), carbon dioxide (CO_2)),
- optical (e.g. carbon dioxide (CO_2)).

Most of the monitors provide an alarm in three forms: sound, vibration, and flashing light to attract attention in different environments and situations. It is worth mentioning that some of the detectors, besides triggering the alarm, also continuously calculate the personal time-weighted doses. (Brake, 2015) Examples of detectors are shown in Figure 6.18 and 6.19 (CARBO,2020)

Figure 6.18. Examples of methane detectors (CARBO,2020)

Figure 6.19. Examples of multigas detectors (CARBO,2020)

PAG multigas detector (Figure 6.19 on the left) can measure concertation of five gases: oxygen, methane, carbon monoxide, carbon dioxide and hydrogen sulfide.

6.3.3. Anemometer

As was mentioned at the beginning of this chapter, ventilation aims to supply fresh air to the underground area and remove and dilute danger gases. All these subjects are related to the airflow in underground workings. Airflow velocity and direction in a specified location are the crucial parameters of the ventilation system. These parameters are necessary for the calculation of the volume of air passing through the analysed area. Airflow velocity is very important from the effectiveness of both dilution of toxic gases and maintaining the proper air temperature. It means that proper measurement of the airflow rate is a necessity in sufficient control and management of the ventilation system in the underground mine. Monitoring of airflow at critical locations in real-time should be the best practise to ensure a safe workplace and is also put into law requirements regarding ventilation systems (Belle, 2013). Nowadays, in many cases, measurement is done manually utilizing portable instruments, but stationary systems that provide continuous monitoring and are part of integrated ventilation management systems are becoming more popular.

The device that is used for the measurement of the air velocity in underground working is the anemometer. The most popular type of instrument is rotating vane anemometer. In this type of device, the air passing through the vane causing its rotation. Rotation speed is proportional to the airflow velocity. Typically, vane anemometers have measurement range from 0.2 to 20 m/s. Modern vane anemometers have a digital screen where velocity value can be directly read. An example of vane anemometer is presented in Figure 6.20 (VOLCRAFT, 2020).

Figure 6.20. Examples of vane anemometers

The method that is normally used for velocity measurement using a rotating vane unit is “traverse” of the cross-section to be measured. It is important to traverse the cross-section because air velocity is faster in the centre and slower along the roof, walls, or floor. It means that a single measurement at a fixed position cannot be treated as the average velocity across the entire cross-section. It should be kept in mind that vane anemometers are sensitive to the technique of measurement and location of observer (Martikainen et al, 2010)

Another type of this type of instruments is thermos-anemometers. The principle of operation is based on the cooling effect of the moving gas. In the case of thermos-anemometers (also called hot wire anemometer or hot body anemometer), the heated element is placed in a measured location, and heat energy is removed from the wire by flowing gases. Amount of removed heat energy is proportional to the air velocity. This method is often used for measurement of flow velocities below 1 m/s. This kind of anemometers cannot be used in a potentially explosive atmosphere; in another case atmosphere must be checked before used. An example of this kind of device is shown in Figure 6.21 (Testo,2020).

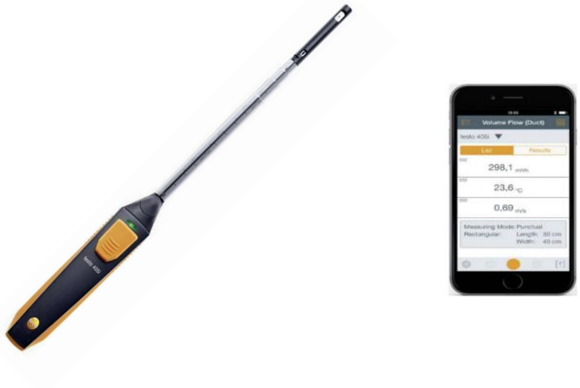


Figure 6.21. An example of thermoanemometer (Testo, 2020)

In recent years, modern sonic anemometers are becoming more popular. These types of units allow monitoring air flow very accurately. Ultrasonic anemometers can measure low velocities, continuous measurement, and can provide a direction of the airflow. Sonic anemometers can measure air velocity in three-dimensional space. It is worth mentioning that this technique does not require correction for air density. This type of anemometer can record rapid changes in velocity (Taylor et al, 2004). An example of ultrasonic anemometer is shown in Figure 6.22, anemometer AS-3ES (EMAG-SERWIS,2020). Measurement range of this device is -5 ÷ + 5 m/s with accuracy ± 0,1 m/s.

Figure 6.22. Station ultrasonic anemometer type AS-3ES manufactured by EMAG-SERWIS (EMAG-SERWIS,2020).

This kind of devices can be easily connected to integrated ventilation measurement systems.

6.3.4. Thermometers

Next major factor that is key in ventilation systems is air temperature. The temperature must be maintained in a range that is acceptable for human physiology. It means that temperature cannot be too low or too high. In relation to underground mining, the most common challenge is the problem with the high temperature. In many cases, there is a necessity to use air conditioning systems to maintain the temperature in the workplace below an acceptable limit. That is the reason that information about air temperature in the ventilation shaft and other key locations is needed to control the ventilation systems. To monitor and control this parameter of the underground atmosphere, different types of thermometers are used. It should be kept in mind, that fresh air is supplied from the surface, so its temperature depends on the seasons (in wintertime can be very cold and in summertime very hot).

In the case of underground applications, wet and dry bulb thermometers are used. Dry temperature is measured by a thermometer exposed directly to the air but protected from radiation and moisture. Wet temperature is measured by a thermometer covered in water-soaked clothes over which air is passed; in other words, it is temperature with humidity equal 100%. In Polish mines, the dry temperature cannot be higher than 33˚C. Scheme of dry and wet bulb thermometer (psychrometer) is shown in Figure 6.23.

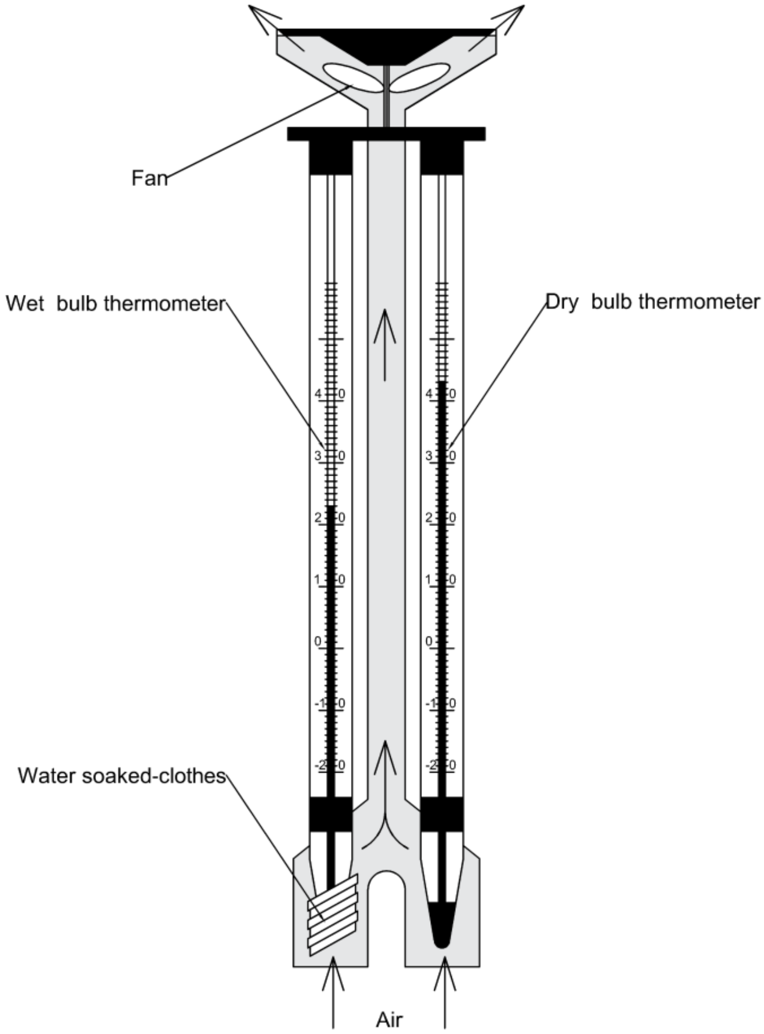


Figure 6.23. Scheme of psychrometer

It is noteworthy that in many cases, the dry temperature is measured together with other parameters and devices, e.g. most of the anemometers, gas detectors, and other devices are also equipped with temperature sensors.

6.3.5. Hygrometers

Thermal comfort of the workers and the operation of the ventilation system is connected to the humidity of the air. Evaporating cooling effects of sweating decreases with rises of relative humidity, meaning that hazards connected with over-heating increase. A device that is used for direct humidity measurement is called a hygrometer. Currently, the most popular hygrometers in use are electronic hygrometers. There are many different types of electronic hygrometers available on the market, e.g. Comet and multifunctional device MCRC-1 (Figure 6.24)

Figure 6.24 Examples of electronic hygrometers

Hygrometers can be also built as stationary units for continuous measurement. Humidity can also be measured indirectly utilizing psychrometers (Figure 6.23). Value of humidity can be read from nomogram on the base of measured wet and dry temperature.

6.3.6. Barometer

Another parameter that has an important impact on the ventilation system is air pressure, both atmospheric and local in different areas of the mine. The value of this parameter is responsible for air velocity and airflow directions in the whole mine. It must be taken into consideration, that in some cases changes in atmospheric pressure may affect the released gas from the rock or goafs as well as cause changes to airflow directions (Aitao et al, 2018). Ventilation pressure can also be affected by gas ejections or fires. The pressure is often measured in sealed areas to control possibilities of danger gases migration to the active ventilation system. All these aspects highlight the need to monitor the air pressure in many locations in the mine ventilation system, in order to provide a safe and effective workplace. It must be noted that static pressure needs to be continuously monitored and recorded for each main ventilation fan and other important fans in the ventilation system.

Pressure measurement can be divided into two methods. The first method is used to determine frictional pressure drop and is based on the pressure gauge and tube or hose in which two ends are located between measured locations (Figure 6.25).

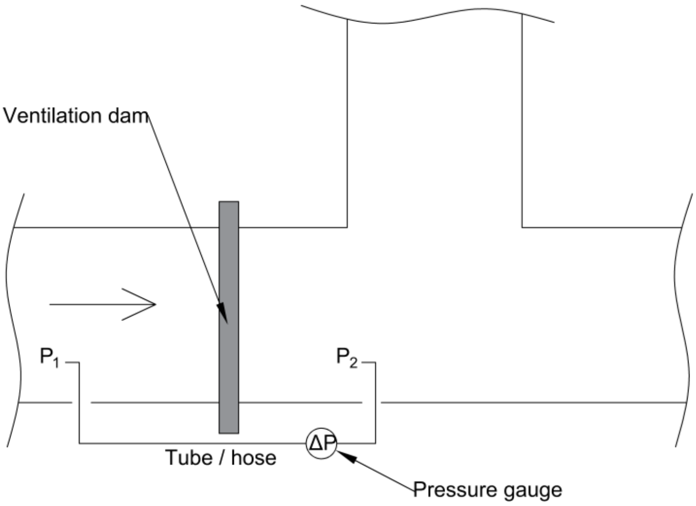


Figure 6.25. The measure of drop pressure between two stations

The second method uses a barometer to measure absolute pressure. Currently, the most popular devices are electronic barometers. In many cases, there are multifunctional units that can measure many different parameters like pressure, temperature, and humidity. Examples of electronic barometers are shown in Figure 6.26.

Multifuncional device
MCRC-1 (Carboautomatyka)

Barometer type testo 511
(Testo)

Figure 6.26. Examples of electronic barometers

6.4. Water and gases

Another type of hazard, that can be present in underground facilities is uncontrolled water (brine), often with loose rock materials, rushing into underground spaces. These threats can put workers at serious risk and can cause serious injuries or even death. There are three kinds of water sources (Bukowski, 2015):

- surrounding rock mass,
- surface water reservoirs,
- technological processes.

To control water hazards, an underground dewatering system must be implemented. It consists mainly of pumps, that are capable of removing water from the mine, and associated infrastructure like pipes, drain holes and lines, water dams, and storage pools. An integrated part of the dewatering system is monitoring, that provides information needed to manage the system safely and efficiently. The capacity of the system must be adjusted to the current water inflow to the mine, and also be prepared for the predictive inflow based on the hydrological recognition and present monitoring. Protection from the water inrush into the underground mine can be done by sealing the connection between the aquifer and the mine workings. This process is based on the injection into the rock mass, special sealing material that fills the cracks and blocks water flow. Another preventive action that can be taken to avoid water hazard is dewatering water reservoirs. It can be done by means of prepared drain holes and pumping water outside the mine area.

Monitoring of the mine water should cover the following data: water level in different locations, the amount of water inflow to the mine, chemical composition, and pumping activities (Drobniewski & Witthaus, 2017). The water level can be measured manually by reading the level value on a water gauge or utilizing an automatic sensor. The water levels of aquifers located in mine areas are measured by piezometers, through specially drilled holes from the surface, which are equipped with water level sensors. Nowadays, the sensors are automated, and data of water level is recorded and transmitted automatically. These systems can control levels of the aquifers in the mine area and monitor the amount of water inflow to the mine if there is a connection between the aquifer and underground tunnels. Data obtained from piezometers provide information about the hydraulic connection between given aquifer and mines.

Data regarding the amount of water that inflows to the underground drifts are estimated based on the volume of water pumped from the mine and observation of the water level in water reservoirs in the underground dewatering system.

Water inflow to the mine can be polluted, and consist of many of contaminants included gases. This requires monitoring of the quality of underground water in order to protect people and the environment from hazard. Analysis should cover physical and chemical parameters that can assess pollution levels and the development of a water purification system to avoid a negative impact on the environment. The quality monitoring system should be adjusted for specific site conditions and include the procedures for the quality analysis, i.e. sample taking, sample preservation and handling; analytical methods used etc. (Bezuidenhout, 2009)

6.5. Organizational

Ensuring a safe workplace depends on not only technical solutions but also on the workers themselves. Still, most of the accidents encountered are caused directly or indirectly by people; therefore regular safety training and activities must be provided for both worker and manager-level personnel involved in underground activities. Organizational aspects of safety issues should cover, among others, the following aspects:

- awareness of hazards,
- competent and trained personnel,
- safety procedures.

Background of all activities that are done in the underground environment should be aware of the type of hazards that can be a presence in this space. In this light, proper training conducted before starting any activities in the working area is a key element of shaping safe behaviour in the workplace. Knowledge about the environment where we are operating is the first line of protection from the hazards.

Next crucial element of safety in the preparation of the competent and proper trained personnel. Proper information about working processes, tools that should be used, proper ways to use the tools etc. decrease the possibility of accidents. This aspect is very important both for workers and managers. Proper work organisation of the work process is also the core element of the safety system.

Description of the safe behaviour in the working place is put in the safety procedures that are part of the safety plan, what is, in most cases, requirements of the labour law. Each of the working processes should have developed safety procedures. As a core element of many safety aspects is the evacuation procedure in case of an emergency. A workplace emergency is an unforeseen situation that threatens workers, customers, guests; disrupts or shuts down working operations; or causes physical or environmental damage. Emergencies can relate to many situations occuring in the underground facilities e.g. inrush water, gas ejections, fires etc. An example of a map from the evacuation plan is shown in Figure 6.27 (Chao & Henshow, 2001; Dec, 2014).

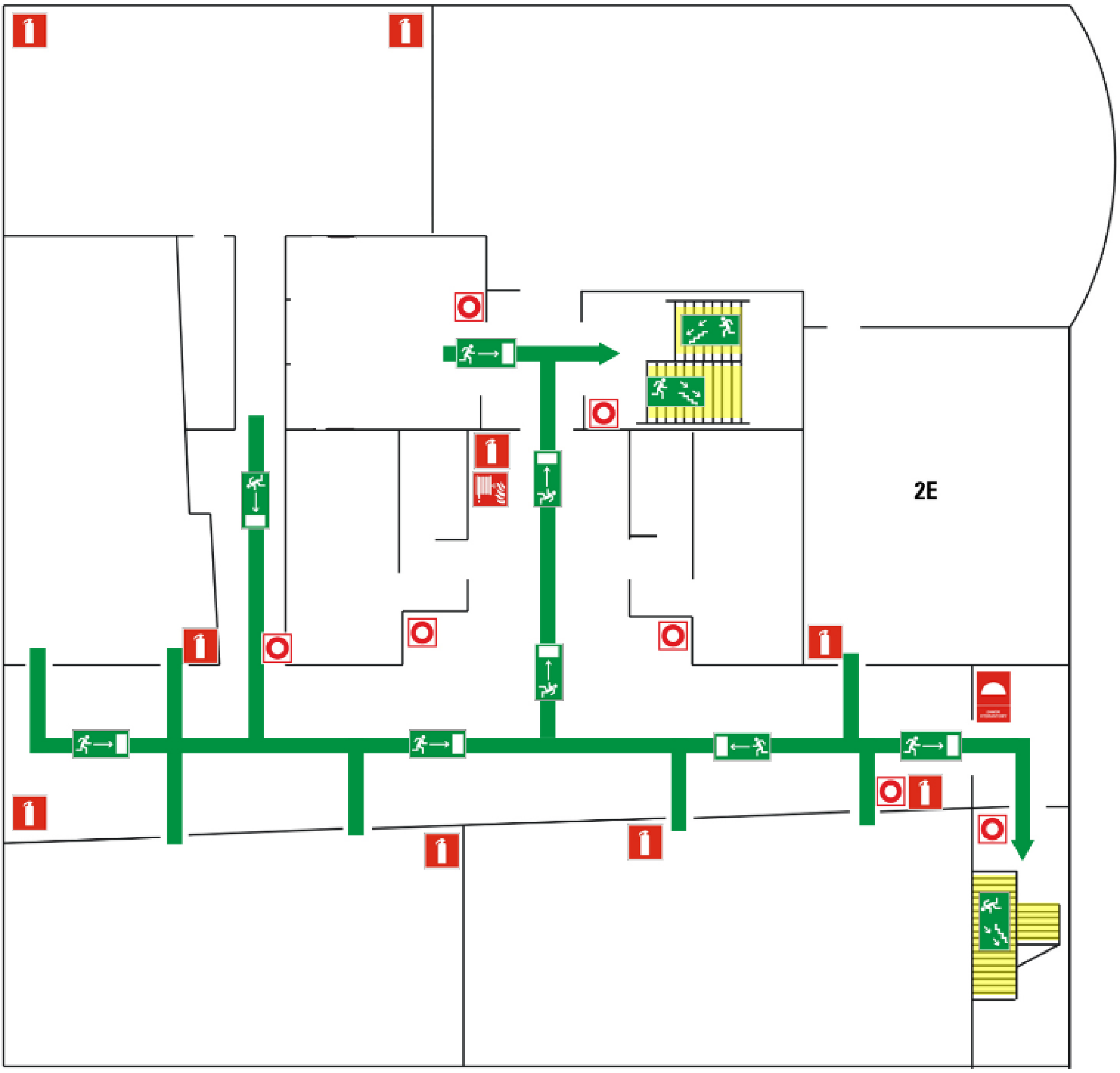


Figure 6.27. An example of evacuation plan (Przerobić na górnicze)

Safety procedures should be written in a simple and clear form to emphasize the most important issues. In many cases, safety procedures are displayed in the form of simple pictograms (Figure 6.28). All safety documents must be revised regularly and updated if needed.

Monitoring of safety practices from the organisation point of view is focused on the detailed records of the accidents and so-called near misses. The goal is to learn from past errors and correct instructions and orders to prevent similar accidents from happening in the future. This is why information on all accidents and near misses must be gathered and analysed.

Figure 6.28. Safety rules in KGHM group

6.6. Socio-economical

Socio-economical aspect in the safety area is focused on the financial transfer to the workers and relates to ensuring the economic security for the employees. This aspect is focused mainly on the managing of the enterprises and depends also on market situations. Monitoring of this kind of threats involves the analysis of the market data in both short- and long-term. In most cases, mitigation of this kind of hazard is based on suitable finance and insurance policy.

7. RISK ASSESSMENT

As is noted by international standard IEC/FDIS 31010 Risk management – Risk assessment techniques (2009), a comprehensive risk assessment should include (Shooks et al., 2014):

- Risk identification,
- Risk analysis in terms of probability and impact,
- Risk evaluation, with conclusions whether the level of risk is acceptable and/or if it can be minimised.

Risk as a concept, is very abstract, and it is difficult to define it unambiguously, as is evidenced by the multitude of different definitions it has been given. For example, according to the *International Organization for Standardization* (ISO), the risk is the effect of uncertainty on objectives (ISO Guide 73:2009). For industry, the risk is often defined as the product of frequency and severity of events (Suddle, 2009; Aven, 2010). Whereas in economic analyses, the risk is described as a mathematical concept in the form of expected consequences, both in terms of losses and profits (UNISDR, 2004). The definition proposed by Fenton and Griffiths (2008), that risk is the product of the probability of failure and the cost of its consequences seems to fit best within the framework of underground engineering, and is widely used in this field.

A review of hazard identification and risk analysis (HIRA) methods are presented below.

7.1. Risk evaluation methods

When analysing suitable methods of risk assessment for facilities located deep underground, one must keep in mind, that underground environments are extremely specific and usually more dangerous than above-ground environments (Martyka, 2015; Groves et al., 2007). One key factor affecting significantly to the level of safety is the depth of the working environment. In most cases, geomechanical hazards increase in tandem with depth (Li at al., 2007). Threats encountered in underground laboratories include (among others) the following: quality of the atmosphere, rock stability, radiation, water etc. All these hazards have to be identified and controlled in order to maintain a safe working place.

Risk is usually used as an indicator of work safety level and may be defined as a result of the probability of an accident (p) and their consequence (C) and can be expressed as (Harms-Ringdahl, 2013):

$$R = \sum p \cdot C \tag{7.1}$$

7.2. Qualitative analysis

Qualitative methods are very economical and can be easily implemented for use (EMA, 2006; Curtis & Carey, 2012; Vardar et al., 2018). At the same time, they may be used as a preliminary method with the joint determination of risk occurrence probability against the potential severity of the analysed event. The estimation of both parameters is usually based on a survey or questionnaire. This method has its disadvantages, though, as the estimation is based on the subjective assessment of employees (Smolarkiewicz et al., 2011). However, this method enables the characterization of the most dangerous risks relatively quickly. Consequently, it is possible to prioritise individual events from least to most dangerous. There are currently in use multiple methods of qualitative analysis, of which the most popular are:

- **Delphi Technique** – method of risk assessment based on brainstorming among experts with deep knowledge about the examined issue. It centres around experts reviewing experts notes, and during all process, some consensus should be reached.
- **Structured What-If Technique (SWIFT)** – this method uses a systematic, team-based evaluation of each risk in the form of a workshop. During risk assessment process, the effect or impact of different hypothetical situations is analysed with the use “What if” considerations.
- **Decision Tree Analysis** – approach close to Event Tree Analysis, but without quantitatively presenting the result. In most cases, this method has been used to determine the best way to achieve a goal with the lowest level of risk.
- **Bow-tie Analysis** – in this method, each risky event is examined from two directions. One branch describes all the potential causes of the event, while the second branch lists potential consequences. As a result, it is possible to identify risk and apply preventative solutions to minimise hazards.
- **Risk Matrix** –One of the most frequently used techniques of qualitative risk assessment is the method based on the so-called two-dimensional risk matrix (Figure 7.1). At the moment, this is the most commonly utilised approach in establishing risk severity. In result, it is possible not only to determine the impact of each event but also identify how the risk is affected by its probability or consequence. This information is essential to the development of mitigations procedures (PMI, 2013; Dumbravă et al., 2013).

According to recent research works, in terms of underground risk analysis, the risk matrix technique is one of the most suitable methods for preliminary analysis.

7.2.1. Risk Matrix method

The risk assessment method based on a risk matrix for underground laboratories can be applied already during the design stage of a given facility. The assessment must be carried out exclusively by specialists in each particular field. Only a thorough and critical analysis allows the identification of activities which involve a high level of risk. The assessment enables the early implementation of appropriate preventative and risk mitigation measures. There are also no technical limitations to using it as the basis of classifying selected events as part of periodic risk assessment conducted throughout the lifecycle of an underground facility.

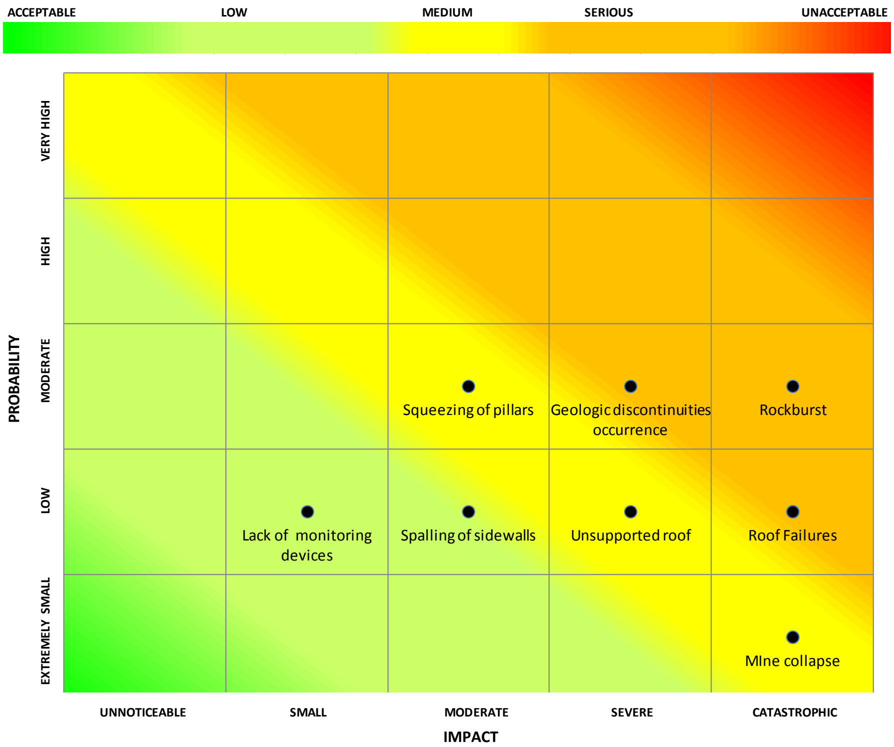


Figure 7.1. Example of a 5x5 risk matrix

7.3. Quantitative analysis

The second group of techniques comprises the so-called quantitative approach, which is usually based on statistical and numerical calculations. Quantitative methods are much more reliable than qualitative methods, as they are not directly based on subjective evaluation of the personnel involved in the analysis. Unfortunately, in order to carry out this kind of risk analysis properly, access to a large amount of detailed data on the examined facility or event is required (Bell & Glade, 2004; Radu, 2009).

7.3.1. Event tree analysis

To determine the risk of complex events resulting from the overlapping of several negative factors, the "event tree" method may be used. This method can be applied to identify all elements that can initiate a series of consecutive events (branch of a tree) leading to specific consequences (Clemens, 1998). Each case within a branch of the tree must have a certain probability of occurrence. The product of successive probabilities is the resultant probability of the occurrence of a specific sequence of events (Clifton & Ericson, 2015). In terms of underground laboratories' operation, the event tree method should be used, especially, to assess the risk of complex events, e.g. when analysing the rockburst hazard. It enables the simultaneous consideration of the probability of a high energy tremor and the occurrence of excavation instability, as a result of the dynamic seismic event (RocScience, 2018).

As it was highlighted by Clemens & Simmons (1998), Event tree analysis (ETA) is a risk assessment method which allows to determine the probabilities of both success and failure, including different types of events at each analysis path (Figure 7.2).

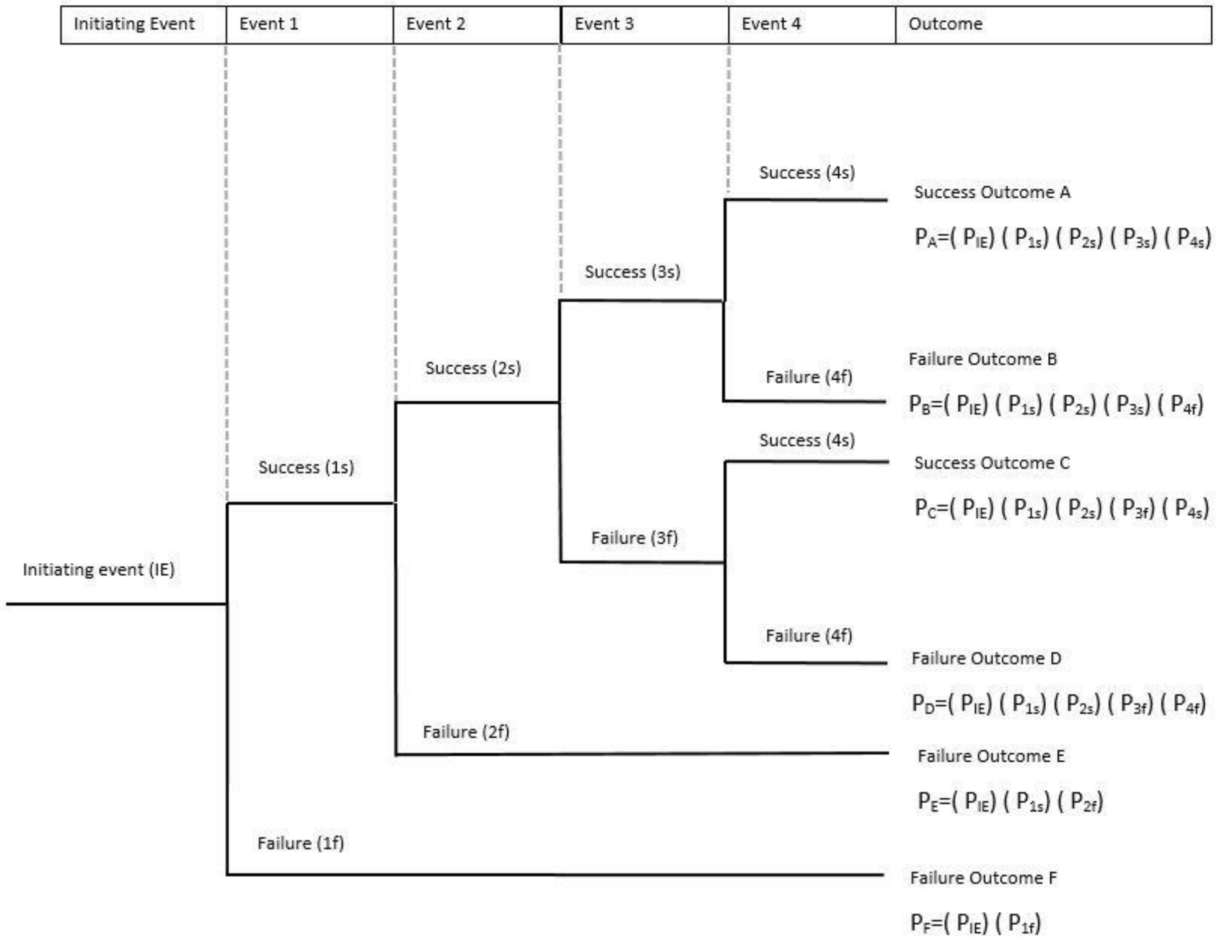


Figure 7.2. Example of risk evaluation with ETA methodology

ETA technique may be used to examine the effects of operating or failed systems given that an event has occurred (Wang et al., 2000). ETA method of risk assessment is a powerful tool, but it must be highlighted that the probability of each event occurrence on the subsequent patch must be assessed with high reliability. In another case, it may lead to over- or underestimation of results. The mathematical assumption is very simple. Namely, for each path sum S of the probability of success (PS) and the probability of failure (PF) need to be equal to 1.

$$S_{(P_S+P_F)} = P_S + P_F = 1 \tag{7.2}$$

Then probabilities determined for each event are multiplied in each path to determine overall path probability OPP probabilities of failure and success in each path.

$$OPP = P_{E(1)} + \cdots + P_{E(n)} = 1 \tag{7.3}$$

7.3.2. Fault Tree Analysis

Fault tree analysis (FTA) is a deductive approach in which an undesired event is examined using Boolean logic to combine a series of lower-level events. According to recent research, this method is mainly used in reliability and safety engineering to identify how structures may fail. FTA is used in nuclear power and chemical process risk evaluations, (CCPS, 1999 & 2008; OSaHA, 1994, Iverson et al., 2001; Gupta et al., 2006), the aerospace (Goldberg et al. 1994)and underground mining industries as well (Ignac-Nowicka, 2018; Shahani et al., 2019). An example of FTA analysis scheme is presented on figure 7.3.

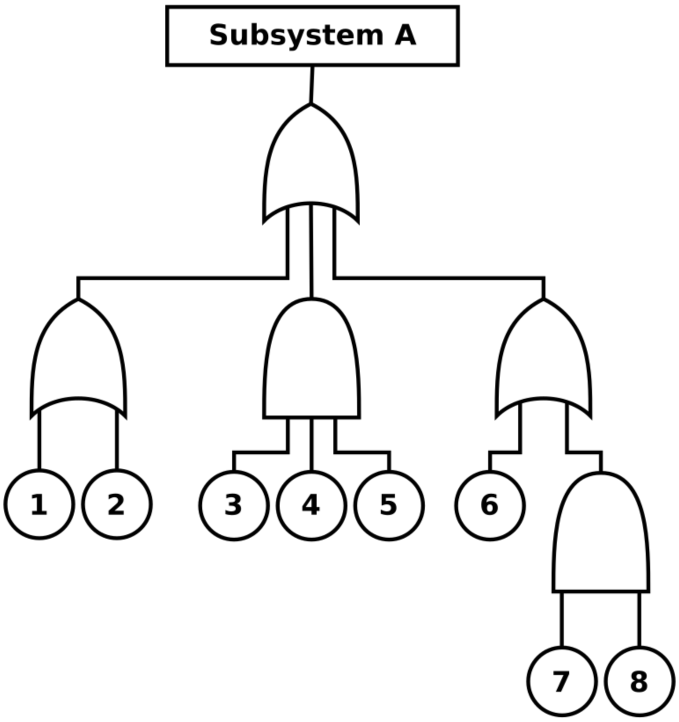


Figure 7.3. example of FTA scheme

FTA methodology is associated with statistical probabilities. For example, facility/object failures may occur at some failure rate λ which is a constant hazard function. In such case the probability of failure depends on the rate λ and the exposure time t:

$$P = 1 - \exp(-\Delta t) \tag{7.4}$$

Where:

$$P \approx \lambda\mathrm{t} \text{ if } \lambda\mathrm{t} < 0{,}001 \tag{7.5}$$

7.3.3. Probabilistic Risk Assessment

Probabilistic risk assessment (PRA) is a reliable approach, which allows the assessing of risks related to complex facilities such as flotation tailing ponds, dams etc. (USEPA, 2014). It may also be utilised in case of underground laboratories.

In PRA methodology, the risk is defined as a potential outcome of specific actions. In PRA, the risk is characterized by two quantities:

- the magnitude probable unfavourable consequences,
- the probability of each consequence occurrence.

It needs to be highlighted that consequences, as well as likelihoods of occurrence, are expressed in the quantitative domain in PRA methodology (USEPA, 2014).

7.3.4. Bayesian Network

Bayesian Network (BN) is a very functional method for analysing which kind of events/parameters may lead to a risky situation, and in result, trigger a dangerous incident. In this type of analysis, different scenarios are considered to evaluate the significance of each risk and present it in a quantitative way (Fenton & Neil, 2012).

Risk analysis based on BN uses tables of conditional probability and Bayesian theory to determine the relationships between the parameters affecting each event. Consequently, it is possible to systematically understand the relationships between them (Hänninen & Kujala,2012).

The Bayes Theorem is presented as follows:

$$P(A|B) = \frac{P(A)P(B|A)}{P(B)} \tag{7.6}$$

According to O'Hagan et al (2006), Bayesian Network graphs the important factors of the unwanted events with the undetermined relationship between them.

The BN method uses the n-dimensional nodes and a directed acyclic graph. Each node represents the subsequent variables, while arrows indicate the relation between the variables. It must be highlighted that variables are not allowed to impact each other in a loop (Morrison,2005; Laitila, 2013).

Assuming that variables in the network are denoted as $X_i = \{X_1, X_2 \ldots X_n\}$ and the a_i is the probability of an antecedent variable X_i occurrence, then the distribution of the variables is presented with the following formula:

$$PX = P(X_1, X_2 \ldots X_n) = \prod_{i=1}^{n} P(X_i|a_i) \tag{7.7}$$

The BN methodology may be successfully implemented in risk assessment in underground mining (Fatma & Bersam, 2019) and risk evaluation in underground laboratories as well.

7.3.5. Failure mode and effects analysis (FMEA)

The FMEA method is used to identify potential mechanisms of facility failure and to estimate their consequences. This kind of analysis is based on the information on the object construction, the type of operation, and the strategy for the development of underground workings included in the design documentation.

In the Failure Mode and Effects Analysis (FMEA), an unwanted event is described by three factors such as (Chin et al., 2008):

- Severity (S),
- likelihood of occurrence (O),
- the difficulty of detection of the failure mode (D),

In a typical version of FMEA methodology, each factor is described with numbers in the range of 1 to 10. In this case, one means the test situation, while ten is the worst (Shariati,2014).

By multiplying the values for severity (S), occurrence (O), and detectability (D), the parameter called Risk Priority Number (R_{PN}), is determined.

$$R_{PN} = S \cdot O \cdot D \tag{7.8}$$

Description of each level of S, O and D according to Chin et al. (2008) and Wang et al. (2009) is presented in tables 7.1 ÷7.3

Table 7.1. Table for the occurrence of a failure O rating according to Chin et al. (2008) and Wang et al. (2009)

Rating	Probability of occurrence	Failure probability
10	Very high: failure is almost inevitable	>1 in 2
9		1 in 3
8	High: repeated failures	1 in 8
7		1 in 20
6	Moderate: occasional failures	1 in 80
5		1 in 400
4	Low: relatively few failures	1 in 2,000
3		1 in 15,000
2	Remote: failure is unlikely	1 in 150,000
1		<1 in 1,500,000

Table 7.2. Table for the occurrence of a failure O rating according to Chin et al. (2008) and Wang et al. (2009)

Rating	Effect	Severity of effect
10	Hazardous without warning	Very high severity ranking when a potential failure mode affects safe system operation without warning
9	Hazardous with warning	Very high severity ranking when a potential failure mode effects safe system operation with warning
8	Very high	System inoperable with destructive failure without compromising safety
7	High	System inoperable with equipment damage
6	Moderate	System inoperable with minor damage
5	Low	System inoperable without damage
4	Very low	System operable with significant degradation of performance
3	Minor	System operable with some degradation of performance
2	Very minor	System operable with minimal interference
1	None	No effect

Table 7.3 Table for detection of a failure D rating according to Chin et al. (2008) and Wang et al. (2009)

Rating	Detection	Likelihood of detection by the design control
10	Absolute uncertainty	Design control cannot detect potential cause/mechanism and subsequent failure mode
9	Very remote	Very remote chance the design control will detect potential cause/mechanism and subsequent failure mode
8	Remote	Remote chance the design control will detect potential cause/mechanism and subsequent failure mode
7	Very low	Very low chance the design control will detect potential cause/mechanism and subsequent failure mode
6	Low	Low chance the design control will detect potential cause/mechanism and subsequent failure mode
5	Moderate	Moderate chance the design control will detect potential cause/mechanism and subsequent failure mode

4	Moderately high	Moderately high chance the design control will detect potential cause/mechanism and subsequent failure mode
3	High	High chance the design control will detect potential cause/mechanism and subsequent failure mode
2	Very high	Very high chance the design control will detect potential cause/mechanism and subsequent failure mode
1	Almost certain	Design control will detect potential cause/mechanism and subsequent failure mode

The failure scenario with the highest R_{PN} is the most significant from a safety point of view. Thus, the R_{PN} factor helps to identify processes which are a priority in risk mitigation (Ericson, 2005).

The FMEA is an effective model because it (i) includes failure rates for each failure mode to achieve a quantitative probabilistic analysis and (ii) can be extended to evaluate failure modes that may result in an undesired system state, such as a system hazard, and thereby be used for hazard analysis. The traditional FMEA procedure is summarized as follows (Tay & Lim, 2006):

7.3.6. Failure Mode Effect and Critical Analysis (FMECA),

Failure Mode, Effects and Criticality Analysis (FMECA) can also be used to assess the risks of underground laboratories' operation. In turn, the FMECA method is additionally extended by a semi-quantitative classification of destruction mechanisms based on the occurrence frequency of particular events and the severity of their consequences (IEC, 2006)

7.3.7. Historical analyses

The incident rate (I_R) should be calculated in relation to working time according to the formula (OSHA, 2018):

$$I_R = \frac{N_c \cdot 200{,}000}{N_{Elh}} \tag{7.9}$$

where: I_R- incident rate, N_c- number of recorded cases, N_{Elh}- the number of employee labour hours worked, hours.

The number of 200,000 in the formula refers to the number of hours worked in a year by 100 employees (100 employees x 40 hours per week x 50 weeks per year). The incident rate may also be calculated in relation to the number of employees. For every 1,000 employees, I_R is calculated, e.g. from the formula:

$$I_R = \frac{N_c \cdot 1{,}000}{N_E} \tag{7.10}$$

where: N_E- the number of employees.

Calculated incident rates can be used to define the probability of an incident according to the relationship (Rothman, 2002):

$$P_{oI} = 1 - e^{(-I_R \cdot T)} \tag{7.11}$$

where: P_{oI} - probability of an incident, I_R - calculated incident rate, T- time, year.

7.4. Numerical modelling

Numerical modelling is a very useful tool in risk analysis of UL's. It merges the advantages of both qualitative and quantitative results. In many numerical simulation softwares using, e.g. DEM, FEM and LEM methods, besides the stress/strain results in static and dynamic conditions, also probabilistic analysis is available. As a result, it is possible to estimate the probability of, e.g. loss of stability of underground excavations, while taking into account the uncertainty and variability of model input parameters. The probabilistic risk assessment method of this type is widely used in geotechnical (Park et al., 2005; Zennir et al., 2011) and geomechanical analysis all over the world (Idris et al. 2011; Szurgacz, 2015; Ghorbani et al., 2017). Numerical models of underground workings utilized in these analyses can be formulated as 2- or 3-dimensional (Figure 7.4, Figure 7.5) problems, depending on the requirements and local geomechanical and mining conditions.

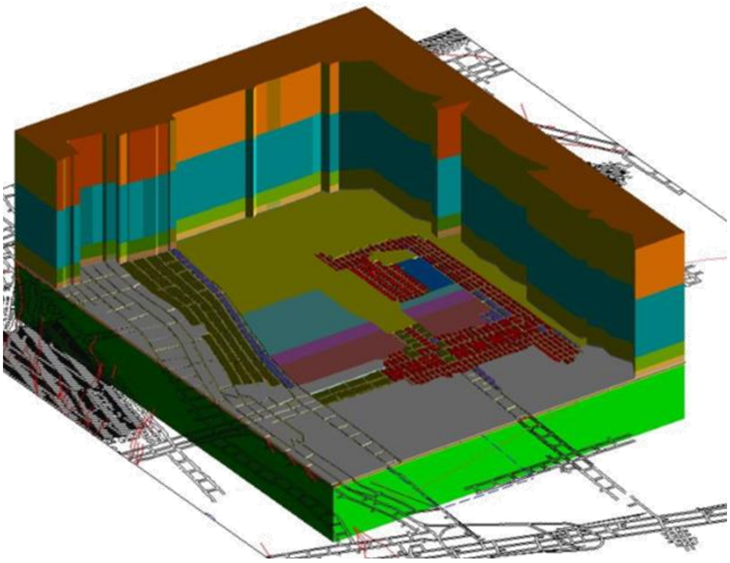


Figure 7.4. Geometry of 3D numerical FEM-based model

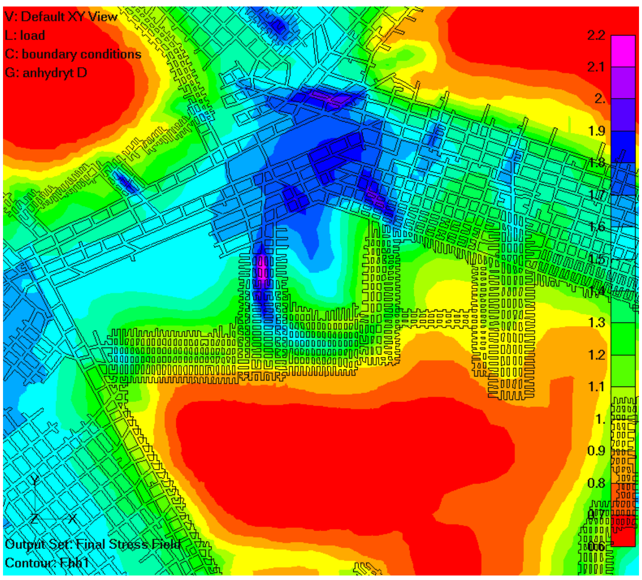


Figure 7.5. Results of 3D FEM-based numerical model of underground excavations with predicted impact of geomechanical hazard occurrence

Numerical models assist in determining the range of a hazard and possible consequences. Therefore, the numerical analysis combined with probabilistic analysis shall be required already at the design stage of the UL's life cycle. Moreover, for safety purposes, this kind of analysis should be conducted periodically, as the conditions ensuring the stability of excavations are crucial for these types of facilities.

Of course, numerical tools are not fully useful to determine the risk of all types of events. In the case of events related to, e.g. fires or traffic accidents, it is possible to use so-called incident rates, which allow determining the frequency of an incident and its effect expressed in the time of inability to work.

Numerical modelling may be described as a special type of risk analysis.

7.4.1. Limit Equilibrium Method

The limit equilibrium method (LEM) is used to determine the safety factor inside analysed parts of the model. Recently LEM methodology is mostly related to slope stability assessment. Nevertheless, it is also possible to implement this kind of calculation to 3-D underground environments. As it was mentioned in (RocScience, 2020), the safety factor calculations that use LEM, consider only force equilibrium in the direction of sliding. Moment equilibrium is not considered. The factor of safety is then calculated according to the following formula:

$$FS = max(FS_f, FS_u, FS_s) \tag{7.11}$$

Where:
FS_f - the falling factor of safety
FS_u - the unsupported factor of safety
FS_s - the supporting factor of safety

Example of LEM analysis results in the case of an underground chamber is presented in Figure 7.6.

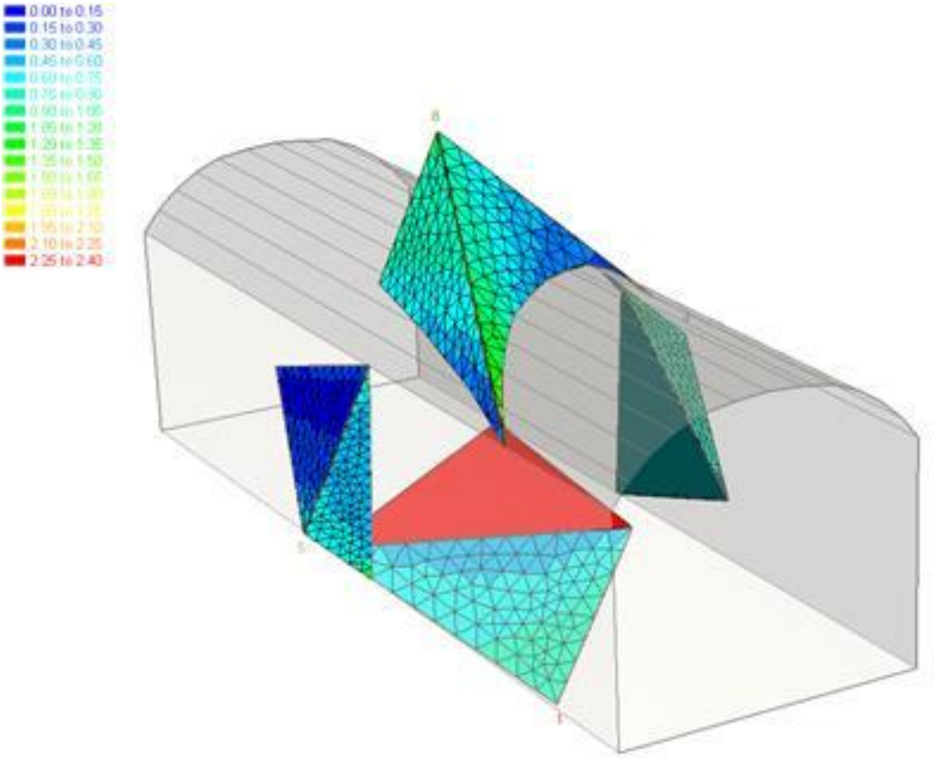


Figure 7.6. Results of 3d LEM analysis of underground excavation

7.4.2. Finite Element Method

At the moment Finite Element Method (FEM) or Finite Element Analysis (FEA) is most commonly utilized in numerical modelling of underground environments. Many years of experience allowed the development of reliable versatile solutions for geomechanical purposes. The most developed software allow the simulation of the effect of roof support, joints and faults, and excavation stages on the stability of the environment. Examples of FEM stress analysis results are presented in figure 7.7, and Figure 7.8.

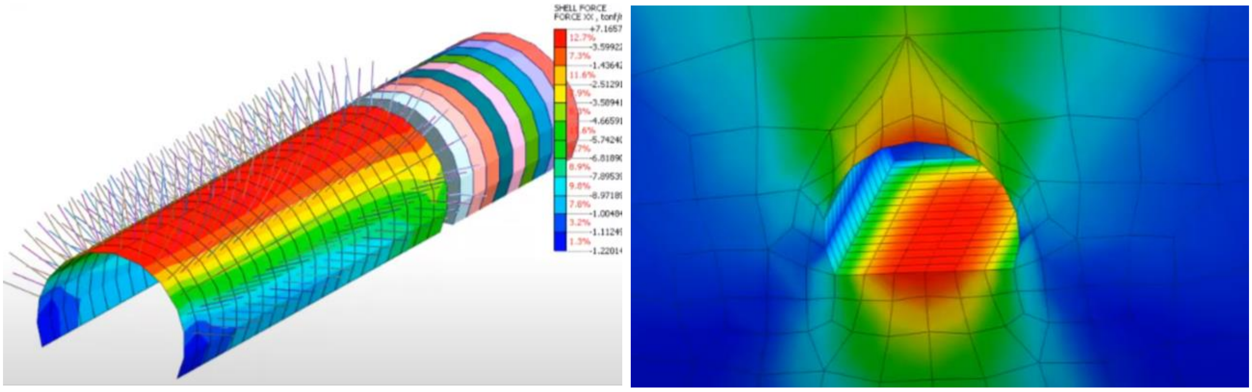


Figure 7.7. Stress field around tunnel excavation simulated with FEA-based simulation with the use of MIDAS GTS NX software (Midas, 2020)

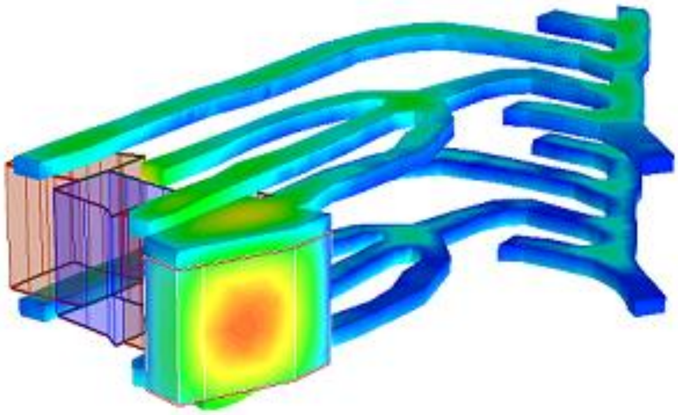


Figure 1.8 FEM-based stope excavation model simulated with RS3 software (RocScience, 2020)

As was pointed out by Martins and Kövesdy (2012), the determination of stresses field, and deformations in an analyzed facility are of extreme importance. Analyzing the safety of the UL should be obligatory before building the facility, as well as during every development of workings.

7.4.3. Discrete Element Method

Discrete Element Method (DEM) consists of separate, discrete elements, which are interconnected to each other and may be rigid or deformable as well (Lisjak & Grasselli, 2014) (Figure 7.9). Impressive is the fact, that through DEM modelling, it is possible to simulate the detachment of elements in the model. Also, it is possible to simulate particle motion in six degrees of freedom. In the case of ULs, this method will be a suitable one when jointed rock mass around the workings occur.

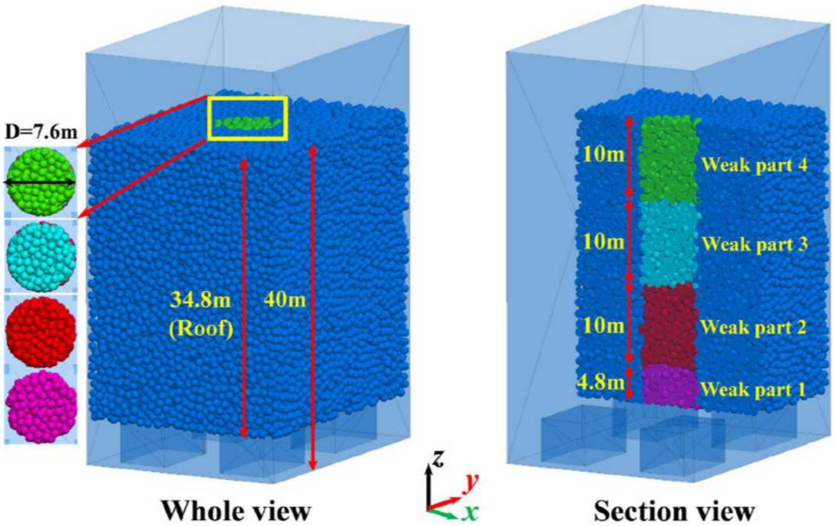


Figure 7.9. Example of the DEM model of mining panel with excavated with the room-and-pillar method (Konietzky, 2020)

When comparing DEM and FEM models, some advantages to DEM may be noticed. Features like automatic contact detection algorithms, while making calculations more time and hardware consuming, offer unique possibilities in terms of simulation results (Konietzky, 2020).

7.4.4. Finite-Discrete Element Method

Finite-Discrete Element Method is a relatively new, hybrid method of numerical modelling. Utilizing this method makes it is possible to solve the complex problems involved in the simulation of the disintegration process. It combines the advantages of FEM and DEM methods, but the practical application of FDEM requires understanding its applicability and the limits as well (Ilyasov et al., 2018; Munjiza, 2004). Example of numerical simulation of the underground chamber located in jointed rock with the use of 2D FDEM numerical modelling is presented in figure 7.10.

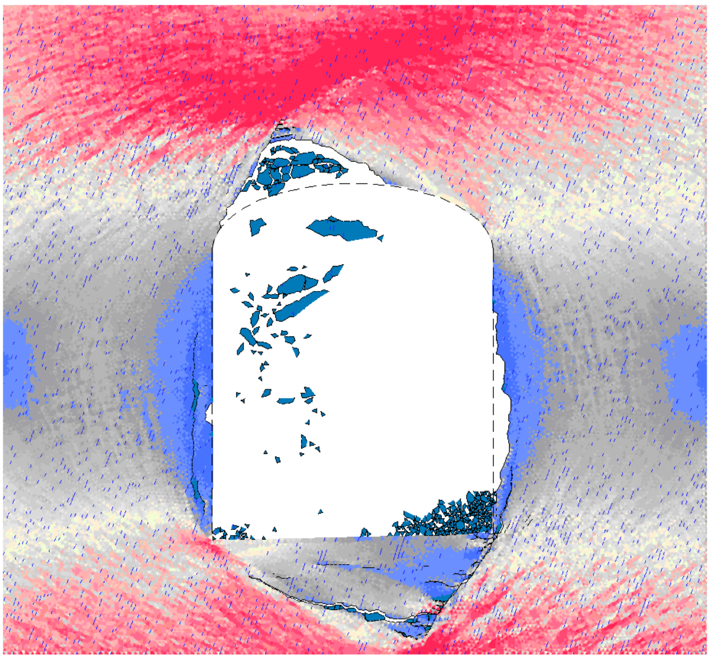


Figure 7.10. Example of FDEM simulation results (Teretau, 2020)

According to Elmo and Stead (2009), FDEM enables you to investigate in detail the process of rock mass failure. FDEM-based numerical simulations are used to analyse both the anisotropic and inhomogeneous effects joints i.e. surrounding underground workings. Therefore, obtained results may be more reliable than FEM and DEM methods utilised separately.

7.4.5. Building Information Modelling

The Building Information Modelling (BIM) is a sort of 4D analysis of a facility during its whole lifecycle. A 4D environment consists of three spatial dimensions of the model, with an additional fourth one as time. This method of analysis is rather related to the management of the facility than strict hazard assessment. Still, according to recent works, proper planning and management help reduce the risk of accidents due to improper management of the facility. Building Information Modelling may also be combined with geotechnical analyses (Morin, 2018), which makes it useful for UL lifecycle analysis.

According to Ghaffarianhoseini et al. (2017), by utilising BIM analysis, facility management may reduce construction risk significantly. Moreover, as Chien et al. pointed out in report [2014], the application of BIM reduces costs and increases efficiency of the facility usage.

The advantages of BIM during the facility lifecycle, as according to Morin et al. (2014), are presented in figure 7.11.

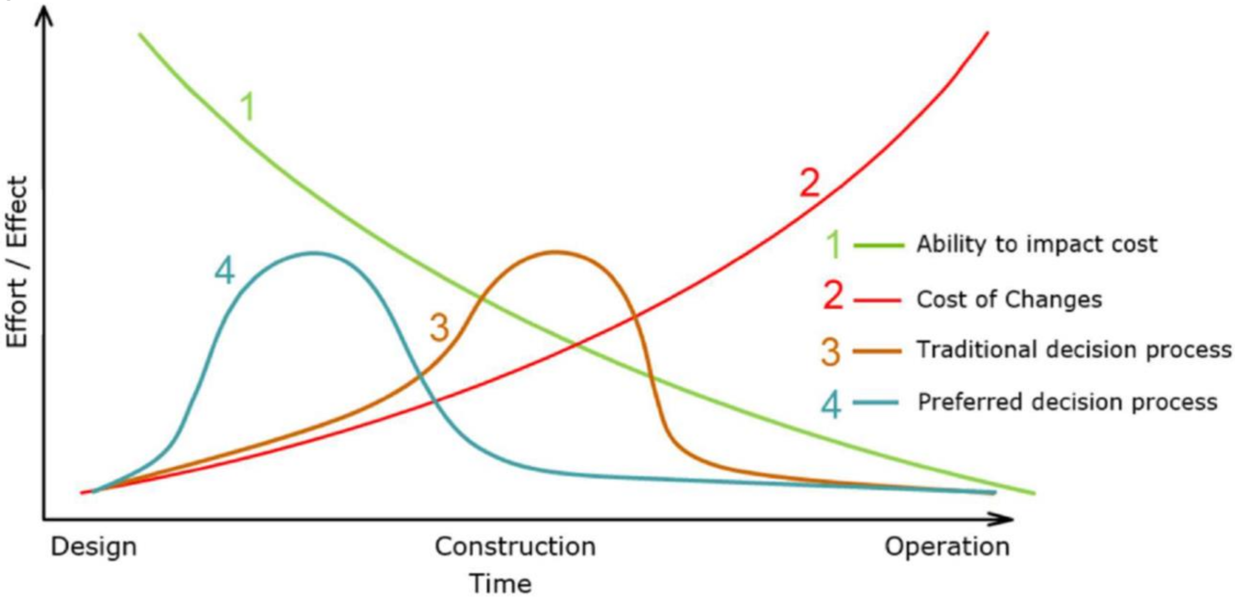


Figure 7.11. McLeamy's effort curve [Morin et al. 2014]

7.4.6. 2D vs 3D numerical modelling

The spatial distribution of the model is crucial for ensuring both efficiency and reliability of the calculations. Evidently, using 2D models is less time consuming, but in the case of underground constructions, the result may be too simplified. Especially the in case of complex distribution of underground workings around the projected facility. As many research works showed, the choice between 2D and 3D should be considered separately in each case (Dhawan et al., 2002; Viggiani, 2013; Do & Dias, 2017). In the case of parallel distribution of layers with unified strength parameters for each stratum, and lack of external influences (Figure 7.12), results of numerical simulations should be converged.

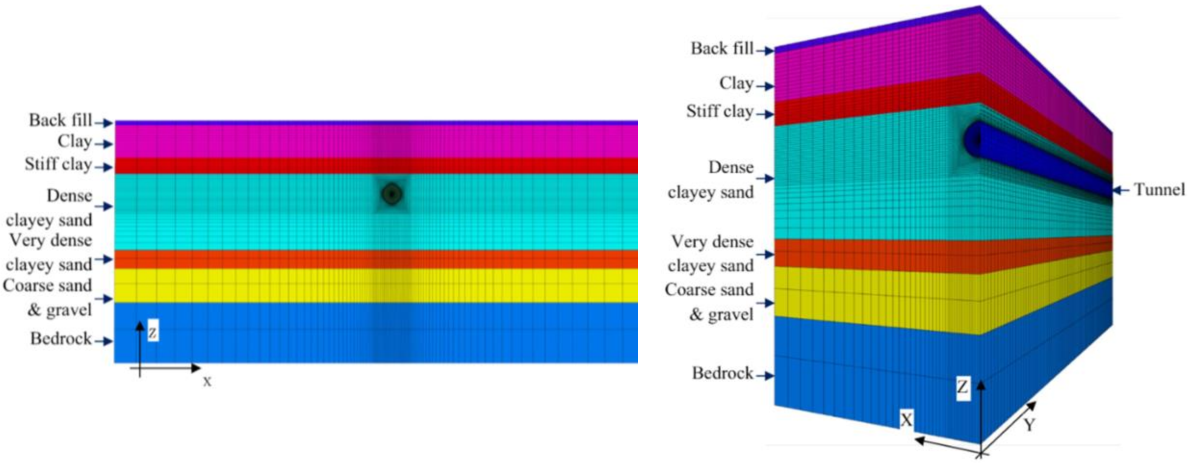


Figure 7.12. View od 2D numerical model and its extension to 3D

Concerning the safety regulations, it may be assumed that 2D simulations are efficient for the modelling of straight tunnels or chambers in the relatively isotropic rock mass. In case of occurrence of any joints, faults, or geological anisotropy 3D modelling is recommended.

7.5. Review of risk evaluation approaches

Because of the high complexity of underground excavation methods, there is no universal and 100% reliable solution of risk assessment in underground conditions. Regardless of how well the underground workings are constructed and monitored, there will always be potential for serious or even fatal accidents. At the same time, only experienced mine management have knowledge which allows mitigation of observed risk. Any external company, even those well-versed in risk assessment, will not be able to carry out a reliable assessment without deep knowledge of the source of the risk. Indeed, it is important to develop a tool which allows to identify, categorise, and evaluate risk properly.

The main goal of risk evaluation is to recognize and examine threats, the event sequences leading to a dangerous situation, and finally, consequences of hazardous events. Recently, many techniques are utilised to perform a risk assessment of underground facilities. Each of them has its strengths and weaknesses.

Hazard and Operability Study (HAZOP) – a definition proposed by Qureshi (1987) describes risk assessment as a structured and systematic analysis of a complex planned or existing process or operation in order to identify and evaluate challenges that may present risks to personnel or equipment. Subsequent steps in this method are as follows (Figure 7.13):

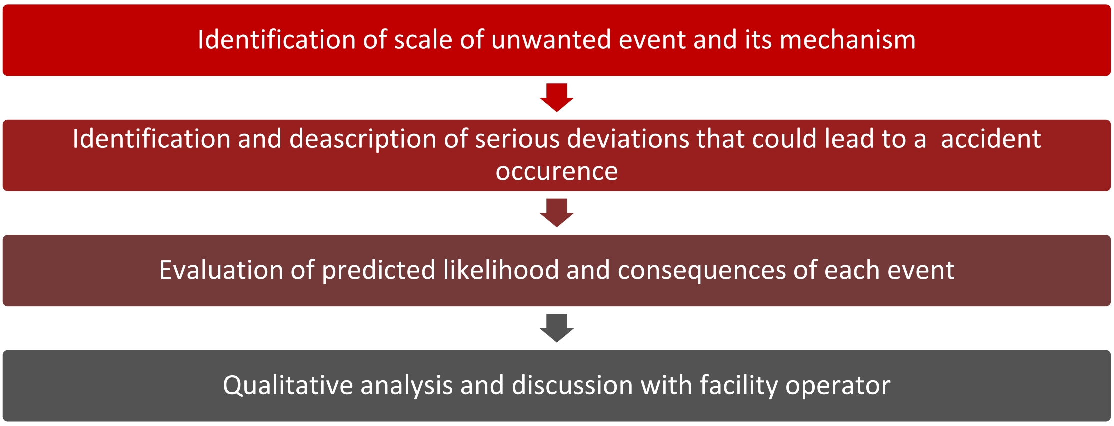


Figure 7.13. Risk evaluation process according to HAZOP methodology

Optimal risk analysis (ORA) – definition recommended by Khan and Abbasi (1995) is based on hazard identification and further evaluation with use of qualitative methods and modified fault tree analysis (MFTA) (Figure 7.14).

In turn, risk assessment methodology proposed by Carpignano et al. (1998) applied quantitative risk analysis (QRA) for the description of dangerous occurrences with the estimation of their frequency and the consequences. The QRA approach is based on such methods as Preliminary Hazard Analysis, Failure Mode Effect and Critical Analysis, Fault Tree Analysis and Event Tree Analysis. This approach allows to identify the sequence of each event together with events which initiate a series of adverse occurrences.

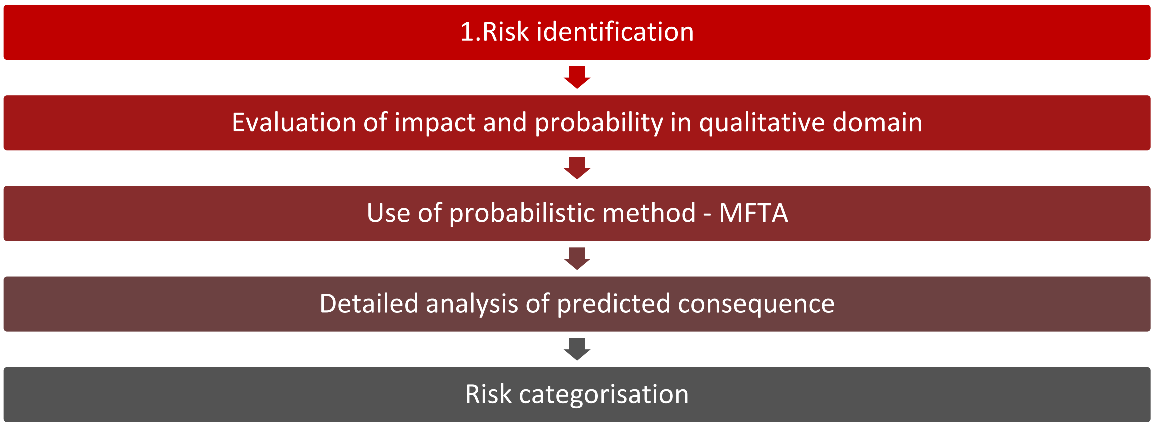


Figure 7.142. Risk evaluation process according to ORA methodology

Also, the analytical description of risk in the quantitative domain was proposed by Khan et al. (2001) who developed the Safety Weighted Hazard Index (SWeHI). SWeHI represents the area under moderate hazard described as a 50% probability of fatality/ damage. The factor may be calculated according to the following equation:

$$\mathrm{S}_{\mathrm{WeHI}} = \frac{B}{A} \qquad (7.12)$$

Where: *B*-Quantitative measures of damage, *A*-credits due to control measures and safety arrangements.

Risk assessment methodology proposed by Bell and Glade (2004) defines risk as a result of multiplying of hazard probability P_h, its consequence C_h and element affected by each risk E_{ar} according to the following formula:

$$R_{B\&G} = P_H \cdot C_h \cdot E_{ar}$$

Jelemensky et al. (2003) used both quantitative and qualitative risk analysis to determine potential event sequences and possible events. From quantitative risk analysis, risk estimation is done and the individual fatality rate was calculated as:

$$IR(x,y) = \sum_{io=1}^{IO} P_{io}(x,y)\,, \sum_{d=1}^{D} P_{io,d} \sum_{i=1}^{I} P_{d,i} f_i \qquad (7.13)$$

Where: $IR(x,y)$ - individual severity of each risk at a specific location (x, y), $P_{io}(x,y)$ - the probability of fatality at a specific location (x, y) at given outcome incident case io; IO- total no. of the incident in each group of event, $P_{io,\,d}$ - the probability that the damage state case d will lead to the incident outcome case io. D - total no. of damage states, $P_{d,\,I}$ - the probability that the initiating event case I will lead to the damage case d, I - total no of initiating events.

In past literature also methods dedicated to specific risk type may be found. For example, Kecojevic and Radomsky (2004) focused on loader and truck work safety in underground conditions. They found out, that the seriousness and quantity of accidents related to the use of loader and trucks are higher when compared to other operations conducted in the mining environment. They established fatal categories and causes of accidents and control strategies are discussed and evaluated to increase hazard awareness. In 2009, Kecojevic continues work with Nor (2009) concerning fatal incidents related to mining equipment usage. As a result, it was concluded that underground machinery such as continuous miners, shuttle cars, roof bolters, and LHD's, contributed to numerous fatalities in the analysed case.

The issue of dangerous events related to transportation was examined also in the paper prepared by Hassan et al. (2009), where the safest way for the transport of harmful materials was carried with the use of QRA.

In turn, Dziubinski et al. (2006) have examined probable consequences of pipeline failure with respect to personal and societal risk. In this approach, the combination of quantitative and qualitative methods used ensured a reliable risk assessment for long pipelines.

Still, these approaches concern specific events and are not considered a universal solution.

Because of the high complexity of risk development in underground conditions, it is recommended to utilize multiple methods. A good example of such attitude may be a workshop presented by Frank et al. (2008) where risk was evaluated with the use of widely used risk management tools. In principle, diagram analysis and risk rating were utilised. Then, if possible, more sophisticated tools such a FTA, HAZOP, HACCP, FMEA were utilised. In result, a severity categorization table was established, which defines each risk in terms of the severity of its consequences.

Summarizing, the reliability of risk assessment depends mainly on the involvement of qualified experts from different fields related to the facility in question. From a geomechanical point of view, the most important factors to determine are the depth and geometry of underground excavations, the development plans, induced seismicity level and the strength parameters of the surrounding rocks. The issues related to monitoring and observation of the rock mass condition and the environmental impact of a facility are also important. Selection of the optimal risk analysis method depends on the quality of input data. Basically, a comprehensive risk assessment for underground laboratories should always begin with qualitative analysis to define the events that have a key impact on occupational safety. Then, a quantitative analysis should be performed, in particular, for events with a potentially high risk.

8. PRELIMINARY RISK EVALUATION IN ULs OF BSUIN PROJECT

A part of the BSUIN project was the preparation of a unified guideline of risk identification and hazard assessment for underground laboratories. According to the procedure that was created, all laboratories engaged in the BSUIN project were analysed, and risks for each of them were determined. Risks were categorized for the following hazard groups (Figure 7.15):

The first step of the safety assessment was the identification of potential threats associated with underground conditions. Analysis of the underground hazards was conducted for laboratories located in active mining areas as well as existing UL's in separated areas. All UL's in the BSUIN project were involved in the risk identification process. The in-depth analysis took into consideration a general review of the wide scope of hazards that can be present in underground areas i.e. depth, type of surrounding rocks, possibilities of gases ejections etc.

In case the facility is located in or near to existing mines, the scope of hazard will be significantly wider, as was proven by the conducted survey. A similar analysis was done in relation to the existing underground laboratories belonging to the project partners. As a result, a list of 129 hazards was prepared (Appendix 1). Based on the collected information, a comprehensive list of threats was divided into categories presented in Figure 8.1.

* in some cases laboratories can be located *in/near to* active mining

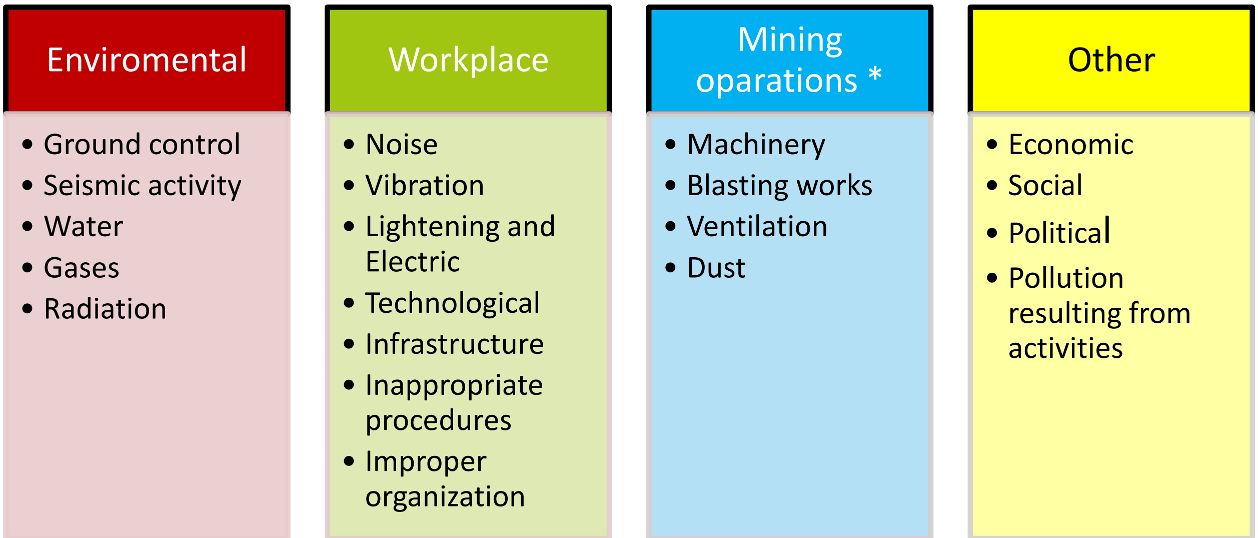


Fig. 8.1 Categories of hazards

During the next step, a preliminary risk assessment questionnaire was sent to all UL's taking part in the BSUIN project. Management personnel of the underground facilities determined which risks could potentially be observed in their laboratories. On the basis of analysis conducted for six facilities from BSUIN network, it was concluded that 106 of the total 129 hazards could be observed. These hazards are presented in Figure 8.2.

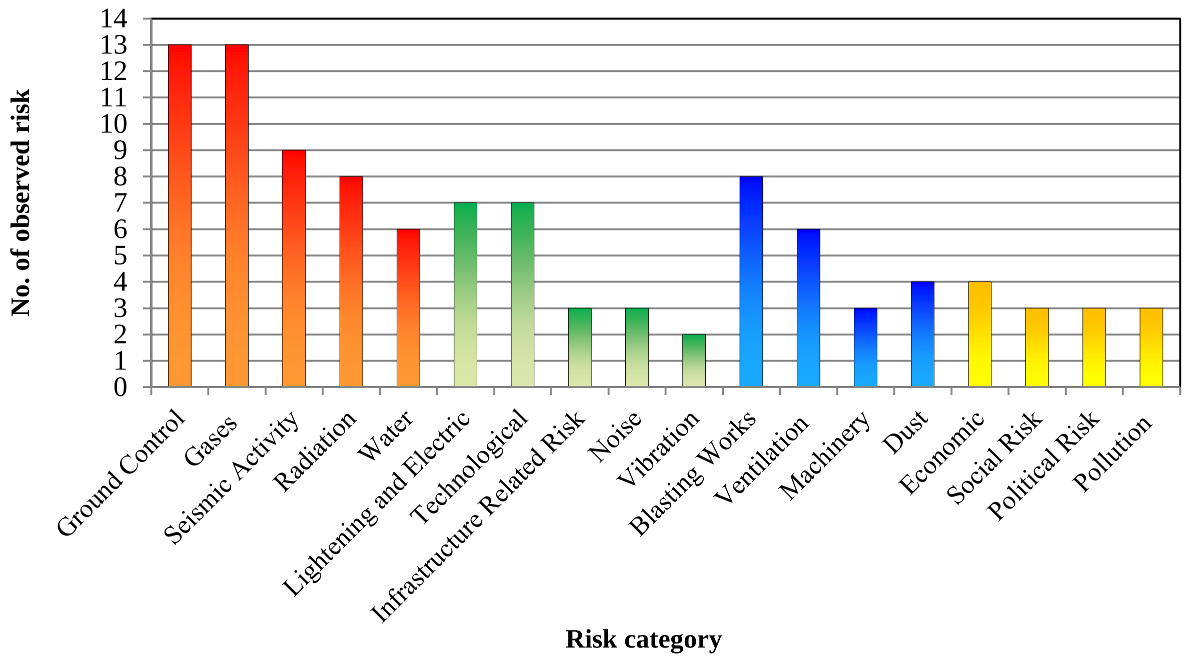


Figure 8.2. Summary of identified risks in particular categories of hazard

It can be seen in Fig. 3 that most of the risks are related to the natural hazards i.e. radiation, ground control, seismic activity etc. This group represents almost 50% of all defined hazards. Risks at the workplace (electric, noise, vibrations etc.) represent about 21%, risk related to the mining operations (blasting works, ventilation, machinery etc.) – 20% and socio-economic risk (social, political etc.) is about 12%. It should be highlighted, that none of ULs indicate the possible occurrence of risk related to inappropriate procedures or improper organization.

It is also worth mentioning, that the statistics presented in this report do not present information about the accident rate. At this stage, authors are focused mainly on the identification of potential unwanted events which can occur in underground conditions.

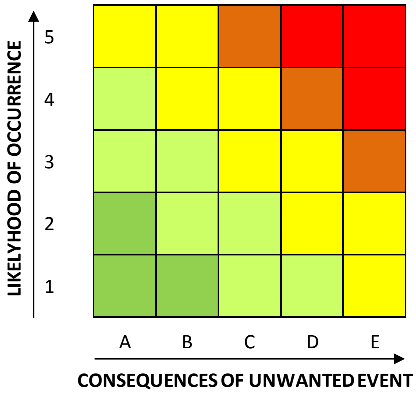
For example, according to current research, a majority of accidents are related to slip, fall or object-handling (Risk at workplace category). For example, in Swedish mines, they accounted for more than 30% of all accidents, and in the case of mines in the USA, it was more than 50% (Lööw et al., 2019).

Thanks to the cooperation between partners and deep research of subject, they were able to provide a comprehensive and wide preliminary assessment procedure for underground laboratories, as concerning safety issues. The prepared guideline will be suitable for both existing and potential facilities located in different underground environments, such as UL's located in existing underground mines with normal exploitation process or in UL's completely separated from active mining.

8.1. Statistical analysis and categorization

In order to carry out a comprehensive risk assessment, the probability and consequences of individual unwanted events have to be estimated. On the basis of the risk matrix that is shown in Figure 8.3, risk for defined threats was estimated. This kind of method is one most often used, and in this case, estimated probability of an event is placed on the vertical axis and consequences on the horizontal axis (PMI, 2013). The risk level for each underground facility was determined by means of a prepared questionnaire.

However, it must be kept in mind, that the estimation level is based on the subjective assessment of workers, and assessment done by two different employees can produce differing results (Smolarkiewicz et al., 2011). Insofar, it is crucial that preliminary risk assessment with use of risk matrix should be conducted only by an expert knowledgeable on the UL operating process.



UA	**Unacceptable / Very high** - The risk will jeopardize the project to a large or very large extent. Measures to eliminate or reduce risk has to be applied
S	**Serious / High** - The risk could jeopardize the project. Measures to eliminate or reduce risk has to be applied
M	**Medium** - The risk could jeopardize the project. The risk reducing measures shall be analysed and applied of so decided
L	**Low** - The risk will affect the project to some or minor extent. The risk is accepted with no further analysis or measures taken
A	**Acceptable / Very low** - The risk wont affect the project. The risk is accepted with no further analysis or measures taken

Probability levels: 1 - Extremely Small, 2 - Low, 3 – Moderate, 4 – High, 5 - Very High,
Impact levels: A – Unnoticeable, B - Small, C - Moderate, D- Severe, E - Catastrophic

Figure 8.3. Risk matrix 5x5

As a result of estimation, the risk for all listed unwanted events was determined. Example of risk assessment in the ground control category is presented in Figure 8.4.

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ENVIRONMENTAL RISK

Interreg Baltic Sea Region EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

No.	Ground Control	Probability	Impact	Risk
1.	GEOLOGIC DISCONTINUITIES OCCURRENCE	MODERATE	SEVERE	MEDIUM
2.	UNSUPPORTED ROOF	LOW	CATASTROPHIC	SERIOUS / HIGH
3.	SPALLING OF WALL	MODERATE	MODERATE	MEDIUM
4.	ROOF FAILURES	LOW	CATASTROPHIC	SERIOUS / HIGH
5.	WORKINGS INSTABILITY	LOW	CATASTROPHIC	SERIOUS / HIGH
6.	OVERBURDEN CAVING	EXTREMELY SMALL	CATASTROPHIC	MEDIUM
7.	LONG TERM CREEP EFFECT	MODERATE	MODERATE	MEDIUM
8.	TOO HIGH IN-SITU STRESS	LOW	SEVERE	MEDIUM
9.	GROUND MOVEMENT	LOW	CATASTROPHIC	SERIOUS / HIGH
10.	COLLAPSE OF SURFACE	EXTREMELY SMALL	CATASTROPHIC	MEDIUM
11.	MINE COLLAPSE	EXTREMELY SMALL	CATASTROPHIC	MEDIUM
12.	LACK OF MONITORING DEVICES OF WORKINGS STABILITY	LOW	SMALL	LOW
13.	CAVE-IN	EXTREMELY SMALL	SEVERE	LOW
14.	SWELLING	MODERATE	SMALL	LOW
15.	SQUEEZING	MODERATE	SMALL	LOW
16.	….			

Figure 8.5. Questionnaire for risk assessment in the ground control category

Questionnaires were filled by the management of all ULs from BSUIN project. Based on the prepared questionnaires, detailed data about the hazard level for each of the categories were determined. In figure 8.6, the percentage of events classified into subsequent risk groups is presented. All unwanted events were analysed separately for each category.

It can be noticed, that among identified events in the seismic activity category, 40% of events were associated with a serious level of risk while ca. 13% with the medium risk, 20% with low and ca. 27% with the acceptable risk level. The highest risk is associated with instability of underground workings that can be caused by seismic events or poor ground support. Analysis of gathered data shows, that 40% of risks in the seismic activity category involve a serious risk of potential accidents. A similar conclusion can be drawn in relation to ground control, where 24% of events were classified as severe accidents. It is important in the case of threats associated with dynamic seismic events, to carry out a deeper numerical analysis. Modelling for the dynamic condition is recommended.

Percentage of risk in each category [%]

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

		Unacceptable	Serious	Medium	Low	Acceptable	Total
ENVIRONMENTAL RISKS	Ground Control	0,00%	24,00%	52,00%	20,00%	4,00%	100,00%
	Gases	0,00%	0,00%	66,67%	28,57%	4,76%	100,00%
	Seismic Activity	0,00%	40,00%	13,33%	20,00%	26,67%	100,00%
	Radiation	0,00%	0,00%	16,67%	50,00%	33,33%	100,00%
	Water	0,00%	5,88%	23,53%	52,94%	17,65%	100,00%
RISK AT THE WORKPLACE	Lightening and Electric	0,00%	8,00%	24,00%	28,00%	40,00%	100,00%
	Technological	0,00%	3,57%	7,14%	75,00%	14,29%	100,00%
	Infrastructure Related Risk	0,00%	0,00%	22,22%	55,56%	22,22%	100,00%
	Noise	0,00%	9,09%	18,18%	45,45%	27,27%	100,00%
	Vibration	0,00%	0,00%	0,00%	50,00%	50,00%	100,00%
RISKS RELATED TO MINING OPERATIONS	Blasting Works	0,00%	31,25%	25,00%	25,00%	18,75%	100,00%
	Ventilation and Air Condition	0,00%	15,79%	26,32%	47,37%	10,53%	100,00%
	Machinery	0,00%	22,22%	33,33%	44,44%	0,00%	100,00%
	Dust	0,00%	0,00%	50,00%	50,00%	0,00%	100,00%
OTHER	Economic	0,00%	0,00%	13,33%	26,67%	60,00%	100,00%
	Social	0,00%	0,00%	8,33%	41,67%	50,00%	100,00%
	Political Risk	0,00%	12,50%	0,00%	25,00%	62,50%	100,00%
	Pollution	0,00%	0,00%	0,00%	30,00%	70,00%	100,00%

Figure 8.6. Summary of the intensity of identified risks for all defined risk categories

More attention should be drawn to the hazard analysis related to laboratories located in active mines. In many cases, there are much more technical equipment like vehicles, moving parts of machines etc. that can be potentially dangerous. Also, laboratories which use explosives for the purposes of research should make more detailed risk analysis, because additional paraseismic load can have a significant effect on changes in stability conditions, even at relatively long distances.

8.2. Summary and conclusions

Analysis of the data and information gathered from project partners allowed to prepare a unified risk assessment procedure that can be used in the future for preliminary estimation of risk for active or future underground laboratories. A block diagram of the procedure is shown in figure 8.7. The step-by-step description covers all activities that should be done to evaluate the risk for the given facility. The procedure consists of the following main steps:

- hazard identification, according to the gathered data (developed questionnaire can be used);
- determination of the probability and potential impact;
- Calculation of the risk assessment

In case of an unacceptable level of risk, a reduction program should be developed and implemented. The procedure can be also used as a periodic assessment program to check the current status of risk or in case of important environmental or technological changes.

Collected data allowed the creation of an initial database of different types of hazards that can be a presence in underground facilities. Additionally, based on their origin, hazards were divided and put in four categories:

- Environment risk,

- Risk at the workplace,
- Risk related to the mining operations,
- Other risks.

It must be emphasized, that this method is useful at every stage of the lifecycle of underground facilities. The versatility of method involves their application to both active mines and separate ULs.

Still, it should be kept in mind that the database of risks presented in the prepared risk assessment questionnaire will be expanded in future and will be available in open access

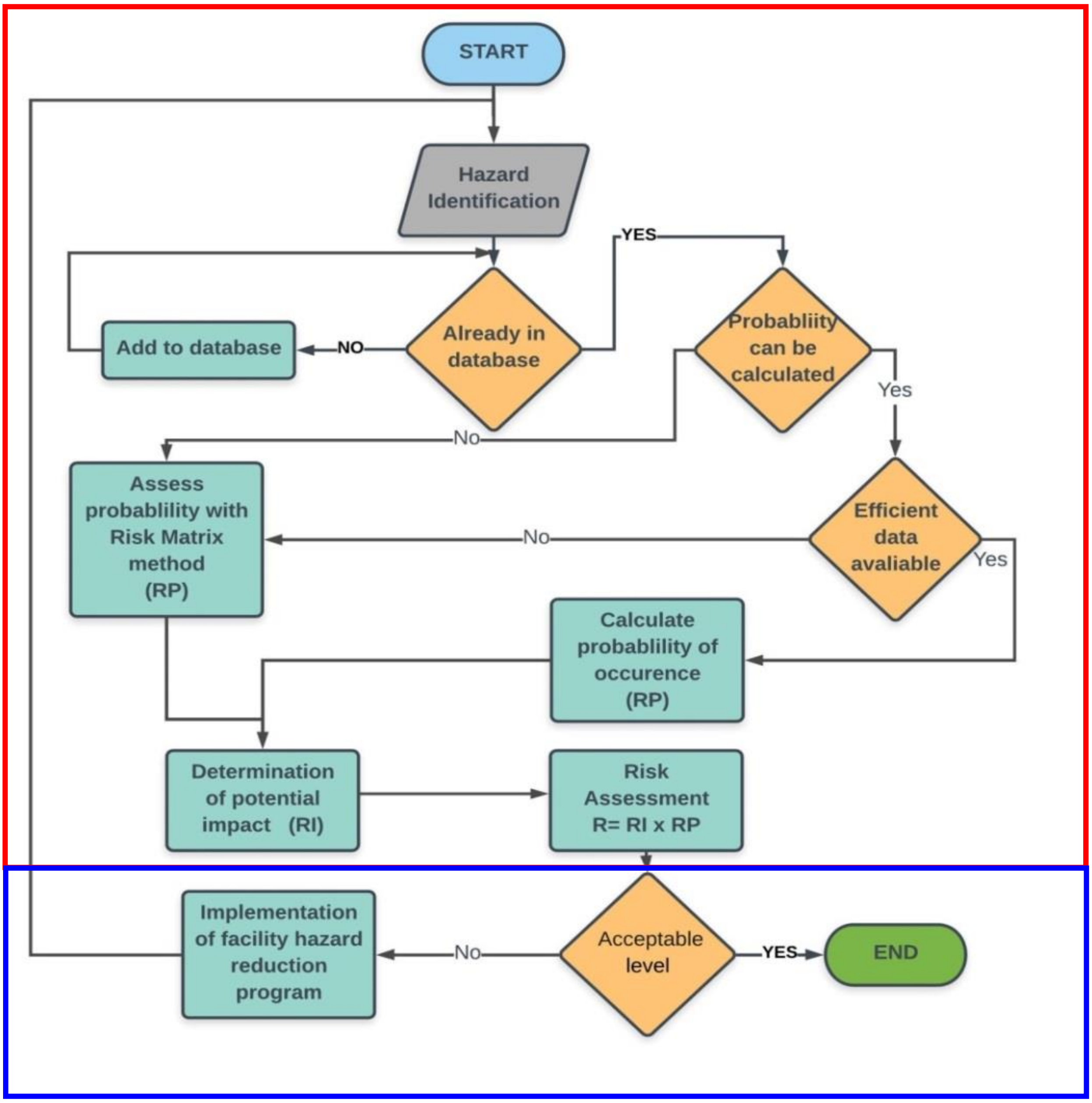


Figure. 8.7. A Block diagram of risk evaluation for underground laboratories

9. PROCEDURES OF RISK PREVENTION AND MINIMISATION

Safety management must be implemented in all workplaces, including operations in underground facilities.

Safety management is composed of risk assessment and all of the activities related to the prevention and minimalization of the hazards. Based on hazard assessment, suitable actions should be taken to limit risk to the acceptable level. It is particularly important in the case of underground activities where the environment can be quite dangerous and risks are relatively complex compared to the facilities located on the surface. Preventative and mitigation actions are described in detail in safety procedures. It must be kept in mind that risk level could change in time, therefore hazard assessment is a continuous process based on data provided from the applied monitoring system. In many cases, local monitoring systems supply real-time data and can warn directly of a developing danger situation. As was mentioned already, risk management is based on three principles, namely:

- **Elimination –** this is the first step of consideration, if it possible to remove the risk (elimination of the related hazard)
- **Mitigation –** if elimination is not possible, action should be taken to decrease risk (limitation the consequence or/and probability of risk)
- **Acceptance –** a decision that some risk level is acceptable (further reduction is pointless or practically irrational).

An inherent part of any risk management strategy is a group of actions conducted to eliminate, mitigate or tolerate the identified risks. These actions are often in the form of procedures and plans, which involve physical or organisational changes in underground operations to achieve the acceptable risk level. These controls can be divided into "hard" or "soft", indicating physical impediments to prevent the undesirable outcome, as opposed to "soft" impediments such as training, procedures, plans, etc, aimed at behavioural change (Hebblewhite, 2009).

9.1. Geomechanical hazard and seismicity

According to conducted preliminary hazard assessment, rock instability, in the form of rockfall or rockburst, is the main, most burning issue associated with underground operations, because these kind of events are related with a high negative impact on operation safety and functionality. All abovementioned cases can be a reason for an unacceptable risk level. Suitable control of the geomechanical hazard is associated with maintaining the stability of underground functional spaces like chambers, drifts, excavations etc. Stability of the underground structure is improved mainly by ground support, which fulfils three functions (Mark & Barczak 2015):

- prevent the collapse of the roof or walls,
- protect workers from small rockfalls from roof and walls,
- control deformations of the working space.

Examples of potential causes of ground or strata instability at underground facilities are listed below (Code of Practice, 2016):

- inadequately designed ground support,

- bad quality or lack of ground support,
- mining-induced or natural seismicity,
- excessive stress around excavations
- groundwater or artificially introduced water
- presence of adverse geological structures like faults, discontinuous in the immediate vicinity of underground facilities
- excessive blast damage to the perimeter of the excavation
- inappropriate shape and size of pillars, roadways, or functional underground structures (shafts, chambers, excavations)

From a practical point of view, in the presence of a geotechnical hazard, the first direct measure should be to remove people from the endangered zone. Afterwards, the area affected by geomechanical risk needs to be closed off, as a short-term solution (especial in case of emergency). Hazardous area should be marked with signs and warnings (Figure 9.1).

Figure 9.1. Example of warning signs

The closing off of the danger area is only a temporary solution and there is a need to do other activities to ensure proper protection of the working place. If loss of stability within the roof propagates, a scaling process, which involves removal of the loose rocks from roof and walls, need to be utilised. It is done manually by means of a scaling bar or mechanically by a scaling machine. This process is very important and should be followed by most or all activities connected with the building or rebuilding of underground support.

Depending on the geologic structure and geotechnical conditions (rock mechanical properties, stress and strain conditions), different types of support should be used.
The support that is used in underground working spaces can be divided into two types:

- intrinsic support (element is installed inside the roof, wall) e.g. rock bolts,
- standing support (elements are installed between roof and floor, or between walls)

In case of underground facilities such as UL's, rock bolts are the most popular intrinsic support and they can be put into roof or walls. The main aim of the rock bolts is reduced bed separation and protection of excavations before rock falls. Length, spacing, and type of rock bolt should be adjusted to the local conditions. It is noted, that bolt length must be at least 1 m more than failure zone (Li, 2017). Support systems based on bolts is often of a combination of rock bolts, cable bolts, and mesh or shotcrete (Figure 9.2).

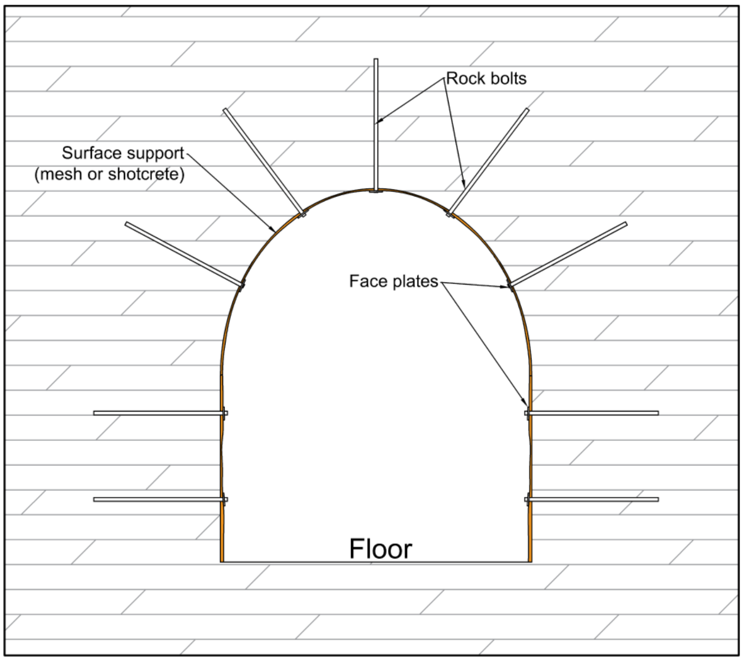


Figure 9.2. Scheme of rock bolts location in excavation (Code of Practice, 2016)

There are many situations where rock structure is not strong enough to support itself and must be reinforced by standing supports, to ensure a safe place for operations in the underground space. It is recommended, to avoid such a place when looking for a potential location of UL. Still, if this kind of location is required i.e. for developing mining technology, or there is no other possibility, then used support have to ensure a sufficient factor of stability as long as needed (HSE Guidance, 2002). An example of standing support is steel arches (Figure 9.3), brick arches, reinforced concrete, timber sets, props, bars, wood cribs etc. Strength and mechanical characteristics of the support must be adjusted to the local conditions e.g. arch walls made of brick or concrete pre-cast elements are recommended to be used in long-life tunnels and chambers located in a rock mass with water inflow or strongly filled with gases, located at small depths (Majcherczyk & Małkowski, 2005).

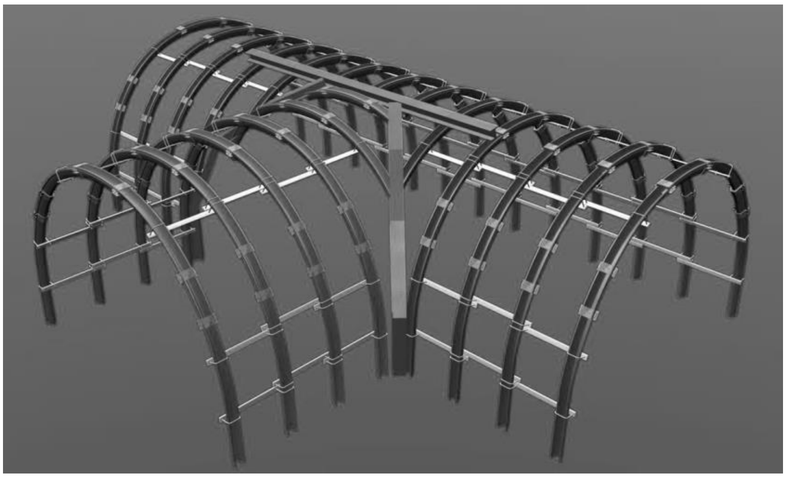


Figure 9.3. An example of a set of steel arches (Becker-mining, 2020)

An integral part of geomechanical hazard management is up-to-date control of the strain and stress state in the rock mass. It means that underground excavations should be equipped with an efficient monitoring system of rock mass behaviour. Regular data analysis gives information about stress and strain changes, so current risk level can be assessed. If some parameters exceed the limits, immediate evacuation could be performed. The analysis could also indicate that risk in a certain area has become unacceptable, and any activities are forbidden and the area must be closed. In other cases, it might be necessary to use an additional support system to decrease risk to the acceptable level.

As an additional part of the minimization of the geotechnical risk numerical modelling could be used. This kind of analysis, validated by data obtained from the monitoring system, provides valuable information of the rock mass state in small and large scale, and helps predict i.e. stress changes around the workings before their excavation (Figure 9.4). It also helps in selecting a proper development project. Information about stress level allow also aids in choosing a proper support system and their parameters.

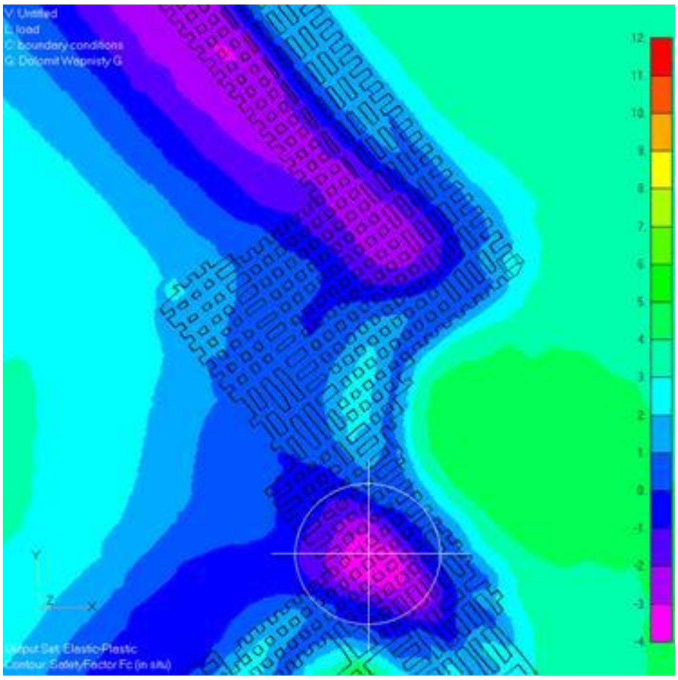


Figure 9.4. An example of an outcome of numerical modelling

An important part of the ground control is the proper design of the underground working areas. It is also an outcome of the geotechnical assessment. It includes detailed information regarding size, shapes, and structures of underground facilities and must be adjusted to the local rock mass conditions, including natural or induced seismicity. To limit hazards related to the damage of underground openings, the pillars or abutments must ensure the stability of the examined area. The designed or selected control measures have to be used without unnecessary risks during the installation and operation at the underground area (Code of Practice, 2016).

Some of the existing underground voids including goafs, chambers, tunnels etc. can create serious hazards of construction stability. The collapse of these empty spaces can substantially change the stress state of the rock mass and impact the stability of the other structures located in the vicinity (Sheshpari, 2015). That is the reason that in some cases, part of underground existing structures like tunnels, chambers etc. must be backfilled to improve stability and ensure acceptable risk level. Depending on the local conditions, this kind of operation can be done during the construction of the underground facility or later during their lifetime. The example of hydraulic backfilling is presented in figure 9.5.

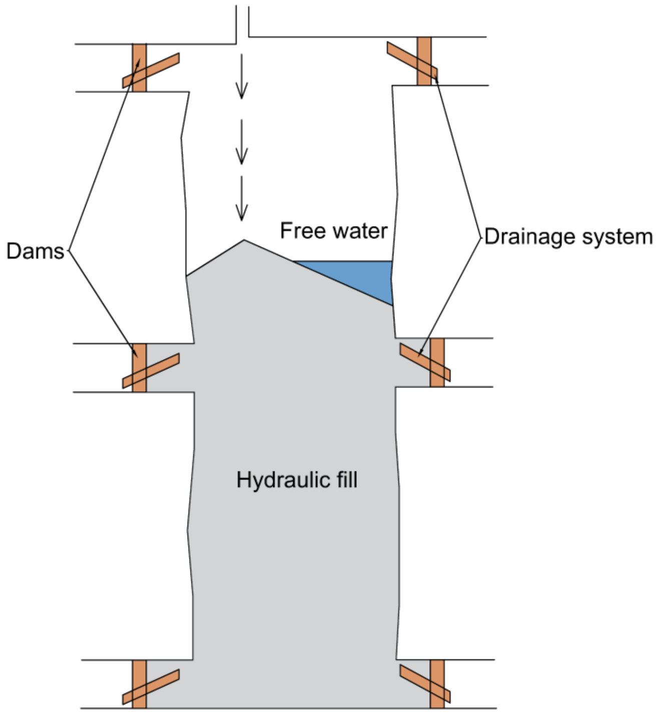


Figure 9.5. An example of hydraulic backfill (Sheshpari, 2015)

In some situation, when the above-mentioned methods of geotechnical risk minimization are not effective enough to limit the risk of the rockburst other methods can be used. These methods, so-called active rockburst preventive methods, are used to decrease strain and stress level in a given area. The most popular active methods are destress blasting or hydraulic fracturing.

Destress blasting can change stress in a certain area of the rock mass by releasing accumulated elastic energy in the form of the triggered seismic event. Another aim of de-stress blasting, is to change the mechanic characteristics of the rock mass from elastic to more plastic to decrease the capacity of the rock mass to the accumulation of the elastic energy. It is done by means of paraseismic waves generated by blasting works that pass through the rock and create the cracks (Figure 9.6).

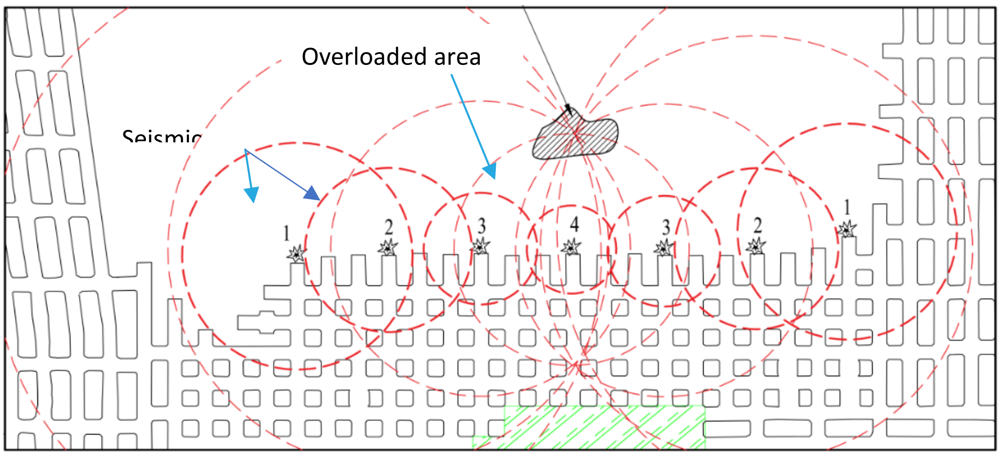


Figure 9.6. An example of de-stress blasting

Another active method of rockburst prevention is hydraulic fracturing. Similar to destress blasting, the aim of this method is to cause a change in the mechanic characteristic of rock mass by creating cracks in the rock mass. However, this method is still under development and there are not many indications of the effectiveness of this method (Kaiser et al, 2013).

There are also situations where hazard cannot be mitigated to the acceptable level, and in this case, the hazardous area has to be closed and all activities involving people must be forbidden. Fixed barriers and signs should be prepared to prevent people from going to the dangerous area. In all cases, proper emergency procedures have to be implemented.

9.2. Flood and fire hazard

Inrush of uncontrolled water, or any fluid material, is one of the hazards that must be assessed and controlled continuously throughout the UL's lifetime. Sudden inrush of a large amount of fluid into the workplace can create an emergency and presents a serious risk to the health and safety of employees.

In many cases, the best option that can be implemented at short notice (especially in case of an emergency) is evacuation and exclusion of the danger zone by means of barriers, signs, and warnings. It is rare that you can permanently close off an entire area, so this is only a temporary solution only and other more permanent solutions need to be applied to ensure proper safety and protection of the working place. Water and other kinds of fluid ingress hazards could include the following (NSW Code of Practice, 2015):

- the significant volume of water or other fluid material,
- material that flows when wet,
- material, which is the result of vibration may be fluidized,
- paste or hydraulic filled areas,
- water storage dams or other man-made water structures,
- water and any liquid used in any working processes,
- lakes, rivers, and other natural water reservoirs.

The cause of the flood may be located on the surface or underground and originate from different sources. For example, if an underground facility is a part of an existing or abandoned mine, there is a possibility that the water reservoir is located in old workings or goafs. It also must be kept in mind that water and other fluid can get into underground spaces from the surface (rivers, lakes, precipitation) through shafts, declines and geological discontinues (e.g. faults). It means that all these aspects must be considered in the risk assessment which is the basis for developing an effective water ingress management plan. Therefore, the following factors should be included in the assessment (NSW Code of Practice, 2015):

- identification of possible inrush hazards,
- determination of the mechanism, volume, and flow rate of inrush water,
- the number and location of people who may be affected by inrush and inundation,
- the path of the inundation or inrush,
- prevention, monitoring and emergency procedures.

All these issues demand that comprehensive knowledge of the water system is needed. To provide this information, proper hydrogeology recognition must be performed. The most popular method of hydrogeology recognition is through drilling a group of special test holes within analysed areas.

All of the above-mentioned actions have to ensure that the risk level related to the water ingress hazard is acceptable, otherwise additional controls must be implemented. As was mentioned before, controls should eliminate or reduce the hazard. As a first step hazard, elimination should be considered. This is the most effective way to prevent fluid ingress. Elimination of the water hazard can be done by means of removing or relocating the water reservoir. In the case of underground water storage structures, a proper draining system can be used to eliminate or relocate water to protect the working area against inundation hazard. Another way to eliminate water hazard is by locating the man-made underground water storage in the lowest part of the underground facility. In most cases, the underground draining system consists of drain holes and lines, pipes, and pumps. Elimination of surface water structures is also a viable option to protect the underground facility. As was mentioned before, in case of emergency, the best option that can be used in a short time is evacuation and exclusion of danger zone utilizing barriers, signs, and warnings.

In many instances elimination of the hazard is not possible. These situations require actions that limit hazard to the acceptable level. Minimization of water hazard can be done also by a draining system. In this case, the amount of water and flow rate can be decreased to the level adjusted to the installed dewatering system. Another possible action is to close or protect the possible connection between the fluid reservoir and underground facility. These kinds of structures are a different kind of barriers that separates working areas from the hazardous zone (Guideline for Inrush Hazard Management, 2007). The following structures can be used as barriers:

- dams,
- pillars,
- plugs,
- seals.

Barriers should be suitable to the local environment. Design of barrier structure must take into consideration the following aspects:

- pressure,
- exploitation time (stability in time),
- geological condition,
- stability of construction material,
- other.

Barriers in use have to be monitored and maintained to ensure they remain intact as required. Barriers cannot be modified in any way without an assessment of the change and its impact on the performance of the barrier. In the case of pillars being used as barriers, proper dimensions must be used to provide adequate risk level (Figure 9.7).

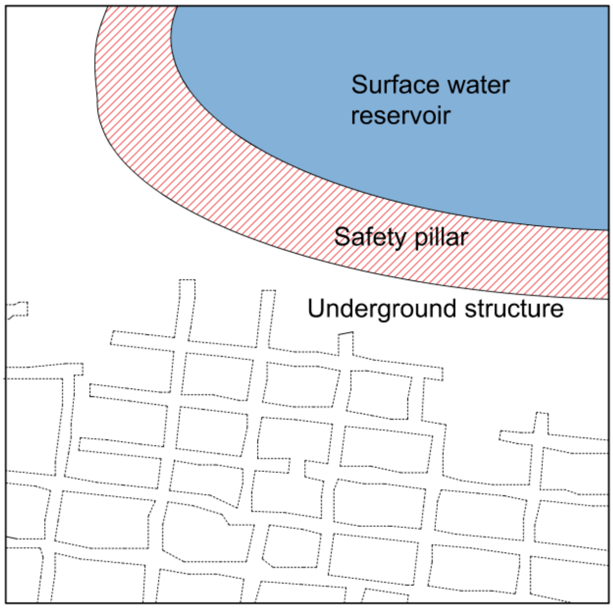


Figure 9.7. Safety pillar between underground structure and surface reservoir

Some structures must be sealed to close connection between the water reservoir and underground space. This kind of protection is often used in the shaft which is passed through aquifers. In many cases, a different type of grout is used as a sealing agent (Goodman et al, 2018). In this process, the sealing agent is injected into specified areas to fill the cracks and block water flow. Areas that have been drained, sealed, and protected in another way should be closely monitored and checked. This option is recommended to maintain safety level under sufficient control.

An important part of this hazard mitigation is a dewatering system, which is based on pumps. The most important features of this system are its capacity and reliability. Pumps capacity must be adjusted to the local conditions and be able to remove extra water inflow. It means that the capacity of the system must allow pumping much more water than standard inflow volume. The system consists mainly of pumps, which are capable of removing water from the mine, and other elements like pipes, drain holes and lines, water dams and storages. An equally important feature of the system is their reliability. To provide a high level of reliability elements of the system must be maintained and checked in a regular manner. In many cases, a pump system is doubled (backup system ready to be taken into use) to achieve a sufficient level of reliability.

Underground water that flows through the dewatering system is often polluted and consist of many contaminants included gases. It means that the dewatering system should contain a purification system to protect people and the environment. Part of this system is quality monitoring that checks the chemical parameters of the water in different places.

There are also situations that hazard elimination or mitigation is not possible, in this case, the hazardous area has to be closed and all activities involving humans must be forbidden. Fixed barriers and signs should be prepared to prevent people from getting in. In all cases, proper emergency procedures have to be implemented.

9.3. Gases and radiation hazards

A crucial element to ensuring safety of the workplace in the underground environment is breathable air. A proper ventilation system has to ensure proper volume of fresh air to maintain acceptable working conditions i.e. remove and dilute contaminants, supply oxygen, maintain thermal comfort etc. It should be noted that the underground atmosphere is a mixture of fresh air and gases emanating from rock mass, mining operations, and fires. Many of these gases that can be present underground are toxic, asphyxiating, or explosive. It means that hazard related to the underground atmosphere is very serious and risk assessment must cover all these aspects. An important part of the risk assessment process is geological recognition that can indicate areas with gas emission hazard. The following gases can be present in underground spaces (Brake, 2015):

- methane (CH_4),
- nitrogen oxides (NO_x),
- carbon dioxide and monoxide (CO_2, CO),
- sulphur dioxide (SO_2),
- hydrogen sulfide (H_2S),
- ammonia (NH_3).

Sources of toxic gases in the underground facilities can be rock mass or working operations (i.e. fumes from diesel engines or blasting operations). The main hazard that relates to the ventilation is unbreathable atmosphere occurrence. It may be caused by:

- low oxygen level,
- concentrations of gases in the working place atmosphere are above acceptable limits,
- natural gases eruption (e.g. methane, carbon dioxide),
- combustive gases explosion or coal dust explosion,
- fires,
- confined space without airflow.

Natural gas eruption

Risk reduction can be achieved by using a draining system that removes gases from the rock mass. These kinds of systems consist of draining holes, pipes, and fans. Other methods that are also possible to utilize include the sealing or closing of dangerous areas by using sealing agents, which are injected into the rock mass, or barriers (dams, pillars, plugs). Scheme of the example of the draining system for methane removal is shown in Figure 9.8.

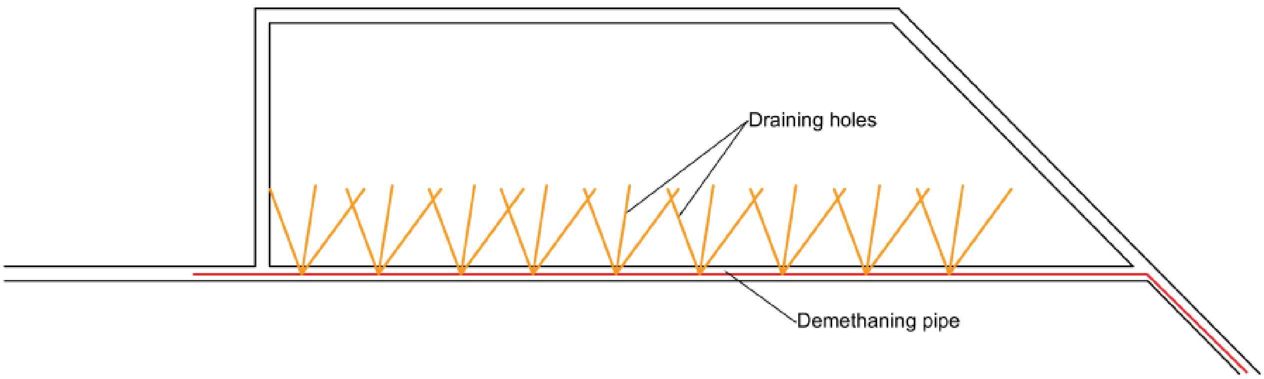


Figure 9.8. Scheme of an example demethaning system (Nawrat, 2006)

Gases from diesel engines and blasting works

If explosives or diesel engines are in use during exploitation of the underground facility, risk prevention should be implemented in the form of a proper ventilation system, which dilutes harmful gases to an acceptable level. Of course, more environmentally acceptable solutions may be proposed. In some cases, blasting works can be replaced by a mechanical process, and machines with diesel engines can be replaced by electrically powered equipment. Still, these solutions are rather expensive and therefore not always possible to implement.

Gas hazard can be also mitigated with the aid of a ventilation system that is able to dilute and remove toxic gases from the underground atmosphere at a fast rate. There are of course many solutions to mitigate these risks, such as isolating workers from hazardous gases by using special hermetic cabins for operators or personal protective equipment, like gas masks with proper filters.

Gas explosion

Due to limited space volume and the possibility of the presence of explosive gases in some places, there is a risk of explosion and fire. The source of explosive gas in the underground environment can be natural (e.g. methane) or artificial, related to the working operations. In some cases, it is possible to minimize this risk by removal of explosives gases by a non-explosive agent. In other instances, mitigation activities should be taken. The following actions can be done:

- remove of explosives gases from rock mass,
- adjust ventilation system (dilution of explosives gases),
- remove the source of ignition (electric systems, sparks from mechanic systems, hot works etc.),
- automatic turn-off of the electric system in case of exceeding gas limits
- others.

Removal of dangerous gases from the rock mass can be done by means of a draining system based on the holes that are drilled into areas where gas is present. Elimination of all gas is practically impossible but the amount of dangerous agent that inflows to the underground space can be decreased significantly (Code of Practice, 2014).

Radiation

Natural radiation cannot be removed and mitigation actions have to be taken if their level is too high. Reduction of this kind of hazard is possible through proper ventilation systems and protected constructions and barriers that isolate workers against radiation. In the case of man-made radiation, if it is possible, use of radioactive substances or processes should be eliminated. Minimization of this kind of threat is also possible by using proper PPE and by limiting working time in the dangerous area.

Summaries

In cases where gas or radiation hazards cannot be eliminated or mitigated to acceptable levels, the hazardous areas have to be closed and all of human activities must be forbidden. Fixed barriers and signs should be prepared to prevent people from getting in. In all cases, proper emergency procedures have to be implemented.

9.4. Workplace hazard

There also some groups of unwanted events which are typical for almost every branch of industry. Prevention of noise, vibration, electricity, and dust, in the long-term, ensure safe and healthy conditions for working in underground areas.

Noise and vibration

As was mentioned before, underground facilities can be considered enclosed areas. In these kinds of environments noise level can be a source of severe risk for the staff, much more so than on the surface. It is caused by the limited amount of space. Sources of noise are machines, devices, and processes that are done in the underground space (e.g. blasting works). The same objects and processes may be a source of harmful levels of vibration. Therefore, if possible, continuous mitigation of noise and vibration threats should be done. In this situation the following solutions can be used:

- replace or modify machinery or devices to limit noise and vibration level,
- separation of workers from hazard, utilizing noise and vibration barriers, soundproof cabins (Figure 9.9), vibration attenuators etc.
- PPE such as earplugs, muffs, anti-vibration gloves,
- Limiting working time.

Figure 9.9. An example of a soundproof cabin (Cab-expert, 2020)

Each area that is affected by a high noise level should be properly marked (Fig. 9.10).

Figure 9.10. An example of a noise warning sign (Seton, 2020)

If the level of noise and/or vibration is too high, and elimination or mitigation of these threats is not possible, hazardous areas have to be closed and all human activities must be forbidden. Fixed barriers and signs should be prepared to prevent people from getting in. In all cases, proper emergency procedures have to be implemented.

Electric hazards

In most cases, electric power is used in underground facilities. The scope of electric use can be different and depends on the type of activities in underground space. In some cases, the existence of an electric power supply is crucial from a safety point of view, because it is necessary to supply energy for ventilation and other very important systems. Use of electricity and electrically-powered machines and tools can also create a hazard for personnel. The following threats are related to electric power (ILO code of practice, 2009):

- electrocution,
- electrical burns,
- fire ignition,
- explosion ignition.

Keep in mind, that these kind of threats can also originate from electric machines and tools equipped with batteries. Elimination or mitigation of this kind of hazard must be done to ensure proper safety level for workers.

All crucial systems (ventilation, dewatering system) that are used in underground working places need a reliable electrical power system. Control of this hazard is ensured by means of properly designed and maintained electrical systems. Mitigation of this kind of threats for important systems is done by means of using two or more independent power systems. An integral part of reliable systems is control sensors, that are installed in neuralgic points of systems.
Electrocution hazard (electric shock, electrical burns) can be limited in multiple ways, for example:

- decreasing working voltage – some systems can be supplied by 12 V instead of 230 V,
- technical isolation, barriers (Figure 9.11)
- signs (Figure 9.12)
- safety fuses,
- emergency safety buttons,
- PPE,

- others.

Figure 9.11. Example of protection of electric devices)

Figure 9.12. Example of a warning sign of high voltage (Creative safety supply, 2020)

In some cases, electrical systems and equipment can be powered by a lower voltage electrical system (12 V DC), that is much safer for workers than standard 230 V AC. In this situation, possibilities of serious injuries are very low. In other cases, elements of electrical systems should be designed in a way that unauthorised access to the system is impossible. It is done in most cases by means of barriers with emergency switch off. Parameters of the safety barriers must be adjusted to the voltage level. To maintain the system in a proper condition, the system must be checked and repaired in a regular manner. An important part of electrical safety systems are safety fuses, which should be adjusted to the systems and allow to switch off the electrical power in case of emergency in a short time (Electrical safety, 2009).

A very important part of the protection system that should be a limited electric hazard is also used proper PPE which cover the following elements:

- nonconductive helmet,
- nonconductive boots,
- rubber-insulating gloves.

Workers that can be exposed to the electric power should also wear, among others, long sleeve shirts, long pants, jackets etc. to protect the rest of the body.

Technological risk

Underground spaces can be used in many different types of activities which all bring different types of threats. In some cases underground structures, like chambers, drifts etc.., change their functions during their lifetime. It means that e.g. workings made in mining activities can be used as an underground laboratory. In this situation, from a technical point of view, the current structure can be unsuitable for the new project and as a result create hazards. Technological hazard could be also related to another aspect like:

- lift system,
- Lack of visibility,
- Machine-related accidents
- new working processes and technologies.

The first step of risk elimination or mitigation is proper site investigation into the requirements for the facility's functions, workings processes, and technologies. Comprehensive knowledge gathered in site investigation helps limit possible hazards.

Hazard management regarding the transportation system is to be implemented, with solutions on how to limit the risk level. Example of these kinds of activities are:

- regular control and proper maintenance of lifts system,
- building other lifts or other structures to improve transport systems (stairs, ladders, declines etc.),
- preparation of proper resources to maintain transport systems (workshops, mechanist),

In case of inadequate ground support, elements of this system must be redesigned and rebuilt if needed. For the working processes and technologies, a reliable necessary media supply system must be implemented and properly maintained. Each of the zones where these activities are performed and can create a hazard must be marked and secured utilizing signs and barriers.

Infrastructure related risk

Underground infrastructure can be, to a greater or lesser extent, a source of hazards. As an example, the transport system can be used. In this case, proper design and capacity of this system are necessary to enable effective evacuation processes in case of emergencies. Infrastructure in other aspects must be adjusted to the working processes that are done in underground facilities to ensure safe working conditions.
On one hand, shafts must transport people and materials and is a necessity to working operations. On the other hand, shafts need to enable effective staff evacuation in case of emergencies. Mitigation of hazard related to the shaft operations is done employing the following tactics:

- proper maintenance of shaft,
- adjust shaft capacity to the requirements,
- ensure alternative access to the underground facilities (other shafts, declines),
- implemented safety procedure.

Another important part of the underground transport system is a horizontal transport system that can be applied through cars, trains, conveyor belts etc. Employee's transport system must be reliable and fulfil requirements regarding their capacity. Risk management related to the horizontal transport system for workers has to limit hazard by means of solutions that ensure suitable reliability and capacity of the system. Reliability and capacity of the system can be based on the proper quality, maintenance, and number of transport devices.

It should be also kept in minds that the transport system is based on the roads that must be kept in good condition, namely:

- proper ground support in transport excavations (tunnels),
- suitable dimensions adjusted to the vehicles and traffic.

Similar attention should be given to the other types of underground infrastructure like pipes, electric systems, telecommunication systems etc.

In many cases, underground infrastructure is built or modified by external companies. To limit hazard in this kind of work, safety audits should be done to ensure control during construction works. These kinds of audits allow the checking of safety procedures, competencies, authorisations etc. Sufficient control can indicate any violations of procedure and help to maintain the proper level of safety during construction works.

All these aspects should be implemented into the safety procedure to ensure sufficient control of risk in underground facilities. Safety procedure should also cover safety training for staff and any underground visitors in applicable scope.

Safety procedures

Safety procedures are very important documents that are part of safe working operations. These are step by step instructions on how to do any given work in a way that ensures safety for workers. In many cases, deviation from the procedure can cause accidents and injuries. In most cases, this kind of document is obligatory for any work activities, especially for dangerous ones, therefore it is key to prepare them in a proper way.

One crucial element of safe working operations, is ensuring that all workers are familiar and trained in evacuation procedure. There were many accidents in the past, where an emergency occurred which required evacuation, and workers did not know the procedure, or the taught procedure was incorrect (Adjiski et al., 2015). As a result, many people were injured or died. In order to mitigate this hazard, a correct evacuation system must be developed and checked regularly. The procedure should be based on conducted risk assessment which included all safety aspects related to the given working operations. Special attention must be paid to one of the fundamental elements of each evacuation procedure, namely exercises. Evacuation training must be done on a regular basis to ensure that all workers know how to behave in case of an emergency. A key element of the evacuation plan is the map with routes that must be used during evacuation from the endangered zone (OSHA, 2001). An example of an evacuation map in an underground facility is shown in Figure 9.13.

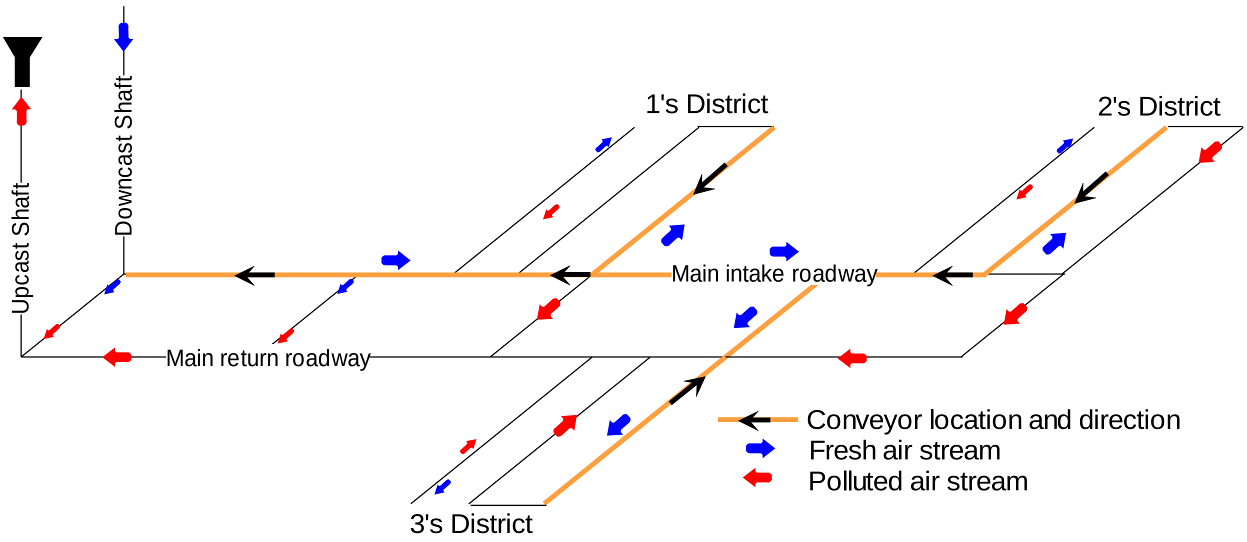


Figure 9.13. Exemplary of evacuation map with description of airflow within the workings

In many cases, working operations are complicated and include many working processes that should have a clear description of the safety procedure. Due to the high complexity of such documents, there is always the risk that their employees are not familiar enough with the procedures. To mitigate this hazard, an effective plan of regular safety audits for all safety procedures and training of employees should be implemented. Regular audits performed by the competitive unit can indicate any errors and discrepancies that have to be corrected. The minimum scope of audits should include the following issues:

- fire management,
- evacuation procedures,
- safety management,
- incident reporting,
- safety communication,
- safety signs and warnings,
- safety training.

Safety audits also verify whether safety procedures fulfil legal requirements. Audits have to also check sensors, installations, and devices which are a part of safety systems like gas/smoke detection systems, oxygen sensors etc. These kind of activities can indicate problems with proper PPE devices as well. On the basis of safety audits, lists of corrective actions that have to be taken can be prepared, which include approximations of time for their realization and the responsible people. In some cases, the auditor can halt any activity that is in violation of procedures.

An equally important aspect of risk prevention is safety awareness of the employees and visitors in the underground facility. All underground workers and visitors should have a minimum knowledge level about the underground environment in which they are. It ought to be done in the form of training that imparts an awareness of specific underground hazards and relative exposure risk, the use of necessary safety equipment and safe operating practice. Finally, until sufficient training is completed, everyone who is unfamiliar with the underground environment should be accompanied into underground facilities by an employee who has the knowledge and experience to act as a guide. This helps to limit accidents and other consequences of present hazards.

Risk related to mining operations

Many times underground laboratories are located in the vicinity of an active mine. It means that hazard related to the mining operation can affect working and activities in the underground facility. Therefore, risk related to the mining activity must be assessed and proper actions should be taken to eliminate or mitigate existing hazards.

One of the most dangerous threats related to mining activity, are the vehicles that move in often times small and dark spaces. Many types of different vehicles can be used in underground operations like trucks, drilling rigs, bolting machines, loaders, trains, etc. There are still many accidents related to traffic in underground mines. As such, this aspect must be analysed each time to assess the risks of this hazard and implement control measures to reduce it to the acceptable level.

The most dangerous accident, which is related to moving vehicles, is getting hit or run over by the moving machine. In many cases, this kind of accidents caused serious injuries or even death. Very dangerous are also collisions between different types of vehicles.

If possible, the first action that should be done to limit hitting hazard is the preparation of special zones for pedestrians only. It can be done by implementing solid barriers or use some excavations or tunnel for pedestrian-only (shape and dimensions are adjusted to the people). Similar special zones for vehicles should be prepared, where the presence of pedestrians is forbidden. An example of this kind of solutions is shown in Figure 9.14.

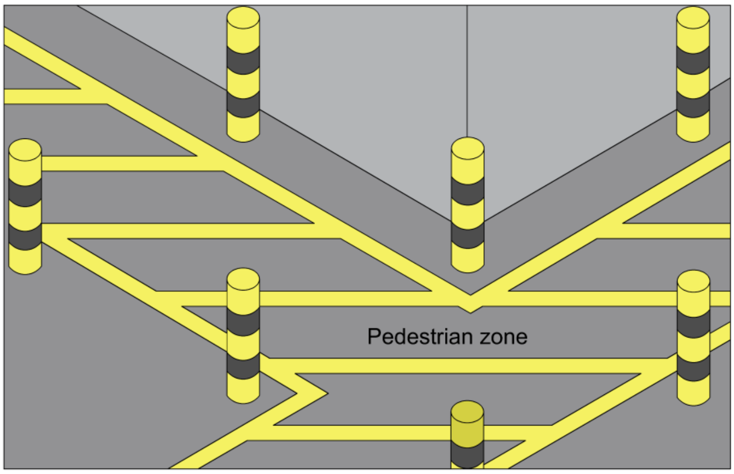


Figure 9.14. Example of the walkway for pedestrian-only (Safe Work Australia, 2014)

An additional element that must be used to mitigate hazard is traffic management, which includes all safety rules and technical measures that must be followed to ensure safety of vehicular traffic. Technical measures such as proper road barriers, traffic signs, traffic lights must be used. To prevent vehicle-related accidents, the following control measures should be implemented:

- speed limiter,
- cameras,
- sensors that indicate the pedestrian presence in close vicinity of vehicles,
- warning flashlights,
- lights,
- other.

Workers in dangerous areas have to wear reflective clothes to improve their visibility. An integral part of traffic management is training workers on the possible hazards of working amidst vehicles and familiarizing them with the safety rules that have to be followed.

9.5. Organizational and socio-economical solutions issues

Good practises in terms of organisational and socio-economical risk minimization may be observed in KGHM Company, Poland. The main motto and target for safety in KGHM is "Zero Harm Policy". Safety is the most important value for the company. All aspects connected with safety are done according to the System of Occupational Health and Safety Management (18001/OHSAS). Threats for each working position were identified and associated risks were assessed. Employees are trained regularly according to a schedule. Constant monitoring of the work environment is conducted. Mobile vehicles and all types of technical equipment are regularly checked and risk assessment is conducted. There is no toleration for illegal and risk-generating behaviours. Golden OSH Principles are applied and regularly updated. Contests testing knowledge of the Golden OSH Principles are often organized. General safety rules were collected into 8 areas (Figure 9.15).

Figure 9.15. Safety rules in the KGHM Group

In 2018 they were working in the area on long-term Program for Improving Occupational Safety and Health. This is an element of the Strategy of KGHM for 2017-2021 to achieve the long-term vision “Zero accidents for personal and technical reasons, zero occupational diseases employees and counterparties”. Key areas of the “Occupational Safety Improvement Program” are shown in figure 9.16.

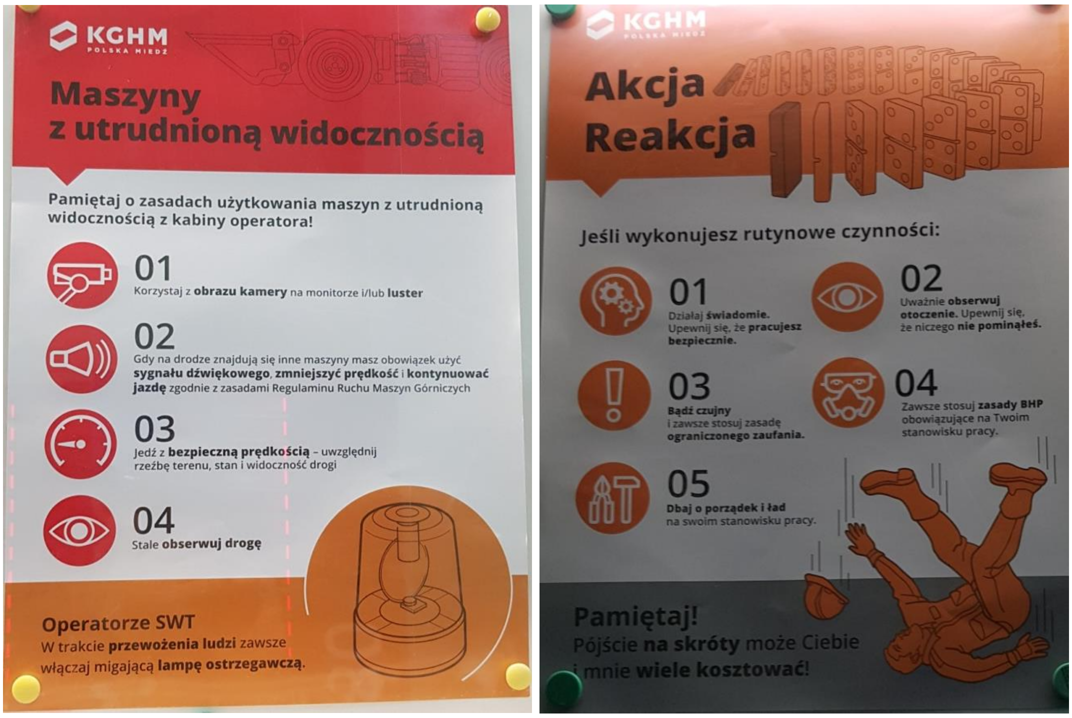
Figure 9.16. Key areas of the “Occupational Safety Improvement Program”

There has been made available a special intranet portal, that contains a lot of articles, infographics, and information about safety at work. As a part of constant improvements, many projects are developing the following:

- automatic device for rock breaking,
- self-driving bolting machine with automatic head,
- innovative system of wireless communication,
- Implementation of an innovative system to support the training of the mining equipment operators.

Plenty of pictograms and information about safety issues are displayed in working areas. Examples are shown in pictures below (Fig. 9.17-9.19):

Figures 9.17. Information about safety rules



Figures 9.18. Information about safety rules

Figures 9.19. Examples of safety labels

Information about the number of days without accidents is also clearly displayed in each of the mining departments. There are also many safety-related activities organized, for example a uniform program called "Healthy employee in a difficult work environment".

Concerning the economical issues, the mitigation of risk is related mainly with proper pre-investment plans and well-developed offer of services provided by UL. However, it is hard to relate strictly economical issues with H&S in the underground facility. Nevertheless, without a proper business plan, all investment may bankrupt, and therefore the development of a business model should be one of the most prioritised actions.

10.FACILITY IMPROVEMENT in ULs of BSUIN project

In case of existing facilities, proper risk assessment helps determine which periods of a facility's lifecycle is related with the highest threat. Knowing potential risks and methods of their monitoring (Chapter 6) as well as minimization and prevention methods (Chapter 9), solutions to facility improvement may be proposed.

For this purpose specialists from KGHM Cuprum, with cooperation from other members of the BSUIN project consortium, have prepared a proposal of preventive solution for each identified risk. On the basis of the risk assessment questionnaire presented (Chapter 8, Appendix 1), description of actions for medium, the serious, and high-risk level was described. The proposed actions are presented fully in appendix 2- facility improvement. Example of proposed actions for chosen risk is presented in table 10.1

Table 10.1. Actions needed for minimization of risk related to the unsupported roof

No.	Ground Control	What if Medium	What if Serious	What if Very High
1.	Unsupported roof	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (i.e. rock bolts, mesh). Regular control. Informing staff, safety toolbox talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (i.e. rock bolts, mesh). Regular control. Informing staff, safety toolbox talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (i.e. rock bolts, mesh). Regular control. Permanent exclusion if needed. Numerical modelling of roof behaviour. Informing staff, safety toolbox talks.
2	…	…	…	…

10.1. Review of the infrastructural improvement of the ULs of the BSUIN project

Regardless of the results of current analysis, management of underground facility are obligated to improve the facility in terms of safety and its monitoring. To check the current development of ULs taking part in BSUIN project, a review of the infrastructural improvement of ULs depending on their different usage was conducted. For this purpose, specialists form KaRC RaS in cooperation with researchers from KGHM CUPRUM have collected information on the infrastructural characteristics of every UL in the BSUIN project.

The scope of collected information concerns current infrastructure description and potential solutions of facility improvement. The main goal was to provide more advanced and safer conditions for a wider range of users.

Specific results of site investigation included:

- a review of possible future infrastructure
- improving ULs
- draft technical ideas for improvement
- availability of ULs
- list of pre-investment measures developed for each ULs

In the result for reach, laboratory investigated such topics like:

- The primary use of area before
- Purpose of use of workings today
- Employment and visitors capacity
- Transport
- Working condition
- H&S monitoring

Finally, some proposals concerning improvement of monitoring systems, communication and accessibility were described. Questionnaires filled by all the participating ULs are presented in **Appendix 3-Review of infrastructural improvement of the ULs of the BSUIN project**.

10.2. Development and testing of universal solutions for risk monitoring - Improving accessibility to ULs through technical ideas

One of the key factors affecting the possibility of implementing facility improvements is economical justification of each development plan. When analysing prices of all devices presented in chapter 6, one may conclude that the majority of devices related to gas monitoring, organisational-improvement and seismic measurements are available and acceptable for most of UL in terms of costs. Therefore, there are no significant obstacles if the necessity of implementation of such devices arises. The situation is quite different in the case of geomechanics surveying equipment. According to authors experience, equipment of this type is not only expensive but also requires the involvement of additional technical resources. For example, any rock bolt, extensometer, or borehole monitoring device may be installed in the rock mass without the use of a drilling rig. This makes the current solution unsuitable for most of the small underground laboratories.

To make underground working stability more accessible and less expensive, the research team from KaRC RaS conducted a series of benchmark measurement with use of different cheap and universal solutions for in-situ monitoring of geomechanical hazard.

The study aimed to develop a methodology for monitoring the stability of the mine such that can be practised by the company operating the underground space on its own. The tasks that need to be addressed when preparing such an object include:

- Identifying the main threats and sources of hazard, which may lead to the destruction or damage of the facility during the process of its use.
- Choosing the methods to monitor these processes (control concepts) that can be used even by persons without special education in the company operating the underground space.

An important condition is that the methods should be optimized both in cost and efficiency. If the proposed solutions do not ensure the visitors' safety, such an underground space should not be used even for a short-term stay.

According to conducted risk analysis, geomechanical threats are especially typical for underground laboratories that are located in abandoned or even working mines (Reiche Zeche mine, KGHM mines and Ruskeala Mining Park). At the same time, if workings are surrounded by hard compacted rock, as is the case in Pyhäsalmi mine, where the Callio Lab is located, and the Aspo Hard Rock Laboratory in Oskarshamn, then such treatment is significantly lower but still exist. Therefore, this work focused on developing a method to control the displacement of walls and roofs which are in an unsupported and semi-fixed state, as well as to control large objects (hundreds of meters long) which can pose danger to visitors and workers.

Based on the research carried out in the Ruskeala Mining Park (Karelia, Russia) [Shekov K. & Shekov V, 2016], the best methods for controlling the movement of rock masses were chosen, including in the underground space and on the walls of the historical quarry [Kim et al.,2018; Sean et al., 2014].

10.2.1. Design and implementation of a pilot photogrammetric measurement program (Tango system)

At present, the main method for documenting underground mine workings in the world is laser techniques using both fixed posts and portable devices that dynamically record the walls and roofs of various mine workings. With sufficiently high quality and accuracy of the resulting "cloud" structures, the costs of such technology remain high, mainly due to the cost of the equipment itself. Owning such equipment is economically justified only if the company constantly uses it.

An alternative to laser technology is photogrammetry-based technology, where cloud structures containing information about the model are produced by taking a large number of photos and processing them using specialized software.

The use of such technology in documenting various objects on the land surface has shown that the accuracy of the results matched those obtained by laser measurements. At the same time, the cost of the equipment (camera and software) is an order of magnitude, if not more, lower than for laser devices.

Laser scanning and photogrammetry allow for high-precision (from 2 to 5 mm) capture of 3D objects and their rendition in the form of models that can be used to control changes in shape, to document objects and for other purposes.

Google has proposed an attractive technology called Tango, which enables making models of objects directly during the survey process, automating the processing procedure, significantly reducing the time required for such work. However, trials of this technology have shown that modern devices cannot yet provide the precision that can be achieved by photogrammetry methods.

One of the challenges when using photogrammetry and laser equipment is the difficulty of documenting small-diameter mine workings of up to 3-4 meters. Therefore, one of the challenges for us was to find a technique permitting for rapid imaging of such workings and making their high-quality models.

Photogrammetry, along with laser scanning, is turning into an important tool for assessing the shape of objects and their changes under the impact of external factors, as well as for evaluating underground workings [Benton, et al., 2017]. These two methods are quite similar in the level of precision: 2 mm to 1 cm [Lague et al., 2013, Benton, et al., 2017], which is acceptable for large spaces in both underground workings and open quarries. At the same time, the cost of the effort using photogrammetry methods is much lower compared to hand-held laser scanners, which cost more than 60,000 Euro. The cost of equipment for photogrammetry will be less than 6,000 Euro (camera and software), and in many cases only a camera will be required. In the Ruskeala Mining Park, various sites were surveyed at an interval of one year.

Figure 10.1. The stability of the vaults in the walls of the Ruskeala quarry in the original survey (left) comparison of changes after a year (right)

The entire space of the quarry in the Ruskeala Mining Park's quarry was documented in 2019. And model of the quarry was prepared (Figure 10.2)

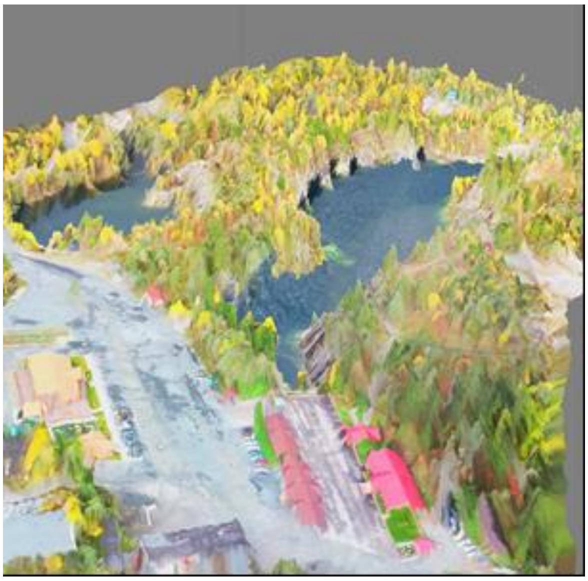


Figure 10.2. Visualisation of the Ruskeala quarry. The simplified model of the quarry.

All of the open pit areas has been documented (the quarry is about 800 meters long. Example of points cloud of the west side of Ruskeala mining park quarry (model resolution 3-5 mm) is presented in figure 10.3.

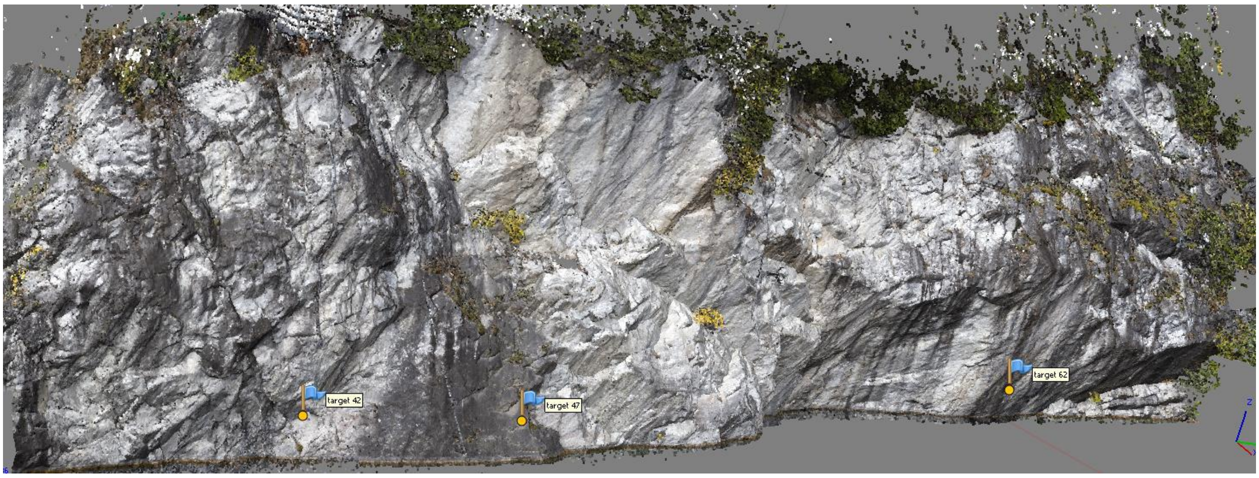


Figure 10.3. Fragment of a dense cloud for part of the western wall of the Ruskeala quarry (model resolution 3-5 mm)

In the case of UL's monitored with laser scanners, a major challenge was taking photos in narrow underground spaces. As a rule, a very expensive and time-consuming method of laser scanning is used for this purpose. Photogrammetry reduces the cost of these efforts by an order of one magnitude, yielding the same "cloud" results as laser photography, sometimes with higher precision.

To evaluate the usefulness of proposed methodology in underground condition, photogrammetric surveys were performed in the underground space under different lighting conditions, using lenses with different focal lengths, as well as using a specialized camera to capture spherical panoramas. As a result, the best configuration of aparature for each situation was chosen. Example comparison of models obtained with the Insta360 ONE X spherical camera and the wide-angle lens (fisheye) with a focal length of 9 mm is presented in figure 10.4

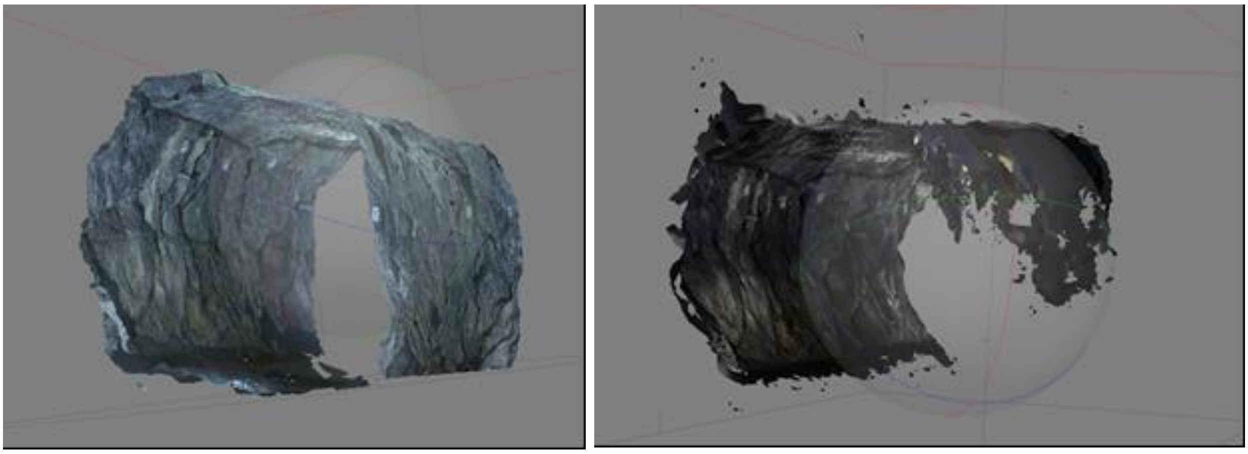


Figure 10.4. Benchmarking of obtained models using the Insta360 ONE X spherical camera (left), and a wide-angle lens (fisheye) with a focal length of 9 mm (right)

The detailed information about the final results of measurements with the use of tango system is presented in one of the deliveries form BSUIN project called:

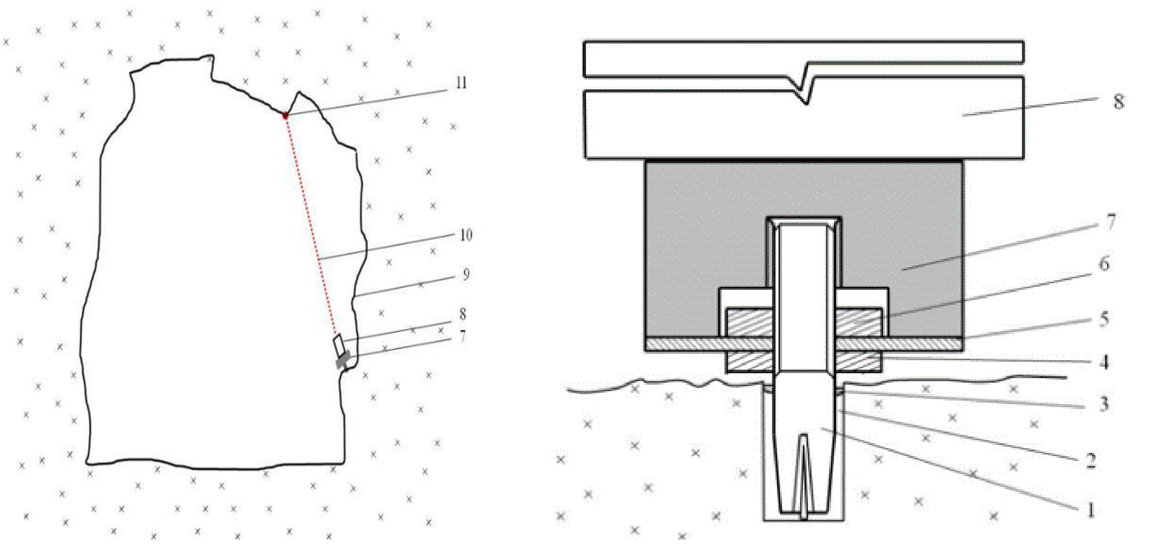
WP4 (A4.3) Report-DESIGN AND PERFORM A PILOT MEASUREMENT PROGRAM (E.G. TANGO SYSTEM)

10.2.2. Development and implementation of point-measurement methods

According to recent research, a photogrammetric method seems to be very useful in long-term assessment of roof, wall, and floor displacement in an underground facility. Still, it may also be necessary to develop or adapt some solutions which allow continuous monitoring of the risk level.

In terms of innovative proposals, the activities implemented included the design and patenting of innovative devices to control the condition of the roof in various settings based on the use of laser rangefinders (KarRC RAS) and non-deformable rods (CUPRUM).

One of the solutions was adapting well-known handy laser-based rangefinders. The procedure with this technology is quite simple. By installing a range finder in a certain position, it becomes possible to measure on a regular basis the distance from the installation site to a certain point. Long-term observations of the behaviour of the network of such points on the inner surface of the mine workings make it possible to evaluate its “mobility” and to identify the most problematic places which require intervention to prevent collapses of the roof and walls of the mine. To fulfil this task, a device was proposed for which a patent was obtained [Shekov et. al. 2018], which allows long-term observations of the relative position of the selected point in space. The essence of the method is that benchmarks of special form are installed in the workings, enabling measurements of the distance between them and the observation points. The 0.5below shows the basic elements of the system.



1 - brass anchor; 2 - hole drilled in rock, diameter up to 15 mm; 3 - lead spacer; 4 - support nut; 5 - support washer; 6 - fastening nut; 7 –thread socket supporting rangefinder; 8 - rangefinder; 9 – surface outline; 10 - laser beam; 11 - checkpoint

Figure. 10.5. The scheme of controlling roof displacement with a laser rangefinder. A - section of the workings, B – structure of the benchmark/rangefinder junction.

The laser rangefinder is fixed directly into the rock at a convenient distance from the checkpoint. To do this, a hole for a brass anchor is drilled in the rock. A metal bolt with a range finder is screwed into the anchor. The uniqueness of the design is that the rangefinder is set in a strictly given position each time and therefore focuses on the same point. Just one device is enough to make many observations on dozens and hundreds of permanent benchmarks. The design details are described in the patent. The rangefinder used in these measurements was Bosch GLM 40 with a 40 m range of measurements (from

0.15 to 40 meters) in the temperature range of -10 to 50 degrees Celsius, with 1.5 mm accuracy of the measurement.
The use of hand-held laser rangefinders to control the stability of the workings proved to be very efficient. E.g., a nearly 400-kg fragment dangerously overhanging a site where visitors stay for quite a while was spotted.

Initially, measurements were made on a daily basis at potentially hazardous sites (15 points). If no roof displacement was observed and the results of measurements were within the accuracy of the device, the frequency of measurements was gradually (at an interval of 2 months) changed and now measurements are made once a week. For a sustainable design, this model remains quite acceptable.

Using this technology, the Ruskeala Mining Park is currently monitoring the most dangerous areas in the underground area in terms of roof falls and movements of the mine rock mass. Examples of benchmark placement are presented in figure 10.6.

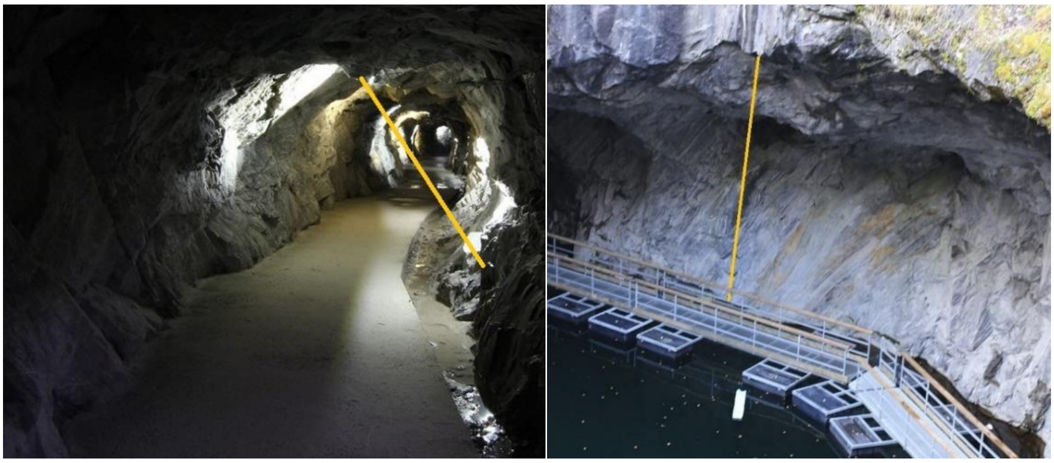


Figure 10.6. Examples of in-situ measurement using portable rangefinder in underground workings (left) and overhanging roof (right)

Another technique, which was proposed by researchers from KGHM CUPRUM is the use of special devices to monitor the stability of internal cracks. Devices called Roof separation gauges were described in Chapter 6 of the present document. The application of special devices to control mine roof stability was analyzed in the paper (Fulawka et al, 2018). The devices are tested and used in the KGHM polish copper mines. Given that in this study, the goal is to control the stability of the workings not in an active mine, but at a tourist site, where the destruction processes are more extended over time, the “Roof bed separation gauges” method seems to be the most preferable and cost-effective. This is the main tool for regular monitoring of roof stability and wall stability in a quarry. Such sensors can be implemented in both mechanical and electronic versions.

11. SUMMARY

The present document is one of the final reports from Work Package 4 of Baltic Sea underground Innovation network project funded by INTERREG BSR programme. The goal of activities within WP 4 was to prepare a general description of H&S in underground conditions. Presented material describes best practices in UL management, procedures of identification and prevention of risk in underground conditions. Activities aimed to improve underground facility in term of risk minimization were described as well.

With cooperation of UL's from BSR region and specialists from deep copper and coal mines from Poland, over a hundred risks were identified and described in detail. Of course, risks differ in source and mechanism of hazard development. Therefore, to make risk evaluation easier, some common methods of hazard monitoring were described.

The broad database of unwanted hazards was used then to assess risk in ULs of BSUIN project. In general, it was concluded that risk within underground laboratories is mainly related to two factors. First is the depth below the surface, which affects the general stress and strain condition around the underground facility. The second was the scope of activity in and around the Underground Laboratory. One may observe that facilities located near active mines may be affected by similar dangerous events like underground mine. On the other hand, setting up of laboratory in an abandoned mine, in post-exploitation stage may be a very reasonable solution as the lack of additional external influences greatly simplifies risk management.

Based on the database and international surveys preliminary risk assessment questionnaire based on the risk matrix method was prepared. Author of this document hopes that this simple tool will contribute to better recognition of dangerous situations and will help in the risk management process in both, active ULs and the projected ones.

Of course, the proper risk assessment should not be based only on qualitative analysis. In-depth analysis of most burning occurrences has to be presented quantitatively. Some solutions were proposed, however, it must be highlighted that proper analysis needs to be conducted separately and independently for each site and there is no universal, fully reliable solution.

Within the scope of this document, procedures and solutions of risk minimization and facility improvement were described and proposed. According to authors experience, a vast majority of observed hazard may be successfully minimised or even totally prevented if proper actions are undertaken immediately after risk identification. For each of the identified events proposes solutions were described and added to the preliminary risk assessment questionnaire. Both documents will be available publicly.As part of WP 4 activities also new, not used so far in regular basis solutions, were developed and tested. As a result, researchers from KarRC RAS proposed some cost-effective and reasonable solutions which may be implemented in almost every underground facility.

To summarise, risk is a very broad concept, and in many situations related to the underground condition, the complexity of unwanted events may be much more expanded than in surface conditions. Still, there are many useful tools which may be successfully implemented into the risk management process of Underground facility

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REFERENCES

Adjiski V., Mirakovski D., Despodov Z., Mijalkovski S., Simulation and optimization of evacuation routes in case of fire in underground mines, Journal of Sustainable Mining, no. 14, pp. 133-143, 2015

Aitao Z., Kai W, Longgang W., Yiwen X, Influence of gas ventilation pressure on the stability of airways airflow, International Journal of Mining Science and Technology 28, pp. 297–301, 2018

Aven T., On how to define, understand and describe risk, Reliability Engineering & System Safety, 2010, vol. 95 (6), pp. 623–631, https://doi.org/10.1016/j.ress.2010.01.011, 2010

Bell R., Glade T., Quantitative risk analysis for landslides – Examples fromB́ıldudalur, NW-Iceland, Natural Hazards and Earth System Sciences (2004) 4: 117–131, 2004

Belle B., Real-time air velocity monitoring in mines - a quintessential design parameter for managing major mine health and safety hazards, Proceedings of the 13th Coal Operators' Conference, University of Wollongong, The Australasian Institute of Mining and Metallurgy & Mine Managers Association of Australia, pp. 184-198, 2013

Benton, DJ, Seymour, JB, Boltz, MS, Raffaldi, MJ & Finley, SA 'Photogrammetry in underground mining ground control — Lucky Friday mine case study', in J Wesseloo (ed.), Proceedings of the Eighth International Conference on Deep and High Stress Mining, Australian Centre for Geomechanics, Perth, pp. 587-598, https://doi.org/10.36487/ACG_rep/1704_39_Benton, 2017,

Bezuidenhout Y., Implementing an efficient mine water monitoring and management program: Key considerations, Proceedings of the International Mine Water Conference, Pretoria, South Africa, pp. 958-965, 2009

Brake R, Specification and Selection of handheld gas monitors (detectors) for underground mines, Proceedings of the Australian Mine Ventilation Conference, Sydney, pp. 143 - 153, 2015

Bukowski P., Evaluation of water hazard in hard coal mines in changing conditions of functioning of mining industry in Upper Silesian coal basin – USCB (Poland), Arch. Min. Sci., Vol. 60, no. 2, pp. 455–475, 2015

Ilyasov B., Alexander Makarov (SRK Consulting (Russia)) | Ivan Biryuchiov (SRK Consulting (Russia)) Document ID ISRM-EUROCK-2018-111 Publisher International Society for Rock Mechanics and Rock Engineering Source ISRM Regional Symposium - EUROCK 2018, 22-26 May, Saint Petersburg, Russia Publication Date 2018

Butra J., Dębkowski R., Pawelus D., Szpak M., Wpływ naprężeń pierwotnych na stateczność wyrobisk górniczych, CUPRUM – Czasopismo Naukowo-Techniczne Górnictwa Rud, vol. 1(58), pp. 43-71, 2011

Cai M., Peng H., Advance of in-situ stress measurement in China, Journal of Rock Mechanics and Geotechnical Engineering, 3 (4), pp. 373–384, 2011

Carpignano,A., Priotti, W., Romagnoli, R., Risk analysis techniques applied to floating oil production in deep offshore environments, International Society of Offshore and Polar Engineers, Vol.1, pp. 253-258, 1998,

Center for Chemical Process Safety, Guidelines for Chemical Process Quantitative Risk Analysis (2nd ed.), American Institute of Chemical Engineers, ISBN 978-0-8169-0720-5, October, 1999

Center for Chemical Process Safety, Guidelines for Hazard Evaluation Procedures (3rd ed.), Wiley, ISBN 978-0-471-97815-2, April, 2008

Chao E., Henshaw J.L., How to Plan for Workplace Emergencies and Evacuations., U.S. Department of Labor Occupational Safety and Health Administration, OSHA 3088, Revised, 2001

Chien K. F., Wu Z-H., Huang S-C., Identifying and assessing critical risk factors

for BIM projects: Empirical study, Automation in Construction, vol. 45, pp. 1- 15, https://doi.org/10.1016/j.autcon.2014.04.012, 2014

Chin K. S., Chan A., Yang J. B., Development of a fuzzy FMEA based product design system, The International Journal of Advanced Manufacturing Technology, vol. 36(7-8), pp. 633-649, 2008

Cichoń-Walczyk M., 2012, the method of reporting work-related incidents used in Orica as part of preventive health and safety in the workplace, Prace Naukowe Instytutu Górnictwa Politechniki Wrocławskiej, vol. 134 (41), pp. 43-53

Clemens P.L., Simmons R.J., System Safety and Risk Management, NIOSH Instructional Module, A guide for Engineering Educators, Cincinnati, 1998

Clifton A., Ericson II, Hazard Analysis Techniques for System Safety, 2nd Edition, 2015, ISBN: 978-1-118-94038-9, 2015

Code of practice, Fire or Explosion in Underground Mines and Tunnels, New Zeeland Health and Safety at Works Act, 2014

Code of practice, Ground or Strata Instability in Underground Mines and Tunnels, New Zeeland Health and Safety at Works Act, 2016

Curtis P., Carey M., Risk Assessment in Practice, Deloitte & Touche LLP, 2012

Dec A., Management of safety culture at work in aspect of health and life protection and infrastructure of work place, Problemy Nauk Stosowanych, T. 2, pp. 193–204, 2014

Detailed project of exploitation in field XIII/4 of G-2 mining district with information about the exploitation progress, KGHM Polska MiedźS .A., Oddział Zakłady Górnicze „LUBIN”, 2016

Dhawan K. R., Singh D. N., Gupta I. D., 2D and 3D finite element analysis of underground openings in an inhomogeneous rock mass, International Journal of Rock Mechanics and Mining Sciences,

vol. 39(2), pp. 217-227, https://doi.org/10.1016/S1365-1609(02)00020-5, 2002

Dhillon B.S., Mine Safety A Modern Approach - Global Mine Accidents, In: Mine Safety, Springer Series in Reliability Engineering, pp. 59-71, DOI: 10.1007/978-1-84996-115-8, 2010

Do N. A., Dias D., A comparison of 2D and 3D numerical simulations of tunnelling in soft soils, Environmental Earth Sciences, vol. 76(3), https://doi.org/10.1007/s12665-017-6425-z, 2017

Drobniewski M., Witthaus H., Monitoring of mine water, Lappeenranta, Finland, Mine Water and Circular Economy, IMWA, pp. 88–93, 2017

Dumbravă V., Vlăduț - Severian I., 2013.Economics and Information Technology Using Probability – Impact Matrix in Analysis and Risk Assessment Project, Journal of Knowledge Management, 2013 Special Issue - December 2013, pp. 76-96.

Dziubinski, M., Fratczak, M., Markowski, A.S., Journal of Loss Prevention in the Process Industries, Vol. 19, pp 399-408, 2006,

Elgstrand K., Vingård E., Safety and health in mining, In: Elgstrand K., Vingård E. (Eds.), Occupational Safety and Health in Mining: Anthology on the Situation in 16 Mining Countries, Arbete & Hälsa, University of Gothenburg, Gothenburg, pp. 1–14, 2013

Elmo D., Stead D., An Integrated Numerical Modelling–Discrete Fracture Network Approach Applied to the Characterisation of Rock Mass Strength of Naturally Fractured Pillars, Rock Mechanics and Rock Engineering, vol. 43(1), pp. 3-19, DOI: 10.1007/s00603-009-0027-3, 2009,

Ericson C. A., Hazard Analysis Techniques for System Safety, John Wiley & Sons, Inc., DOI: 10.1002/0471739421, 2005

European Commission, Health and safety at work in Europe (1999-2007) – A statistical portrait, Publications Office of the European Union, Luxembourg, 2010,

European Medicines Agency, ICH Harmonised Tripartite Guidelines. Quality Guidelines, Q9 Quality Risk Management. 2006

Eurostat, Mining and quarrying statistics - NACE Rev. 2 https://ec.europa.eu/eurostat, 2020

Fatma Y., Bolat B., “A risk analysis model for mining accidents using a fuzzy approach based on fault tree analysis.” J. Enterp. Inf. Manag. 31 pp. 577-594, 2018,

Fenton G. A., Griffiths D. V., Risk assessment in geotechnical engineering, John Wiley & Sons, Inc., New Jersey. DOI: 10.1002/9780470284704, 2008

Fenton N., Neil M., Risk assessment and decision analysis with Bayesian networks, CRC Press, Boca Raton, 2012

Fowler T.W., Miles K., National Institute for Occupational Safety and Health, Electrical safety, Safety and Health for Electrical Trades, Student manual, DEPARTMENT OF HEALTH AND HUMAN SERVICES Centers for Disease Control and Prevention, , 2009

Frank,T., Brooks,S., Creekmore,R., Hasselbalch,B., Murray,K., Obeng,K., Reich, S., Sanchez,E., Quality Risk Management Principles and Industry Case Studies, pp. 1-9., 2008,

Fuławka K., Pytel W., Mertuszka P., The effect of selected rockburst prevention measures on seismic activity - Case study from the Rudna copper mine, Journal of Sustainable Mining, vol. 17, pp. 1-10, https://doi.org/10.1016/j.jsm.2018.03.001, 2018

Fuławka K., Mertuszka P., Pytel W., Monitoring of the stability of underground workings in Polish copper mines conditions, E3S Web of Conferences 29, 00008, https://doi.org/10.1051/e3sconf/20182900008, 2018

Galvin J., Critical role of risk management in ground engineering and opportunities for improvement, International Journal of Mining Science and Technology, vol. 27(5), pp. 725-731, https://doi.org/10.1016/j.ijmst.2017.07.005, 2017

Ghaffarianhoseini A., Tookey J., Ghaffarianhoseini A., Naismith N., Azhar S., Efimova O., Raahemifar K., Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges, Renewable and Sustainable Energy Reviews, vol. 75, pp. 1046-1053, https://doi.org/10.1016/j.rser.2016.11.083, 2017

Ghorbani S., Namin F. S., Lajevardi S. A., A Statistical-Probabilistic Pattern for Determination of Tunnel Advance Step by Quantitative Risk Analysis, Int. Journal of Mining & Geo-Engineering, vol. 51(2), pp. 161-176, DOI: 10.22059/IJMGE.2017.230636.594663, 2017

Goldberg B. E., Everhart K., Stevens R., Babbitt N., Clemens P., Stout L., System Engineering "Toolbox" for Design-Oriented Engineers, Marshall Space Flight Center, pp. 3–35 to 3–48, 1994

Gong H., Kizil M.S., Chen Z., Amanzadeh M., Yang B., Aminossadati S., Advances in fibre optic based geotechnical monitoring systems for underground excavations, International Journal of Mining Science and Technology, https://doi.org/10.1016/j.ijmst.2018.06.007, 2018

Goodman W., Van Dyk D., Grobler N., Osborne A., Water Ingress Mitigation Programs for Underground Mines – Geochemical and Rock Mechanical Demands on Grout Properties, 11th ICARD, IMWA, MWD Conference – "Risk to Opportunity", Wolkersdorfer Ch.; Sartz L.; Weber A.; Burgess J.; Tremblay G. (Ed), pp. 507-511, 2018,

Groves W.A., Kecojevic V.J., Komljenovic D.,. Analysis of fatalities and injuries involving mining equipment, Journal of Safety Research, vol. 38(4), pp. 461-470, ISSN 0022-4375, https://doi.org/10.1016/j.jsr.2007.03.011, 2007

Grzebyk W., Stolecki L., Inclinometric measurements as a tool of monitoring rock mass deformation in underground mines, Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN, no. 86, pp. 97-104, 2014

Gupta S., Ramkrishna N., Bhattacharya J., Replacement and maintenance analysis of longwall shearer using fault tree technique, Mining Technology, 115(2), pp. 49-58, DOI: 10.1179/174328606X111433, 2006

Harms-Ringdahl L., Riskhantering i företag och samhälle (Risk management in companies and society), Framtidens arbetsmiljö- och tillsynsarbete (Work Environment and Supervisory Work of the Future, ed. B. Johansson, K. Frick, and J. Johansson, Lund: Studentlitteratur, pp. 310-327, 2004

Hassan, C.R. Che, Puvaneswaran, B., Aziz, A.R., Zalina, M. Noor, Hung, F.C., Sulaiman, N.M, Quantitative risk assessment for the transport of ammonia by rail, Process Safety Progress, vol. 29 (1), pp. 60-63, 2010, doi:10.1002/prs.10345

Hänninen, M., Kujala, P. Influences of Variables on Ship Collision Probability in a Bayesian Belief Network Model. Reliability Engineering & System Safety. 102. pp. 27–40, 2012,

Health and Safety Executive, Guidance on the design, installation and use of free standing support systems (including powered supports) in coal mines, 2002

Hebblewhite B., Mine safety–through appropriate combination of technology and management practice, The 6th International Conference on Mining Science & Technology, Procedia Earth and Planetary Science, vol. 1(1), pp. 13–19, DOI: 10.1016/j.proeps.2009.09.005, 2009

Idris M. A., Saiangand D., Nordlund E., Probabilistic analysis of open stope stability using numerical modelling, Int. J. Mining and Mineral Engineering, vol. 3 (3), pp. 194-219, https://doi.org/10.1504/IJMME.2011.043849, 2011

IEC 31010:2009 - Risk management – Risk assessment techniques, 2009

IEC 60812, Edition 2.0 2006-01, Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMECA), 2006

ILO code of practice Safety and health in underground coalmines International Labour Office, Geneva, International Labour Office, 2009

Iverson S., Kerkering J.C., Coleman P., Using fault tree analysis to focus mine safety research. In: Proceedings of the 108th annual meeting of the society for mining, metallurgy and exploration, pp. 1–10, 2001,

ISO Guide 73:2009, Risk management – Vocabulary.

Kaiser P. K., Valley B., Dusseault M. B., Duff D., Hydraulic Fracturing Mine Back Trials — Design Rationale and Project Status, pp. 877-891, 2013, http://dx.doi.org/10.5772/56260

Kenneth J. Rothman, 2002. Epidemiology - An Introduction, Oxford University Press, pp. 34-36.

Kim D-H., Balasubramaniam A. S., Gratchev I., Application of Photogrammetry and Image Analysis for Rock Slope Investigation // Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol. 49 No. 2 pp.49-56, 2018, ISSN 0046-5828

Komljenovic D., Groves W.A., Kecojevic V.J., Injuries in U.S. mining operations – A preliminary risk analysis, Safety Science, vol.46 (5), pp. 792-801, 2008, ISSN 0925-7535, https://doi.org/10.1016/j.ssci.2007.01.012.

Laitila P., Improving the use of ranked nodes in elicitation of conditional probabilitiesfor Bayesian networks. M.Sc. thesis, Aalto University, Espoo, Finland, 2013,

Li CC, Principles of rockbolting design, Journal of Rock Mechanics and Geotechnical Engineering vol. 9(3), 2017, pp. 396-414, 2017, doi: 10.1016/j.jrmge.2017.04.002,

Li, T., Cai, M. F., & Cai, M., A review of mining-induced seismicity in China, International Journal of Rock Mechanics and Mining Sciences, , vol. 44(8), pp.1149-1171, 2007,

Lisjak, A., Grasselli, G.,A review of discrete modelling techniques for fracturing processes in discontinuous rock mass. In: Int. J. Rock Mech. Min. Sci., 6: 301-314, 2014,

Lööw J., Johansson B., Andersson E., Johansson J., Designing Ergonomic, Safe, and Attractive Mining Workplaces, CRC Press, Taylor & Francis Group, 2019,

Majcherczyk T., Małkowski P., Strata control in underground tunnels - perspectives for development, Górnictwo i Geoinżynieria, R. 29, Z. 3/2, pp. 61-76, 2005,

Małkowski P., The effect of stratification of the rock mass on the range of fracture zones around roadways, Wiadomości Górnicze, no. 5, pp. 259-269, 2014,

Mandal R., Application of Gas Monitoring Sensors in Underground Coal Mines and Hazardous Areas, International Journal of Computer Technology and Electronics Engineering (IJCTEE), 3, pp. 9-23, 2013,

Mark C., Barczak T.M., Fundamentals of coal mine roof support.In: New Technology for Coal Mine Roof Support, Proceedingsof the NIOSH open industry briefing, NIOSH IC, vol. 9453 pp 23–42, 2000,

Martins A., Kövesdy I., Overview in the application of FEM in mining and the study of case: Stress analysis in pulleys of stacker-reclaimers: FEM vs. Analytical. in book Finite Element Analysis Applications in Mechanical Engineering , 2012, DOI: 10.5772/3249 ISBN: 978-953-51-0717-0,

Martyka J., Stan kultury bezpieczeństwa dozoru Zakładów Górniczych KGHM Polska Miedź S.A. oraz program doskonalenia kultury bezpieczeństwa załóg górniczych [Safety culture state of supervision in mining plant of KGHM Polska Miedz S.A. and program to improve safety culture of mining Staff], CUPRUM – Czasopismo Naukowo-Techniczne Górnictwa Rud, 2015, vol. 3(76), pp. 233-251,

Midas GTS NX manual, 2020,

Mine Safety Operations Division, New South Wales Department of Primary Industries, Guideline for Inrush Hazard Management, 2007,

Monograph of KGHM Polska Miedź S.A, Lubin 2007,

Morin G., Hassall S. and Chandler R., Case study – the real life benefits of geotechnical building information modelling. In: Advances in Soil Mechanics and Geotechnical Engineering, Volume 3: Information Technology in Geo- Engineering, IOS Press, pp. 95-102, 2014,

Morin, G., Applying BIM principles to the subsurface. Autodesk University, TR-21042, 10 p. 1st Edition Geotechnical Aspects of Underground Construction in Soft Ground By Giulia Viggian,, CRC Press 1082, 2018,

Morrison R.G., Thinking in working memory. In: Holyoak KJ, Morrison RG(eds) Cambridge handbook of thinking and reasoning. Cambridge University Press, New York, pp 457–473, 2005,

Nawrat S., Kuczera Z., Napieraj S., Influence of drainage technics for efficiency of drainage in coal mine, Górnictwo i Geoinżynieria, R. 30, Z. 1, pp. 25-36, 2006,

NSW Department of Trade and Investment, Regional Infrastructure and Services NSW code of practice: Inundation and inrush hazard management, www.resourcesandenergy.nsw.gov.au/safety, 2015,

O'Hagan A et al., Uncertain judgements: eliciting experts' probabilities. Wiley, New York, 2006,

Orzepowski S., Butra, J., Method of seismic risk reduction in KGHM Polska Miedź S.A. mines, by borehole deformation monitoring, Rudy i Metale Nieżelazne, R. 56, no. 2, pp. 59-63, 2011,

Park H..J., West T.R., Woo I., Probabilistic analysis of rock slope stability and random properties of discontinuity parameters, Interstate Highway 40, Western North Carolina, USA, Engineering Geology, vol. 79,(3–4), pp. 230-250, 2005. https://doi.org/10.1016/j.enggeo.2005.02.001

Project Management Institute Inc. A Guide to the Project Management Body of Knowledge (PMBOK® Guide) – Fifth Edition, 2013, Newtown Square, Pennsylvania: Project Management Institute, Inc. 2013,

Pytel W., Mertuszka P., Fabiańczyk E., Fuławka K., System obserwacji stropu bezpośredniego oparty na wklejanej kotwi oprzyrządowanej, Wiadomości Górnicze, no. 12, pp. 654-664, 2016,

Radu L.D., Qualitative, Semi-Quantitative And, Quantitative Methods For Risk Assessment: Case Of The Financial Audit, Analele Stiintifice ale Universitatii "Alexandru Ioan Cuza" din Iasi - Stiinte Economice, vol. 56, pp, 643-657, 2009, RocScience - Probabilistic Analysis in RS2, 2018,

RocScience UnWedge Theory Manual Safety Factor Calculations, 2019

Safe Work Australia, General Guide for Workplace Traffic Management, 2014,

Sanmiquel L., Freijo M., Edo J., Rossell J.M., Analysis of work related accidents in the Spanish mining sector from 1982-2006, Journal of Safety Research, vol. 41(1), pp. 1-7, 2010, ISSN 0022-4375, https://doi.org/10.1016/j.jsr.2009.09.008.

Bemis S.P.., Micklethwaite S., Turner D., James M.R., Akciz S., Thiele S.T. Ground-based and UAV-Based photogrammetry: A multi-scale, high-resolution mapping tool for structural geology and paleoseismology //Journal of Structural Geology 69, pp. 163-178, 2014,

Shahani N.M., Sajid M.J., Zheng X. *, Jiskani I.M., Brohi M.A., MUllah. Ali, B., Qureshi A.R. fault tree analysis and prevention strategies for gas explosion in underground coal mines of pakistan Mining of Mineral Deposits, vol. 13, Issue 4, pp. 121-128, 2019,

Shariati S. Underground mine risk assessment by using FMEA in the presence of uncertainty.Decision Science Letters , 3(3), 295-304., 2014,

Sheshpari M., A Review of Underground Mine Backfilling Methods with Emphasis On Cemented Paste Backfill, Electronic Journal of Geotechnical Engineering, 20(13), pp. 5183-5208, 2015

Shekov K., Shekov V., Ruskeala mining park phenomenon // 16th International multidisciplinary scientific geoconference SGEM Book 5. Ecology, Economics, Education and Legislation. Conference proceedings. Volume III. Pp. 515 – 522, 2016,

Shekov V.A., Skamnitskaya L.S., Ivanov A.A., Sokolov S.Ya., Bubnova T.P. Patent No. 188601 "Device for measuring the displacement of the roof of rocks." Application No. 2018137387, priority dated October 22, 2018

Shooks M., Johansson B., Andersson E., Lööw J., Safety and Health in European Mining – A report on safety and health, statistics, tools and laws, produced for the I2 Mine (Innovative Technologies and Concepts for the Intelligent Deep Mine of the Future) project, Division of Human Work Science, Skandinaviens nordligaste tekniska universitet Forskning & utbildning i världsklass, pp. 3-10, 2014,

Smolarkiewicz M., Smolarkiewicz M. M., Biedugnis S., Matrix methods for risk management – Associated Matrices Theory, Środkowo-Pomorskie Towarzystwo Naukowe Ochrony Środowiska, vol.13. pp. 241 – 252, 2011,

Stolecki L., Grzebyk W., Inclinometric measurements as a tool of monitoring rock mass deformation in underground mines, Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN, no. 86, pp. 97-104, 2014, Suddle S., The weighted risk analysis, Safety Science, vol. 47(5), pp. 668–679, 2009, DOI:10.1016/j.ssci.2008.09.005

Szurgacz D., 2015, Numerical analysis for an optimization of a powered roof support operating in hazard conidtions of minig tremors, Mining Science, vol. 22, pp. 171−179

Taylor C. D., Timko R. J., Senk M. J., Lusin A., Measurement of airflow in a simulated underground mine environment using an ultrasonic anemometer, Trans Soc Min Metall Explor pp. 201-206, 2004,

UNISDR, Living with risk – a global review of disaster reduction initiatives, 2004,

U.S. Department of Labor Occupational Safety and Health Administration, Process Safety Management Guidelines for Compliance (PDF). U.S. Government Printing Office. OSHA 3133, 1994,

U.S. Department of Labor, Occupational Safety and Health Administration, How to Plan for Workplace Emergencies and Evacuations, OSHA 3088, 2001,

Vardar O., Zhang C., Canbulat I., Hebblewhite B., A semi-quantitative coal burst risk classification system,International Journal of Mining Science and Technology, vol. 28 (5), pp. 721-727, 2018, ISSN 2095-2686, https://doi.org/10.1016/j.ijmst.2018.08.001

Wang, Y. M., Chin, K. S., Poon, G. K. K., & Yang, J. B., Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean.Expert Systems with Applications, 36(2), pp.1195-1207, 2009,

Wang J., Marvin L.R.,What Every Engineer Should Know About Risk Engineering and Management, p. 69, 2000,

Webpage of Occupational Safety and Health Administration: https://www.osha.gov (access in 2018)

Yaşlı F., Bolat B., A Bayesian Network Analysis for Occupational Accidents of Mining Sector. In: Durakbasa N., Gencyilmaz M. (eds) Proceedings of the International Symposium for Production Researc, Springer, 2019

Zeroual N.,F., Iazharb B., Zennirc A., Probabilistic analysis of slope stability towards the slip by the kinematic method, Physics Procedia, vol. 21, pp. 93- 100, 2011, https://doi.org/10.1016/j.phpro.2011.10.014

Zorychta A., Burtan Z., Conditions of fault activation in the area of exploitation. AGH Journal of Mining and Geoengineering, vol. 36(3), pp. 509-519, 2012,

Webpage: https://www.safeworkaustralia.gov.au

Webpage: https://www.beckermining.com

Webpage: https://www.cab-expert.com

Webpage: https://www.seton.co.uk

Webpage: https://www.creativesafetysupply.com

Webpage: http://emagserwis.pl (EMAG-SERWIS, 2020)

Webpage: https://www.beckermining.com, (Becker-mining, 2020)

Webpage: https://www.cab-expert.com (Cab-expert, 2020)

Webpage: https://carbo.com.pl (CARBO, 2020)

Webpage: https://www.cdc.gov (CDC, 2020)

Webpage: https://www.cometsystem.pl (Comet, 2020)

Webpage: https://www.conrad.pl (VOLTCRAFT, 2020)

Webpage: https://www.creativesafetysupply.com (Creative safety supply, 2020)

Webpage: https://www.osha.gov (OSHA, 2018)

Webpage: https://www.seton.co.uk (Seton, 2020)

Webpage: https://www.testo.com (TESTO, 2020)

Webpage: https://zpue.pl (ZPUE, 2020)

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Health & Safety in Underground Environment
Appendix no. 1 - Preliminary Risk Assessment

Baltic Sea Underground Innovation Network (BSUIN)

Interreg Baltic Sea Region
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EUROPEAN UNION
BSUIN

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PRELIMINARY RISK ASSESSMENT GUIDELINE

Risk identification

- Fill in the risk identification form
- Write down all threats observed during site investigation,
- Write down all historical accidents and unwanted events,
- Also all risks mentionet in this document should be analysed in term of probability of their occurence,
- If possible, OWNER (entity responsible for praticular risk minimization) should be determined.

Probability Assesment

- Analyse probability of specific risk occurence based on one of following methods:
  - Historical Analysis,
  - Surveys and discussions with experts, who knows analysed site,
  - Results of probabilistic calculations,
  - In case of lack of abovementioned, evaluate probabilty only in qualitative way (not recomended).
- Determine if probability is EXTREMELY SMALL, LOW, MODERATE, HIGH or VERY HIGH

Impact Assesment

- Evaluate possible impact of specific event based on one of following methods:
  - Historical analysis,
  - Numerical Modelling,
  - Survey with Experts in investigated topic,
  - In case of lack of abovementioned, evaluate probabilty only in qualitative way (not recomended).
- Determine if predicted impact is UNNOTICEABLE, SMALL, MODERATE, SEVERE or CATASTROPHIC

Risk Assesment

- Use evaluated probability and impact levels to fill in the risk matrix.

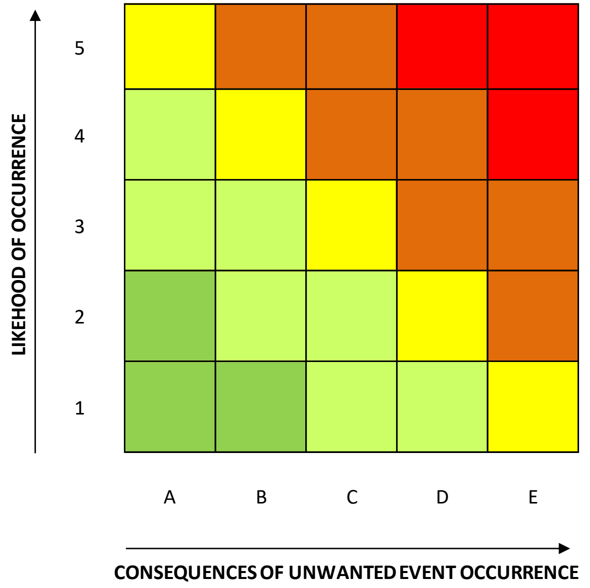
Risk prevention

If specific risk is categorised as **MEDIUM**, **SERIOUS** or **VERY HIGH**, took prevention and minimisation measures.

RISK IDENTIFICATION FORM

Site Supervisor:		**Site:**	
Company Name:		**Company Adress**	
Field of activity:		**Contact person:**	

Site Details:	
Summary of Incident History:	



UA	**Unacceptable/ very high** - The risk will jeopardize the project to a large or very large extent. Measures to eliminate or reduce risk has to be applied
S	**Serious/High** - The risk could jeopardize the project. Measures to eliminate or reduce risk has to be applied
M	**Medium** - The risk could jeopardize the project. The risk reducing measures shall be analysed and applied of so decided
L	**Low** - The risk will affect the project to some or minor extent. The risk is accepted with no further analysis or measures taken
A	**Acceptable/very low** - The risk wont affect the project. The risk is accepted with no further analysis or measures taken

1 -	**EXTREMELY SMALL**
2 -	**LOW**
3 -	**MODERATE**
4 -	**HIGH**
5 -	**VERY HIGH**

A -	**UNNOTICEABLE**	Any on employees health; No economic loss; Does not cause any disturbances in the work continuity of UL facility
B -	**SMALL**	No impact on employees health; Negligible economic loss which can be restored in short time; Does not cause disturbances in the work continuity of UL facility
C -	**MODERATE**	No direct impact on health or a minor temporary impact; Economic loss which can be restored; Damage to machines and workings can be removed or repaired
D -	**SEVERE**	Reduced health; Can cause Large economic loss which cannot be restored; Serious damage of workings and machines can be noticed; Long time suspension of the business
E -	**CATASTROPHIC**	Can cause death or permanent reduction of health; Huge economic loss which cannot be restored; Serious or permanent workings damage; Long time suspension of the business or even permanent closure of the facility

ENVIRONMENTAL RISKS

Ground Control					
No.	Risk Type	Owner	Probability	Impact	RISK LEVEL
1.	Geologic discontinuities occurrence				
2.	Unsupported roof				
3.	Spalling of wall				
4.	Roof Failures				
5.	Workings instability				
6.	Overburden caving				
7.	Long term creep effect				
8.	Too high In-Situ Stress				
9.	Ground Movement				
10.	Collapse of surface				
11.	Mine collapse				
12.	Lack of monitoring devices of workings stability				
13.	Cave-in				
14.	Swelling				
15.	Squeezing				
16.	....				

Seismic Activity					
No.	Risk Type	Owner	Probability	Impact	RISK LEVEL
1.	High frequency of tremors occurrence				
2.	Strain bursts				
3.	Pillar bursts				
4.	Fault slip bursts				
5.	Earthquakes				
6.	Seismic magnitude of tremors > 3 ML				
7.	Seismic magnitude of tremors > 4 ML				
8.	Seismic magnitude of tremors > 5 ML				
9.	Lack on seismic activity monitoring devices				
10.	....				

ENVIRONMENTAL RISKS

Water					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Water ingress				
2.	Chemical leakage into water				
3.	Problem with surface waters associated with depression craters				
4.	Gassing of underground waters				
5.	Deep bedrock water pockets				
6.	Flood				
7.	....				

Gases					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Toxic gases occurrence after blasting works				
2.	Exceedances of sulphur dioxide (SO2) limits				
3.	Exceedances of hydrogen sulphide (H2S) limits				
4.	Exceedances of nitric oxide (NO2), other nitrogen oxides (NO) limits				
5.	Exceedances of hydrocarbons (HC) limits				
6.	Exceedances of carbon monoxide (CO) limits				
7.	Exceedances of carbon dioxide (CO2) limits				
8.	Exceedances of radon gas limits				
9.	Exceedances of Methane (CH4) limits				
10.	Gas explosion				
11.	Fluid (gas and / or liquid) eruption, including hydrogen sulphide				
12.	....				

ENVIRONMENTAL RISKS

Radiation					
No.	Risk Type	Owner	Probability	Impact	RISK LEVEL
1.	Naturally occurring radiation				
2.	Man-made radiation				
3.	Uranium (U-238, U-235)				
4.	Thorium (Th-228,Th-232)				
5.	Radium (Ra-226, Ra-228)				
6.	Radon (Rn-222)				
7.	Polonium (Po-210)				
8.	Lead (Pb-210)				
9.	....				

RISK AT THE WORKPLACE

Noise					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Noise caused by mining machinery				
2.	Noise caused by blasting				
3.	Noise caused by machinery of UL				
4.	…				

Lightening and Electric					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Inadequate existing power supply				
2.	No permanent power supply available				
3.	Frequent power failure				
4.	Electrocution				
5.	Short circuit				
6.	Ignition of electrical devices				
7.	No access to the additional light source				
9.	…				

Technological					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Inaccurate designs of facility				
2.	Inaccurate site investigation				
3.	Unproven technology/ equipment failures				
4.	Lift breakdown				
5.	Car breakdown				
6.	Breaks in process water supply				
7.	Incorrect bolting pattern				
8.	…				

RISK AT THE WORKPLACE

Inappropriate procedures / Improper organization					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Risk of inadequate access control and evacuation procedures				
2.	No fire management and prevention				
3.	No emergency evacuation procedure				
4.	No safety management during tank construction and outfitting				
5.	Risk of safety incident during delivery underground				
6.	No safety management leadership				
7.	Failure in safety communication and direction				
8.	Risk that safety incident is inadequately reported				
9.	Risk that safety training is inadequate				
10.	Risk that safety procedures will violate local, regional, national or international legal requirements				
11.	Integrated safety / emergency plan not properly integrated with mine/tunnel authorities				
12.	Risk of inadequate orientation training of staff and visitors				
13.	Risk of unauthorised people entering the in the lab				
14.	Risk of inadequate first aid and other emergency training				
15.	Risk of inadequate Safety signs, posters and notices				
16.	No gas/smoke detection system				
17.	No oxygen concentration sensors				
18.	No personal protection devices including defibrillators and other devices in the lab				
19.	No temperature sensors provided				
20.	No provision of emergency safety rooms underground				
21.	…				

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RISK AT THE WORKPLACE

Infrastructure related risk					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Usefulness of closest existing shaft				
2.	Passenger capacity				
3.	Too small dimensions of existing workings				
4.	Risk of safety incident during construction underground				
5.	Risk of tank rupture during filling				
6.	…				

RISKS RELATED TO MINING OPERATIONS

Machinery					
No.	Risk Type	Owner	Probability	Impact	RISK LEVEL
1.	Hit by the machine				
2.	Collision of machines during material transport				
3.	Collision of machines during staff transport				
4.	…				

Blasting Works					
No.	Risk Type	Owner	Probability	Impact	RISK LEVEL
1.	Magnitude of vibrations				
2.	Low from blasting works				
3.	The possibility of finding employees in the danger zone				
4.	Premature Blast				
5.	Transportation				
6.	Misfires				
7.	Risk of uncontrolled explosion				
8.	Explosives Fumes				
9.	…				

Ventilation and Air Condition					
No.	Risk Type	Owner	Probability	Impact	RISK LEVEL
1.	Temperature of the rock				
2.	Too high temperature of air				
3.	Insufficient air flow speed				
4.	Poor Air quality				
5.	Insufficient number of ventilation devices				
6.	Risk of fire occurrence				
7.	Endogenous fire				
8.	Exogenous fire				
9.	…				

RISKS RELATED TO MINING OPERATIONS

Dust					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Dust laying on the surfaces (particles < 30 µm)				
2.	Particles reaching upper airways (particles < 10 µm)				
3.	Particles reaching alveolar level (particles < 2,5 µm)				
4.	Coal dust explosion				
5.	…				

OTHER

Social Risk					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Limited possibility of experienced staff employment				
2.	Adverse local community operations				
3.	Lack of suitably trained UL workers				
4.	...				

Political Risk					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	National Import/Export limitations				
2.	Act of terrorism				
3.	Political demonstrations				
4.	...				

Economic					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Economic Crisis				
2.	Reduction in Finanse				
3.	Local Taxes				
4.	Inflation				
5.	...				

Pollution resulting from activities					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Water pollution				
2.	Waste management				
3.	Chemikal leakage				
4.	...				

Health & Safety in Underground Environment
Appendix no. 2 - Facility Improvement

Baltic Sea Underground Innovation Network (BSUIN)

Interreg Baltic Sea Region
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EUROPEAN REGIONAL DEVELOPMENT FUND
BSUIN

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EUROPEAN REGIONAL DEVELOPMENT FUND

RISK PREVENTION

Threats

Find out identified threats in table.

Risk prevention

Write down the specify risk for each of threats accordingly.
Use MEDIUM, SERIOUS or VERY HIGH indicator as risk level.

Prevention and minimalization measures

According to the risk level take appriopriate measures in order to eliminate or limit risk level to the acceptable level.
Use suggestions collected in the tables.

ENVIRONMENTAL RISKS

Ground Control					
No.	**Risk Type**	**RISK LEVEL**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Geologic discontinuities occurrence		Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of additional support (e.g. rock bolts, mesh, bars, etc.). Regular control, assembling of control sensor. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of additional support (e.g. rock bolts, mesh, bars, etc.). Regular control, assembling of control sensors. Accurate geological recognition. Informing staff, safety tool box talk.	Exclusion of danger zone, signs and warnings, barriers, scaling and assembling of additional support (e.g. rock bolts, mesh, bars, etc.). Permanent exclusion zone if needed. Regular control, assembling of control sensors. Accurate geological recognition. Numerical modelling of rock behaviour. Informing staff, safety tool box talk.
2.	Unsupported roof		Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (e.g. rock bolts, mesh, bars, etc.). Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (e.g. rock bolts, mesh, bars, etc.). Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (e.g. rock bolts, mesh, bars, etc.). Regular control. Permanent exclusion zone if needed. Numerical modelling of roof behaviour. Informing staff, safety tool box talk.
3.	Spalling of wall		Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (e.g. rock bolts, mesh, bars, etc.). Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (e.g. rock bolts, mesh, bars, etc.). Regular control, assembling of control sensors. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (e.g. rock bolts, mesh, bars, etc.). Regular control, Regular control, assembling of control sensors. Permanent exclusion zone if needed. Informing staff, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
4.	Roof failures		Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (e.g. rock bolts, mesh, bars, etc.). Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of additional support (e.g. rock bolts, mesh, bars, etc.). Regular control, assembling of control sensors. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of additional support (e.g. rock bolts, mesh, bars, etc.). Regular control, assembling of control sensors. Permanent exclusion zone if needed. Accurate geological recognition. Numerical modelling of rock behaviour. Informing staff, safety tool box talk.
5.	Workings instability		Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of support (e.g. rock bolts, mesh). Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of additional support (e.g. rock bolts, mesh). Regular control, assembling of control sensor. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, scaling and assembling of additional support (e.g. rock bolts, mesh). Regular control, assembling of control sensors. Permanent exclusion zone if needed. Accurate geological recognition. Numerical modelling of rock behaviour. Informing staff, safety tool box talk.
6.	Overburden caving		Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.). Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of additional support (e.g. rock bolts, mesh, bars, etc.). Regular control, assembling of control sensors. Accurate geological recognition. Informing staff, safety tool box talk.	Exclusion of danger zone, signs and warnings, barriers, assembling of additional support (e.g. rock bolts, mesh, bars, etc.). Permanent exclusion zone if needed. Regular control, assembling of control sensors. Accurate geological recognition. Numerical modelling of rock behaviour. Informing staff, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
7.	Long term creep effect		Marking of the danger zone, signs with warnings, barriers. Regular control. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.). Regular control, assembling of control sensors. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.). Permanent exclusion zone if needed. Regular control, assembling of control sensors. Accurate geological recognition. Numerical modelling of rock behaviour. Informing staff, safety tool box talk.
8.	Too high in-situ stress		Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh). Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh). Regular control, assembling of control sensors. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh). Permanent exclusion zone if needed. Destress blasting. Regular control, assembling of control sensors. Accurate geological recognition. Numerical modelling of rock behaviour. Informing staff, safety tool box talk.
9.	Ground movement		Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, shotcrete). Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, shotcrete). Regular control, assembling of control sensors. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, shotcrete). Regular control, assembling of control sensors. Accurate geological recognition. Numerical modelling of rock behaviour. Permanent exclusion zone if needed. Informing staff, safety tool box talk.
10.	Collapse of surface		Exclusion of danger zone, signs with warnings, barriers. Backfilling, safety pillars. Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Backfilling, safety pillars. Regular control, assembling of control sensors. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Backfilling, safety pillars. Regular control, assembling of control sensors. Accurate geological recognition. Numerical modelling of rock behaviour. Permanent exclusion zone if needed. Informing staff, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
11.	Mine collapse		Exclusion of danger zone, signs with warnings, barriers. Backfilling, safety pillars. Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Backfilling, safety pillars. Regular control, assembling of control sensors. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Backfilling, safety pillars. Regular control, assembling of control sensors. Accurate geological recognition. Numerical modelling of rock behaviour. Permanent exclusion zone if needed. Informing staff, safety tool box talk.
12.	Lack of monitoring devices of workings stability		Exclusion of danger zone, signs with warnings, barriers and assembling of monitoring devices. Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers and assembling of monitoring devices. Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers and assembling of monitoring devices. Regular control. Informing staff, safety tool box talk.
13.	Cave-in		Exclusion of danger zone, signs with warnings, barriers. Backfilling, safety pillars. Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Backfilling, safety pillars. Regular control, assembling of control sensors. Accurate geological recognition. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Backfilling, safety pillars. Permanent exclusion zone if needed. Regular control, assembling of control sensors. Accurate geological recognition. Numerical modelling of rock behaviour. Informing staff, safety tool box talk.
14.	Swelling		Marking of danger zone, signs with warnings, barriers, scaling. Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Scaling, assembling of support (e.g rock bolts, mesh, bars). Regular control, assembling of control sensors. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Scaling, assembling of support (e.g rock bolts, mesh, bars). Regular control, assembling of control sensors. Informing staff, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
15.	Squeezing		Marking of danger zone, signs with warnings, barriers, scaling. Regular control. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Scaling, assembling of support (e.g. rock bolts, mesh, bars). Regular control, assembling of control sensor. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Scaling, assembling of support (e.g. rock bolts, mesh, bars). Regular control, assembling of control sensors. Informing staff, safety tool box talk.
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ENVIRONMENTAL RISKS

Seismic Activity					
No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
1.	High frequency of tremors occurrence		Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Permanent exclusion zone if needed. Regular control and data analysis. Accurate geological recognition. Numerical modelling of rock behaviour. Staff informing, safety tool box talk.
2.	Strain bursts		Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Permanent exclusion zone if needed. Regular control and data analysis. Accurate geological recognition. Numerical modelling of rock behaviour. Staff informing, safety tool box talk.
3.	Pillar bursts		Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Permanent exclusion zone if needed. Regular control and data analysis. Accurate geological recognition. Numerical modelling of rock behaviour. Staff informing, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
4.	Fault slip bursts		Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of control sensors. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Permanent exclusion zone if needed. Regular control and data analysis. Accurate geological recognition. Numerical modelling of rock behaviour. Staff informing, safety tool box talk.
5.	Earthquakes		Assembling of control sensors. Regular control and data analysis. Staff informing, safety tool box talk.	Assembling of control sensors. Regular control and data analysis. Permanent exclusion underground workings if needed. Staff informing, safety tool box talk.	Assembling of control sensors. Regular control and data analysis. Permanent exclusion underground workings if needed. Staff informing, safety tool box talk.
6.	Seismic magnitude of tremors > 3 ML		Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.), assembling of control sensor. Regular control and data analysis. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.), assembling of control sensor. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Regular control and data analysis. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.). Assembling of control sensor. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Numerical modelling of rock behaviour. Permanent exclusion zone if needed. Regular control and data analysis. Informing staff, safety tool box talk.

BSUIN

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
7.	Seismic magnitude of tremors > 4 ML		Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.), assembling of control sensor. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Regular control and data analysis. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.), assembling of control sensor. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Numerical modelling of rock behaviour. Permanent exclusion zone if needed. Regular control and data analysis. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.), assembling of control sensor. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Numerical modelling of rock behaviour. Permanent exclusion zone if needed. Regular control and data analysis. Informing staff, safety tool box talk.
8.	Seismic magnitude of tremors > 5 ML		Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.), assembling of control sensor. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Numerical modelling of rock behaviour. Permanent exclusion zone if needed. Regular control and data analysis. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.), assembling of control sensor. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Numerical modelling of rock behaviour. Permanent exclusion zone if needed. Regular control and data analysis. Informing staff, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, assembling of support (e.g. rock bolts, mesh, bars, etc.), assembling of control sensor. Backfilling, safety pillars, destress blasting, hydraulic fracturing. Accurate geological recognition. Numerical modelling of rock behaviour. Permanent exclusion zone if needed. Regular control and data analysis. Informing staff, safety tool box talk.
9.	Lack on seismic activity monitoring devices		Assembling of monitoring devices. Regular control. Staff informing, safety tool box talk.	Assembling of monitoring devices. Regular control and analysis. Staff informing, safety tool box talk.	Assembling of monitoring devices. Regular control and analysis. Staff informing, safety tool box talk.
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ENVIRONMENTAL RISKS

Water					
No.	**Risk Type**	**RISK LEVEL**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Water ingress		Exclusion of danger zone, signs with warnings, barriers. Dams, rock mass sealing, pumps. Assembling of control sensors. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Dams, rock mass sealing. Assembling of control sensors. Assembling of effective and reliable dewatering system. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Dams, rock mass sealing. Assembling of control sensors. Assembling of effective and reliable dewatering system. Permanent exclusion zone if needed. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.
2.	Chemical leakage into water		Exclusion of danger zone, signs with warnings, barriers, dams, sealing, assembling of control sensors. Chemicals removal system. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing, assembling of control sensors. Chemicals removal system. Assembling of effective and reliable dewatering system. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing, assembling of control sensors. Chemicals removal system, sewage treatment. Assembling of effective and reliable dewatering system. Permanent exclusion if needed. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.
3.	Problem with surface waters associated with depression craters		Assembling of control sensors. Regular control and data analysis. Staff informing, safety tool box talk.	Assembling of control sensors. Assembling of effective and reliable water control system. Rock mass sealing. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Assembling of control sensors. Assembling of effective and reliable water control system. Rock mass sealing. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
4.	Gassing of underground waters		Exclusion of danger zone, signs with warnings, barriers, dams, pumps, assembling of control sensors. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing. Assembling of control sensors. Assembling of effective and reliable dewatering and ventilation system. Savage treatment system. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing. Assembling of control sensors. Assembling of effective and reliable dewatering and ventilation system. Sewage treatment system. Permanent exclusion zone if needed. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.
5.	Deep bedrock water pockets		Exclusion of danger zone, signs with warnings, barriers, dams, rock mass sealing, safety pillars. Assembling of control sensors. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing, safety pillars. Assembling of control sensors. Assembling of effective and reliable dewatering system. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing, safety pillars. Assembling of control sensors. Assembling of effective and reliable dewatering system. Dewatering of bedrock water packet. Accurate hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.
6.	Flood		Exclusion of danger zone, signs with warnings, barriers, dams, sealing, safety pillars. Assembling of control sensors. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing, safety pillars. Assembling of control sensors. Assembling of effective and reliable dewatering system. Accurate hydrological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, safety pillars. Assembling of control sensors. Assembling of effective and reliable dewatering system. Permanent exclusion zone if needed. Accurate hydrological recognition. Regular control and data analysis. Staff informing, safety tool box talk.
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ENVIRONMENTAL RISKS

Gases					
No.	**Risk Type**	**RISK LEVEL**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Toxic gases occurrence after blasting works		Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gases sensors with warning system. Proper PPE. Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gases sensors with warning system. Proper PPE. Application of new type of explosives (less toxic).Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gases sensors with warning system. Proper PPE. Application of new type of explosives (less toxic). Elimination of explosives if possible. Ventilation system improvement. Permanent exclusion zone if needed. Regular control and data analysis. Staff informing, safety tool box talk.
2.	Exceedances of sulphur dioxide (SO2) limits		Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Machines improvement. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Use of new types of machines (less toxic exhaust, zero emission electric machines). Application of new type of explosives (less toxic). Accurate geological recognition. Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Use of new types of machines (less toxic exhaust, zero emission electric machines). Application of new type of explosives (less toxic).Ventilation system improvement. Elimination of explosives and diesel machines if possible. Permanent exclusion zone if needed. Regular control and data analysis. Staff informing, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
3.	Exceedances of hydrogen sulphide (H_2S) limits		Exclusion of danger zone, signs with warnings, barriers, ventilation dams, rock mass sealing. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams, rock mass sealing. Assembling of gas sensors with warning system. Proper PPE. Accurate geological recognition. Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams, rock mass sealing. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Permanent exclusion zone if needed. Regular control and data analysis. Staff informing, safety tool box talk.
4.	Exceedances of nitric oxide (NO_2), other nitrogen oxides (NO) limits		Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Use of new types of machines (less toxic exhaust, zero emission electric machines). Application of new type of explosives (less toxic).Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning. Proper PPE. Use of new types of machines (less toxic exhaust, zero emission electric machines). Application of new type of explosives (less toxic).Ventilation system improvement. Elimination of explosives and diesel machines if possible. Permanent exclusion zone if needed. Regular control and data analysis. Staff informing, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
5.	Exceedances of hydrocarbons (HC) limits		Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Use of new types of machines (less toxic exhaust, zero emission electric machines). Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors. Proper PPE. Use of new types of machines (less toxic exhaust, zero emission electric machines).Ventilation system improvement. Elimination of diesel machines if possible. Permanent exclusion zone if needed. Regular control and data analysis. Staff informing, safety tool box talk.
6.	Exceedances of carbon monoxide (CO) limits		Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Use of new types of machines (less toxic exhaust, zero emission electric machines). Application of new type of explosives (less toxic). Ventilation system improvement. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with waring system. Proper PPE. Use new types of machines (less toxic exhaust, zero emission electric machines). Application of new type of explosives (less toxic).Ventilation system improvement. Elimination of explosives and diesel machines if possible. Permanent exclusion zone if needed. Regular control and data analysis. Staff informing, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
7.	Exceedances of carbon dioxide (CO_2) limits		Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Use of new types of machines (less toxic exhaust, zero emission electric machines). Application of new type of explosives (less toxic). Ventilation system improvement. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Use new types of machines (less toxic exhaust, zero emission electric machines). Application of new type of explosives (less toxic).Ventilation system improvement. Elimination of explosives and diesel machines if possible. Permanent exclusion zone if needed. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.
8.	Exceedances of radon gas limits		Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Proper PPE. Ventilation system improvement. Accurate geological recognition. Permanent exclusion zone if needed. Regular control and data analysis. Staff informing, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
9.	Exceedances of Methane (CH4) limits		Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Ventilation system improvement. Accurate geological recognition. Automatic turn off electric systems. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Ventilation system improvement. Accurate geological recognition. Automatic turn off electric systems. Application of demethanization system of the rock mass. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, ventilation dams. Assembling of gas sensors with warning system. Ventilation system improvement. Accurate geological recognition. Automatic turn off electric systems. Application of demethanization system of the rock mass. Regular control and data analysis. Permanent exclusion zone if needed. Staff informing, safety tool box talk.
10.	Gas explosion		Exclusion of danger zone, signs with warnings, barriers, dams. Assembling of explosive gases sensors with warning system. Ventilation system improvement. Accurate geological recognition. Automatic turn off electric systems. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams. Assembling of explosive gases sensors with warning system. Ventilation system improvement. Accurate geological recognition. Automatic turn off electric systems. Removal system of dangerous gases. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams. Assembling of explosive gases sensors with warning system. Ventilation system improvement. Accurate geological recognition. Automatic turn off electric systems. Removal system of dangerous gases. Permanent exclusion zone if needed. Regular control and data analysis. Staff informing, safety tool box talk.

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
11.	Fluid (gas and / or liquid) eruption, including hydrogen sulphide		Exclusion of danger zone, signs with warnings, barriers, dams. Assembling of control sensors. Ventilation and dewatering system improvement. Proper PPE. Accurate geological and hydrogeological recognition. Automatic turn off electric systems. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, safety pillars. Assembling of control sensors. Ventilation and dewatering system improvement. Proper PPE. Accurate geological and hydrogeological recognition. Automatic turn off electric systems. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, safety pillars. Assembling of control sensors. Ventilation and dewatering system improvement. Proper PPE. Accurate geological and hydrogeological recognition. Automatic turn off electric systems. Regular control and data analysis. Permanent exclusion zone if needed. Staff informing, safety tool box talk.
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ENVIRONMENTAL RISKS

Radiation					
No.	**Risk Type**	**RISK LEVEL**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Naturally occurring radiation		Exclusion of danger zone, signs with warnings, barriers, dams. Assembling of radiation sensors. Ventilation system improvement. Proper PPE. Accurate geological and hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams. Assembling of radiation sensors. Ventilation system improvement. Proper PPE. Accurate geological and hydrogeological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams. Assembling of radiation sensors. Ventilation system improvement. Proper PPE. Accurate geological and hydrogeological recognition. Regular control and data analysis. Permanent exclusion zone if needed. Staff informing, safety tool box talk.
2.	Man-made radiation		Exclusion of danger zone, signs with warnings, barriers. Assembling of radiation sensors with warning system. Ventilation system improvement. Proper PPE. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Assembling of radiation sensors with warning system. Ventilation system improvement. Changing of radiation agent to less dangerous. Proper PPE. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Assembling of radiation sensors with warning system. Ventilation system improvement. Proper PPE. Regular control and data analysis. Changing of radiation agent to less dangerous or its removal. Permanent exclusion zone if needed. Staff informing, safety tool box talk.
3.	Uranium (U-238, U-235)	Not applicable			
4.	Thorium (Th-228,Th-232)	Not applicable			
5.	Radium (Ra-226, Ra-228)	Not applicable			

No.	Risk Type	RISK LEVEL	What if Medium	What if Serious	What if Very High
6.	Radon (Rn-222)		Exclusion of danger zone, signs with warnings, barriers. Assembling of gas sensors with warning systems. Ventilation system improvement. Proper PPE. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Assembling of gas sensors with warning. Ventilation system improvement. Proper PPE. Accurate geological recognition. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Assembling of control sensors. Ventilation system improvement. Proper PPE. Accurate geological recognition. Permanent exclusion zone if needed. Regular control and data analysis. Staff informing, safety tool box talk.
7.	Polonium (Po-210)	Not applicable			
8.	Lead (Pb-210)	Not applicable			
9.	….				

RISK AT THE WORKPLACE

Noise					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Noise caused by mining machinery		Exclusion of danger zone, signs with warnings, noise barriers. Proper PPE. Regular control. Assembling of sound sensors. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, noise barriers. Proper PPE. Regular control. Assembling of sound sensors. Use of soundproof cabin. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, noise barriers. Application of new type of machines (less noise) Proper PPE. Regular control. Assembling of control sensor. Use soundproof cabins. Permanent exclusion zone if needed. Staff informing, safety tool box talk.
2.	Noise caused by blasting		Exclusion of danger zone, signs with warnings, noise barriers. Proper PPE. Regular control. Assembling of sound sensors. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, noise barriers. Proper PPE. Regular control. Assembling of sound sensors. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, noise barriers. Proper PPE. Regular control. Assembling of control sensor. Permanent exclusion zone if needed. Stoppage of blasting works. Staff informing, safety tool box talk.
3.	Noise caused by machinery of UL		Exclusion of danger zone, signs with warnings, noise barriers. Proper PPE. Regular control. Assembling of sound sensors. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, noise barriers. Proper PPE. Use of soundproof cabins. Regular control. Assembling of control sensor. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, noise barriers. Proper PPE. Application of new type of machinery (less noise). Use of soundproof cabins. Regular control. Assembling of control sensor. Staff informing, safety tool box talk.
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RISK AT THE WORKPLACE

Vibration					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Vibration caused by moving mining machines		Exclusion of danger zone, signs with warnings, barriers. Use of vibration dumper. Proper PPE. Regular control. Assembling of vibration sensor. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Use of vibration dumper. Proper PPE. Regular control. Assembling of vibration sensor. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Use of vibration dumper. Application of new type of machines. Proper PPE. Regular control. Assembling of vibration sensor. Staff informing, safety tool box talk.
2.	Vibration caused by equipment in UL		Exclusion of danger zone, signs with warnings, barriers. Use of vibration dumper. Proper PPE. Regular control. Assembling of vibration sensor. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Use of vibration dumper. Proper PPE. Regular control. Assembling of vibration sensor. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Use of vibration dumper. Application of new type of equipment. Proper PPE. Regular control. Assembling of vibration sensor. Staff informing, safety tool box talk.
3.	…				

Lightening and Electric					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Inadequate existing power supply		Application of proper power supply. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper power supply. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper power supply. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.
2.	No permanent power supply available		Application of proper permanent power supply. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper permanent power supply. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper permanent power supply. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.

No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
3.	Frequent power failure		Application of proper, reliable, power supply. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper, reliable, power supply. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper, reliable, power supply. If necessary, ensure another independent power supply. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.
4.	Electrocution		Exclusion of danger zone, signs with warnings, barriers. Proper PPE. Application of proper and safe electrical network. Application of electric shock protection system. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Proper PPE. Application of proper and safe electrical network. Application of electric shock protection system. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Proper PPE. Application of proper and safe electrical network. Application of electric shock protection system. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.
5.	Short circuit		Application of proper and safe electrical network. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper and safe electrical network. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper and safe electrical network. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.
6.	Ignition of electrical devices		Application of proper and safe electrical devices. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper and safe electrical devices. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.	Application of proper and safe electrical devices. Automatic fire extinguisher system. Regular control. Assembling of control sensors. Staff informing, safety tool box talk.
7.	No access to the additional light source		Provide access to the proper and reliable light source. Staff informing, safety tool box talk.	Provide access to the proper and reliable light source. Staff informing, safety tool box talk.	Provide access to the proper and reliable light source. Staff informing, safety tool box talk.
9.	…				

RISK AT THE WORKPLACE

Technological					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Inaccurate designs of facility		Facility designs correction. Safety audits. Staff informing, safety tool box talk.	Facility designs correction. Safety audits. Staff informing, safety tool box talk.	Facility designs correction. Safety audits. Staff informing, safety tool box talk.
2.	Inaccurate site investigation		Correct site investigation.	Correct site investigation.	Correct site investigation.
3.	Unproven technology/ equipment failures		Application of proven technology, certification, regular control. Safety audits. Staff informing, safety tool box talk.	Application of proven technology, certification, regular control. Safety audits. Staff informing, safety tool box talk.	Application of proven technology, certification, regular control. Safety audits. Staff informing, safety tool box talk.
4.	Lift breakdown		Signs with warnings, barriers. Reparation of the lift. Regular control. Staff informing, safety tool box talk.	Signs with warnings, barriers. Reparation of the lift. Regular control. Staff informing, safety tool box talk.	Signs with warnings, barriers. Reparation of the lift. Regular control. Staff informing, safety tool box talk.
5.	Car breakdown		Signs with warnings. Reparation of the car or its replacement. Regular control. Staff informing, safety tool box talk.	Signs with warnings. Reparation of the car or its replacement. Regular control. Staff informing, safety tool box talk.	Signs with warnings. Reparation of the car or its replacement. Regular control. Staff informing, safety tool box talk.
6.	Breaks in process water supply		Signs with information. Reparation of the water supply system. Regular control. Staff informing, safety tool box talk.	Signs with information. Reparation of the water supply system. Regular control. Staff informing, safety tool box talk.	Signs with information. Reparation of the water supply system. Regular control. Staff informing, safety tool box talk.
7.	Incorrect bolting pattern		Exclusion of danger zone, signs with warnings, barriers. Scaling and bolting (proper pattern). Regular control. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Scaling and bolting (proper pattern). Regular control. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers. Scaling and bolting (proper pattern). Regular control. Staff informing, safety tool box talk.
8.	…				

RISK AT THE WORKPLACE

Inappropriate procedures / Improper organization					
No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
1.	Risk of inadequate access control and evacuation procedures		Risk assessment. Correction actions to ensure proper access. Implementation of safety procedures. Regular safety audits. Safety trainings. Regular of evacuation exercise. Staff informing, safety tool box talk.	Risk assessment. In case of serious gaps, closing facilities till proper access is provided. Implementation of safety procedure. Regular safety audits. Safety trainings. Regular of evacuation exercise. Staff informing, safety tool box talk.	Risk assessment. In case of serious gaps, closing facilities till proper access is provided. Implementation of safety procedure. Regular safety audits. Safety trainings. Regular of evacuation exercise. Staff informing, safety tool box talk.
2.	No fire management and prevention		Implementation of fire management and prevention system. Risk assessment. Corrective actions if needed. Regular safety audits. Safety trainings. Staff informing, safety tool box talk.	Implementation of fire management and prevention system. Risk assessment. In case of serious gaps, closing facilities till correction actions completed. Regular safety audits. Safety trainings. Staff informing, safety tool box talk.	Implementation of fire management and prevention system. Risk assessment. In case of serious gaps, closing facilities till correction actions completed. Regular safety audits. Safety trainings. Staff informing, safety tool box talk.
3.	No emergency evacuation procedure		Implementation of the emergency evacuation procedure. Risk assessment. Corrective actions if needed. Regular safety audits. Regular evacuation training. Staff informing, safety tool box talk.	Implementation of the emergency evacuation procedure. Risk assessment. In case of serious gaps, closing facilities till correction actions completed. Regular safety audits. Regular evacuation training. Staff informing, safety tool box talk.	Implementation of the emergency evacuation procedure. Risk assessment. In case of serious gaps, closing facilities till correction actions completed. Regular safety audits. Regular evacuation training. Staff informing, safety tool box talk.

No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
4.	No safety management during tank construction and outfitting		Implementation of the safety management procedure for tank construction and outfitting. Risk assessment. Regular safety audits. Using competent and qualified construction companies. Staff informing, safety tool box talk.	Implementation of the safety management procedure for tank construction and outfitting. Risk assessment. Regular safety audits. Using competent and qualified construction companies. Staff informing, safety tool box talk.	Implementation of the safety management procedure for tank construction and outfitting. Risk assessment. Regular safety audits. Using competent and qualified construction companies. Staff informing, safety tool box talk.
5.	Risk of safety incident during delivery underground		Implementation of the delivery procedure. Risk assessment. Regular safety audits. Safety trainings for delivery staff. Staff informing, safety tool box talk.	Implementation of the delivery procedure. Risk assessment. Regular safety audits. Safety trainings for delivery staff. Staff informing, safety tool box talk.	Implementation of the delivery procedure. Risk assessment. Regular safety audits. Safety trainings for delivery staff. Staff informing, safety tool box talk.
6.	No safety management leadership		Implementation of safety management leadership system. Risk assessment. Regular safety audits. Staff informing, safety tool box talks.	Implementation of safety management leadership system. Risk assessment. Regular safety audits. Staff informing, safety tool box talks.	Implementation of safety management leadership system. Risk assessment. Regular safety audits. Staff informing, safety tool box talks.
7.	Failure in safety communication and direction		Repairing of communication system. Implementation of emergency communication system. Risk assessment. Regular technical service. Regular safety audits. Staff informing, safety tool box talks.	In case of serious failures, closing facilities till repairing of communication system. Implementation of emergency communication system. Risk assessment. Regular technical service. Regular safety audits. Staff informing, safety tool box talks.	In case of serious failures, closing facilities till repairing of communication system. Implementation of emergency communication system. Risk assessment. Regular technical service. Regular safety audits. Staff informing, safety tool box talks.

No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
8.	Risk that safety incident is inadequately reported		Implementation of incidents reporting system. Risk assessment. Regular safety audits. Safety training.	Implementation of incidents reporting system. Risk assessment. Regular safety audits. Safety training.	Implementation of incidents reporting system. Risk assessment. Regular safety audits. Safety training.
9.	Risk that safety training is inadequate		Implementation of safety training procedure. Risk assessment. Regular safety audits. Staff informing, safety tool box talk.	Implementation of safety training procedure. Risk assessment. Regular safety audits. Staff informing, safety tool box talk.	Implementation of safety training procedure. Risk assessment. Regular safety audits. Staff informing, safety tool box talk.
10.	Risk that safety procedures will violate local, regional, national or international legal requirements		Implementation of procedure of review of safety procedures from the legal requirements point of view. Risk assessment. Regular legal audits.	Implementation of procedure of review of safety procedures from the legal requirements point of view. Risk assessment. Regular legal audits.	Implementation of procedure of review of safety procedures from the legal requirements point of view. Risk assessment. Regular legal audits.
11.	Integrated safety / emergency plan not properly integrated with mine/tunnel authorities		Integration of safety / emergency plan with authorities. Regular safety audits.	Integration of safety / emergency plan with authorities. Regular safety audits.	Integration of safety / emergency plan with authorities. Regular safety audits.
12.	Risk of inadequate orientation training of staff and visitors		Implementation of training procedure for staff and visitors. Risk assessment. Safety audits. Staff and visitors informing, safety tool box talk.	Implementation of training procedure for staff and visitors. Risk assessment. Safety audits. Staff and visitors informing, safety tool box talk.	Implementation of training procedure for staff and visitors. Risk assessment. Safety audits. Staff and visitors informing, safety tool box talk.
13.	Risk of unauthorised people entering the in the lab		Implementation of entrance procedure with proper control measures (e.g. electronic ID cards, guards). Risk assessment. Staff informing.	Implementation of entrance procedure with proper control measures (e.g. electronic ID cards, guards). Risk assessment. Staff informing.	Implementation of entrance procedure with proper control measures (e.g. electronic ID cards, guards). Risk assessment. Staff informing.

No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
14.	Risk of inadequate first aid and other emergency training		Implementation of the emergency training procedure. Risk assessment. Regular first aid and others emergency trainings made by qualified and competent trainer. Regular safety audits.	Implementation of the emergency training procedure. Risk assessment. Regular first aid and others emergency trainings made by qualified and competent trainer. Regular safety audits.	Implementation of the emergency training procedure. Risk assessment. Regular first aid and others emergency trainings made by qualified and competent trainer. Regular safety audits.
15.	Risk of inadequate safety signs, posters and notices		Implementation of the procedure for safety signs, posters and notices. Risk assessment. Regular safety audits. Safety trainings.	Implementation of the procedure for safety signs, posters and notices. Risk assessment. Regular safety audits. Safety trainings.	Implementation of the procedure for safety signs, posters and notices. Risk assessment. Regular safety audits. Safety trainings.
16.	No gas/smoke detection system		Installation of gas/smoke detection system. Regular technical service. Risk assessment. Regular safety audits. Staff informing, safety tool box talk.	Closing facility till installation of gas/smoke detection system. Regular technical service. Risk assessment. Regular safety audits. Staff informing, safety tool box talk.	Closing facility till installation of gas/smoke detection system. Regular technical service. Risk assessment. Regular safety audits. Staff informing, safety tool box talk.
17.	No oxygen concentration sensors		Installation of the oxygen concentration sensors. Risk assessment. Regular safety audits. Regular technical service. Staff informing, safety tool box talk.	Closing facility till installation of the oxygen concentration sensors. Risk assessment. Regular safety audits. Regular technical service. Staff informing, safety tool box talk.	Closing facility till installation of the oxygen concentration sensors. Risk assessment. Regular safety audits. Regular technical service. Staff informing, safety tool box talk.

No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
18.	No personal protection devices including defibrillators and other devices in the lab		Equip personnel with proper PPE and other safety devices (defibrillators). Regular safety audits. Safety training how to use PPE and other safety devices in the lab.	Equip personnel with proper PPE and other safety devices (defibrillators). Regular safety audits. Safety training how to use PPE and other safety devices in the lab.	Equip personnel with proper PPE and other safety devices (defibrillators). Regular safety audits. Safety training how to use PPE and other safety devices in the lab.
19.	No temperature sensors provided		Provide temperature sensors. Regular safety audits. Staff informing, safety tool box talk.	Provide temperature sensors. Regular safety audits. Staff informing, safety tool box talk.	Provide temperature sensors. Regular safety audits. Staff informing, safety tool box talk.
20.	No provision of emergency safety rooms underground		Provide of the emergency safety room underground. Regular safety audits. Staff informing, safety tool box talk.	Provide of the emergency safety room underground. Regular safety audits. Staff informing, safety tool box talk.	Provide of the emergency safety room underground. Regular safety audits. Staff informing, safety tool box talk.
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RISK AT THE WORKPLACE

Infrastructure related risk					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Usefulness of closest existing shaft		Upgrade of the shaft. Modification of the shaft work schedule. Start using another shafts or other access (e.g. decline). Staff informing, safety tool box talk.	Upgrade of the shaft. Modification of the shaft work schedule. Start using another shafts or other access (e.g. decline). Staff informing, safety tool box talk.	Upgrade of the shaft. Modification of the shaft work schedule. Start using another shafts or other access (e.g. decline). Staff informing, safety tool box talk.
2.	Passenger capacity		Modifications of passengers transport systems (capacity adjustment). New transport devices. Staff informing, safety tool box talk.	Modifications of passengers transport systems (capacity adjustment). New transport devices. Staff informing, safety tool box talk.	Modifications of passengers transport systems (capacity adjustment). New transport devices. Staff informing, safety tool box talk.
3.	Too small dimensions of existing workings		Rebuild of existing workings (dimensions adjustment)	Rebuild of existing workings (dimensions adjustment)	Rebuild of existing workings (dimensions adjustment)
4.	Risk of safety incident during construction underground		Risk assessment. Implementation of safety procedures. Regular safety audits. Using of qualified and certified construction companies. Safety trainings.	Risk assessment. Implementation of safety procedures. Regular safety audits. Using of qualified and certified construction companies. Safety trainings.	Risk assessment. Implementation of safety procedures. Regular safety audits. Using of qualified and certified construction companies. Safety trainings.
5.	Risk of tank rupture during filling		Implementation of safety procedures. Safety control of the tank construction before filling. Regular technical service. Filling by qualified and certified workers. Safety trainings.	Implementation of safety procedures. Safety control of the tank construction before filling. Regular technical service. Filling by qualified and certified workers. Safety trainings.	Implementation of safety procedures. Safety control of the tank construction before filling. Regular technical service. Filling by qualified and certified workers. Safety trainings.
6.	…				

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RISKS RELATED TO MINING OPERATIONS

Machinery					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Hit by the machine		Implementation of traffic procedure. Traffic signs, lights and barriers. Speed limitation. Emergency stop system. Reflective clothes. First aid training. Safety audits. Staff informing, safety tool box talk.	Implementation of traffic procedure. Traffic signs, lights and barriers. Speed limitation. Emergency stop system. Introduction of zones for pedestrian only. Warning sensors in machines - pedestrian presence in close vicinity. Reflective clothes. First aid training. Safety audits. Staff informing, safety tool box talk.	Implementation of traffic procedure. Traffic signs, lights and barriers. Speed limitation. Emergency stop system. Introduction of zones for pedestrian only. Warning sensors in machines - pedestrian presence in close vicinity. Reflective clothes. First aid training. Safety audits. Staff informing, safety tool box talk.
2.	Collision of machines during material transport		Implementation of traffic procedure. Traffic signs, lights and barriers. Speed limitation. Emergency stop system. Use of warning flashing lights. First aid training. Safety audits. Staff informing, safety tool box talk.	Implementation of traffic procedure. Traffic signs, lights and barriers. Speed limitation. Emergency stop system. Use of warning flashing lights. Machine positioning system with anti-collision system. Safety audits. Staff informing, safety tool box talk.	Implementation of traffic procedure. Traffic signs, lights and barriers. Speed limitation. Emergency stop system. Use of warning flashing lights. Machine positioning system with anti-collision system. Safety audits. Staff informing, safety tool box talk.
3.	Collision of machines during staff transport		Implementation of traffic procedure. Traffic signs, lights and barriers. Speed limitation. Emergency stop system. Use of warning flashing lights. First aid training. Safety audits. Staff informing, safety tool box talk.	Implementation of traffic procedure. Traffic signs, lights and barriers. Speed limitation. Emergency stop system. Use of warning flashing lights. Machine positioning system with anti-collision system. Safety audits. Staff informing, safety tool box talk.	Implementation of traffic procedure. Traffic signs, lights and barriers. Speed limitation. Emergency stop system. Use of warning flashing lights. Machine positioning system with anti-collision system. Safety audits. Staff informing, safety tool box talk.
4.	…				

RISKS RELATED TO MINING OPERATIONS

Blasting Works					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Magnitude of vibrations		Adjusting blasting parameters to decrease magnitude of vibrations. Assembling vibration sensors. Regular vibration control. Staff informing, safety toll box talk.	Adjusting blasting parameters to decrease magnitude of vibrations. Assembling vibration sensors. Regular vibration control. Staff informing, safety toll box talk.	Adjusting blasting parameters to decrease magnitude of vibrations. Assembling vibration sensors. Regular vibration control. Staff informing, safety toll box talk.
2.	Low distance between blasting works and UL site		Implementation of blasting procedure for work with low distance to the UL. Adjusting blasting parameters to given location. Limitation of blasting works. Staff informing, safety tool box talk.	Implementation of blasting procedure for work with low distance to the UL. Adjust blasting parameters to given location. Stoppage blasting works if needed. Introduction of mechanical work instead of blasting. Staff informing, safety tool box talk.	Implementation of blasting procedure for work with low distance to the UL. Adjust blasting parameters to given location. Stoppage blasting works if needed. Introduction of mechanical work instead of blasting. Staff informing, safety tool box talk.
3.	The possibility of finding employees in the danger zone		Implementation of blasting procedure (abort of blast in case of emergency). Warning signs and barriers, warning sounds. Checking of the danger zone before blasting. Guards on the entrance to danger zone. Staff informing, safety tool box talk.	Implementation of blasting procedure (abort of blast in case of emergency). Warning signs and barriers, warning sounds. Checking of the danger zone before blasting. Guards on the entrance to danger zone. Introduction of central blasting from surface without any staff underground. Staff informing, safety tool box talk.	Implementation of blasting procedure (abort of blast in case of emergency). Warning signs and barriers, warning sounds. Checking of the danger zone before blasting. Guards on the entrance to danger zone. Introduction of central blasting from surface without any staff underground. Staff informing, safety tool box talk.

No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
4.	Premature blast		Follow blasting procedure. Warning signs and barriers, warning sounds. Secure of blasting equipment. Checking the danger zone. Trained and competent blasting team. First aid and evacuation if needed. Staff informing, safety tool box talk.	Follow blasting procedure. Warning signs and barriers, warning sounds. Secure of blasting equipment. Checking the danger zone. Trained and competent blasting team. First aid and evacuation if needed. Staff informing, safety tool box talk.	Follow blasting procedure. Warning signs and barriers, warning sounds. Secure of blasting equipment. Checking the danger zone. Trained and competent blasting team. First aid and evacuation if needed. Staff informing, safety tool box talk.
5.	Transportation		Implementation of traffic procedure for explosives. Traffic signs, lights and barriers. Speed limitation. Emergency stop. Safety audits. Staff informing, safety tool box talk.	Implementation of traffic procedure for explosives. Traffic signs, lights and barriers. Speed limitation. Machine positioning system with anti-collision system. Emergency stop. Safety audits. Staff informing, safety tool box talk.	Implementation of traffic procedure for explosives. Traffic signs, lights and barriers. Speed limitation. Machine positioning system with anti-collision system. Emergency stop. Safety audits. Staff informing, safety tool box talk.
6.	Misfires		Implementation of blasting procedure to avoid misfires. Qualified and competent blasting staff. Proper quality of explosives and detonators. In case of misfires follow misfire procedure. Secure misfires place. Regular safety training.	Implementation of blasting procedure to avoid misfires. Qualified and competent blasting staff. Proper quality of explosives and detonators. In case of misfires follow misfire procedure. Secure misfires place. Regular safety training.	Implementation of blasting procedure to avoid misfires. Qualified and competent blasting staff. Proper quality of explosives and detonators. In case of misfires follow misfire procedure. Secure misfires place. Regular safety training.

No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
7.	Risk of uncontrolled explosion		Implementation of blasting procedure. Qualified and competent blasting staff. Regular safety training. Securing of blasting site. Regular safety audits. Risk limitation by using modern and safe explosives and initiation systems.	Implementation of blasting procedure. Qualified and competent blasting staff. Regular safety training. Securing of blasting site. Regular safety audits. Risk limitation by using modern and safe explosives and initiation systems.	Implementation of blasting procedure. Qualified and competent blasting staff. Regular safety training. Securing of blasting site. Regular safety audits. Risk limitation by using modern and safe explosives and initiation systems.
8.	Explosives fumes		Implementation of blasting procedure (proper waiting time). Warning signs and barriers, ventilation dams. Use self-rescuer if needed. Guards on the entrance to danger zone. Adjustment of ventilation system. Regular safety audits. Staff informing, safety tool box talk.	Implementation of blasting procedure (proper waiting time). Warning signs and barriers, ventilation dams. Use self-rescuer if needed. Guards on the entrance to danger zone. Adjustment of ventilation system. Risk limitation by use of central blasting system (no staff underground during blasting works). Assembling of fume sensors and oxygen content sensors. Regular safety audits. Staff informing, safety tool box talk.	Implementation of blasting procedure (proper waiting time). Warning signs and barriers, ventilation dams. Use self-rescuer if needed. Guards on the entrance to danger zone. Adjustment of ventilation system. Risk limitation by use of central blasting system (no staff underground during blasting works). Assembling of fume sensors and oxygen content sensors. Regular safety audits. Staff informing, safety tool box talk.
9.	…				

RISKS RELATED TO MINING OPERATIONS

Ventilation and Air Condition					
No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
1.	Temperature of the rock		Upgrade ventilation system (increase of ventilation capacity). Assembling of air condition system. Regular temperature control. Access to the drinking water. Staff informing, tool box talk.	Upgrade ventilation system (increase of ventilation capacity). Assembling of air condition system. Regular temperature control. Access to the drinking water. Work time limitation if needed. Staff informing, tool box talk.	Upgrade ventilation system (increase of ventilation capacity). Assembling of air condition system. Regular temperature control. Access to the drinking water. Work time limitation if needed. Staff informing, tool box talk.
2.	Too high temperature of air		Upgrade ventilation system (increase of ventilation capacity). Assembling of air condition system. Regular temperature control. Access to the drinking water. Staff informing, tool box talk.	Upgrade ventilation system (increase of ventilation capacity). Assembling of air condition system. Regular temperature control. Access to the drinking water. Work time limitation if needed. Staff informing, tool box talk.	Upgrade ventilation system (increase of ventilation capacity). Assembling of air condition system. Regular temperature control. Access to the drinking water. Work time limitation or closing of the too hot area. Staff informing, tool box talk.
3.	Insufficient air flow speed		Increase air flow speed. Upgrade of ventilation system if needed. Regular control of air flow speed. Assembling of air speed sensor. Staff informing, tool box talk.	Increase air flow speed. Upgrade of ventilation system if needed. Regular control of air flow speed. Assembling of air speed sensor. Staff informing, tool box talk.	Increase air flow speed. Upgrade of ventilation system if needed. Regular control of air flow speed. Assembling of air speed sensor. Staff informing, tool box talk.
4.	Poor air quality		Improve ventilation system. Regular air quality control. Staff informing, tool box talk.	Improve ventilation system. Assembling sensors for continuous air quality measurement. Staff informing, tool box talk.	Improve ventilation system. Assembling sensors for continuous air quality measurement. Staff informing, tool box talk.

No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
5.	Insufficient number of ventilation devices		Provide missing ventilation devices. Regular technical service of ventilation devices. Regular safety audits. Staff informing, safety tool box talk.	Provide missing ventilation devices. Regular technical service of ventilation devices. Regular safety audits. Staff informing, safety tool box talk.	Provide missing ventilation devices. Regular technical service of ventilation devices. Regular safety audits. Staff informing, safety tool box talk.
6.	Risk of fire occurrence		Implementation of the fire protection system and firefighting procedures. Equip UL with proper fire extinguishers and other firefighting systems. Assembling of fume sensors. Implement of combustible material management. Regular safety audits. Staff informing, safety tool box talk.	Implementation of the fire protection system and firefighting procedures. Equip UL with proper fire extinguishers and other firefighting systems. Assembling of fume sensors. Implement of combustible material management. Regular safety audits. Staff informing, safety tool box talk.	Implementation of the fire protection system and firefighting procedures. Equip UL with proper fire extinguishers and other firefighting systems. Assembling of fume sensors. Implement of combustible material management. Regular safety audits. Staff informing, safety tool box talk.
7.	Endogenous fire	Not applicable			

No.	Risk Type	Risk level	What if Medium	What if Serious	What if Very High
8.	Exogenous fire		Implementation of the fire protection system and firefighting procedures. Equip UL with proper fire extinguishers and other firefighting systems. Assembling of fume sensors. Implement of combustible material management. Regular safety audits. Regular evacuation exercise. Staff informing, safety tool box talk.	Implementation of the fire protection system and firefighting procedures. Equip UL with proper fire extinguishers and other firefighting systems. Assembling of fume sensors. Implement of combustible material management. Implementation of automated firefighting systems in machines. Regular safety audits. Regular evacuation exercise. Staff informing, safety tool box talk.	Implementation of the fire protection system and firefighting procedures. Equip UL with proper fire extinguishers and other firefighting systems. Assembling of fume sensors. Implement of combustible material management. Implementation of automated firefighting systems in machines. Regular safety audits. Regular evacuation exercise. Staff informing, safety tool box talk.
9.	…				

RISKS RELATED TO MINING OPERATIONS

Dust					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Dust laying on the surfaces (particles < 30 µm)		Remove dust from surface if possible. Use proper dust mask. Use water sprinklers if necessary. Assembling air filters for dust control. Upgrade working equipment and procedures to imitate dust. Staff informing, safety tool box talk.	Remove dust from surface if possible. Use proper dust mask. Use water sprinklers if necessary. Assembling air filters for dust control. Upgrade working equipment and procedure to limit dust. Staff informing, safety tool box talk.	Remove dust from surface if possible. Use proper dust mask. Use water sprinklers if necessary. Assembling air filters for dust control. Upgrade working equipment and procedure to limit dust. Staff informing, safety tool box talk.
2.	Particles reaching upper airways (particles < 10 µm)		Remove dust from surface if possible. Use proper dust mask. Use water sprinklers if necessary. Assembling air filters for dust control. Upgrade working equipment and procedure to limit dust. Staff informing, safety tool box talk.	Remove dust from surface if possible. Use proper dust mask. Use water sprinklers if necessary. Assembling air filters for dust control. Upgrade working equipment and procedure to limit dust. Staff informing, safety tool box talk.	Remove dust from surface if possible. Use proper dust mask. Use water sprinklers if necessary. Assembling air filters for dust control. Upgrade working equipment and procedure to limit dust. Staff informing, safety tool box talk.
3.	Particles reaching alveolar level (particles < 2,5 µm)		Use proper dust mask. Assembling air filters for dust control. Upgrade working equipment and procedure to limit dust. Staff informing, safety tool box talk.	Use proper dust mask. Assembling air filters for dust control. Upgrade working equipment and procedure to limit dust. Staff informing, safety tool box talk.	Use proper dust mask. Assembling air filters for dust control. Upgrade working equipment and procedure to limit dust. Staff informing, safety tool box talk.
4.	Coal dust explosion	Not applicable			
5.	…				

OTHER

Social Risk					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Limited possibility of experienced staff employment		Provide proper number of experienced employees. Additional staff trainings.	Provide proper number of experienced employees. Additional staff trainings.	Provide proper number of experienced employees. Additional staff trainings.
2.	Adverse local community operations		Implementation of safety procedures. Close access to the underground facility.	Implementation of safety procedures. Close access to the underground facility.	Implementation of safety procedures. Close access to the underground facility.
3.	Lack of suitably trained UL workers		Provide proper training for UL workers and enough employees for UL operations. Regular safety audits.	Provide proper training for UL workers and enough employees for UL operations. Regular safety audits.	Provide proper training for UL workers and enough employees for UL operations. Regular safety audits.
4.	…				

Political Risk					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	National import/export limitations	Not applicable			
2.	Act of terrorism	Not applicable			
3.	Political demonstrations	Not applicable			
4.	…				

OTHER

Economic					
No.	**Risk Type**	**Risk level**	**What if Medium**	**What if Serious**	**What if Very High**
1.	Economic crisis		Implementation of special procedure (operations in special external conditions). Provide proper insurance.	Implementation of special procedure (operations in special external conditions). Provide proper insurance.	Implementation of special procedure (operations in special external conditions). Provide proper insurance.
2.	Reduction in finance		Implementation of special procedure (operations in special external conditions). Provide proper insurance.	Implementation of special procedure (operations in special external conditions). Provide proper insurance.	Implementation of special procedure (operations in special external conditions). Provide proper insurance.
3.	Local taxes		Implementation of special procedure (operations in special external conditions). Provide proper insurance.	Implementation of special procedure (operations in special external conditions). Provide proper insurance.	Implementation of special procedure (operations in special external conditions). Provide proper insurance.
4.	Inflation		Implementation of special procedure (operations in special external conditions). Provide proper insurance.	Implementation of special procedure (operations in special external conditions). Provide proper insurance.	Implementation of special procedure (operations in special external conditions). Provide proper insurance.
5.	…				

OTHER

Pollution resulting from activities					
No.	**Risk Type**	**Owner**	**Probability**	**Impact**	**RISK LEVEL**
1.	Water pollution		Exclusion of danger zone, signs with warnings, barriers, dams, sealing. Assembling of control sensors. Pollution removal. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing. Assembling of control sensors. Pollution removal. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing. Assembling of control sensors. Pollution removal. Regular control and data analysis. Staff informing, safety tool box talk.
2.	Waste management		Remove of wastes. Implementation of proper waste management. Staff informing, safety tool box talk.	Remove of wastes. Implementation of proper waste management. Staff informing, safety tool box talk.	Remove of wastes. Implementation of proper waste management. Staff informing, safety tool box talk.
3.	Chemical leakage		Exclusion of danger zone, signs with warnings, barriers, dams, sealing. Assembling of control sensors. Remove of chemical. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing. Assembling of control sensors. Remove of chemical. Regular control and data analysis. Staff informing, safety tool box talk.	Exclusion of danger zone, signs with warnings, barriers, dams, sealing. Assembling of control sensors. Remove of chemical. Regular control and data analysis. Staff informing, safety tool box talk.
4.	…				

Health & Safety in Underground Environment Appendix no. 3 - Review of infrastructural improvement of the ULs of the BSUIN project

Baltic Sea Underground Innovation Network (BSUIN)

BSUIN

Underground Infrastructure Description

Infrastructural information about underground space						
Underground Facility	**CUPRUM**	**ASPOO SKB**	**Khlopin**	**CALLIO LAB**	**RUSKEALA**	**Mine Reiche Zeche**
Primary use of area before	Mining activity	R&D activities are mainly related to final disposal of spent nuclear fuel since 1986. Pre-investigation phase 1986-1990. Underground construction phase 1990-1995.The operation phase of the underground laboratory started 1995 and is still ongoing and is planned to be continued until 2023 at least.	-	Pyhäsalmi Mine Oy	Extraction of carbonate raw materials for lime production	Ore mining
Purpose of use of workings today	Mining activity	-	-	-	-	-
- for Tourism and education purpose	-	Education activities related to geological disposal of spent nuclear fuel, geosciences and rock engineering	-	Education	-	-
- for R&D purpose	-	1. Geological disposal of spent nuclear fuel. 2. External customers doing various experiments in the facilities.	-	I.e. Testing	-	-
- Other	-	Communication activities in order to build confidence and public acceptance for final disposal of spent nuclear fuel, organized guided tours for schools and	-	Other business directly by companies	Sporting events, concerts, entertainments	Geothermal heat exchange units for TUBAF, hospital and Terra Mineralia museum

		public.				
Number of employees, staff	N.a.	Fully and with growing multi-purpose aims			Staff 10 persons. In total, the kolmas karelia group of companies works during the summer season	Seven
The degree of use of underground space (fully, multi-purpose, partially with redemption, in conjunction with the operating enterprise)	Fully, copper exploitation	"Mid-term", the underground laboratory (UL) will be used by SKB until at least 2023 and we actively try to prolong the operation in co-operation with enterprises, universities and institutes	Fully	Partially with redemption, in conjunction with the operating enterprise Pyhäsalmi Mine Oy	20 000 m ^{2}. Partly due to a network of untrained workings. The data are given according to the topographic plan of the main horizon of the workings, excluding the volume of workings and other horizons (including flooded) The degree of use is complete, the object is in long-term lease from the state	Partly
Term of primary use, i.e. Long-term or short-term	Long-term	The underground activities are ongoing daily throughout the year	Long-term	Long term	Long-term use	Both, long term and short term
Continuity of operation (seasonal work) before / now in accordance with temperature-humidity conditions in the workings by the seasons	Full year operation	No mining activities. A spiral tunnel 3600meters long and 460 meters deep	All year	No by Pyhäsalmi Mine Oy, fro 2022 onwards by Callio Pyhäjärvi	Full year / full year	Operations at Reiche Zeche independent of seasonal conditions
Parameters of mining workings to apply: mine depth number, levels of occurrence, area volume (width, depth, extent)	Depth up to 1200 below surface, one level, 150 km2	Maximum number of persons at the same time under ground is 60	Approx. 60 m	1437 m, more details from www.callio.info	One horizon is used for tourism (the so-called "third"), the upper horizons are fragmented (worked), the lower horizons are flooded	Max depths of mine 230 m, access via two shafts, 4 levels of possible accessibility in different dimensions

Interreg Baltic Sea Region EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

The maximum / minimum number of people to visit (per visit, per day)	20 people per visit	Generally no ongoing mining activities. No low roofing and narrow spaces. When construction and installation activities are ongoing the affected working area is closed off	-	We have max capacity of 150 people i.e. With conferences, practical limit is max 15-20 people as a one group visiting	Groups up to 15 every 30 minutes	Maximum 200 persons underground at the same time
The need to overcome obstacles in the process of movement on the mine workings (low roofing, narrow passage)	Na. These kind of workings are unavailable for visitors	Generally no ongoing mining activities. No low roofing and narrow spaces. When construction and installation activities are ongoing the affected working area is closed off	-	Limited availability of mine-proof vehicles for transportation and drivers	Low roofing. Without obstacles, all narrow passages are widened, blockages are dismantled	Depending on tour, in case of level shifts groups need to climb ladders, tours on the first level only have no obstacles
The degree of workings roof and walls support (no support, concrete, wooden support etc.)	Fully support, rock bolts, additional support: wooden support, hydraulic support, shotcrete	By the elevator or by car/buss/truck along the access tunnel	Lining	-	Partly concert roofing	Depending on location and rock conditions, normally rock bolts, in areas of uls also shotcrete
The possibility / necessity of using transport for the movement of people within the sub-space	Due to size of mine, there is necessity of using car transport for people	By the elevator or by car/buss/truck along the access tunnel	-	See previous	Transport is not required, small technical trackless trolleys and wheelchairs, including self-propelled, for inspection by specialists of a large columned hall, a polymer boat is used (constantly located on the route)	Shaft hoisting and mine train
Way of getting into the mine workings / between underground levels (on foot, by elevator, by car, by stairs etc.)	In case of short distances, by foot, on the other hand by car	RFID (Radio Frequency Identification) tags are always worn by the staff personnel and the visitors. The same for vehicles of different kind. The positions of the RFID tags are monitored and can be followed from the facility	-	On foot to the top levels, by car via VT decline, via elevator in Timo-shaft	On foot	On foot, elevator, mine train

		operators room.				
Underground space management (special control service, monitoring attendants, guides)	Monitoring attendants, guides	It is free to pick rock samples. If drilling is needed to get a sample then the activity is classified as an research activity and have to be planned accordingly	-	According to Pyhäsalmi Mine Oy processes and tools	Special control service, guides	Guides or trained employees
Possibility and conditions for permitting sampling for teaching or touristic purposes	Possible, special request and permissions is needed	There are no old machines, mechanisms or equipment available. The UL is a modern and active research facility	-	Not known or understood	The possibility of sampling on the surface in open pits with administration permission	-
Availability for demonstration of old machines, mechanisms, equipment	There is no this type of activity	It is free for the public to visit the research village. There are no fences or other obstacles. The island Äspö and the landscape around are also free for outdoor activities of any kind, but the rules according to the right of public access need to be followed. The one-site visitor service centre (+46-491-767807, besok@skb.se) has to be contacted before arrival if a visit in the UL is wanted	-	More or less all equipment is still in use, mine is operational	Single specimens. Trolleys at the entrance to the route, on the route there are only old metal rings for attaching equipment items	-
The possibility of independent visits, what equipment for this is provided	Possible, permission is needed	-	-	Visits only in accordance of Pyhäsalmi Mine permits and Callio's projects & personnel	only for surface trails	-
The ability to visit the facility for people with disabilities	There is no access with disabilities. Normal mining activities, too dangerous for	-	-	-	partially. Underground route accepts people with disabilities on preferential terms with an	depending on disabilities

	people with disabilities				accompanying person upon prior request	
Characteristics of an array of enclosing rocks, mostly for teaching and touristic purpose but for the stability control too						
Underground facility	**CUPRUM**	**ASPOO SKB**	**Khlopin**	**CALLIO LAB**	**RUSKEALA**	**Mine Reiche Zeche**
Geological characteristics of the deposit	Stratoidal deposit, small inclination	Detailed descriptions are available	Clay	Stable rock. The main level, tunnels, and research facilities are fortified by rock bolts, iron netting, and shotcrete	Marble . Detailed descriptions are available.	Narrow hydrothermal polymetallic ore vein deposit of steep incline, bedrock Orthogneiss
Geoformological features of the area, relief over the mine (for example, mountains, waste heaps, volcanoes, etc.)	Small hills, plain terrain	Area is a typical Baltic sea archipelago with visible outcrop rock and pine forests. Partial of tunnel is located under the sea	Lowland	-	Flat terrain with slight elevations	Ore mountain medium mountain range
The presence of complex mining and geological processes in the area of the mine (karst, water cut, seismic, tectonic and other disturbances, gas content, cryological features)	Faults, fossils, layers of different kind of rocks - (dolomite, sandstones, shale, rock salt)	-	-	-	The groundwater	Vein deposits themself with over 1000 listed veins, system of spare veins, also including 800 years of mining/ mining history
Do you have information on physical and mechanical properties of the enclosing rocks and mineral (compressive strength, tension, shear, bending, fracture parameters, delamination and stratification, bulk mass, porosity, modulus of elasticity and Poisson's	Compressive strength 20 - 130 MPa, tensile strength 2 - 15 Mpa, Poisson ratio 0.13 - 0.23,	Detailed descriptions are available in the Äspö site description and model	-	https://calliolab.com/research/publications/	Detailed descriptions are available in the archive	120 MPa rock strength (Gneiss)

ratio)						
Is there a need to define indicators to determine the category of stability of rocks in which development has been completed (for example, in Russia according to снип-II 94-80)	Selected support system is matched to the geotechnical conditions (type of rocks, geological structure, rock strength etc.)	Very stable rock conditions. Granite and diorite	-	Underground research locations are stable environments. Experiments, conducted underground, are safe from the varying conditions on the ground, such as weather changes or air quality. The rock over-burden also provides technological advantages, such as an absence of disruptive acoustic or electrical noise and enhanced IT security options or even a complete isolation from the grid is possible	-	-
Stress-strain state of the array, the stability of the roof. Do you have data or you need additional measuring?	Stress-strain stress is determined by numerical modelling for some areas	Detailed descriptions are available in the Äspö site description and model	stability	Can be available via Pyhäsalmi Mine Oy	-	-
Geotechnical state of the array, do you need additional control?	Stress-strain stress is determined by numerical modelling for some areas, seismic tomography	Regular controls and measures	-	Can be available via Pyhäsalmi Mine Oy	additional control is desirable	-
Whether preliminary or subsequent hardening of the rock mass is required	There is no need for rock hardening.	The maintenance of the rock stability is ongoing according to an actual plan. Use of rock bolts, nets and shotcrete are used by underground maintenance	-	It depends. table rock. The main level, tunnels, and research facilities are fortified by rockbolts, iron netting, and shotcrete.	partially	-
Land acquisition	Some land acquisition is	Agreement with land	-	Pyhäsalmi Mine Oy is the owner of the land. Callio	the object is in long-term	-

	done if needed	owner, NPP OKG AB		Pyhäjärvi has a exclusive rights to rent land and facilities above and underground.	lease from the state	
The need for recultivation at the facility. Do you plan to carry out the reclamation, at what stage of operation	There is special recultivation plan. Plan has to be saprepred and approved by mining authorities.	If there is no long-term need of the UL in the future SKB will decide to close down and plug the facility	-	Not known or understood	Regular remediation measures are carried out over the object in the area of the mine bureau and the "Forest adit". continuation of landscaping works and technical arrangement of new territories	-
Works to determine the parameters and characteristics of the underground workings that can be used for various purposes						
Underground facility	**CUPRUM**	**ASPOO SKB**	**Khlopin**	**CALLIO LAB**	**RUSKEALA**	**Mine Reiche Zeche**
Classification of workings (longitudinal-extended, horizontal-inclined-vertical)	Vertical (shafts), horizontal and inclined workings (small inclination)	Facility has a local coordinate system based on SWEREF99	-	Can be available via Pyhäsalmi Mine Oy	Data is 2011-2013, but periodic monitoring is needed	mine maps available
Lithological composition and thickness of rock layers of the roof and sole	Floor - dolomite, shale, roof - sandstone (different thickness for all layers)	The crystalline rock at site is solid and not layered	-	Can be available via Pyhäsalmi Mine Oy	Data is 2011-2013, but periodic monitoring is needed	geological maps and models available
Characteristics of the support systems (the dimensions of the pillars, the degree of their stability in big caves, life time)	Characteristic of support systems is depended on local conditions (different dimensions)	-	-	Can be available via Pyhäsalmi Mine Oy	Data is 2011-2013, but periodic monitoring is needed	only measures of roof support (shotcrete and rock bolts)
The change in the bearing capacity of the support in time	-	Regular maintenance of underground facility. Large rock inspection every 3rd year	-	Especially for the "Old mine" site	Data is 2011-2013, but periodic monitoring is needed	-

Accessibility and / or use of technological transport (carts, etc.)	Staff transport is carried out by cars	By the elevator or by car/buss/truck along the access tunnel. Fork lift and machines for rock enforcement are used	-	Cars needed from Pyhäsalmi Mine Oy. Normal cars /civil cars are not allowed in the mine in any circumstances.	Boat for inspection of a large columned hall	mine train and shaft hoist
Radiation level of rocks	There is no radiation hazards but measurements are done periodically	Low values from regularly radon gas measurements	-	Via University of Oulu	Data is 2011-2013, but periodic monitoring is needed	-
Temperature fluctuations (external, in sub products)	Depends on surface temperature (close to the ventilation shafts), on the working area far from shafts, small fluctuation of temperature, air condition systems must be used is some areas	About 14 degrees Celsius all year	-	The humidity and temperature vary from level to level. The maximum temperature at the main level (1410) is 25 degrees Celsius. Humidity between levels can range from 50-100%. It is important to note however, that the temperature and humidity at a certain level stays stable.	Data is 2011-2013, but periodic monitoring is needed	-
Humidity (fluctuation if exist)	From 0 to 100%, depends on working area	Due to season	-	The humidity and temperature vary from level to level. The maximum temperature at the main level (1410) is 25 degrees Celsius. Humidity between levels can range from 50-100%. It is important to note however, that the temperature and humidity at a certain level stays stable.	Data is 2011-2013, but periodic monitoring is needed	-
Lighting /natural lighting	There is electric lights only, underground conditions	Intelligent lighting	lighting	No natural light at underground mine. Decline has no lights. Main level at 1410m has sufficient lights,	Artificial lighting (working, decorative), natural in a large columned hall	cap lights and electric lights at ULs and other POI

				also in research & working areas.		
Height difference in the interior (in workings)	Different hights of workings from 1.6 m to 6.0 m (in most cases)	The height of the drifts are about 4,5-5,5 meters. Some large caverns exist	-	Can be available via Pyhäsalmi Mine Oy	Low elevation on the route within 1 m	-
Presence of flora, fauna (special ecosystems, plants)	-	Microorganisms in the groundwater. Large research efforts have been carried out since 1986 and published in scientific journals	-	-	Tube flora in selected sections of the route. exchange of information on the appropriateness of research and | or methods of control	fungi, moss as some points
Water regime during the seasons within the boundaries of the subzone of the workings	-	The groundwater regime is stable and in general not season dependent	-	-	Data is 2011-2013, but periodic monitoring is needed	water is always available
Conditions for water removal - natural removal, special equipment, dry conditions	Water system is built (pipelines, pumps)	-	dry conditions	-	Monitoring the condition of the drainage trench is carried out daily by a technician	dewatering drift
Equipment for water disposal (equipment, water collectors, waterproofing)	Water collectors, pumps, sewage treatment plant	Pump stations in four levels with sedimentation and oil separation before outlet to the Baltic Sea. The waste water (sewage) from the research village is pumped to the wastewater treatment facility owned by the NPP-company OKG located 2 km south of the research village at Äspö	-	Can be available via Pyhäsalmi Mine Oy	gutter	normally not needed due to dewatering drift
Aerology (natural, forced ventilation), short	Forced ventilation system, several ventilation shafts	Forced ventilation automated from the control room. Always fresh air from	ventilation	Forced ventilation. Good air quality is ensured via a continuous and maintained	natural	forced ventilation

description		the atmosphere in the whole underground facility		fresh air supply from above ground.		
Geotechnical monitoring (exist or not) if yes - who is responsible (specially educated personal or not)	Manager of department	The evolution of the bentonite material used in the experiment is monitored. Unique monitoring solutions for experiments	-	Microseismic monitoring, as well as real-time monitoring and warning of harmful gases, are the key in providing a safe environment for all.	the staff of mountain Park. It is necessary to develop a monitoring regulation	-
Geoecological monitoring (exist or not) if yes - who is responsible (specially educated personal or not)	Manager of department	During some mid-term research projects, but not ongoing at the moment	-	Microseismic monitoring, as well as real-time monitoring and warning of harmful gases, are the key in providing a safe environment for all.	It is necessary to develop a monitoring regulation	-
Estimation of stresses and deformations in supported of workings materials (is it used or not, if yes - short comment for understanding)	There are many systems to measure of rock deformation (geodetic measurements, inclinometers, sensor of convergence) and stresses (numerical modelling, seismic tomography, special instrumented rock bolt for stress measurement)	Visual control and inspection is required before establishment of new experiment. Generally experiments takes place in competent rock conditions	-		identification of employees of KarSC RAS in the course of work. It is necessary to develop a monitoring regulation	-
Control over the movement of rock mass - yes or not, if yes - short description of technology	Laser scanning, sensor of convergence, sensors of dissection of rock layers	By experience, very small and slow moments in the surrounding rock	-	Micro seismic monitoring, as well as real-time monitoring and warning of harmful gases, are the key in providing a safe environment for all.	inspection by employees and identification of employees of KarSC RAS in the course of work. It is necessary to develop a monitoring regulation	-
What parameters are under control besides mentioned abowe	Seismic activity, seismoacustic activity	-	-	Can be available via Pyhäsalmi Mine Oy. According to their safety procedures.	-	-

Frequency of safety parameters checking	There are special procedures to measure safety parameters with strictly defined frequency. Each of shift must be follow by short safety tool box talk and checking of workplace.	Regular on yearly basis.	-	-	daily and / or regularly. A daily inspection of the caving route is carried out by a technician; in winter, additional inspection and cleavage of ice formations on the arch above the caving route in a large columned hall	depending on parameter (daily to annually)
Measures to protect the substitute space from the effects of aggressive environments	Danger areas are equipped with special control devices to measure important, from safety point of view, parameters (e.g. oxygen content in atmosphere, presence of toxic gases etc.)	Large inflow of groundwater from the ceilings are taken up by tarpaulins leading it to the walls and down to the side ditch.	-	Can be available via Pyhäsalmi Mine Oy. According to their safety procedures.	It is necessary to continue monitoring and identify hazardous factors (karst and groundwater, ice formations, their movement, freezing of certain sections of walls and arches)	not necessary

BSUIN

Current status and possible improvement

Based on survey

CUPRUM		
	Description	Proposition of improvement
Is there a warning system about the possibility of instability of life support systems	Roof separation gauge	Instrumented rock bolts with permanent data transfer and danger indicator (flashing light, buzzer)
Type of emergency signalling	Sirens, red flashing light, warnings messages transmitted by telephones and mobile transmitters	Personal emergency indicator (information about evacuation)
Is there a safety chamber	Safety chambers and additional stations with self rescuers	-
Is there a roof monitoring system	Roof separation gauge	Instrumented rock bolts with permanent data transfer and danger indicator (flashing light, buzzer)
Is there a good escape road plan, accessibility for visitors	Emergency plan contains information of all escape routes, plan is checked regular by mining authorities	-
How many possible escape roads are there (basic additional)	Many escapes roads available to the different shafts	-
The availability and equipping of emergency evacuation routes from the sub. space. Are there any signs for escape road	Escapes roads are marked by reflective markers, that show escape routes to the different shafts. In some of evaluation routes safety chambers or additional stations of self rescuers are available	-
Is there communication system with a dispatcher? What type?	Telephones and mobile transmitters	Increase range of mobile transmitters
System for counting and controlling the number of people which are underground	Information blackboard, information provided to the dispatcher	Personal location system
Availability of first aid, access to first aid kit and other	Lots of first aid kits are available underground, storage places	-

emergency response facilities	are determined and marked, medical point with nurses is available on surface	
Electrification of underground space. Access to electricity	Underground space is electrified	-
Are there any air condition monitoring system	-	-
The need and presence in the team of people who speak foreign languages. At least one person with good English language skills available	-	-
Is there a lot of water and mud on the floors of UL workings, at least on the paths?	Floor condition depends on mining area.	Potential UL should be located in dry place with good floor condition.
Need for a radioactivity monitoring system	There is no need for permanent radioactivity measurement system, periodically measurement is done	Measurement system assembling if needed.
Use of fixing the walls of the developed underground space. Control of the support systems	Support system is monitored and controlled	Assembling additional support system with instrumented rock bolts.
Place for sit/rest during trip	Rest chambers are available	-
Adequate lighting	-	-
Access to room where presentation/slideshow can be made	There is no special room for this purpose	Preparing room for this purpose with proper equipment.
Availability / necessity of a rest room, WC	Limited access to WC	Installation of additional toilet cabins
Access to water underground	Drinking water available in bottle only, industrial water available (not drinkable)	System installation of drinkable water
The presence or the need to use layouts, posters with additional information on the path of the tour route	-	-

The need to use additional protective equipment umbrella, boots, raincoat, etc.)	Protective equipment available. There is a need to use proper PPE.	-
Possibility of excursions for people with disabilities (which category)	There is no access with disabilities. Normal mining activities, too dangerous for people with disabilities.	-
Organization of an accessible environment for various categories of visitors	Limited access to the visitors, special permitting needed	-
Staff members who have experience with people with disabilities	NA, see above	-
The possibility of independent visits, passing the tour route. What equipment for this is provided	Limited access to the visitors, special permitting needed	-
The presence or the need a place where you can change clothes	Baths available	-
The need to use workwear	PPE required and available for visitors	-
The need to use personal protective equipment (for example, gloves, boots, apron, respirator)	See above	-
Access to computer	-	-
Access to internet	-	-
Access to underground communication system	-	
Supervisor available for external researchers	-	Training more guides who speaks foreign languages
Explosives are used to research?	-	-

Are harmful and hazardous substances used for research?	-	-
Availability of premises for group studies, lectures	Limited access, permission needed	-
Equipping specialized premises for practical, laboratory classes	Not available	-
The possibility of independent visits and working	Limited access, permission needed	-
The possibility of receiving (selection, purchase, gift) of various samples and other results of the work performed (for example, a crystal grown from a salt solution or a piece of rock)	Possible, special formal request is needed	Simplification of procedures.

ASPOO SKB		
	Description	Proposition of improvement
Is there a warning system about the possibility of instability of life support systems	There is a fire monitoring system and on-line cameras at key positions in the facility.	-
Type of emergency signalling	There are warning flashing lights, sound and recorded voice messages through speakers.	-
Is there a safety chamber	There are mobile rescue chambers at prioritized locations and one large rock cavern designed as an rescue chamber taking 60 persons.	-
Is there a roof monitoring system	The roof stability is checked regularly and reinforced when needed. No needs for further improvements.	-
Is there a good escape road plan, accessibility for visitors	Signs with escape routes approved by local emergency service. The staff personnel and visitors can escape to rescue chambers or to the nearest elevator stop level (-220m, -340 m and -450 m).	-
How many possible escape roads are there (basic additional)	One access tunnel and one elevator shaft. At least one escape way need to be available to have ongoing activities underground.	-
The availability and equipping of emergency evacuation routes from the sub. space. Are there any signs for escape road	Escape signs exist and the staff has repeated mandatory training. Signs with escape routes and training are approved by local emergency service.	-
Is there communication system with a dispatcher? What type?	A local DECT mobile communication system exists and is used by everyone working underground and in the office area above ground.	-
System for counting and controlling the number of people which are underground	The number of persons including visitors are monitored on-line by the implemented RFID based system.	-
Availability of first aid, access	Available at many key position	-

to first aid kit and other emergency response facilities	underground and in the research village.	
Electrification of underground space. Access to electricity	The whole tunnel system is electrified and there are several distribution boxes along the tunnel and the main working areas.	-
Are there any air condition monitoring system	Not needed. The ventilation of the underground space is regulated from the control room. There is no need to monitor the quality (condition) of the air. Temperature is measured. If the ventilation is stopped the radon gas levels will increase. Hence, it is important to ventilate the underground laboratory.	-
The need and presence in the team of people who speak foreign languages. At least one person with good English language skills available	The on-site staff can communicate in English.	-
Is there a lot of water and mud on the floors of UL workings, at least on the paths?	The roads and floors underground are in very good standard (asphalted) and the incoming ground-water is drained continuously. There could be water puddles if the drainage system fails due to lack of maintenance.	-
Need for a radioactivity monitoring system	The radon gases are regularly measured and some members in the staff is wearing dosimeters to have an extra control of the situation underground.	-
Use of fixing the walls of the developed underground space. Control of the support systems	Stability of walls and ceilings are checked regularly and rock reinforcements are used where needed.	-
Place for sit/rest during trip	Short distances between the facilities. By the elevator you can easily reach restrooms above ground.	-
Adequate lighting	Intelligent lighting is installed in the tunnel.	-

Access to room where presentation/slideshow can be made	Conference rooms are available in the research village above ground.	-
Availability / necessity of a rest room, WC	Also available at the 420 m level.	-
Access to water underground	At several positions. There is one main valve at the 420 m level.	-
The presence or the need to use layouts, posters with additional information on the path of the tour route	There are "posters" close to our experiment locations.	-
The need to use additional protective equipment umbrella, boots, raincoat, etc.)	Boots and raincoats are available for the visitors, but they are seldom needed.	-
Possibility of excursions for people with disabilities (which category)	Depends of the category of disability. Every one need to have the ability to walk in normal speed to the nearest rescue chamber/area in case of alarm (fire, smoke…).	-
Organization of an accessible environment for various categories of visitors	Not planned.	-
Staff members who have experience with people with disabilities	Maybe, but not as a result by planning for guiding visitors with disabilities.	-
The possibility of independent visits, passing the tour route. What equipment for this is provided	It is not possible/permitted to visit the underground space without a guide from the on-site staff.	-
The presence or the need a place where you can change clothes	There is a dressing room for changing clothes.	-
The need to use workwear	If needed, not included in the laboratory services.	-
The need to use personal protective equipment (for example, gloves, boots, apron,	Every one need to wear helmet with chinstrap, clothing with reflexes, working shoes/boots	-

respirator)	and an escape hood.	
Access to computer	Only for the SKB staff and in-hose consultants. An improvement is needed.	-
Access to internet	Only for the SKB staff and in-hose consultants. An improvement is needed.	Requires an open network underground. A complementary open access network will be installed underground.
Access to underground communication system	Possible to borrow DECT phone for underground work.	-
Supervisor available for external researchers	Supervisors/Coordinators and technicians are available.	-
Explosives are used to research?	Only when new tunnels and caverns are needed for new experiments.	-
Are harmful and hazardous substances used for research?	Minor amounts of radioactive tracers are used in some experiments, but very seldom. Chemicals have to be approved by SKB before use.	-
Availability of premises for group studies, lectures	Some of the conference rooms in the research village can be furnished for lectures and conferences.	-
Equipping specialized premises for practical, laboratory classes	Could be arranged in cooperation with customer.	-
The possibility of independent visits and working	All visits and working activities need to be planned and performed together with an on-site coordinator or guide from our staff.	-
The possibility of receiving (selection, purchase, gift) of various samples and other results of the work performed (for example, a crystal grown from a salt solution or a piece of rock)	New samples (groundwater, minerals, piece of rock) or results from previous analysis of samples can be ordered. Results from research activities are owned by the researcher.	-

CALLIO LAB		
	Description	Proposition of improvement
Is there a warning system about the possibility of instability of life support systems	-	-
Type of emergency signalling	-	-
Is there a safety chamber	In almost every level of the mine. Also big safety station at the main level with safety gear, O2, rescue gear etc.	-
Is there a roof monitoring system	-	-
Is there a good escape road plan, accessibility for visitors	Emergency plan contains information of all escape routes, plan is checked regularly by mining authorities. Also for every Project it is a MUST to prepare an emergency and security plan.	-
How many possible escape roads are there (basic additional)	One VT access tunnel and one elevator shaft	-
The availability and equipping of emergency evacuation routes from the sub. space. Are there any signs for escape road	Escapes roads in VT tunnel are marked by reflective white markers, that show escape routes to the safety chambers or additional stations.	-
Is there communication system with a dispatcher? What type?	Mandatory radiophones for all. Additionally a 3G access at the main level of the mine. Wi-Fi access at the main level, 660 level, 400 level and 990 level.	-
System for counting and controlling the number of people which are underground	RFID keys for all employees and visitors, information screen for all people underground	-
Availability of first aid, access to first aid kit and other emergency response facilities	Lots of first aid kits underground, two ambulances at the main level available to serve in case of emergency	-
Electrification of underground space. Access to electricity	Underground space is electrified	-

Are there any air condition monitoring system	At the main level and at the refinery control room	-
The need and presence in the team of people who speak foreign languages. At least one person with good English language skills available	English is used, but all emergency information is in Finnish	-
Is there a lot of water and mud on the floors of UL workings, at least on the paths?	Main roads and caverns are dry at the bottom of the mine	-
Need for a radioactivity monitoring system	There is no need for permanent radioactivity measurement system, periodically measurement is done	-
Use of fixing the walls of the developed underground space. Control of the support systems	Support system is monitored and controlled by seismic sensors	-
Place for sit/rest during trip	Social facilities at the main level, restaurant and toilets and Sauna	-
Adequate lighting	-	-
Access to room where presentation/slideshow can be made	Yes	-
Availability / necessity of a rest room, WC	Social facilities at the main level, Retka restaurant and toilets and Sauna	-
Access to water underground	Social facilities at the main level, Retka restaurant and toilets and Sauna	-
The presence or the need to use layouts, posters with additional information on the path of the tour route	Posters of the tour routes should be done. Mine is in operational mode at the moment and posters not needed	-
The need to use additional protective equipment umbrella, boots, raincoat, etc.)	According to PMO safety procedures: boots, helmet, flashlight etc. Protective equipment.	-
Possibility of excursions for people with disabilities (which category)	Too dangerous and not according to the PMO safety standards. Same for kids under age 18.	-

Organization of an accessible environment for various categories of visitors	Limited access but can be planned per case	-
Staff members who have experience with people with disabilities	-	-
The possibility of independent visits, passing the tour route. What equipment for this is provided	-	-
The presence or the need a place where you can change clothes	Dressing rooms, several	-
The need to use workwear	PPE required	-
The need to use personal protective equipment (for example, gloves, boots, apron, respirator)	PPE required	-
Access to computer	No public PC's	-
Access to internet	Callio Wi-Fi free	-
Access to underground communication system	According to the PMO standards	-
Supervisor available for external researchers	Support services from Callio as needed	-
Explosives are used to research?	Not at the moment	-
Are harmful and hazardous substances used for research?	-	-
Availability of premises for group studies, lectures	Meeting rooms and Retka facility	-
Equipping specialized premises for practical, laboratory classes	Can be arranged in cooperation with customer and PMO	-
The possibility of independent	Limited access, a security personnel needed to host	-

visits and working	visitors	
The possibility of receiving (selection, purchase, gift) of various samples and other results of the work performed (for example, a crystal grown from a salt solution or a piece of rock)	-	-

RUSKEALA		
	Description	Proposition of improvement
Is there a warning system about the possibility of instability of life support systems	partially. There is a fire monitoring system	The creation of an integrated monitoring and warning system based on fibber-optic Internet technologies is being discussed
Type of emergency signalling	sound and recorded voice messages through speakers.	-
Is there a safety chamber	Conventionally, such premises can be considered a mine office and a tunnel between the adits and a large columned marble hall	-
Is there a roof monitoring system	Partially	-
Is there a good escape road plan, accessibility for visitors	-	-
How many possible escape roads are there (basic additional)	Three escape routes (main entrance, marina exit to the water area of the Grand Marble Canyon, ascent to the surface from the Great Column Hall using rope rescue equipment)	-
The availability and equipping of emergency evacuation routes from the sub. space. Are there any signs for escape road	partially. There are no evacuation signs on the route, as the guide and the accompanying technician who own all the necessary information are responsible for the evacuation	-
Is there communication system with a dispatcher? What type?	partially. Communication with the dispatcher on mobile and radio communications from the nodal points of the route.	The creation of an integrated monitoring and warning system based on fibber-optic Internet technologies is being discussed
System for counting and controlling the number of people which are underground	The calculation is carried out by the administrator on duty at the entrance to the route and the accompanying technician, providing the group boarding the ferry in the summer mode of using the route	-
Availability of first aid, access to first aid kit and other emergency response facilities	The first-aid kit is stored by the duty administrator at the mine office	-

Electrification of underground space. Access to electricity	The underground space is electrified. 350 low-current monochromatic and colour waterproof LED lamps controlled from a single centre are installed on the caving route	-
Are there any air condition monitoring system	-	The creation of an integrated monitoring and warning system based on fibber-optic Internet technologies is being discussed
The need and presence in the team of people who speak foreign languages. At least one person with good English language skills available	partially. English and Finnish speaking guides are called upon prior request.	-
Is there a lot of water and mud on the floors of UL workings, at least on the paths?	partially. There is practically no dirt on the route. In flood periods, waterlogging zones appear on concrete walkways that do not require special shoes	-
Need for a radioactivity monitoring system	Preliminary studies showed the absence of increased background radiation along the entire speleo route. Observations of the volumetric activity of radon also yielded results significantly below normal.	In the section between the intersection of the adits and the Great Column Hall, a comparatively higher indicator was recorded (179 Bq / cubic meter at a rate of 250 Bq / cubic meter). The plans include continued monitoring of indicators in this zone.
Use of fixing the walls of the developed underground space. Control of the support systems	Additional static systems for supporting walls and roofs are created between the intersection of adits and the Great Column Hall, they are constantly under visual observation	-
Place for sit/rest during trip	The specifics of the underground route do not provide seating	-
Adequate lighting	-	-
Access to room where presentation/slideshow can be made	Partially. Upon prior request, one of the three cafes of the park will be transformed into the presentation area (usually,	The building of the Museum of the Mountain Park is being completed at the entrance to the underground route, in

	the Summer cafe)	addition,
Availability / necessity of a rest room, WC	there is	-
Access to water underground	to drinking - no	-
The presence or the need to use layouts, posters with additional information on the path of the tour route	-	The development of a large wall-mounted electrified scheme of the underground route is in development plans; project assistance is appropriate for this task
The need to use additional protective equipment umbrella, boots, raincoat, etc.)	Using hard hat, comforter, life vest	-
Possibility of excursions for people with disabilities (which category)	The staff has experience working with wheelchair users, hearing impaired	-
Organization of an accessible environment for various categories of visitors	The staff has experience with older people	-
Staff members who have experience with people with disabilities	A preliminary application is desirable, but all on-duty personnel have basic working skills	-
The possibility of independent visits, passing the tour route. What equipment for this is provided	The caving routing allows only group visits. An exception is made only for film crews on a commercial basis and for researchers with tasks agreed upon with the administration. In all cases, the group is accompanied by an accompanying technician responsible for safety.	-
The presence or the need a place where you can change clothes	Partially	-
The need to use workwear	sometimes	-
The need to use personal protective equipment (for example, gloves, boots, apron, respirator)	-	-
Access to computer	Delivered if necessary	-

Access to internet	At the entrances to the route mobile Internet is available	-
Access to underground communication system	Mobile and radio communications are available at the main sections of the route.	-
Supervisor available for external researchers	Upon preliminary request, one of the guides provides such support to researchers, he can take readings from installed instruments	-
Explosives are used to research?	-	-
Are harmful and hazardous substances used for research?	-	-
Availability of premises for group studies, lectures	-	Such classes will be possible in the premises of the Museum of the Mountain Park, finishing
Equipping specialized premises for practical, laboratory classes	-	While there is no special equipment, project assistance is appropriate
The possibility of independent visits and working	partially. By request and approval	-
The possibility of receiving (selection, purchase, gift) of various samples and other results of the work performed (for example, a crystal grown from a salt solution or a piece of rock)	By request and approval	-

Mine Reiche Zeche		
	Describtion	Proposition of improvement
Is there a warning system about the possibility of instability of life support systems	CO2 Gas detection Systems	Implementation of a Mine Control Station
Type of emergency signalling	Computer Alert	Implementation of a Mine Control Station
Is there a safety chamber	-	-
Is there a roof monitoring system	regular manual checking of roofs, Geophone and seismic stations	-
Is there a good escape road plan, accessibility for visitors	maps on all crossings to point to nearest shaft, escape route, first aid kit and emergency phone	-
How many possible escape roads are there (basic additional)	emergency exit possible via Reiche Zeche shaft and Alte Elisabeth, on nearly every point 2 possible escape routes exist	Plans for a new (additional) access are worked on
The availability and equipping of emergency evacuation routes from the sub. space. Are there any signs for escape road	Unclear question. Signs are available, escape via shaft hoist and stair cases in case of shut down	-
Is there communication system with a dispatcher? What type?	phones at several marked locations	continuously increasing the data access network
System for counting and controlling the number of people which are underground	Tags for guides and miners for manual control, lists at the hoisting machine with claimed guided routes and number of participants	plans for RFID Tags at helmets IN ADDITION to counting (not replacing it) for monitor exact position of visitors in time
Availability of first aid, access to first aid kit and other emergency response facilities	together with signs and installed phones at marked locations	In case of new Research facilities, the availability of first aid kits will be increased
Electrification of underground space. Access to electricity	in areas of research well equipped, not available at all locations in the mine	In case of new Research facilities electrification will be increased
Are there any air condition monitoring system	control of functionality of main fan / CO2 gas detection	-
The need and presence in the team of people who speak foreign languages. At least one	Guides available for English tours. All members of the TU scientific staff speak English. All independent research teams,	Y, plans of the touristic association independent of the mine or TUBAF

person with good English language skills available	groups and tours require at least one person capable of communicating in German language	
Is there a lot of water and mud on the floors of UL workings, at least on the paths?	on several paths and routes, ULs have concrete floors	-
Need for a radioactivity monitoring system	Radon is measured regularly on major routes - obtained data well below reporting level	-
Use of fixing the walls of the developed underground space. Control of the support systems	roof support mostly via rock bolts, in ULs also shotcrete	Y, roof and wall stability in the whole mine checked regularly, and improved wherever necessary
Place for sit/rest during trip	on first level at several locations	not by the mine
Adequate lighting	cap lights are used for every person, electric light at the shaft and major points of interest and Uls, as well as special illumination	-
Access to room where presentation/slideshow can be made	seminar rooms on first level	-
Availability / necessity of a rest room, WC	on surface as well underground on first level, only at one point	-
Access to water underground	access to service water available at all important points on the first level	In case of new Research facilities, the access to service water will be increased
The presence or the need to use layouts, posters with additional information on the path of the tour route	-	new information boards along the main route currently installed , plans for renewal of additional signs and posters
The need to use additional protective equipment umbrella, boots, raincoat, etc.)	hardhats are issued by the mine, especially for longer tours it is necessary to use equipment handed out due to dirt, mud, wetness	-
Possibility of excursions for people with disabilities (which category)	depending on the disabilities possible, but due to safety regulations it is necessary that all persons can reach the second shaft on their own, due to road conditions wheelchairs are not allowed	-

Organization of an accessible environment for various categories of visitors	short tours especially for children and seniors	Restructuring of the exhibition as part of the state exhibition
Staff members who have experience with people with disabilities	-	-
The possibility of independent visits, passing the tour route. What equipment for this is provided	All underground tours require a guide	-
The presence or the need a place where you can change clothes	given at the surface, not underground	-
The need to use workwear	due to mine climate and safety regulations	-
The need to use personal protective equipment (for example, gloves, boots, apron, respirator)	due to mine climate and safety regulations	-
Access to computer	on surface tablets are provided in the touristic area, no researcher computer provided by the mine	Depending on the tests, the operators of the test stands are responsible to provide their own computers
Access to internet	WLAN / LAN / Eduroam on surface as well as at certain points on the first level reserved for research, as this is the main level for research	continuously increasing the data access network
Access to underground communication system	Phones, as well as W-Lan and LAN at certain points on the first level	continuously increasing the data access network
Supervisor available for external researchers	-	-
Explosives are used to research?	-	-
Are harmful and hazardous substances used for research?	not currently used regularly, but the possibility exists / can be created as long as it fulfils the requirements by the German mining law	-

Availability of premises for group studies, lectures	-	-
Equipping specialized premises for practical, laboratory classes	-	-
The possibility of independent visits and working	All tours require a guide, either TUBAF, the mine, or provided by the tourist association, long term research teams will get trained to provide their own guide	-
The possibility of receiving (selection, purchase, gift) of various samples and other results of the work performed (for example, a crystal grown from a salt solution or a piece of rock)	ore samples can and have been handed out, but not on regular bases	-