BIOMOre

An Alternative Mining Concept

A new mining concept for extraction metals from deep ore deposits by using biotechnology

Deliverable 5.2.

Results of assessment made for the underground test facility and the outcome of the stakeholder seminars/workshops.

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Public Document

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AGH – AGH University of Science and Technology, Poland

KIP – *(Karta Informacyjna Przedsięwzięcia):* a document submitted to polish environmental authority.

FIGB – Ferric iron-generation bioreactor

JRGH – (*Jednostka Ratownictwa Górniczo-Hutniczego),* Mine-Smelter Rescue Team at KGHM

UIT - Umwelt-und Ingenieurtechnik GmbH, Germany.

MSDA - substances data sheet

MGB – major groundwater basin

TUT – Tampere University, Finland

VTT- Technical Research Centre of Finland

WUG – *Wyższy Urząd Górniczy* (State Mining Authority)

OUG – *Okręgowy Urząd Górniczy* (Regional Mining Authority)

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1. Executive summary

In this report results of assessment of environmental, health and safety (EHS) aspects of underground bioleaching test facility (BioMore project) are presented. This assessment was done in order to obtain environmental stakeholders acceptance, as well as to evaluate potential environmental impacts and risks related to preparation, operational, and the post operational phases of the test.

The first section provides a general description of the process phases. The description of the preparation and operational phases has been based on the project documentation, describing the technology of water tests, and of the final reactor preparation (by drilling and blasting), on the process modeling-based information, as well as on the data of the solution circulation installation and the system of process monitoring (draft versions of the documentation) delivered by Partners. The post-operational phase was described and then evaluated, on the basis of the concept previously assumed, which is being revised and developed by Partners.

In the next part, an analysis of the possible impacts and risks of the test is presented. The analysis is based on technical documentation and other data about the process received from project Partners. The analysis includes also information on media, raw materials and energy required for the process and possible emissions and their impacts on the environment. Analysis of these aspects is required by law.

Based on the assessment it may be concluded that a use of sulfuric acid in the mine is the most significant aspect that may potentially influence the EHS aspects of the Biomore pilot test. For the three process phases safety measures and environmental protection tools are described.

In the last part of the report, the activities taken in order to obtain administrative decision from local environmental authorities for the bioleaching test, is shortly presented. The administrative decision, obtained in March 2016, indicates that a more detailed environmental procedure to get the environmental permit for the bioleaching test is not required. The decision is justified both by a formal qualification of the test, as well as by the fact that the process is a short-term operation and its environmental impacts are not significant.

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Content

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2. Description of the underground test facility

The bioleaching pilot test will be performed in one of existing underground copper mine in Poland (Rudna mine in Polkowice, south-west Poland), operated by KGHM Polska Miedź S.A.

The test will be conducted in a block of the stimulated copper rock (**a reactor**) with dimensions of: 2 x 10 x 5 m. A leaching solution will be circulated inside of it. The solution will be injected into the block through injection holes (upper part of the block) and collected with using of production wells (bottom part of the reactor). In front of the reactor (from the side of the working) another 6 m of the body of the rock will be a safety pillar of the reactor. The injection and production holes will be connected through hoses with the solution circulation installation, delivered by HATCH. The installation will be located in the front of the safety pillar, in a selected working (W-332) of Rudna mine (details of the site selection are given in the Deliverable 3.1 – *Site selection and drilling,* KGHM, Feb.2016).

The test will consists **of the three following phases**:

- **preparation phase**, which includes: water tests (Deliverable 3.1.), selection and preparation of the final reactor in the body of rock, verification of the feasibility of the solution circulation in the rock by water injection, preparation of the working in which the system of solution circulation will be situated, transport and assembly of the pilot installation, monitoring system and other underground equipment.
- **operational phase**, including circulation of water and acidic leaching solution in the circulation system, bacteria delivery to the mine and the bioleaching operation,
- **post-operational phase** consisting in disassembly of the installation and an appropriate liquidation of the safety pillar.

Currently, the water tests and the preparation of the final reactor in the body of rock (by drilling and blasting) is done. Also a design documentation of the chamber (i.e. the area of the selected working, in which the test will be carried out) preparation is finalized.

A short description of the three phases is given below.

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2.1. Preparation phase

2.1.1. Water tests

The goal of these tests was to verify if the solution circulation in the stimulated body of rock is feasible. The tests were carried out in the W-332 working in Rudna mine (the same, as the final reactor site. They included the following activities: chamber preparation, drilling of blasting, injection and production holes, and blasting – in order to stimulate the rock inside of the reactor for water circulation between the injection and production wells. At the end, water was injected into the body of the rock in order to verify that the hydraulic connection between injection/production wells was achieved, and that there was not leaks into the working through the safety pillar. Two water tests were performed so far. Based on their results the final reactor site in the sandstone rock was selected. Details of the water tests are described in the **Deliverable 3.1**. (BiOMOre). The works performed within the water tests were carried out based on design documentation prepared and internally accepted by Rudna mine, in accordance with applicable regulations.

2.1.2. Preparation of the final reactor and of the test chamber

Preparation phase of the final reactor was preceded by elaboration of models of the rock stimulation and water circulation within the reactor: they were proposed by AGH. Based on the results of the modeling, a decision on geometry and the way of the final reactor preparation was taken (see Figures 1 A and B). The works of the reactor preparation involved drilling of blasting holes, blasting with an explosive, drilling of injection, production and monitoring holes. An acid resistant isolation material to fill the pipes and to liquidate of unnecessary holes in the safety pillar was also selected.

Currently, all works related with blasting and drilling are completed and verification of the hydraulic connection between injection and production holes, as well as revision of the tightness of the safety pillar are underway.

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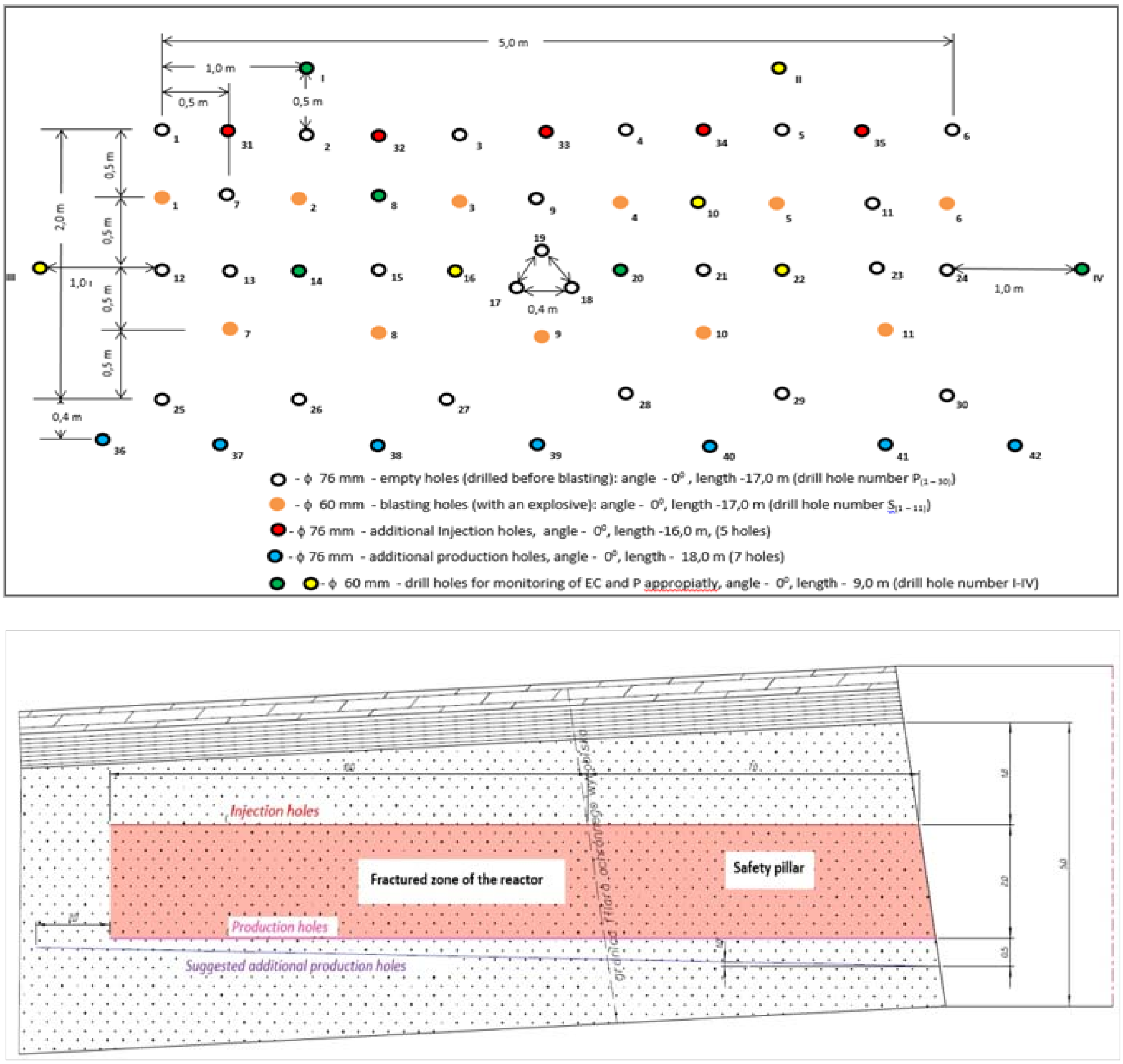

A.

B.

Figure 1. **By KGHM**: Final reactor model : A – location of blasting, compensation, injection, production and monitoring drill holes, B- cross section of the reactor and safety pillar (attention: the safety pillar is no 7 m any more – after blasting c.a. 1 m of the safety pillar was destroyed and the width of the safety pillar is 6 m).

Based on the assumptions of the process and a technical documentation (draft versions) on solution circulation and monitoring systems, an executive technical documentation of the chamber preparation was elaborated. It includes the following parts of design: mechanical/installation, mining and construction, and electrical and teletechnical. It was assumed that the chamber preparation will consist in the following works:
- bringing the media to the test site, i.e. electric power, equipment, measuring equipment, lighting, mine water line and fiber network,

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- preparation of the floor in the area of the test by concreting and secure the roof and side walls (grid on the roof, possibly small concrete walls along the sidewalls) .
- fencing and labeling of the test area (gates open work),
- other works: e.g. preparation of a site for acid storage, a service works stand, alarm and warning installation.

A goal of a number of solutions proposed in this project is to limit potential, environmental impacts of the operation and to ensure safe working conditions at the test site.

Then, the solution circulation system from Hatch and monitoring equipment from UIT will be transported underground. The Hatch's installation is constructed on two platforms (Figure 2). The provided system comprises two buffer tanks, an aerated (with a compressor) bioreactor tank - FIGB, wherein the leaching agent will be produced by bacterial culture, drums with the concentrated sulfuric acid, and other elements of the pumping system. The monitoring system will consist of several sensors, a unit of signals registration and transfer, and an autosampler.

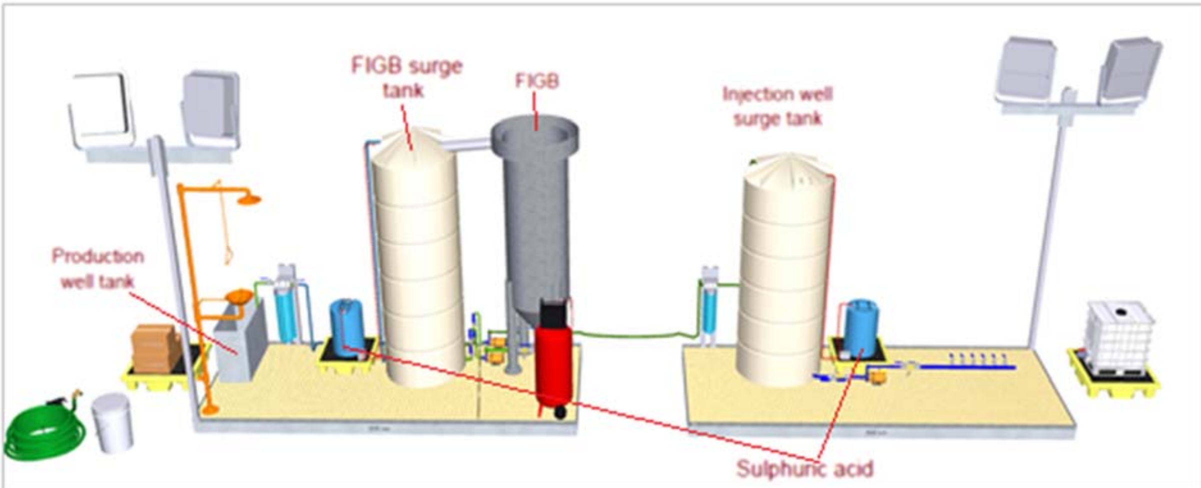

Figure 2. **By Hatch**: General idea of solution circulation system of the pilot[1].

Operational phase will begin with introducing of a tap water to the solution circulation system and its injection into the injection holes. The water will be circulated in the system in order to wash out chlorides from the rock which inhibit microbial activity. The water will be partially removed from the system and will be replaced with fresh portions. After that, the concentrated sulfuric acid will be dosed to the system, in order to remove

[1] by HATCH (GA of the Biomore project, Essen 2016).

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carbonates from the rock (acidification phase) and to maintain the pH (~2) of the leaching solution, which is appropriate for the bacteria. The acid will be stored in the mine, next to the pilot and will be dosed into circulation system directly from original drums (of 10-20L) in which it will be purchased from a producer. The total volume of the liquid circulating in the system should be circa 6 m^3.

A majority of the bacteria will be attached to the wet activated carbon carrier in the FIGB: some microorganisms may also grow in suspension. The microbial culture will be introduced into FIGB after acidification phase. The microorganisms are acidophilous bacteria - mainly *Leptospirillum ferriphilum* and *Sulfobacillus* sp. and some *Ferroplasma* sp.[2]

The process will be controlled and monitored, also in order to verify an effect of the process for the surrounding rock.

The modeling of water and acidic solution circulation washing steps and acidification suggest that they may last up even to 100 days. These models are currently being verified.

2.2. Post-operational phase

The work involving a development of a detailed strategy of the pilot decommissioning is planned to be performed mostly in the second half of the BioMOre project. Therefore, the assessment provided in this report is done on the basis of assumptions adopted at the planning stage of the project, and in relation to identified conditions in the mine premises.

It was assumed that after bioleaching, the solution circulating in the system would be collected in acid-resistant tanks, transported to the surface and transferred to the project Partners or laboratories for further analyses.

The reactor in the body of rock will be preserved. It will be washed (probably with mine water) to remove acid from the pores of rock: the option of washing with mine water is being considered. Another possibility is to neutralize the rock to pH ~7 with an addition of a neutralizing agent solution underground.

[2] Information from TUT, responsible for the culture preparation.

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Then, the treated rock will remain in the body because it will be chemically and microbiologically inert: it is supposed to be exploited together with the surrounding rock, according to the mining plan. Also, the injection and production holes are planned to be closed (filled with a selected material) after the test.
Then, the installation will be decommissioned, and its elements will be brought to the surface. The elements will be managed in accordance with appropriate regulations.

3. Basic criteria of EHS assessment related with the underground bioleaching test

In the assessment of the bioleaching test all aspects and requirements related to its specificity, as well as the fact that the test will be carried out in the operating mine should be considered. The assessment of the underground test performance must refer to local, i.e. polish, environmental and mining (in terms of safety) regulations.

A reference to the assessment of the local regulations was necessary in order to get an environmental permit and meet local requirements based on mining law. In this field an environmental act[3] and its implementing acts that refer to several EC Directives[4] were taken into account: this act concern basically an assessment of effects of individual projects on the environment and public access to environmental information. Also, other environmental requirements were analysed. There were basically: environmental law[5], or waste and mining waste codes[6].

In relation to these regulations and taking into account specificity of the pilot plant, the following environmental aspects were analysed:

- an estimation of water, raw materials, fuel and/or energy consumption,

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[3] ustawa o *udostępnianiu informacji o środowisku i jego ochronie, udziale społeczeństwa w ochronie środowiska oraz o ocenach oddziaływania na środowisko, z dnia 3 października 2008 r. (*Dz.U.2013.1235 z późn. zm)

[4] For example:
- COUNCIL DIRECTIVE of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment (85/337/EEC), No L 175/40, (5. 7. 85.);
- DIRECTIVE 2001/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment, No L 197/30 (21.7.2001);
- DIRECTIVE 2003/4/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 28 January 2003 on public access to environmental information and repealing Council Directive 90/313/EEC, No L 41/26 (14.2.2003);
- DIRECTIVE 2003/35/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 May 2003 providing for public participation in respect of the drawing up of certain plans and programmes relating to the environment and amending with regard to public participation and access to justice Council Directives 85/337/EEC and 96/61/EC, L 156/17;
- DIRECTIVE 2008/1/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 January 2008 concerning integrated pollution prevention and control, L 24/8 (29.1.2008).

[5] ustawa z dn. 27 kwietnia 2001 *Prawo ochrony środowiska* (Dz. U. 2013.1232 – j.t. z późn. zm.)

[6] ustawa *o odpadach* z dnia 14 grudnia 2012 r. (Dz. U. 2013.21 z późn. zm.); ustawa *o odpadach wydobywczych* z dnia 10 lipca 2008 (Dz. U. 2013.1136 j.t. z późn. zm.).

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- types and expected amounts of substances and energy that would be released to the environment, as well as possible measures to prevent the emissions,
- other environmental impacts and their scale (an area which would be affected by the test).

Concerning the safety aspects, the three basic acts were considered: the mining and geological code[7] and its two implementing acts: - an act regulating EHS aspects of underground mining activities[8], and, - an act on natural hazards in underground mines[9]. The rules included in these acts are based on experience of polish mining industry, related with difficult mining and geological conditions of the mines. Among the most significant risks that impact the safety of activities carried out in mines, the following "natural hazards" can be distinguished, e.g.: rock bursts, fires, methane and/or others gases or a coal dust explosions, ejections of gases, rocks, and of water into the workings, as well as hazards related form machines and people working in the mine. The statistics show that the last type of risks causes the highest number of accidents in polish mines[10].

These natural hazards can occur in the mine during the bioleaching test : they may result both from current mining activities and from works carried out within the BioMOre test. The hazards and their prevention tools are listed in the operating plan of the mine, and in the risk assessment sheet of employees[11].

Potential risks that are specific to the bioleaching test are also determined. Information about them is based on data received from project partners until now. As the final, technical documentation is not completed yet, the assessment of the test in some cases is based on assumptions. The process should be also assessed after the test is completed: this would be included in the next report (D.5.4.[12]), for better evaluation of the future, in-situ installation bioleaching technology.

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[7] Ustawa z dnia 9 czerwca 2011 r. Prawo geologiczne i górnicze (Dz. U. 2011 Nr 163 poz. 981 z późn. zm.

[8] Rozporządzenie Ministra Gospodarki z dn. 28 czerwca 2002 r w sprawie bezpieczeństwa i higieny pracy, prowadzenia ruchu oraz specjalistycznego zabezpieczenia przeciwpożarowego w podziemnych zakładach górniczych. (Dz.U.02.139.1169 z późn. zm.)

[9] Rozporządzenie Ministra spraw Wewnętrznych i Administracji z dn. 14 czerwca 2002 r. w sprawie zagrożeń naturalnych w zakładach górniczych (Dz.U. Nr94 poz. 841 z późn. zm.)/ Rozporządzenie Ministra Środowiska z dnia 29 stycznia 2013 r. w sprawie zagrożeń naturalnych w zakładach górniczychDz.U.2013 nr 0 poz. 230 z późn. zm.)

[10] State of health and safety aspects related with a mining rescue and general safety aspects of mining and geology-related works in 2015: *Ocena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo-geologiczną w 2015 roku*, Wyższy urząd Górniczy, Katowice 2016).

[11] Technical design of the BioMore project (Projekt techniczny BioMore), water tests. KGHM Polska Miedź S.A., Rudna mine 2015.

[12] D.5.4. *Environmental impacts from a future full-scale production facility based on in-situ leaching from a stimulated ore body* (Work plan of BioMore Project No 642456 (Horizon 2020 programme of EU)).

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4. Assessment of test preparation phase

4.1. Potential, natural risks related with the pilot test location in the running mine

The most important risks that should be considered in mining activities are defined in the basic regulations, mentioned in the previous chapter. At the preparation phase, these risks were analyzed in the mine, mainly in terms of drilling and blasting carried out to prepare the reactors. The possibility of occurrence of these hazards has to be taken into account also during preparation of the chamber (an area in the selected working), in which the pilot will be located: it will involve mining, construction, or electromechanical works.

- **Rock burst hazard**: means a risk of rock burst occurrence in the mine, which is a dynamic phenomenon caused by rock mass shock. As a result of the burst, an area of the working can be damaged or destroyed rapidly, influencing its functionality and operational use. According to the *WUG*'s[13] statistics the 6 rock burst occurred in the Polish copper mines in the period of 2011-2015. During such 1 miner has died and 33 had the light body injures[10].

According to the Polish law there are three degrees of the rock burst hazard in the underground copper mines. According to the decision of the Wroclaw OUG[13] (P/7022/5/2003 from 17.12.2003 r.) the area of the tests in Rudna mine, is qualified to the third degree of the rock burst danger. The danger degree is defined according to the roof's and floor's rock classification. The classification is based on the selected indicators of the rock resistance parameters and also, on statistical, rock burst occurrence in the past.

- The rock burst and shock occurrence is the most common cause of **the roof and side walls fallings** into the working.

The possibility of occurring of these hazards is related to the mining-geological conditions. Geological disturbances recognized at the test site are in the form of vertical and horizontal fractures; the faults are not anticipated in this area. Locally (in the working W-332 in a proximity of the final reactor, an inclined fracturing at an angle of 80° (NE-SW) has been found[14]. The geological conditions at the selected test site has been described in Deliverable 3.1.

[13] WUG – Wyższy Urząd Górniczy (State Mining Authority); OUG – Okręgowy Urząd Górniczy (Regional Mining Authority)
[14] Deliverable 3.1.: Site selection and drilling, BioMOre project, by KGHM.

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- **Water hazard:** it means possibility of water breaking or uncontrolled water inlet (also a salted mine water) including a loose, rock material into the workings: this may cause a danger for mine functionality and safety of employees.

According to the Polish law there are three degrees of the water hazard. The test site (water and final reactor site) are placed in the area of the first degree of water hazard. The test site is connected to the mine drainage system so the water hazard from the rock mass are not expected. In the case of drillings performed for the BioMore project such water inlets have not been found.

- **Ejection of the gasses and rocks (gas-geo dynamic phenomenon's) –** it means dynamic moving of the crushed rocks from the rock mass into the workings, caused by an energy of the gasses emanated in the rock. They may cause air blast, noise effects, lining and machines damages, forming after-blast cavern, aeration disturbances or forming an atmosphere unfit to breath.

A potential risk of occurrence of gas-geo dynamic phenomenon's in the case of preparation of the leaching tests is related mainly to the drilling works. Such hazard has not been found during these works carried out at the site of the final reactor as well as previously – before water tests.

- **Fire:** During the preparation of the chamber, more specific precautions should be taken into account during fusion works.
- **Methane hazard:** It means possibility of methane emission from the rock mass and its accumulation in the working. The methane hazard are not expected at the test site.
- **Dust hazard connected with accumulation of different dust types:** Such hazard is not expected during preparation of the chamber and also later on – during operational and post-operational tests. The possibility of dust hazard has been considered during blasting works.
- **Gas and dust explosion (explosive atmosphere):** the atmosphere of the test site located in the Rudna mine is not explosive.
- **Climate hazard:** related to increment of microclimate parameters of the mine (for example temperature).
- **Radiation hazards (natural radioactive substances):** such hazard is not expected.

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- **Slippery, irregular surfaces –** falls, e.g. during works of mining machines and vehicles.
- **Noise:** occurring mainly at the stage of drilling and blasting works.

4.2. Hazards connected with explosives and the blasting works

The hazards which may occur during the blasting works are related to[15]:

- The rock throwing during the drilling on missed hole or its improper removal: such cases are known in the Rudna,
- The rock throwing during firing,
- The hazard of intoxication with waste gas formed durring exploision,
- The hazard of prematural explosive detonation, due to stray voltages,
- The hazard of explosives detonation during the transport to the test site.

None of the listed hazards has been found, during the blasting works performed for the BioMore project. Destruction i.e. falling into working of approx. 1 m of the reactor safety pillar was observed during blasting: similar case both for water test and in the final reactor[16]. It didn't cause any threat for the miners.

4.3. Machinery and equipment hazards

Those hazards are related with potential malfunctions of mining machinery and equipment and the risk they may cause for the operators. Those hazards can concern both machines used for transportation e.g. mine hoist malfunctions, but also equipment necessary for performing the water tests and for the reactor preparation (drills, water injection equipment): the devices which were used for the water tests have been described in the Deliverable 3.1. During the water tests and during preparation of the final reactor such risks were not identified.

The hazard which can also occur during the preparation phase, can be caused by the maladjustment of the installation for the mine conditions. Generally, according to the law[17], the chemical and plastic products can be used in the mine if they are non-toxic,

[15] Technical design of the BioMore project (Projekt techniczny BioMore), water tests. KGHM Polska Miedź S.A., Rudna mine 2015.

[16] According to the blasting reports made in the Rudna, 2016.

[17] § 360 of the act: Rozporządzenie Ministra Gospodarki z dn. 28 czerwca 2002 r w sprawie bezpieczeństwa i higieny pracy, prowadzenia ruchu oraz specjalistycznego zabezpieczenia przeciwpożarowego w podziemnych zakładach górniczych. (Dz.U.02.139.1169 z późn. zm.)

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retardant and antistatic. In the case of the pilot some elements of the equipment must be also acid-resistant and/or anticorrosive: it has been considered during production of the pilot at Zeton company (Netherlands) (for Hatch). Fulfilling of those conditions and other various branch standards (i.e. mechanical, electrical) by the equipment used in the test is being verified by an external unit, to allow their safe use in mine conditions.

The equipment working under pressure is used both in the water tests and the pilot test. They may cause the hazards for the surroundings of the installation and during the service works. Also, a mechanical and electrical equipment will be used during all project phases: if not properly used, they may be life and health threatening.

A risk of running into/or hitting the personnel, caused by the moving mining machinery should be also considered at each project stage. It may occur for example during a transportation of construction materials for the chamber preparation, the transport of installation or/and raw materials to the test site.

4.4. Other, safety-related risks

- People's work at heights – above 1 m.
- Errors caused by other people working in the area – „a human factor",
- Risks related to manual lifting of materials during the chamber construction site.

These hazards refer also to operational and post-operational phases of the test.

4.5. Prevention and environmental protection tools

Measures of natural hazards that may occur in Rudna mine :

- In the terms of hazards related to loosing of rocks or moving objects – the lining condition has to be up to date constantly, and in case of necessity, the rock ripping has to be performed by an authorized personnel.
- A firefighting – an internal instruction of Rudna mine determines rules of safe performance of works (like a welding, of higher possibility of fire) in terms of the firefighting.
- Water hazards: such risks are eliminated by the constant mine drainage system. As during preparation phase, the risk could appear especially during drilling works. A „drilling technology manual at KGHM PM S.A. mines", gives instructions how to deal with this kind of risk.

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- Gasses and rocks ejection hazard: according to the drilling technology manual for KGHM, in the case of the gasses occurrence in drill holes, the operators should proceed in accordance to the instructions contained in “Proceeding rules in case of gas hazard occurrence during mining works in the KGHM PM S.A. mines” [18].
- Climate hazard: such hazard is eliminated by the ventilation of the tests site; however although ventilated (air flow: c.a. 670 m^3/min), the temperature at the test site is circa 31˚C. Because of the temperature drinking water must be always available underground.

Measures of natural hazards related with the use of explosives, machines and equipment:

- The blasting works in the Rudna mine were performed according to internal instruction of Rudna mine that include “principles of safe explosives storage and transportation and the blasting works performing in the mining divisions and the others internal regulations”.
- The workers conducting assembly and operational works of the pilot (including works with mechanical and electrical devices, as well as the equipment working under pressure), works connected with transportation (materials, pilot installation), have to be trained and authorized conducting of these type of works.

General rules in order to keep the works safe:

- All construction and the pilot assembly works have to be carried out according to regulations and instructions listed in the design documentation. These are: legislations determining basic rules of the safe construction works, general EHS regulations[19] and detailed instructions of performing particular types of works in the mine (drilling, blasting, welding, machinery and equipment manuals, chemicals usage (paints, etc.).
- The basic protective clothing, glasses, ears protection, dust masks, safety braces (work at heights) and others, has to be used during the work shift.

[18] Technical design of the BioMore project (Projekt techniczny BioMore), water tests. KGHM Polska Miedź S.A., Rudna mine 2015.

[19] - Rozporządzenie Ministra Infrastruktury z dnia 6 luty 2003 r. w sprawie bezpieczeństwa i higieny pracy podczas wykonywania robót budowlanych (Dz. U. Nr 47, poz. 401): - Obwieszczenie Ministra Gospodarki, Pracy i Polityki Socjalnej z dnia 28 sierpnia 2003 r. w sprawie jednolitego tekstu rozporządzenia Ministra Pracy i Polityki Socjalnej w sprawie ogólnych przepisów bezpieczeństwa i higieny pracy. (Dz. U. Nr 169, poz. 1650) z późniejszymi zmianami Dz. U. Nr 49 poz. 330 z 2007r. i Dz. U. Nr 108 poz. 690 z 2008 r.: - Rozporządzenie Ministra Gospodarki z dnia 28 czerwca 2002 r. w sprawie bezpieczeństwa i higieny pracy, prowadzenia ruchu oraz specjalistycznego zabezpieczenia przeciwpożarowego w podziemnych zakładach górniczych (Dz. U. Nr 139, poz. 1169) z późniejszymi zmianami (Dz. U. Nr 124, poz. 863 z dnia 9 czerwca 2006r.)

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- All works carried out in the mine are subjected to a rescue mining plan, approved by maintenance officer of the mine. At the preparation phase there is no need of preparation of additional procedures related with the test specification.

5. Assessment of the operational phase

5.1. Water, raw materials and energy consumption

- **Water**: several cubic meters of tap water will be used for water washing stage, in order to remove chloride salts from the rock (at this stage, difficult to estimate the amount: this aspect is subjected to the modelling). The tap water for the test will be transported underground and stored at the test site in 1m^3 plastics containers. During the process additional volumes of water will have to be also added to the system (during bioleaching ~ 1m^3/d – information from Partners). The tap water will be also used for emergency shower and an eyewash, situated next to the pilot. The mine water (available underground) in Rudna mine is the salty water. That is why it cannot be used for the process. It was used for drilling purpose only.

- **Raw materials:**
  - copper ore in the form of a block of rock, inside of which ~6 m^3 of acid leaching solution (pH ok. 2,0) will circulate.
  - chemical substances [20]:

Table 1. Chemicals used during operation.

Sulfuric acid (VI)	c.a. 500 kg
Iron sulfate(II) and small amounts of other salts, i.e. magnesium sulfate.	c.a. 100 kg
Chemicals for pH adjustment	5 L
Sodium hydrooxide or sodium(bi)carbonate	20 kg
Limestone	amount - tbd.

[20] Facility Description, Technical Documentation – Pilot Plant, Draft version, 8 Jan 2016, by HATCH.

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- the culture of acidophilous bacteria - mainly *Leptospirillum ferriphilum* and *Sulfobacillus* sp. and some *Ferroplasma* sp.[21]. The microorganisms are of natural origin, and have not been genetically modified. The culture will be prepared by TUT, and as "ready to use" and will be delivered to Rudna mine in canisters of HD polyethylene. The culture will be delivered in sulfuric acid solution (pH ~2): the content of the solution is given in the **table 2.** In the solution the bacteria will be immobilized on a selected, granular activated carbon (FILTRASORB 200).

Table 2. Composition of the laboratory scale FIGB feed solution (from TUT).

Component	Concentrations (g/L)
$(NH_4)_2HPO_4$	0.05 – 0.35
K_2CO_3	
$MgSO_4$	
$FeSO_4*7H_2O$	49.8

- **Energy and fuels**: electrical energy will be the main source of energy needed for the test. It will be used for solution circulation system (for pumps, air compressor, bioreactor's mixers), monitoring system, and also for ventilation and lighting of the test site. The total power consumption of the main unit of the pilot will be c.a. 4 – 4.5 kW (information from Hatch): it is similar than a common household loads. Also, small amounts of fuel will be used for machines transporting the media (like tap water) and construction materials to the test site.

5.2. Possible emissions

- ***Gases:***

During the process (particularly during acidification of the rock) emissions of **carbon dioxide** (CO_2) is expected. The CO_2 production will result from chemical reaction of sulfuric acid with carbonates present in the rock. The gas will be released in the body of rock and will be transported together with leaching solution to the tanks of the solution circulation system, and finally to the atmosphere of the mine.

21 Information from TUT.

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Based on analysis of the carbonate content in the core samples taken from inside of the final reactor the rate of CO_2 emission it was estimated[22]. The estimation indicates that the maximum rate of CO_2 release from the reactor of 100 m^3 of rock may be about 0.012 m^3/min[23]: This is less than the emission previously assumed (Deliverable 3.1, KIP)[24]. Under respect of the assumed uncertainties (see **Annex 3**), in average, rate of CO_2 emission from the pilot is about 0.008 m^3/min.
CO_2 is a colourless and odourless gas, taste slightly acidic, with a density higher than air, so it may accumulate at the floor of not ventilated workings.
Carbon dioxide is a gas suffocating and irritating to mucous, membranes and skin. The CO_2 content in the air to 2% causes a slight changes of breathing. Shortness of breath and weakness is observed at the CO_2 concentrations of 5%; the concentration of 10% may cause a loss of consciousness, and the higher concentrations – a death[25]. Because of that, its limits are regulated by law: the limit of CO_2 concentration in the air in the mine is <1%[26]. At the airflow through the test facility (approx. 670 m^3/min), the limit of CO_2 concentration in the atmosphere of the mine will not be exceeded and will provide negligible volume of gases (insignificant from the point of view of environmental impact) directed by the mine ventilation system to ventilation shafts. Some amounts of CO_2 could be also expected from machines used for transport of materials/ media to the test site.

Trace amounts of **sulfur dioxide** (SO_2) may be present in a commercial sulfuric acid. A part of SO_2 introduced with acid to the circulation system, can desorb from the solution, and be discharged from the tanks to the mine atmosphere.

SO_2 is a non-flammable, colourless gas, of a strong and pungent smell and taste. Irritates the mucous membranes of the eyes and respiratory tract. The density of sulphur dioxide is much higher than the air density.

Based on results of measurements obtained for similar industrial process, it is possible to estimate a level of SO_2 emission from pilot unit for:

- Assuming the worst case (see Annex 2), i.e. assuming 3,7 t of total acid consumption during 100 days: the maximum concentration of SO_2 would be 0,138 mg/m^3.

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[22] Annex 2: the estimation was done by GEOS.
[23] due to an immediate dissolution of carbonates at the beginning of the process (i.e. during acidification phase)
[24] based carbonates content analyses taken from the sidewall of the final reactor.
[25] *„Przewietrzanie kopalń"*: http://www.czek.eu
[26] Rozp. Ministra Gospodarki z dnia 28 czerwca 2002 r. z późn.. zm.w sprawie *bezpieczeństwa i higieny pracy, prowadzenia ruchu oraz specjalistycznego zabezpieczenia przeciwpożarowego w podziemnych zakładach górniczych*.

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- Assuming the acid consumption of 20 kg/day of total acid consumption (Hatch's, documentation 8 Jan 2016): the SO_2 emission would be circa 0,074 mg/m^3).

These values are much lower than the limits of this gas concentration in the mine air[26, 27]. The emission from the test will be negligible and not influencing the quality of the air in the mine. It will also provide negligible, and not significant from environmental impact point of view, volume of gas flow in the air directed by the ventilation system to ventilation shafts of the mine.

The **concentration of sulfuric acid mists**, which could be formed from the concentrated sulfuric acid stored at the test site in plastic, closed drums (canisters) of 10-20 L for is **negligible**[28]. Breathing of sulfuric acid mists is the most probable and often way of peoples' exposure negative effects of the acid.

However, an instruction of how to deal with the canisters in terms of sulfuric acid mists generated inside should be included in the manual of process operation. The concentrated sulfuric acid will be used for the process by replacing empty drums from the circuit by the new ones with fresh acid portions, in order to avoid operations of the acid transferring „form tank to tank". The acid will be added to the solution circulating in the installation by an unmanned and closed pumping system.

Due to the fact that the partial pressure of H_2SO_4 over acid solutions drop down with the decrease of its concentration (e.g. for a solution of approx. 20% it is c.a. 9 orders lower than for 95%) emissions of acid mists from the circuit during acidification and bioleaching would be also negligible.

These analysis also confirms that **no odorous gases are expected from the pilot**[29].

- ***Solid waste***: The waste directly related to the applied bioleaching technology won't be produce during the test. Possible (if any), small amounts of fine rocks released together with leaching solution from the reactor to PLS collection tank

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[27] 5 mg/m^3: the short-term value, and 2 mg/m^3: the long term value of the limit of SO_2 average weighted concentration in the mine air.

[28] Partial pressure of H_2SO_4 over concentrated sulphuric acid (95-98%) is < 0,001 mmHg (0,133 Pa), at the temperature of about 31°C (as it is at the test site). So the concentration of over the stored and added to the circuit H_2SO_4 would be < 5,16 mg/m^3. For the case of consumption of c.a.3.7 Mg of the acid during 100 (see Annex 2) the emission of acid mists over its concentrated solution would be c.a. 7 x 10^{-5} mg/min. Assuming the air flow at the test site, the potential emissions would be of c.a. u 10^{-7} mg/m^3. It does not cause any danger from the environmental and safety point of view: the concentrations are below permissible exposure limits given in polish law (Rozporządzenie ministra pracy i polityki społecznej z dnia 6 czerwca 2014 r. z późn. zm. *w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy*, poz. 817)

[29] Facility Description, Technical Documentation – Pilot Plant, Draft version, 8 Jan 2016, by HATCH.

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will be removed from the system after solution neutralisation – they will be innocuous. As they would have the same composition as the rock, it will be possible to manage them in the mine.

At this stage of knowledge about the process, the following types of waste (not directly related with the bioleaching installation) can be expected: waste of plastic and/or metal packaging of (codes of the waste[30]: 15 01 02 and/or 15 01 04) and packaging with residues of hazardous substances (15 01 10*) (e.g. empty sulfuric acid drums). These waste are of the same type as those produced typically in the mine, under a valid (until 2025) permit given to Rudna mine by local, environmental Agency. The permit determines also a way of further waste management (recycling and/or disposal). An analysis of existing permits allows to conclude that activities carried out in the mine within the BioMOre project, do not require changes of the permit.

- ***<u>Wastewater</u>***: Production of wastewater is not expected during normal operation of the pilot.

It is not expected, that the sulfuric acid solution will migrate beyond the tested (stimulated) reactor in the rock, even if the worst case scenario (see Chapter 5.3). During the stage of the rock washing with (tap) water, a part of the water will be removed from the circuit: it will be managed underground, as its content is the same as the mine waters content. From time to time small volumes (several litters) of PLS will be neutralised in order to clean the collection sump from fines of rock: the neutralized solution will have a content similar to the content of mine waters, so it will be possible to manage it underground. The amount of the saline waters produced from the pilot is negligible in relation to waters form dewatering of the mine: these waters are directed from the mine to KGHM's technological waters circuit.

During the operation phase some volumes of the solution circulating in the system will be transported on surface, and delivered to laboratories and/or to project Partners for analyses. Getting out the acidic solution outside the circulation system is possible only in case of emergencies, for example in case of unsealing of the safety pillar or elements of the circulation system (pipes, hoses, tanks, drums). For such case, prevention tools, described in the table 3 are anticipated.

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[30] According to polish law, the type of waste are listed and classified according to the catalogue of the waste (*Rozporządzenie Ministra Środowiska z dnia 9 grudnia 2014 r. w sprawie katalogu odpadów*)

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Both the very small scale of the process, as well as the fact that the test is carried out in the mine which uses the permanent drainage system, guarantee that the test will not affect the groundwater contamination of a major groundwater basin (MGB)[31], nor contamination of surface waters in the area of the mine.

No other materials or energy will be released from the operation to the environment.

5.3. Risk of acidic solution migration to rocks surrounding the reactor and through the safety pillar: modelling-based decision on final reaction geometry

The main aspect of the preparation phase was to define an ultimate model to meet process, environmental and safety requirements, i.e.:

- provide **the tightness of the safety pillar, and thus guarantee a safety** of activities carried out in the working area.
- minimize a **potential risk of migration of liquids** (water followed by leaching solutions) **into the rock surrounding the stimulated reactor**, and thus avoid migration of acidic solutions to the mine waters circuit.

In order to mitigate these potential environmental and safety impacts, the following simulation and activities had to be carried out:

- *Simulation of water circulation in the stimulated reactor (by AGH):*

A decision about the final model of the reactor was taken in the mine based on verification of the adopted location of blasting, injection and production holes and on the basis of modelling of water circulation in the reactor performed by AGH. The AGH's model assumed 11 injection holes in the upper part of the reactor and 6 production holes at the bottom. The simulation indicated that the permeability of the rock is low and the water circulation will occur mainly through the fractures, so the flow resulting from diffusion through the rock (and also around of the reactor) will not be significant. The model also indicated that the safety pillar remain be tight even during 12 months of water circulation at injection efficiency of 4,0 [m^3/d] (higher than assumed in the test). However by analyses of this simulation (see Figure 3) and taking into account a probability of non-regular fractures formation during the blasting works, it was decided

[31] The bioleaching test site is located at a distance of 7.5 – 10.5 km from the nearest MGBs.

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that an additional line of 7 production wells will be drilled in order to avoid the water/solution migration outside of the reactor at the bottom part of the reactor. The final location of the holes in the final reactor is shown in Figure 1.

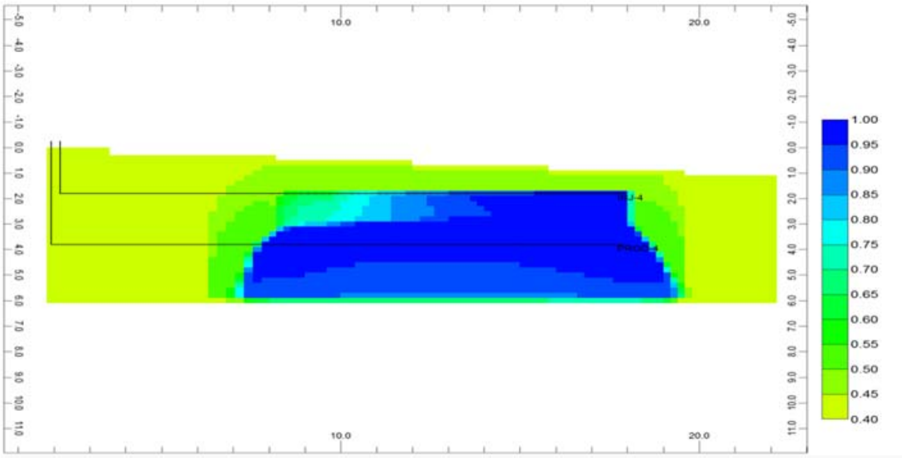

Figure 3. **By AGH:** Cross section of the reactor – water saturation (at a selected injection and production holes) after 12 months of the water circulation at 4,0 m^3/d, for the safety pillar of 6 m.

- *Simulation of sulfuric acid migration from the underground reactor into surrounding rocks, including the safety pillar (by GEOS) :*

The simulation was done as worst-case scenario, in which:

- the total sulfuric acid migrates out of the reactor.
- and the total amount of acid will be lost, since there are path ways along the reactor.

The calculations have shown that the distribution of acid in the surrounding rock can reach in the worst case 0.82 m. It means, **no ecological impact caused by the sulfuric acid is expected.**
The simulation was performed by GEOS and is attached to this report (see Annex 2).

- *Verification of the tightness of the reactors in Rudna mine*

For reactors prepared for water tests (described in Deliverable 3.1.(D3.1)), the tightness of safety pillars of the reactors was checked in the mine. It was performed through water injection into the stimulated bodies of rock under certain pressures. At this moment, the same activity is being prepared for the final reactor. This work is performed with using of the mining equipment (D.3.1.).

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The blasting holes will be liquidated with using a selected, acid resistant substance (available on market). Its acid-resistant properties were checked by AGH to make sure the safety pillar will remain tight during leaching operation. Additionally, stainless steel, acid resistant pipes for solution injection into the reactor will be used along the safety pillar. The same pipes will be installed for production holes.

5.4. Risks and impacts associated with the use of substances and microorganisms, and their prevention tools

The most important risk related to the pilot test are chemicals, and basically the sulfuric acid, used in the operation. The amounts and impact of other substances or materials are less significant. Potential risks and impacts associated with the use of all substances, as well as the microorganisms are listed in the table 3.
In this table the prevention tools are also described: they will be verified and accepted by a department responsible for EHS aspects in Rudna mine, when final process documentation will is available.

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Table. 3. Risks and impacts associated with the use of substances, including microorganisms, and their prevention tools: operational phase.

Substance	Risk	Impact	Prevention tools
Sulfuric acid concentrated	The acid leaks during transportation.	Potential acute health effects: very hazardous in case of skin and eyes contact (irritant). When ingested or inhaled, causes damages of tissue, especially mucous membranes of eyes, mouth and respiratory tract. Contact with skin can cause burns. Inhalation of aerosols can cause severe irritation of the respiratory tract characterized by coughing, choking or shortness of breath. An excessive exposure can lead to death.[32]	- Peoples' training, instruction, - neutralisation agent available during the underground transportation, - if necessary, information to the Mine-Smelter Rescue Team *(JRGH)*.
	The leaks outside of the underground chemicals' storage site (caused by natural risks in the mine like crumps, etc.), and outside of the installation (caused by its damages or service errors).		- In the case of a serious emergency effluents (significant amounts of sulfuric acid), the leaks would be neutralized with help of Mine-Smelter Rescue Team (*JRGH*): neutralization agents available on-site, - sulfuric acid underground storage at the test site in a distance from possible places of working machines, - the storage place concreted, fenced, the warnings and other signalization installed, - installation equipped with the shower and eyewash* (with tap water transported from surface), - ventilation of the test site (c.a. 670 m^3 of air/min, temperature at the site – c.a. 31˚C) - acid resistant and/or stainless elements of the pilot installation, against their corrosion and leaks, - an automated acid dosing*: to limit the acid exposure and necessity of its contact with people, - spillage trays under acid drums in the solution circuit*, - mining grid on the roof and on the side walls: protection from rock falling and mechanical damages acid drums and tanks and other elements: an additional protection tool over the solution circulation - installation equipped with the shower and eyewash (with tap water transported from surface) - Workplace instruction: including an information about precautions, like protective clothing and equipment.

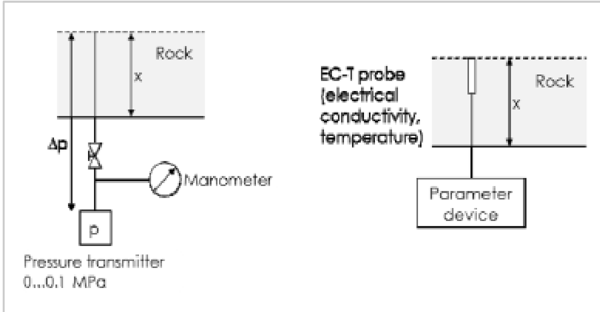
[32] – based on a MSDA

Substance	Risk	Impact	Prevention tools
	Leaks during replacing of empty drums with the fresh acid portions.		- Neutralisation agent available on the test site, - if necessary, information for neutralized with help of Mine-Smelter Rescue Team *(JRGH)*. - installation equipped with the shower and eyewash* (with tap water transported from surface) - peoples' training, - workplace instruction: including an information about precautions, like protective clothing and equipment.
	Risk of water use to remove the leaks of concentrated sulfuric acid.	Sulfuric acid reacts strongly with water, releasing large amounts of heat and dangerous fumes (sulfur oxides). Treatment of the leaks with water leads to a violent reaction leading to a temperature increase and a spreading of a caustic solution, which may cause serious injuries.	-Workplace instruction: including an information about precautions, like protective clothing and equipment. The instruction should clearly indicate that water cannot be used for cleaning of leaks of the concentrated sulfuric acid. Also, during a potential fire at the test site, other (not water) tools should be used. - ventilation of the test site (c.a. 670 m^3 of air/min, temperature at the site ~31˚C).
	Accumulation of acid vapors from the tanks with the concentrated acid and keeping tight sealed empty acid drums underground and on the surface.	MSDS: an aaccumulation of corrosive vapors over the solution, increasing the pressure on drums and destruction - the risk to human health: the same as described above.	- Acid drums and the empty acid drums should be periodically opened to release eventual vapors. When emptied, they shouldn't be stored underground, but should be taken on surface and managed according to waste management rules in Rudna mine. - ventilation of the test site (c.a. 670 m^3 of air/min, temperature at the site ~31˚C) - workplace instruction: including an information about precautions, like protective clothing and equipment.

Substance	Risk	Impact	Prevention tools
Sulfuric acid solutions (10-200 g/l), used for acidification and bioleaching phases.	Leaks from the solution circulation system caused by: - installation damages caused by natural risks in the mine (Chapter 4), - overflow tanks in the circuit -damages of installation elements, like pipes, hoses, - during maintenance activities.		- The floor will be concreted (30 cm layer). Surface of the concreted floor will be inclined in two directions, allowing the solution to down flow into the sump including a small discharge channel in the floor, along the sidewall that will allow to carry away possible effluents from the safety pillar and from the installation to a sump. Inclination of the surface in the a/m directions equal to 3‰. - in the sump (of capacity approx. 2,5 m^3) potential effluents will be collected. The sump will be concreted and neutralized. Then, the neutral solution will be pump out and taken away from the pilot site by a mining machine. - in the case of small effluents of diluted acid from the installation, the spillages will be neutralized with sodium carbonate or hydroxide, or limestone, to pH 7.(Hatch, 8Jan 2016). - in the case of power failure, the control system will leave all pumps switched off: as all tanks are at the same top surface level, so there cannot be solution draining from one tank to another[33]. In such case, the system will also stop the circulation of injection fluid and PLS production. A manual shutdown of the whole circulation system by the emergency button is also possible*. - applying of the acid resistant and/or stainless elements of the installation's equipment (to avoid its corrosion and the leaks) - an overwrap of the installation pipes with acid and the acid solution, - spillage trays under the tanks with diluted sulfuric acid*. - mining grid on the roof and on the side walls: protection from rock falling and mechanical damages acid drums and tanks and other elements: an additional protection tool over the solution circulation system is being considered,

[33] Hatch: Facility description Technical documentation – Pilot Plant, draft, 8 Jan 2016.

Substance	Risk	Impact	Prevention tools
			- installation equipped with the shower and eyewash* (with tap water transported from surface) - PLS (for analyses) done by the auto-sampler provided by UIT, in order to limit people's contact with the solution, - people's training, instruction, - neutralisation agent available on site, - if necessary information for neutralized with help of Mine-Smelter Rescue Team (*JRGH*), - workplace instruction: including an information about precautions, like protective clothing and equipment.
	Leaks from the safety pillar of the reactor: -through the mass of rock of the pillar -through injection/production hoses and their connections with the reactor.		- applying of the safety pillar of width approx. 6 m in the tested block of rock from the working side, which will prevent from a potential leakages of the liquid to the working. - other prevention tools **– as the above-mentioned.**
	Migration of the acidic solution to rocks surrounding the reactor	Risks of the acidic waters migration to mine waters, and then to KGHM's technological water circuit.	Application of the additional (in relation to the AGH's model) line of production holes, to prevent eventual migration of the solution from the reactor. Such migration is also naturally limited by carbonates content (which neutralize acid) in the surrounding rocks. The information about effluents would be provided by the monitoring system. Potential influence of the installation on the reactor surrounding rocks will be controlled by the system of monitoring holes (with sensors) which will be drilled around the reactor in order to detect effluents of the leaching solution from the

Substance	Risk	Impact	Prevention tools
			tested rock block. The detection will be based on controlling of the following parameters: electrolytic conductivity and pressure (Figure 4). There will be also possibility of liquid sampling for analyses.  **Figure 4**. A general idea of monitoring of the rock surrounding the reactor in the block of rock: by UIT.
Iron sulfate (II)	Supplied to the mine and stored in the form of a solid. Accordingly, there is a limited risk of spillage during addition of substance in one of the solution circulation system.	In the case of direct contact irritate the skin and eyes. May be dissolved in potential effluents present at the test site.	- the spilled substance should be collected avoiding its contact with water/solutions, with using a protective equipment and cloths - installation equipped with the shower and eyewash* (with tap water transported from surface) - workplace instruction: including an information about precautions, like protective clothing and equipment.

Substance	Risk	Impact	Prevention tools
Microbial culture inacidic (pH ~ 2) solution	**<u>No microbiological hazards are expected</u>** – The microorganisms are of natural origin, and have not been genetically modified. They are not hazardous to the environment and pose no harm to humans (information from TUT). At higher pH (like >3) they lose their activity. • More detailed opinion from Prof Barrie Johnson on microbial hazards related with the microorganisms use in the is presented in the **Annex 1**.		
Activated carbon	Used to immobilize micro-organisms in the acidic nutrient solution: will be introduced to the FIGB.	As wet activated carbon removes oxygen from air. As dry, may cause dusts formation and a danger of fire.	-Handling of large quantities of the wet FILTRASORB 200 in enclosed or confined spaces (outside the continuously aerated bioreactor) should be avoided (TUT). -all the carrier material will be provided to the pilot site in the wet form (dissolved in sulfuric acid containing solution) to prevent dust formation and to rule out any chance of ignition. It will not be stored underground - ventilation of the test site (c.a. 670 m^3 of air/min at the test site) -other, above-mentioned prevention tools as described for diluted sulfuric acid solutions. - workplace instruction: including an information about precautions, like protective clothing and equipment.
Sodium hydroxide or sodium(bi)carbonate, limestone: for pH regulation and neutralization	A risk of spillage, during transportation and at the site.	In the case of direct contact irritate the skin and eyes. Reacts with acid: the carbonates may release additional, small amounts of CO_2.	- the spilled substance should be collected, avoiding its contact with water/solutions, with using a protective equipment and cloths, - it should be added carefully to acidic solution, according to the workplace instruction, -installation is equipped with the shower and eyewash (with tap water transported from surface), - workplace instruction: including an information about precautions, like protective clothing and equipment.

**proposed by Hatch : Facility Description, Technical Documentation – Pilot Plant, Draft version, 8 Jan 2016.*

A detailed information about measures and safety tools should be included in the workplace instruction: it will be based on documentation delivered by Partners, including MSDA (substances data sheet from producers) and it will be verified and accepted the mining unit responsible for EHS aspects.

5.5. Natural risks occurring in the mine and their measures

The „natural risks“ related with the bioleaching test performed in the running mine are analogous to those determined for the preparation phase (see Chapter 4). Additionally, the following measures are/will be applied:

- **Tests site ventilation (c.a. 670 m^3/min):** it is important in order to assure appropriate air content and working conditions at the test site, as well as to enable a storage and use of substances and materials during the test. The ventilation applied by Rudna mine will remove the CO_2 emitted from the pilot and will avoid further temperature increase (temperature in the ventilated site is ~ 31°C). Taking into consideration a comfort of people, the workplace (with table and chair, etc.) will be located at the entrance to the area of the test site, so it will be aerated with the fresh air form the mine as first. The air stream in the W-332 working will be then passing through the installation, and the chemicals’ storage place at the end.
  It is important to notice that the quality of both inlet and outlet air, which is transferred further to the workings of the mine is important. The closest place where the mining works will be carried out during the bioleaching test, is located in a distance of approx. 1,5 km from the tests site.
- A stationary phone will be available at the workplace, allowing the connection with the mine personnel, which is especially important in the case of emergency.
- The site is equipped with foam and dry-powder extinguishers.
- Luminous warning banners, will be applied, where required.

As in the case of all activities carried out in the mine, the operation will be subjected to the mining rescue plan. Except that, due to the specificity of the process related mainly to using of the sulfuric acid, the information for the Mine-Smelter Rescue Team[34] about the process will be prepared.

[34] The Mine-Smelter Rescue Team (Oddział/Jednostka Ratownictwa Górniczo-Hutniczego KGHM (JRGH)) is a rescue service of KGHM Polska Miedź S.A. dealing with protection of KGHM’s mines and smelters. It is also one of three Polish units, professionally engaged in mines rescue activities.

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6. Assessment of the post-operational phase

6.1. Emissions and their impacts

Gases:

Gases emissions are not expected at this stage. In case of decision about neutralisation of the PLS with using carbonates-like compounds, some amounts of CO_2 will be released from their decomposition. The amount will not be significant but they should be evaluated before the process.

Waste water:

Due to the use of the method of washing of the rock of the reactor, as well as because of high carbonates content in the surrounding rocks, there is no risk of acid migration to outside of the reactor (see the worst case described in the Annex 2).

It was assumed that after bioleaching, the solution circulating in the system would be collected in acid-resistant tanks and then transported to the surface to be transferred to project Partners or other units for analyses. Another possibility is to neutralize the solution to pH ~7 underground: the neutral solution (as having similar content and neutral pH) could be managed with the mine waters: this possibility however will be evaluated in the next project phase.

Also the bacteria present in the solution will not be active at neutral pH. VTT is verifying the microbial activities in different conditions.

Metals will not be recovered from PLS produced in the pilot. The PLS will be used for analyses and further research only. It means that no metals production is expected from PLS at the stage of the project.

Solid waste:

Relatively small amounts of waste can be expected from the post-operational phase. There would be the elements of the installation, as for example steel (the waste code: 170405), or other metals scraps, elements from plastics, like pipes, hoses (070213), and also some packing-type waste, like empty acid drums (15 01 10*) and others without dangerous substances content (150102 and/or 150104). These waste are of the

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same type as those produced typically in the mine, under a valid (until 2025) permit given to Rudna mine by a local, environmental Agency. The permit determines also the way of further waste management (directed to recycling and/or disposal).

After the test, the mining waste (also received after the treatment of the rock) will not be produced. It is assumed that the treated rock of the reactor, after washing, will remain in the body of the rock, as it will be chemically and "microbiologically" inert. As the rock will still contain some metals, it will be mined with the surrounding ore in the future, according to the mining plan. That is why any kind of rock transferring e.g. out of the working will not take place, as well. From this point of view, the test will not influence the future mining plan.

6.2. Other risks and/or impacts related with the liquidation of the pilot

- Washing/neutralisation of the rock with (probably with using of the pumping system): risks, and prevention tools related to solutions of the sulfuric acid and chemicals for neutralisation use are analogous as for the operational phases. If neutralisation will be applied, an instruction of this operation must be available at the test site.
- A liquidation and permanent filling of the injection and production drillholes will be applied (probably with a cement-like material).
- As for previous phases, an occurrence of natural risks (chapter 4) that may occur in the mine is also possible. The same measures must then be applied.

7. Other, environmental impacts analysis of the BioMore activities in Rudna mine

- **Possible transboundary impacts of the pilot test:**

No possible transboundary impacts are expected.

- **Analysis of possible impacts on the environmentally protected areas listed in polish law** [35]

Does not concern. The installation will be located in the underground mine, in the existing working.

[35] *Ustawa z dnia 16 kwietnia 2004 r. o ochronie przyrody.*

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8. Area impacted by the test

The installation will be located in the underground mine, in the existing working (KGHM Polska Miedź S.A.). Its potential impact could be expected only at a small surface around the R-I shaft area at Rudna mine, through which the installation and all materials will be transported underground.

9. Activities related to stakeholders acceptance. Environmental permit

An analysis of formal requirements related to the preparation, operational and post-operational phase, in terms of their potential impacts and hazards was done by Cuprum and KGHM (Rudna mine).

It was found that for the preparation phase (water tests, preparation of the final reactor in the block of rock by drilling and blasting, and verification of its tightness by water injection), no additional permits are required. The works performed during this phase are mining activities that are carried out by Rudna mine during the exploitation, and their performance its regulated based on required decisions of appropriate authorities and internal documentation (technologies, design, instructions, etc.) of the mine. In these documentations the EHS aspects are also considered. In similar way, the construction, mechanical or electrical works during chamber preparation will be regulated. The works performed within the preparation phase of the test do not impact the environment, and possible hazards related with health and safety, and their measures are described in this report.

For the operational and post-operational phases, an analysis of possible administrative environmental procedures for bioleaching test in Rudna mine was performed: the possible procedures were described and included in the BioMore documentation in Rudna mine, indicating the most appropriate one. This analysis, as well as a description of the idea of bioleaching tests (in polish) and its environmental aspects was presented to local authorities in Polkowice by KGHM and Cuprum. The explanations about the process and its aspects were given to the agency during a meeting (June 2015) and further contacts, by phone and e-mails. As a result of common discussion, an environmental procedure was determined. A document (*KIP*[36]) in polish, was prepared according to the polish law and submitted to the agency. It includes an assessment of several environmental aspects of the test, requested by

[36] *KIP – Karta Informacyjna Przedsięwzięcia,* the document in polish.

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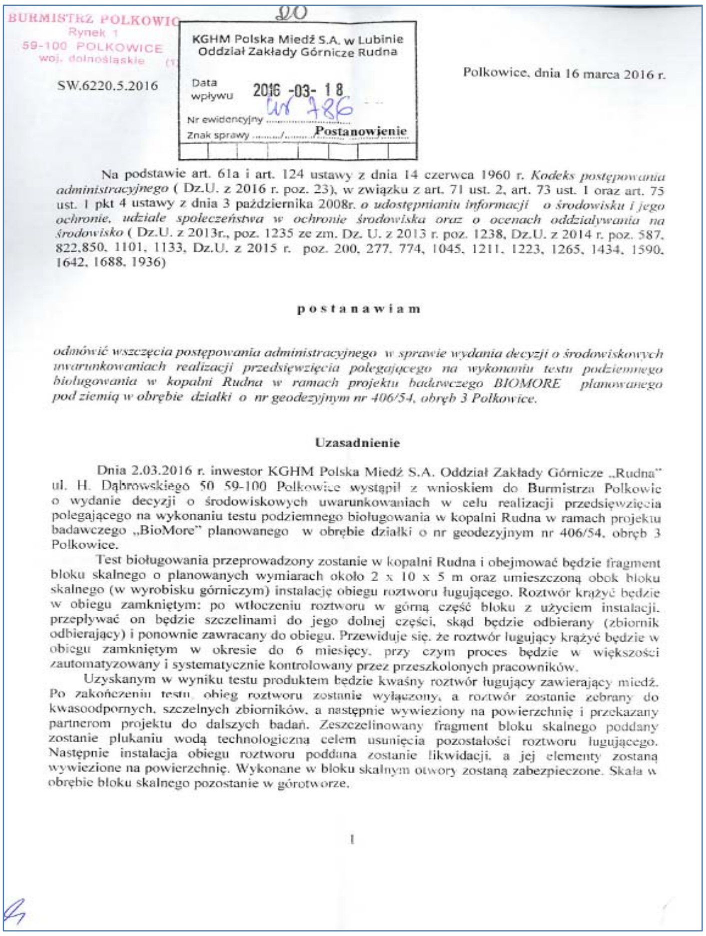
the law, i.e.: information about raw materials and energy consumption, possible emissions and environmental impacts (both in terms on underground and on surface environment), information about microbiological aspects, measures and prevention activities to avoid or limit the possible EHS impacts or information about an area that may be impacted by the test.

Based on the procedure the agency decided (<u>see a copy of the first page of the **administrative decision**[37] below</u>) that based on the documentation submitted to the Agency, a more detailed environmental procedure to get the environmental permit is not required. The decision is justified both by a formal qualification of the test, as well as by the fact that the process is a short-term operation and its environmental impacts are not significant.



BURMISTRZ POLKOWIC
Rynek 1
59-100 POLKOWICE
woj. dolnośląskie

KGHM Polska Miedź S.A. w Lubinie
Oddział Zakłady Górnicze Rudna
Data wpływu 2016 -03- 18
Nr ewidencyjny ... wr 786
Znak sprawy ....../......

SW.6220.5.2016

Polkowice, dnia 16 marca 2016 r.

Postanowienie

Na podstawie art. 61a i art. 124 ustawy z dnia 14 czerwca 1960 r. *Kodeks postępowania administracyjnego* (Dz.U. z 2016 r. poz. 23), w związku z art. 71 ust. 2, art. 73 ust. 1 oraz art. 75 ust. 1 pkt 4 ustawy z dnia 3 października 2008r. *o udostępnianiu informacji o środowisku i jego ochronie, udziale społeczeństwa w ochronie środowiska oraz o ocenach oddziaływania na środowisko* (Dz.U. z 2013r., poz. 1235 ze zm. Dz. U. z 2013 r. poz. 1238, Dz.U. z 2014 r. poz. 587, 822,850, 1101, 1133, Dz.U. z 2015 r. poz. 200, 277, 774, 1045, 1211, 1223, 1265, 1434, 1590, 1642, 1688, 1936)

p o s t a n a w i a m

odmówić wszczęcia postępowania administracyjnego w sprawie wydania decyzji o środowiskowych uwarunkowaniach realizacji przedsięwzięcia polegającego na wykonaniu testu podziemnego bioługowania w kopalni Rudna w ramach projektu badawczego BIOMORE planowanego pod ziemią w obrębie działki o nr geodezyjnym nr 406/54, obręb 3 Polkowice.

Uzasadnienie

Dnia 2.03.2016 r. inwestor KGHM Polska Miedź S.A. Oddział Zakłady Górnicze „Rudna" ul. H. Dąbrowskiego 50 59-100 Polkowice wystąpił z wnioskiem do Burmistrza Polkowic o wydanie decyzji o środowiskowych uwarunkowaniach w celu realizacji przedsięwzięcia polegającego na wykonaniu testu podziemnego bioługowania w kopalni Rudna w ramach projektu badawczego „BioMore" planowanego w obrębie działki o nr geodezyjnym nr 406/54, obręb 3 Polkowice.

Test bioługowania przeprowadzony zostanie w kopalni Rudna i obejmować będzie fragment bloku skalnego o planowanych wymiarach około 2 x 10 x 5 m oraz umieszczoną obok bloku skalnego (w wyrobisku górniczym) instalację obiegu roztworu ługującego. Roztwór krążyć będzie w obiegu zamkniętym: po wtłoczeniu roztworu w górną część bloku z użyciem instalacji, przepływać on będzie szczelinami do jego dolnej części, skąd będzie odbierany (zbiornik odbierający) i ponownie zawracany do obiegu. Przewiduje się, że roztwór ługujący krążyć będzie w obiegu zamkniętym w okresie do 6 miesięcy, przy czym proces będzie w większości zautomatyzowany i systematycznie kontrolowany przez przeszkolonych pracowników.

Uzyskanym w wyniku testu produktem będzie kwaśny roztwór ługujący zawierający miedź. Po zakończeniu testu, obieg roztworu zostanie wyłączony, a roztwór zostanie zebrany do kwasoodpornych, szczelnych zbiorników, a następnie wywieziony na powierzchnię i przekazany partnerom projektu do dalszych badań. Zeszczelinowany fragment bloku skalnego poddany zostanie płukaniu wodą technologiczną celem usunięcia pozostałości roztworu ługującego. Następnie instalacja obiegu roztworu poddana zostanie likwidacji, a jej elementy zostaną wywiezione na powierzchnię. Wykonane w bloku skalnym otwory zostaną zabezpieczone. Skała w obrębie bloku skalnego pozostanie w górotworze.

1

[37] **The decision of the Mayor of Polkowice, No 6220.5.2016, given on March 16th, 2016 on the permit of environmental conditions of the underground bioleaching test performed in Rudna mine (on the cadastral parcel No 406/54, precinct 3 of Polkowice), within the BIOMORE research project** (Postanowienie Burmistrza Polkowic z dn. 16 marca 2016 r. (znaków.6220.5.2016) *w sprawie wydania decyzji o środowiskowych uwarunkowaniach realizacji przedsięwzięcia polegającego na wykonaniu testu podziemnego bioługowania w kopalni Rudna w ramach projektu badawczego BIOMORE planowanego pod ziemią w obrębie działki o nr geodezyjnym nr 406/54, obręb 3 Polkowice*).

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As Rudna mine is working under permits determining type and limits of emissions (gases, waste) given by local environmental agencies, an analyses of necessity of their modification in terms the bioleaching test was done. At this stage of the project (and knowledge about the test) it was concluded that no obligation to obtain another type of environmental permits is required.

The “health and safety” are regulated by the followings:

- Information about all risks that may occur during the three phases of the underground test will be included in the technical documentation of the BioMOre project, including documentation received from Partners responsible for the test. The documentation is accepted by the manager of mining plant operation at Rudna mine, according to law. Before that, an opinion about a conformity of the equipment used in the test will be given by an external certification unit: this is an ongoing process, which will be possible to be finalized after final technical and other required documentation is available. This further guarantees the safety of the installation.

- Information on hazardous substances used in the test is required to be included into the mining plan of Rudna mine. Such information was prepared by Cuprum and will be presented by the mine to the local mining authority.

  The mining authority was previously informed about the activities that will be carried out in the frame of the project: Representative of the mining agency has participated at the Kick-off meeting of the BioMOre Project. Also a meeting at the agency was organized by KGHM in 2015. Additional information may be also delivered in future, if necessary.

10. Annex 1. Risk Assessment Information: in situ bioleaching at the Rudna mine, Microbiological Hazards and Containment Measures (by Bangor)

Risk Assessment Information: *in situ* Bioleaching at the Rudna mine

Microbiological Hazards and Containment Measures

- The microorganisms present in the ferric iron-generating bioreactor (FIGB) that will be installed within the Rudna mine, are bacteria and archaea that occur naturally within surface and deep-buried geological rock strata (including *kupfershiefer*) that contain significant amounts of sulfide minerals;
- They have not been genetically modified;
- The microorganisms are obligate acidophiles, i.e. they are only active and thrive in waters that are acidic (and contain sulfuric acid, rather than other mineral or organic acids);
- All of the microorganisms can be considered to be harmless to human health. Most of them grow on energy derived from breaking down and minerals rather than on organic materials. None is pathogenic;
- During the operation of the FIGB, most of the microorganisms will be retained in the main reactor vessel. Some will be present in the lixiviant liquor (separating them from the solution phase is neither pragmatic nor desirable). The approximate numbers of microorganisms in the lixiviant (and the PLS generated) will be known following the commissioning and testing of the FIGB before it is installed in the Rudna mine;
- Following the termination of the bioleach test phase, the microorganisms remaining in the fractured ore deposit will be inactivated (and killed) using protocols to be developed in WP1 (most likely by flushing with dilute solutions of an innocuous organic acid, such as acetic);
- Injection of the lixiviant liquor (and prior to that, of sulfuric acid during the acid-leach cycle) will doubtless stimulate any indigenous mineral-degrading acidophilic bacteria present in the ore body, though numbers of these are likely to be insignificant compared to those in the ferric iron-rich lixiviant;
- Bacteria and archaea present in any liquor that spills from the ore body during the bioleaching test are likely to be short lived. However, it is advisable to remove an spilled liquor and have to hand slightly alkaline solutions containing mild beach (hypochlorite) to mop up any spills. Since bioleaching bacteria are readily killed by dilute solutions of most detergents (such as sodium lauryl sulfate) the majority of commercially-available materials (including washing powders and concentrates) are suitable for this purpose;
- The microorganisms present in the FIGB are considered to pose an insignificant environment risk to the area of the mine in which the test is to be conducted, or to the Rudna site in general.

Professor D. Barrie Johnson

Bangor University, UK

March 2nd, 2015

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11. Annex 2. Assessment of Sulfuric Acid Migration from the Underground Reactor into the Surrounding Rock (by GEOS)

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Motivation and Concept

During the leaching experiments concentrated sulfuric acid will be used to solve the carbonic minerals in the test reactor. To exclude ecological hazards by the low pH it is necessary to make an assessment about the scope of the acid on the surrounding rock. For this purpose a worst case scenario calculation was done, in which the migration of acid was validated.

The planning of the test field reactor at the Rudna Mine is already finished. It is mentioned, that the reactor will have the dimensions of 10 m x 5 m x 2 m (/1/) and will be situated in the sandstone layer. According the deliverable 3.1 (/2/) the test field is restricted by the sandstone

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formation at the bottom, at the front wall and the side walls. Furthermore the reactor is restricted by the shale layer at the top of the reactor and the safety pillar at the back wall. A sketch of the test reactor is illustrated in Figure 1. Since the Safety Pillar should be completely sealed, the release of sulfuric acid can take place at the top, the bottom, the front and the side walls of the reactor.

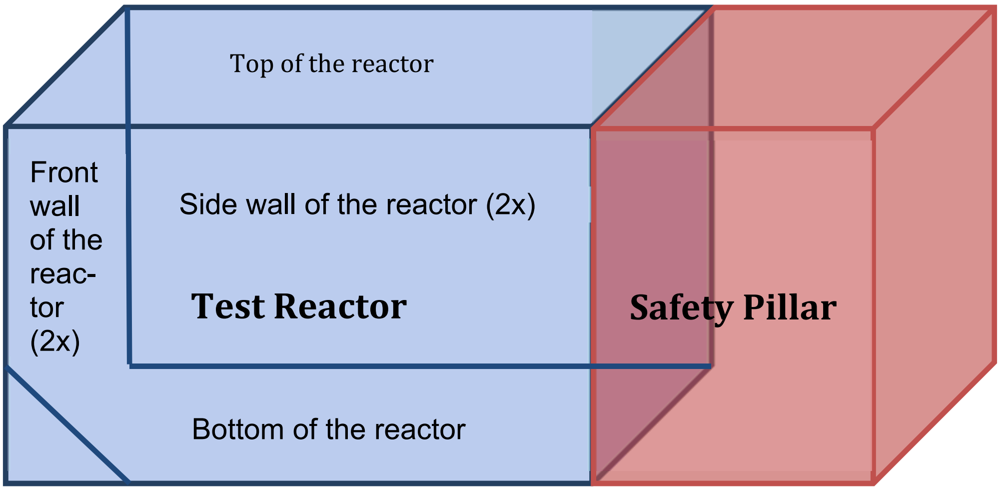

Figure 1: Sketch of the test reactor at the Rudna Mine

To get a feasible amount of sulfuric acid which can leave the reactor block, it was first calculated the theoretically necessary amount of sulfuric acid to solve the total carbonates in the test reactor. This amount is the basis for all scenario calculations. The scenarios are divided regarding the migration possibilities of the acid. Table 1 shows the weighting factor of the acid migration direction. In the worst case scenario the total acid amount leaves the reactor and migrates in every direction, whereby the movement to the top is the factor 2.25 less than the other directions. The listed weighting factors for the scenario are derived by multiplication with the cross-sectional areas.

Table 1: Weighting Factors for the movement direction of sulfuric acid

Scenario	Top	Side Wall	Front Wall	Bottom
5	18%	16% (1 side wall)	8%	41%

It will be investigated at which distance the sulfuric acid will be completely neutralized by the natural amount of carbonates.

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Calculations and Results

a. Acid Amount in the test reactor

The amount of acid depends on the amount of carbonates in the reactor block. According the Measurements (/3/) there is an average carbonate content (MgO/CaO) of 1.5% (0.4%/1.1%). To calculate the absolute carbonate amount of the reactor, it was assumed a rock density of 2700 kg/m³ and the reactor volume of 100 m³.

Table 2: Calculation of the amount of carbonates in the test reactor

Species	Mass Content [%]	Molar Mass [g/mol]	Amount [mol/kg]	Amount [mol]	Amount [kg]
MgO	0.4	40.32	0.10	24973.8	1006.9
CaO	1.1	56.08	0.20	49854.4	2795.8
	1.5	-	0.30	**74828.2**	**3802.7**

According the stoichiometric factors, there are about 3.7 t of sulfuric acid needed to solve the total amount of carbonates in the reactor block.

Table 3: Amount of sulfuric acid to solve the total amount of carbonates in the test field

Species	Amount [mol]	Molar Mass [g/mol]	Amount [kg]
H_2SO_4	74828.2	98.072	**3669.3**

b. Scenario Calculation

In the scenario the total amount of acid (3669 kg) is leaving the test reactor in every direction. It is assumed that the spread of acid towards the top is less than the other directions. Therefore it is estimated that 10% of acid leave through the top of the reactor, while the other directions have a distribution of respectively 22.5%. Multiplied by the relative percentage of the cross sectional area for the transport paths, it results in the acid portion, that is spreading in the correspondent direction.

Table 4: Results of the balance calculations for the migration in every direction

Direction	Portion [%]	Volume [m³]	Cross-sectional area [m²]	Distance [m]
Top	18	5.24	50.00	**0.10**

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Direction	Portion [%]	Volume [m³]	Cross-sectional area [m²]	Distance [m]
Side Wall (one)	16	16.36	20.00	**0.82**
Front Wall	8	8.18	10.00	**0.82**
Bottom	41	40.91	50.00	**0.82**

Conclusions

The Calculation is deliberately done as worst case scenario, where the total sulfuric acid migrates out of the reactor. Actual it is unlikely, that the total amount of acid will be lost, since there are path ways along the reactor. The calculations have shown that the distribution of acid in the surrounding rock can reach in the worst case 0.82 m. That means there would only be a small area around the reactor, which is influenced by the acid. Also for the little extended shale layer exists no danger. Since the carbonate concentration of this layer is even higher, the acid will be neutralized at a maximum pathway of 0.10 m. Furthermore the above lying layer, the dolomite, has a still higher buffering capacity, in fact of its higher carbonate content. **In summary there is expected no ecological impact by the sulfuric acid.**

References

/1/ E-mail of Agnieszka Szubert from 24.05.2016, final reactor geometry and other issues
/2/ Deliverable 3.1 Site selection and drilling
/3/ E-mail of Agnieszka Szubert from 07.06.2016; BioMOre – modeling (including geochemical analyses of drill cores sampled from the final reactor)

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12. Annex 3. Assessment of the Degassing Potential of Carbon Dioxide during the Acidic Leaching Phase (by GEOS)

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Motivation and Concept

The test reactor at Rudna Mine is situated in the sandstone layer "Rotliegend". To leach the copper ore by the bioleaching technology it is necessary to achieve low pH - values. To reach this goal the total carbonate content of the test reactor must be previously solved. A product of the dissolution of carbonates is CO_2, which can be solved in water up to an amount of approximately 1 g/l at the temperature of 35°C - 40°C and pressure of 1 bar. The CO_2 content above this threshold degasses and enriches the air of the Mine, what can become a toxic problem.

The CO_2 can escape in different ways from the test reactor. The most common way will be that it firstly becomes solved in fact of the high pressure situation (up to 5 bar; /1/) in the reactor block, transported to the production drillings and degas, because of the pressure drop. Another pathway could be that it is not solved after the dissolution process of the carbonates. Then it will move upwards to the roof of the reactor and degases partly into the surrounding rock by diffusion or advection towards the mine. In this case there are a lot of uncertainties, like the change of pressure and the corresponding problem of dissolution, the portion of CO_2 that diffuse through rock or clocking of fractures. In fact of these high uncertainties it is not possible to model the second scenario seriously. Furthermore it is our point of view that the degassing through production drilling has the higher probability and larger impacts.

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Based on the numerical transport model of GEOS (/2/) there was added a new module, which considers the CO_2 production at the production drillings. With Monte Carlo simulations uncertainties especially regarding the internal structure of the reactor have been included, so that a feasible assessment about the CO_2 volume flow was possible.

Model Concept

The numerical model is implemented in GoldSim. The basic hydraulic model represents an advective transport though the fracture, while there is a diffusive transport through the rock matrix perpendicular to this fracture.

The geo-chemistry is rather easy implemented. It involves the dissolution of NaCl and the neutralization of sulfuric acid by carbonates with consideration of their reaction products.

Furthermore the model includes technical aspects like recirculation and the replacement of leaching agents at defined times. Besides it is possible to add sulfuric acid to keep a constant concentration gradient between the end and the beginning of the reactor block. The initial acid concentration was assumed to be 50 g/l. Additionally there has been assumed, that the acid concentration of the fluid coming out of the production holes will be increased by 50 g/l acid up to a maximum concentration of 200 g/l. This slightly increase of the acid concentration was done to limit the temperature rise during acid addition.

The expended model considers the degassing of CO_2 at the production drillings. Therefore it is assumed that the total carbonate content is completely dissolved during the transport in the test reactor. At the end of the reactor the model is able to separate the gaseous CO_2, so that only the maximum concentration of 1 g/l stays in solution. The other portion will degas.

The model is buildup of the following key parameter:

- Diffusion coefficient: 1e-9 m²/s
- Tortuosity: 3
- Total Flow: 1.4 m³/d
- Block Length: 10 m
- Block Thickness: 2 m
- Block Width: 5 m

Besides the key parameter, there are implemented a couple of uncertainties listed below:

- Porosity: TR(0.10; 0.12; 0.15) (TR - Triangular distribution)
- Fracture distance X: TR(0.025m; 0.25m; 1m)

- Carbonate Content: N(0.03; 0.005) (N - Normal distribution)

The simulation describes the water wash and the acid wash stages. Both last respectively 100 days. A total of 50 realizations were simulated to get a feasible prognosis.

Results and Conclusions

The following figures show the distribution of mass of the carbonates in the reactor (Figure 2) and the released CO_2 into the mine air (Figure 3). It is obvious that carbonates dissolution and CO_2 production rises immediately. Under respect of the assumed uncertainties the maximum CO_2 rate is about **0.012 m³/min**. In average the CO_2 rate is about **0.008 m³/min**. It is pointed out that the uncertainties have a huge impact on the carbonate dissolution and the CO_2 release, respectively. Based on these results the dimensioning of ventilation can be derived.

It is also recommended to control the CO_2 content, which can deliver some redirected information to reduce uncertainties. Besides it should be noticed that there will be a less portion of CO_2, which will diffuse in the surrounding rock.

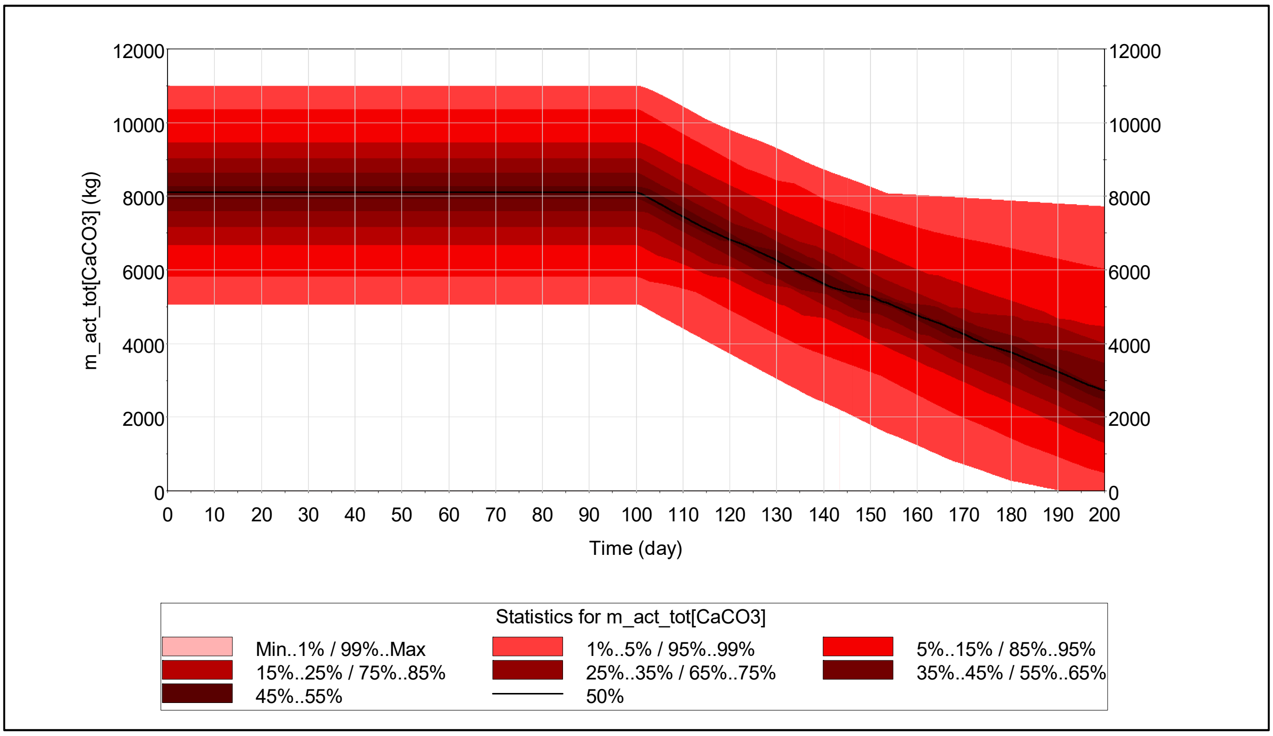

Figure 2: Amount of total carbonates in the test reactor in the water wash (up to day 100) and in the acid leach (from day 100 to day 200) phases taking into account the uncertainty in the carbonate content

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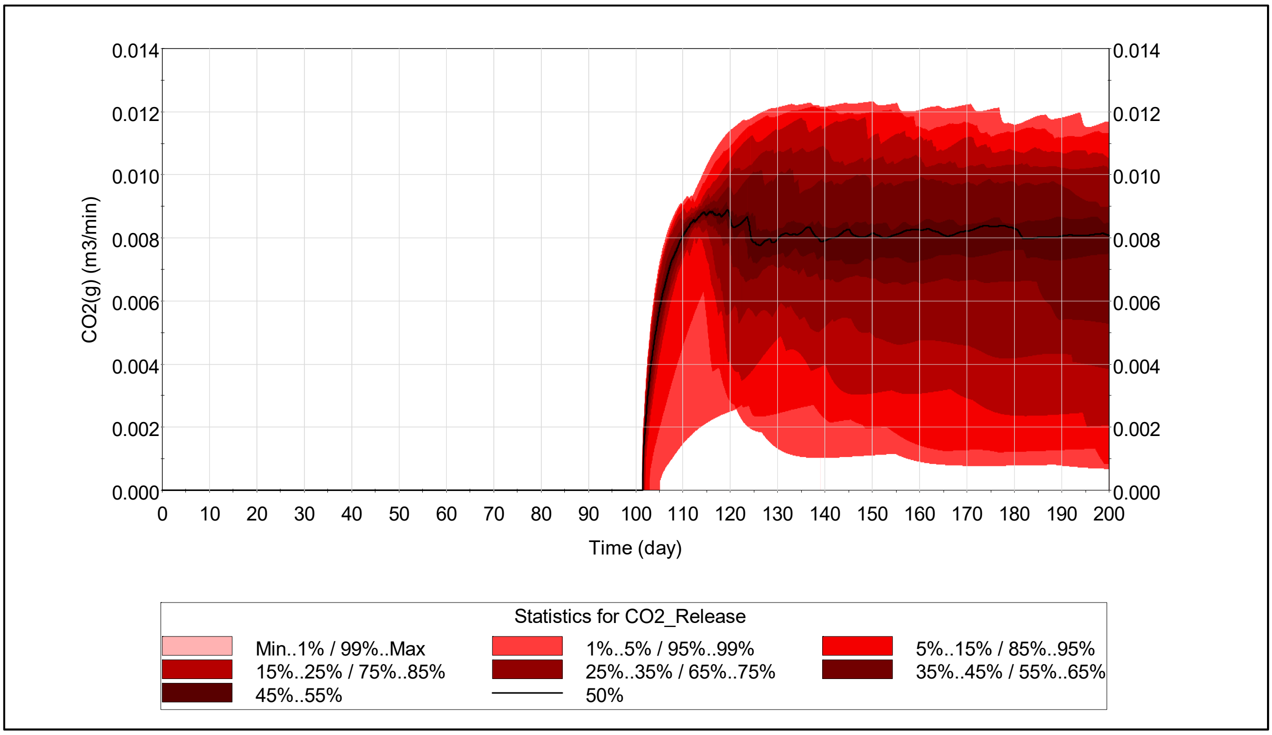

Figure 3: Prognosis of the CO_2 flow rate at the production drillings taking into account the uncertainty of the internal structure of the reactor

References

/1/ E-mail of Agnieszka Szubert from 24.05.2016, final reactor geometry and other issues

/2/ GEOS; Results of initial leaching model simulations for optimization of reactor operation