



## **SCIENCE BUSINESS SOCIETY DIALOGUE CONFERENCE**

**Linking Science, Society, Business  
and Policy for the Sustainable Use of  
Abandoned Mines in the SADC Region**

**28 – 30 November 2017**  
Indaba Hotel, Johannesburg,  
Gauteng, South Africa



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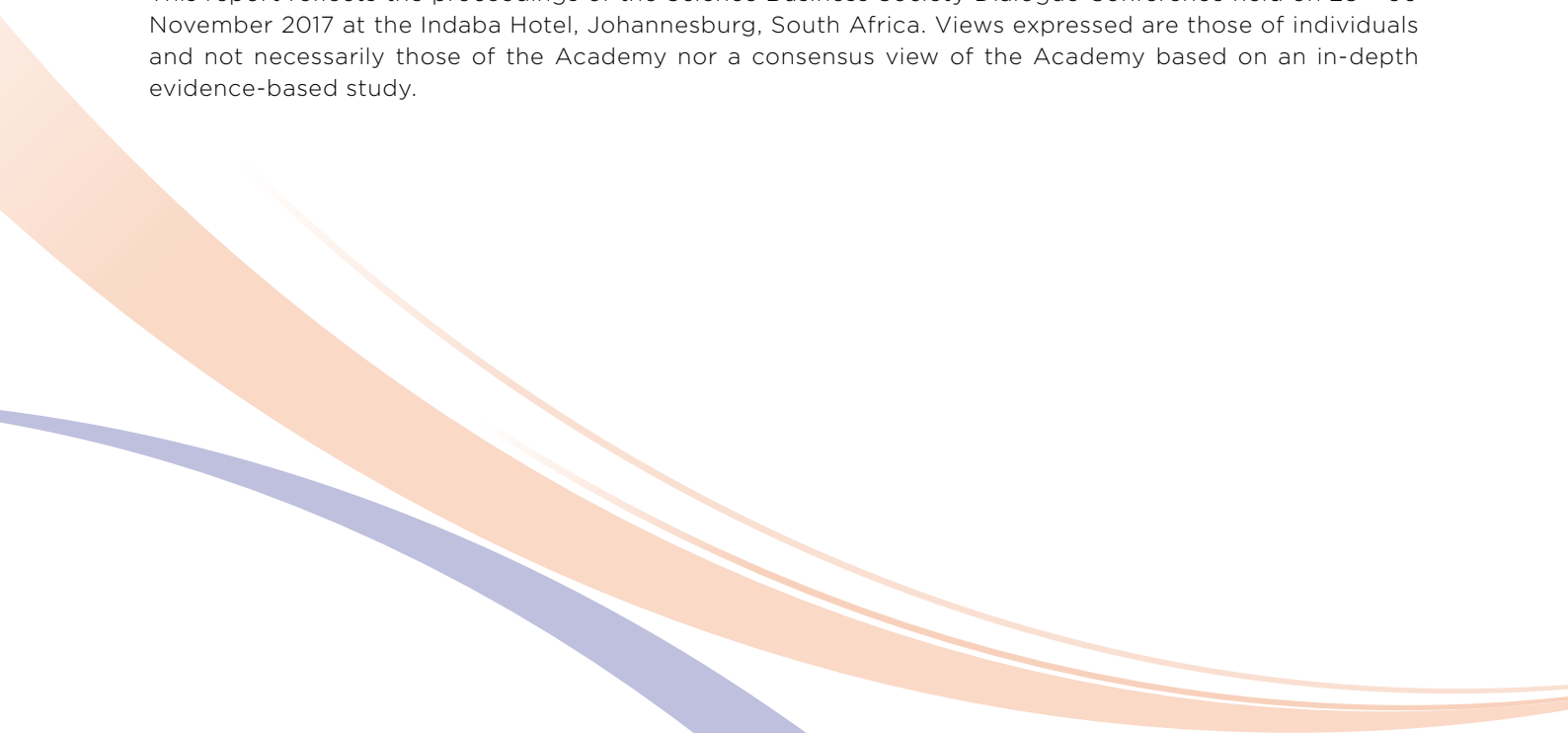
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The Academy of Science of South Africa (ASSAf) was inaugurated in May 1996. It was formed in response to the need for an Academy of Science consonant with the dawn of democracy in South Africa: activist in its mission of using science and scholarship for the benefit of society, with a mandate encompassing all scholarly disciplines that use an open-minded and evidence-based approach to build knowledge. ASSAf thus adopted in its name the term 'science' in the singular as reflecting a common way of enquiring rather than an aggregation of different disciplines. Its Members are elected on the basis of a combination of two principal criteria, academic excellence and significant contributions to society.

The Parliament of South Africa passed the Academy of Science of South Africa Act (Act 67 of 2001), which came into force on 15 May 2002. This made ASSAf the only academy of science in South Africa officially recognised by government and representing the country in the international community of science academies and elsewhere.

This report reflects the proceedings of the Science Business Society Dialogue Conference held on 28 – 30 November 2017 at the Indaba Hotel, Johannesburg, South Africa. Views expressed are those of individuals and not necessarily those of the Academy nor a consensus view of the Academy based on an in-depth evidence-based study.



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## SESSION ONE: OPENING AND INTRODUCTION

(Facilitator: Prof Roseanne Diab, Executive Officer, Academy of Science of South Africa)

### **Prof Brenda Wingfield** (Vice President, ASSAf)

Prof Brenda Wingfield welcomed delegates to the second Science-Business-Society Dialogue Conference jointly hosted by the Academy of Science of South Africa (ASSAf) and the German National Academy of Sciences Leopoldina, supported by the Southern African-German Chamber of Commerce and Industry and the German Federal Ministry of Education and Research. This conference forms part of a series of conferences on the Science-Business-Society Dialogue that ASSAf and Leopoldina started in December 2016 when the two academies jointly hosted the first conference, which was on “Strengthening the Science-Business-Society Dialogue in the SADC Region” and was attended by more than 100 delegates representing science, business and government from 19 countries. Delegates were invited to participate and share knowledge and experience on the difficult and important topics confronting the region, the rest of the continent and many countries around the world.

ASSAf has hosted a number of joint projects with Leopoldina, the most recent being a symposium on air pollution and health in Düsseldorf, Germany, which brought together experts from Germany and the BRICS countries (Brazil, Russia, India, China, South Africa) to deliberate on key global challenges in respect to air pollution. Science academies have a role to play in showcasing evidence supported by science on certain topics. ASSAf’s definition of ‘science’ is very broad and embraces not only the natural sciences, but also the humanities.

Prof Brenda Wingfield thanked Prof Cyril O’Connor, ASSAf’s scientific coordinator and Prof Frank Winde, Leopoldina and chairperson of the conference organising committee, and members of the committee for putting together the programme. The secretariats of ASSAf and Leopoldina were also thanked for their contributions to the organisation of the conference.

### **Prof Volker ter Meulen** (Immediate Past President, Leopoldina, Germany)

Prof Volker ter Meulen welcomed all delegates to the conference organised jointly by the South African and German Academies of Science, assembled from science, business and the wider society to engage on innovations for the sustainable use of

abandoned mines in Southern Africa. In organising the conference, the two academies received important input from the Department of Science and Technology (DST) and the Southern Africa-German Chamber of Commerce and Industry. The conference was made possible through funding from the German Federal Ministry of Education and Research (BMBF).

The mining sector plays a crucial role in the Southern African Development Community (SADC) and there are around 3 000 active registered mines throughout the region. Mining remains a very important driver of the economy and much industrial activity and engineering innovation are connected to it. However, SADC member countries have to face a number of major challenges resulting from the increased exhaustion of raw material extraction and hence a rising number of mine closures. There are over 6 000 abandoned mines in South Africa (SA) alone. The challenges posed by these mines have hardly been explored and include the use of abandoned mine shafts, serious environmental damage and health risks due to air, water and land pollution, and the loss of jobs. It is important to work on the best possible solution for abandoned mines now in order to avoid a great societal and environmental burden in southern Africa in the future. There is a strong likelihood that mining will continue to play an important role in sustaining the rapidly growing population in the region. ASSAf and Leopoldina believe that science, business and society must come together to find ways to ensure that mining activities have the least possible negative impact on communities and the environment.

Cooperation between southern Africa and Germany is particularly pertinent in the area of mining as Germany has centuries of experience in mining and a well-established network of mining research. There are already a number of environmentally friendly ideas for the use of abandoned mines to store and generate energy, not only in Germany and southern Africa, but also in countries such as Australia and the United States (US). Exhausted mines can be converted into sustainable energy production facilities by utilising some of these technologies and thereby preventing the development of acidic mine water. In this way, serious environmental damage and significant extra costs could be avoided. In addition, new jobs could help prevent social and economic decline of former mining areas.

Prof Volker ter Meulen thanked Prof Frank Winde for his valuable contribution to the planning of this

conference. His commitment and that of several very dedicated colleagues from ASSAf made this conference possible.

Prof Volker ter Meulen wished the delegates a very interesting and stimulating conference, with fruitful interactions between the many different stakeholders present who would have the opportunity to create contacts that would enable more and better use of abandoned mines in the SADC region.

### **Prof Dan Kgwadi**

*(Vice Chancellor, North-West University, South Africa)*

Prof Dan Kgwadi welcomed the delegates to the conference.

Universities in South Africa (SA) are interested in the activities of the science academies and participate enthusiastically in the Science-Business-Society Dialogues. Those universities located in areas where mining takes place, such as North-West University (NWU), take a direct interest in the topic of this conference and are cognisant of the fact that abandoned mines often present health and environmental risks in the communities in which they operate and could place large financial burdens on future generations. The universities are therefore fully engaged in finding solutions to these problems. A multi-disciplinary team of scientists at NWU was working on a variety of areas related to this field. This is a very important project.

In SA controlled flooding of closed deep level mines has resulted in large volumes of badly polluted water decanting into the environment, threatening groundwater resources and underground infrastructure. NWU has already made a multiple publicised scientific contribution in this regard through assessing risks of high rise buildings in central Johannesburg affected by acid mine drainage (AMD). Furthermore, NWU has signed a Memorandum of Understanding (MoU) with a leading energy research centre in Germany. This collaboration is aimed at pioneering research into the use of closed deep level mines in SA for storing renewable energy, thereby avoiding the formation of AMD. Underground pumped hydro energy storage will be a focal point of this conference. All five research teams currently investigating actual sites in Europe, Australia and SA will meet here to share their results for the first time. Owing to the interest shown by the mining industry as well as Eskom (SA energy utility), the existing MoU between NWU and the German researchers was expanded to include

two major mining houses, as well as the bilateral research consortium consisting of the NWU Mine Water Research Group, the Council for Scientific and Industrial Research (CSIR) and Eskom. More information about these developments will be shared in the presentations at this conference and NWU is committed to this project.

### **Strengthening Mining Policies and Research in the SADC Region**

*(Mr Nikisi Lesufi, Senior Executive, Chamber of Mines of South Africa)*

The Chamber of Mines of South Africa is a mining industry employers' organisation representing about 80 companies comprising 245 operations (representing about 90% of mineral production in the country) of the almost 2 000 issued mining licenses, employing close to 495 000 people. It supports and promotes the South African mining industry, serves its members and promotes their interests by providing strategic support and advisory input. It also facilitates interaction among mining employers to examine policy issues and matters of mutual concern, acts as a principal advocacy group for mining in SA and internationally, and co-ordinates and represents certain producers in centralised negotiations with organised labour.

The Chamber is a member of the Mining Industry Association of Southern Africa (MIASA) as well as the International Council on Mining and Metals (ICMM), which sets global standards for industry performance, in particular with regard to the role of minerals in society, material stewardship, occupational health and safety, and environmental and social stewardship. The challenges facing the SA mining industry contribute to premature closure of mines, namely:

- Global commodity prices fluctuations
- Domestic cost pressures rising too quickly for mining inputs
- Plunging productivity
- Trust deficit amongst stakeholders and other role players
- Social and environmental legacy issues.

Although abandoned mines occur throughout the world, the historical and political context of abandoned mines in SA is specific. Mining companies are held accountable for their current actions but cannot be held accountable for historical mining companies' practices. Inadequate legislation and corporate greed contribute to this complex problem, which cannot be resolved simplistically.

Integrated mine closure needs to consider not only land rehabilitation, but also socio-economic circumstances. A dynamic national mine closure framework and strategy that takes scientific advancements and new policies and information into account is necessary. As mines (and water resources) are not confined by geopolitical boundaries, regional integrated closure approaches are essential. A major factor necessary for preventing the abandonment of mines in future is the enhancement of collaboration amongst stakeholders and role players at all levels, and individual mining companies have an obligation to comply with regulatory requirements at all levels.

The Chamber of Mines promotes and ensures the development of voluntary integrated frameworks for collaboration and implementation of industry-wide initiatives to enhance and facilitate the sustainable closure of mining operations through a variety of programmes.

**Responsibilities of the Competence Centre Mineral Resources: Business Considerations on Both Sides**  
*(Mr René Zarske, Head of Competence Centre for Mineral Resources, Southern African-German Chamber of Commerce and Industry, South Africa)*

The mandate of the Southern African-German Chamber is based on three pillars: service, trade promotion and networking. The Chamber is the official representative of German industry and commerce in southern Africa (almost all the countries within sub-Saharan Africa), with regional representations and offices in SA, Mozambique and Zambia. Its network comprises over 600 member companies.

The German Chamber has competence centres in mineral resources, corporate social responsibility and sustainable energy, which aim to create specialised industry knowledge and support. The Mineral Resources Competence Centre aims to be the central point of contact for German as well as South African companies that want to do business with each other in the mining sector, and its current focal countries are SA, Zimbabwe, Zambia and the Democratic Republic of Congo (DRC). The Centre's objectives are to create market transparency, communicate and cooperate, provide services (such as consulting and market studies), and promote German technologies through events such as the Mining Indaba.

The Centre identifies opportunities along the entire value chain, from exploration to processing, that are available to German companies and supports these companies by providing:

- Continuous market monitoring and analysis of information
- Specific market information
- Placement of business partners
- Accompaniment and support for business meetings
- Organisation and accompaniment of business trips and delegations
- Organisation of thematic workshops and seminars
- Creating individual market studies.

The Centre is part of the German Mining Network, which has an inner circle comprising all the Competence Centres of the German Chambers of Commerce and Industry around the world, as well as a variety of partnerships. The website, [www.resources.germanchamber.co.za](http://www.resources.germanchamber.co.za), contains information on a variety of matters as well as market studies and upcoming events, and is a platform to promote German technologies.

The Centre has undertaken numerous projects and events (some of them collaboratively) to promote and strengthen the mining sector in southern Africa. Upcoming events include:

- Mining Indaba, Cape Town (4-5 February 2018)
- Bauma Conexpo Africa, Johannesburg (13-16 March 2018)
- Electra Mining, Johannesburg (10-14 September 2018)
- VDMA Lenkungskreise Afrika (quarterly meetings)
- Bauma 2019.

**Strengthening Collaboration between Research and Development (R&D) and Industry**  
*(Mr Bernd Oellermann, Director, Department of Trade and Industry, South Africa)*

Mr Oellermann shared some of the Department of Trade and Industry's (the dti's) learning gathered over the last few years in relation to collaboration in the research and development (R&D) sector and industry in SA.

Figures from 2016 show that SA spends about 0.77% of its Gross Domestic Product (GDP) on R&D while the international weighted average is about 2.23%. The dti has indicated that programmes would be put in place to increase the R&D spend in SA to 1.5% by the year 2020. Figures released by the dti in November 2017 show that the country's economy remains fairly flat, with low expectancies for growth in the coming year, which also affects the mining industry.

The dti's research that looked at collaboration between R&D and industry highlighted key success factors, namely:

- Close collaboration between R&D, universities and industry
- Business location
- Clustering (groups of companies that collaborate in a particular value chain)
- Support involving incentives, funding programmes and infrastructure.

Collaboration can be strengthened by:

- Focussing on niche areas in the industry
- Co-funding programmes across disciplines and between countries
- Long-term planning at different levels
- Using the media to foster collaboration
- Building relationships
- Facilitating events and building networks
- Sharing knowledge
- Proper co-ordination of collaborative projects.

The dti is pursuing ways to improve relationships and build collaborations.

## QUESTIONS AND ANSWERS

**Prof Harold Annegarn** (Cape Peninsula University of Technology) commented that, with regard to the legacy issue relating to silicosis from hard rock mining, large mining companies agreed to pay compensation in terms of a class action suit brought on behalf of former miners in a recent out of court settlement. However, the compensation scheme for workers in industry that created this situation in the first place is still in place and the legal legacy has not yet been corrected. He enquired whether the Chamber of Mines has any initiative to research and upgrade the legislation and personnel policies to protect hard rock miners in the future.

**Mr Nikisi Lesufi** responded that the class action comes from an employee of an old Ashanti mine who had been working in the industry for over 20 years and has discovered that he had silicosis when he was due to retire. His pension was a pittance because of the apartheid legacy. The case went to the Constitutional Court, which concluded that bearing in mind that the compensation system in place was inequitable, unfair and unjust, it could not be reasonably expected that the normal no fault principle applied and therefore workers have the right to sue the employer if they believe that they acquired diseases due to their exposure to occupational hazards. This judgement led to ex-

mine workers suing gold mining companies who protested their innocence. The Chamber of Mines was implicated in that it had not provided thought leadership for the industry. Only one of the two compensation systems that exist is compliant with global standards. The other has many loopholes and is inequitable. The compensation business processes are arduous and pay-outs to affected miners can take up to 15 years. The Chamber of Mines is not involved in the litigation but is involved in the settlement and took steps to improve business processes at the Medical Bureau for Occupational Diseases (MBOD). In terms of the long-term solution, it was proposed that all current mine workers should fall under the better compensation system (Compensation for Occupational Injuries and Diseases Act (COIDA)), but the unions disagreed with this resulting in a stalemate. In the short-term, the Chamber of Mines decided to assume that the current and future mineworkers would fall under COIDA and improve the benefits of the other compensation system to equal those of COIDA. However, this proposal carries significant challenges with regard to ensuring that past mineworkers are ensured of fair compensation. The only way to do this is for the companies responsible for the problems (gold mining companies in particular) to work out a mechanism in terms of the settlement of the litigation where they not only pay for the current workers who have sued them, but also make provision for any other workers who have worked for those companies in the past to come forward and claim compensation. The last man standing cannot take responsibility for the plight of all ex-mine workers.

**Mr Igor Klopčič** (Consultant) thought that the Chamber of Mines has the right to initiate things such as epidemiological studies. On the West Rand, the mines are older than 100 years and no such studies have been done. He asked who failed in this regard in SA, historically, where the initiative for these studies should come from, and where the initiative in Germany came from.

**Mr Nikisi Lesufi** responded that the Mine Health and Safety Act stipulated that the Mine Health and Safety Council is responsible for the research on occupational health and safety matters. Companies pay a levy per worker and these levies are used to invite researchers to undertake various studies. Companies need to report on their occupational health and safety related data and these reports are translated into programmes to assess risk profiles of particular companies and propose mitigations. Any studies have to be initiated at the Council level. The Chamber of Mines is responsible for appointing representatives in the Mine Health and Safety Council structures.

**Dr Moagaba Mathiba** (University of Botswana) asked whether the mining industry has a fund for research, and if not, what the impediments to this were.

**Mr Bernd Oellermann** responded that the dti's research did not pay particular attention to funding from the mining industry. The dti has a cluster development programme that provides funding for development of clusters. It is possible that other government departments have funding programmes relevant to the mining industry.

**Mr David van Wyk** (Bench Marks Foundation) informed the delegates that the Bench Marks Foundation has recently completed a household health survey of communities impacted by old mine dumps. The National Institute for Occupational Health did a study focussing on the content of the mine dumps and the extent of dust pollution inside the households, which included taking blood samples from the inhabitants. The dust and water are problems not only for mine workers but also for near-mine communities. The Foundation has presented its findings to the Mine Health and Safety Council. The historical research shows that in the past, the Chamber of Mines used to have a Tailings Unit, which maintained the grassing and vegetation of tailings, but the Unit seems to have disappeared. The National Institute for Occupational Health recommended a 5 000 m exclusion zone around tailings, but this is not happening in practice. The security around the tailings is a significant problem that needs to be addressed for the sake of the people who live in close proximity to the tailings. Government has an incredible responsibility to prevent developers from developing property inside the exclusion zones. Prof Annegarn has done extensive research in this regard. Mining is not just about business and profit. It is also about the safety of human lives.

**Mr Nikisi Lesufi** remarked that it is a pity that the regulator is not present at this conference. He explained that during the turn of the century when the mine dumps were established there were no settlements around them, but people have moved closer to the mine dumps over the years. The ownership of the mine dumps is a fundamental issue as the owners have an obligation to maintain and monitor the impacts of those dumps. If the abandoned mines were rehabilitated and transferred to the state, then the state is responsible for taking remedial measures. The Chamber of Mines has taken initiatives in this regard and has done a study of all the mine dumps and abandoned mines in Gauteng to determine the economic viability of re-mining the dumps. An integrated plan was developed for those that could be re-mined so that the proceeds of that

re-mining would provide the wherewithal to remove what cannot be re-mined. However, these plans failed because those mines that had economically viable returns suddenly had owners. The Chamber of Mines is currently undertaking research to assess the possibility and consequences of returning the dumps underground, and whether this would contribute to the management of AMD. Preliminary studies indicate that by taking the dumps underground into the AMD points, the mobilisation of minerals and the use of separation techniques would create a platform to self-fund this option. The current rehabilitation guidelines provide for a 500 m buffer zone, but over the years people have moved closer to the mine dumps and this requires the guidelines to be updated. The Chamber of Mines will be doing this work in the next few months.

**Prof Volker ter Meulen** commented that the situation with regard to cooperation between industry and science in SA described by Mr Bernd Oellermann was similar to that in Germany 20 years ago. Intellectual Property Rights (IPR) and publication were important. Germany has managed to resolve the situation to some extent. He asked whether the dti has a plan of how to address the situation in SA.

**Mr Bernd Oellermann** responded that the revised South African Intellectual Property Protection Act was put forward recently. The dti encourages entrepreneurial development and partnerships with technologies from overseas to build a critical mass of new products and technologies. The dti intended to build collaborations and fora where industry can contribute through industry associations to funding specific research together with government. Funding for R&D is the responsibility of the DST.

**Mr Nikisi Lesufi** responded that the Chamber of Mines used to have its own research facility, which was donated to the CSIR in the 1990s with the understanding that the facility would primarily serve the industry. However, over the years the facility has lost its research capability and was later closed down, and companies outsourced their research. The Mining Phakisa in 2014 identified the need for collaborative research. The Chamber of Mines has an agreement with the Minister of Finance to co-fund research together with the DST (with a commitment to provide R28.5 million per annum for the next three years approved recently by the Chamber's Council), but the current fiscal constraints could have an impact on this agreement.

**Mr Llanley Simpson** (DST) clarified that in terms of the current agreement, government agreed to put R213 million and the Chamber of Mines to put R33 million into research in the mining sector. The

Mining Phakisa was a South African initiative that involved 17 government departments, the Chamber of Mines and South African mining companies, but no foreign companies or supply chains. The Phakisa process led to the development of the South African Minerals Extraction R&D Initiative and this document has been contracted for the development of the R&D programme connected to mining extractions research as well as to the input cluster. In addition, the dti has contributed R12 million over a period for this particular process. The previous research facility is being re-established and rebuilt and the launch of this new facility will take place early in 2018.

**Prof Frank Winde** (NWU) asked whether the Chamber of Mines could play a role in facilitating collaboration between its members and how the chamber could incentivise the different role players to collaborate with each other. He emphasised that collaboration is essential when dealing with abandoned mines as an integrated approach is necessary that looks beyond competitive interests for common solutions.

**Mr Nikisi Lesufi** responded that the Disaster Management Act gives the responsibility of managing land subsidence, sinkhole prevention, storm water management and so on to the local authorities. In some cases the local authorities do not have the expertise or resources to undertake these functions and entities such as the Far West Rand Dolomitic Water Association (FWRDWA) are continuing to do this work. When the mines diversify and consolidate, the structure and membership changes accordingly and there is reliance on the regulator to ensure that the condition of the issuance of water use licences dictates that the mine must become part of the FWRDWA to ensure that there is forced collaboration that requires a regional and common approach to water management. In other areas where there are abandoned mines, the Chamber of Mines has a Mine Water Co-ordinating Body made up of all role players in the province to look at the closure plans of each mine. The Green Engine is a mega-project funded by the mines to look at the terms and conditions of exit of each mine.

## KEYNOTE ADDRESSES

(Facilitator: Dr Christine Diehl, Deputy Director, International Relations, Leopoldina)

### Why this Conference?

*(Prof Frank Winde, Head of Mine Water Research Group, NWU, South Africa)*

First World countries tend to think that mining is a thing of the past and is of no relevance today. In fact, mining has shaped our history and will continue to define how civilisation is developed. Mines have provided everything humans have needed and continue to need to survive and develop. Mining has provided the energy base for the world, starting with coal then moving to oil and gas, uranium and more recently renewables in terms of the rare earth elements used to make solar panels and wind turbines, for example, and high tech metals. Renewable energy based economies will need more resources per energy unit created than before and together with unprecedented population growth this implies that mining is on the rise rather than the demise.

Polluted mine water decanting into the environment from abandoned mines occurs throughout the world, but is particularly problematic in South Africa where it affects very densely populated areas. It is estimated that there are about 6 000 derelict and ownerless mines (abandoned) scattered across the country. The SADC region is particularly well-endowed in terms of the value of the minerals mined, yet remains among the poorest of mining regions globally. There is a direct connection between people and the effects of mining, particularly in Third World countries, with questions being raised about how mines can be trusted to uplift communities once the operations have been terminated if there was failure to uplift the people while the mines were operational. The legacy of mining is an indefinite burden and new solutions are needed to make this burden bearable. This conference aims to find a convincing response to these questions.

The conference is structured in nine sessions as follows:

**Sessions 1 & 2:** Nature and magnitude of the problem: raising awareness

**Sessions 3 & 4:** International experiences in remediation: case studies

**Sessions 5, 6 & 7:** Technological solutions: converting liabilities into assets

**Session 8:** Implementing solutions: social and legal aspects

**Session 9:** Wrap up, lessons learned: conference resolution.

The conference brings together various role players from science (ideas, concepts, technologies, solutions), policymaking (enabling force), mines (implementing agent) and civil society (social licence) to deliberate on the sustainable use of abandoned/exhausted mines in the SADC region.

### How Mining can and should be a Benefit to Investors, Workers, Local Communities and Host Nations

*(Mr Bobby Godsell, Director, Industrial Development Corporation, South Africa)*

In 2001 a group of mining and metal companies, and national and regional mining and metal associations met and formed a body called the International Council for Mining and Metals (ICMM), a pre-eminent and important body in the global economy. They met to consider how they belong in the world and how they relate to their countries, people and stakeholders in the global economy. The Toronto Declaration, which remains at the heart of the ICMM, gives the following standards that have been adopted by the world's major mining companies and regional and national mining associations, and are accepted as the currency of their social license to operate:

- Mining should reward its investors with fair and sustainable returns for their investment.
- Mining should be a good steward of the physical environment in which it operates leaving that environment, at least not worse, as it found it.
- Mining should offer its employees fair reward and a workplace that both protects the safety and preserves the dignity of the employee.
- Mining should produce real benefits for the communities in which it operates, both during and after the mining process.

Manifestly, these standards have not been fully met everywhere where mining takes place. What has gone wrong and what can be done to get closer to that standard of successful mining being an important pillar of a prosperous and good society?

All human activity leaves a mining footprint on its natural environment. Economic activity and societal needs should be a general concern. Mining should have an advantage. Once an ore body is found, there is a process of delineating that ore body and producing a life-of-mine plan, which

holds the potential for making the impact on the environment a premeditated conscious plan declared activity. A further plan, one for rehabilitation (restoring particularly the physical environment to an acceptable state), is required by regulators and would be embraced by sensible mining companies. The advances made in mining technologies, metallurgical recovery technologies and the environmental science should enable mining to be a good steward of its physical resources. Problems occur where regulations are poorly framed and poorly enforced. Where a responsible relationship between mining and the environment does not occur during the life of mine, environmental damage can often outlive the economic life of a mining company, resulting in 'orphan mines'. Good laws and good management should largely prevent this. The impact of the environment should be built into the legal license to mine and operate. There may be a critical role for mining associations and industry-wide insurance schemes where this has failed.

Though the use of high energy technologies in often confined work spaces poses particular health and safety challenges, there is no reason why mine workers should not complete their shifts in safety. This goal is now at the top of most mining companies' objectives. Real progress is being made in the area of worker safety in SA and elsewhere. The threats to health are often less obvious, but not less important.

As mines extract value from minerals and as these minerals are often seen in the community and in the country as a national patrimony, it is not surprising that communities have very high and sometimes unrealistic expectations of the mining company and the benefits they should derive from the presence of mining. These expectations are often poorly articulated and are not as emphatically, clearly and concretely negotiated as wages and working conditions for employees. If it is true that mining companies cannot meet all the expectations of communities, it is equally true that they can meet some of them. A three-way partnership between mines, communities and governments at all levels is absent. In the context of SA and elsewhere in Africa, the three-way partnership is particularly the relationship between local government and regional government, the mines and the communities themselves. Many issues of intense conflict between traditional authorities, mines, communities and local government have been seen in the context of SA. This partnership should include fiscal sharing, where at least part of the taxes paid by mines is spent in the communities in which the mines operate. Mines require infrastructure such as water, power, roads and Wi-Fi. This infrastructure can often be extended

and shared where successful partnerships are created between government, community and mines.

Substantial investment is crucial in order to commence mining operations and large amounts of money are needed to push mining to new frontiers. Here, more than ever, a robust partnership is needed between mines, governments and communities. Mines must commit to a goal of fiscal morality, paying a fair share of their profits over the life of the mine, and avoid corrupt 'seizing of rent' and the corrupt use of taxes. Regulations need to be clear, certain, fit for purpose, transparent, both in their development and in their enforcement.

The above present some of the agendas to ensure that the vision of the Toronto Declaration is fulfilled, and that when mining takes place it can simply be part of human history.

**Cleaning up after Mines Long Gone: Understanding the Complex Dimensions for Inclusive Development**  
*(Dr Shingirai Mutanga, Mapungubwe Institute for Strategic Reflection (MISTRA) Fellow, Human Science Research Council, South Africa)*

Although none of the 17 Sustainable Development Goals (SDGs) address mining directly, there is an inextricable link between mining and each of the SDGs, particularly SDG 15 (Life on Land), as mining has contributed to unprecedented land degradation and substantial loss of arable land, and SDG 6 (Clean Water and Sanitation), as 1.7 billion people's water use exceeds the recharge capacity of the river basins they live in. Land destruction resulting from mining operations can lead to sinkholes that cause serious and costly damage to infrastructure and the loss of life. Huge mine dumps on the 6 000 abandoned mines are detrimental to the environment. About 62 megalitres of AMD was being decanted into the environment per day post-closure of coal mines in Mpumalanga. AMD, referred to as the ticking time bomb of the 21st century, threatens human health, the biodiversity and aquatic life systems.

Mining legislation from 1903 to 2004 focussed on operations but was lax in addressing the ramifications of mining on the environment. The challenges faced today did not exist in the 1900s' regulatory environment. Complexity Science with a specific focus on water and land resources can be used to understand the negative externalities of production, which are important in assessing the short-term and long-term benefits of mining activities. Systems thinking falls within this discipline and is a structured way of analysing complex inter-relationships that are problematic or of interest. It is

also a methodology for increasing the understanding of certain phenomenon in establishing the consequences of different options and helps find solutions to the 21st century challenges.

Strategies for post-mining land reclamation include:

- Sustainable ecological systems theory (afforestation)
- Focussing on second generation opportunities derived from the abandoned mines taking an interdisciplinary approach, such as economic evaluation, environmental authorisation and engineering.

Strategies for water resource management include:

- Passive treatment systems (constructed or natural wetlands), which have challenges with regard to issues relating to policy, finance, geotechnical issues and climate variability.
- Active treatment systems (such as a chemical amendment approach to the treatment of AMD, chemical precipitation, ion exchange, solvent extraction, electrolytic techniques, membrane technologies and adsorption processes).

The main challenge with regard to financing abandoned mines has to do with who takes the responsibility for rehabilitation strategies. There is a need for long-term sustainable mining financing, which can be in the form of a mine closure model, a rule-based model or private and public funding models. There should be a focus on the benefits that can be derived from cleaning up a mine. These include opportunities to upscale the second generation products and create enterprises around the recovery of drinking water from mine effluent, utilising lime-treated AMD for agricultural crops and recovery of certain metals.

In conclusion, ecological and socio-economic systems are complex and adaptive, integrating phenomena across multiple scales of space, time and organisational complexity. The enormity of the challenge and complex dimensions cannot be underestimated and liabilities apportionment is important. There is a need to advance collective or shared responsibility in order to protect the environment. Integrated holistic approaches are required to face the multiple challenges. The way forward is to re-imagine the business model by seeing abandoned mines as an opportunity for the betterment of the environment, rather than a challenge that has to be addressed.

### **An Innovative Approach to Socio-Economic Closure on the West Rand of Johannesburg**

*(Mr Grant Stuart, Senior Vice-President:  
Environment, Sibanye Gold, South Africa)*

Over the last 100 years there has been a significant amount of mining activity on the West Rand and this has resulted in 1.3 billion tons of tailings material (waste) scattered across the West Rand. Historically, deposition sites were put anywhere, typically on top of dolomite and water aquifers because they drain quickly. This has created an unfortunate legacy of the past, which has seen AMD, dust pollution and illegal mining activity becoming a common reality.

The West Rand Tailing Retreatment Project (WRTRP) is focussed on finding low technical risk solutions to treat the tailings dams for the benefit of all the stakeholders (environment, employees, communities and shareholders). In order for the solution to be sustainable, it requires economic rationale and must be beneficial. A funding solution for the WRTRP enables a socio-economic closure solution to become a reality.

WRTRP has a 10-year history of development with around R800 million being spent on studies. The project has been substantially de-risked through extensive technical studies as well as designing inherent flexibility for phased development and staging of capital. Technical studies have benefited from vast amounts of historical knowledge and experience while incorporating appropriate modern technologies and world leading environmental standards. The scale of the project includes gold and uranium using a central metallurgical complex to process all the tailings facilities on the West Rand, depositing into a large deposition site and facilitating the closure of the district. The rationale behind the WRTRP is about understanding the resource base to ensure that the processing of the material is sustainable. Key to this is the utilisation of existing infrastructure, as well as phased development and staging of capital. A robust business case can be developed on the back of the tailings facilities. The project demands a significant amount of water and presents an opportunity to use the impacted mine water for the benefit of environmental clean-up, treating and returning the water into a recirculating circuit to ensure all the tailings material is recovered.

Understanding the resource base is critical to a sustainable solution. A sustainable closure solution must be inclusive of all resources with varying grades. Blending high grade dams with lower grade dams facilitates sustainability. A funding solution for the WRTRP came through a transaction with DRDGOLD, a service treatment company that is

environmentally conscious and totally dedicated to tailing retreatment and the removal of tailings off the dolomites, ensuring that the residue is environmentally benign.

The WRTRP presents a socially responsible closure solution that will see current and future generations benefit and will not become a liability to future tax payers, but offer long-term benefits to the regional and national economy.

### Mine Legacy Sites: A Brief Global Overview on Remediative Approaches to Date

*(Prof Christian Wolkersdorfer, Secretary-General, International Mine Water Association, Tshwane University of Technology, South Africa)*

Prof Christian Wolkersdorfer undertook a study on remediative approaches to address mine legacy sites globally, which found that there were:

- Mine sites where nothing was done. This could be because environmental or social problems are not expected to occur, the potential risks are underestimated, the mining company is bankrupt, the mine operator is irresponsible or a small company with limited resources, or authorities are bribed to ignore the problem. Doing nothing could result in natural attenuation taking over, mine sites becoming risks to local communities, polluted and acidic mine water (and in some cases good water quality), enrichment of shareholders and mining companies, and social and health problems.
- Mine sites where little was done. This could be because there are not enough funds available, the situation is underestimated, no environmental or social issues are expected or because the sites are in remote areas. Usually, site investigations are done and existing data are used to provide recommendations for closure procedures. The results are that buildings are removed and mine openings are sealed. The discharging mine water could be of a good or not so good quality.
- Mine sites where the right things were done. This is usually because sufficient funds are available, mine operators and shareholders are responsible, there is awareness of the potential risks of not remediating correctly and knowledge about the potential environmental impacts and because closure planning is addressed at the beginning of the mining process as part of mine's lifecycle. Site investigations are done and existing data and expert reports (historical) are used. In addition, there is geochemical modelling, a mineralogical understanding of the site, waste rock characterisation, and

geological and geochemical investigations are done. Remediation action is monitored, the contamination potential is quantified and the closure procedure is recommended. The results of taking the right approach are usually very good. Social and environmental aspects are considered fully, stakeholders are satisfied, the mining company will be regarded as responsible and the environmental development of the reclaimed mine site is adequate. 'BATNEEC' ('best available technology not entailing excessive costs') is a principle sometimes used in mine site remediation, and infers that there is no need to put more and more money into a situation that is already satisfying for most people. The current state of technical knowledge is necessary and the requirements of environmental protection need to be properly considered.

- Mine sites where a lot (possibly more than necessary) was done. The study found few examples of this. Reasons for doing too much could be due to uncertainty about what to do, having too much money available and not enough knowledge about the site, the geochemistry and the hydrogeology. It could also be due to pressure for the authorities and playing safe. Doing too much to remedy mine sites could be a waste of money and lead to elevated running costs.
- Mine sites where the wrong things were done. Some of the reasons why remediation of mine sites is done wrongly are:
  - Wrong consultants or advisors are employed
  - Employees are uneducated
  - The risks are underestimated
  - Ignorance
  - Hydrogeochemistry is misunderstood
  - The cheapest option is chosen, instead of the option that would best suit this specific case
  - Small mining companies, with limited resources.
 The results of doing the wrong thing are similar to having done nothing.

The study concluded that good mine legacy site remediation requires:

- Knowledgeable players (stakeholders)
- Communication, documentation and record-keeping
- Historical investigation
- Monitoring
- Hydrogeochemistry and hydrogeochemistry modelling
- Statistics (multivariate)
- Tracer tests (hydrodynamics)
- Waste rock characterisation
- Communication of local community
- Funds.

## QUESTIONS AND ANSWERS

**Mr Igor Klopčič** (Consultant) expressed the view that widespread mine pollution is not a failure of the system, but a basic characteristic of the system. Widespread inequality means that people think about what they are going to eat and not about how to exercise their democratic rights. Power structures develop, but these are unconcerned about the public and are in cahoots with the mining industry. No-one remediates because it is not good business. In Germany, the public is possibly less poor, they exercise their democratic rights and remediation gets done. As long as remediation is not a good business, it will not be done - unless the characteristics of local societies change.

**Prof Harold Annegarn** (Cape Peninsula University of Technology) commented that a major factor that influenced the failure of earlier attempts to consolidate tailing activities was the lack of a suitable mega-deposition site and asked Mr Stuart whether such a site has been identified yet.

**Mr Grant Stuart** (Sibanye Gold) responded that a suitable site has to be able to accommodate all the tailings on the West Rand. Such a site has been identified and permitting the site began about 2 years ago. Full permission for the authorisation of the site had not yet been given but all the environmental impact studies have been completed. Environmental authorisation and approval from the Department of Mineral Resources (DMR) was anticipated.

**Mr Igor Klopčič** (Consultant) asked why the organs of state have failed to undertake epidemiological studies about the West Rand or other mining areas, and which organs of state promoted such an initiative in Germany.

**Prof Andre Niemann** (University of Duisburg-Essen) responded that in Germany, the key challenge was to develop an environmental responsibility with knowledge as a base. The first step is to provide knowledge and agree on the knowledge. Then there is an environmental responsibility that leads to monitoring and transparency of ecological status, but this requires money. There was a long discussion between the mining operators and those that are taking care of the environment in order to come to an agreement on the refunding of such activities. This refunding is controlled and the money that is agreed for refunding is ringfenced for this purpose. This is called the polluter-pays principle and is an environmental responsibility concept. Both sides must agree and there must be a win-win situation or it will definitely not work. The moderating

issue has to do with environment supervision and environmental monitoring.

**Mr Piet Smit** (Land Rehabilitation Society of Southern Africa) disagreed that new legislation has improved performance in terms of land rehabilitation and pointed out that Prof Christian Wolkersdorfer's presentation did not refer to legislation as a success factor, but to corporate morality as a driver of the whole process. A responsible operator will strive to do what is best. Instead of inculcating corporate morality, there is a move towards over-regulation, particularly in terms of the environment.

**Dr Shingirai Mutanga** responded that most of the abandoned mines operated decades ago and that his presentation refers to the legislation at that time. Some guiding principles force the current mines to abide by the regulations that are in place today. The biggest problem has to do with those mines that are ownerless.

**Prof Christian Wolkersdorfer** agreed that he should have included legislation in his presentation, adding that it is sometimes more important to have responsible mining companies than legislation.

**Mr David van Wyk** (Bench Marks Foundation) pointed out that there is no such thing as 'sustainable mining'. Informal (illegal) miners have told him that there are more than 1 000 people in a 'city' and business community underground (at Crown Mines). It is estimated that 400 000 people in Gauteng are dependent on small-scale mining and it is expected that this mining will increase as industrial mining declines. This important issue needs to be addressed.

**Mr Grant Stuart** (Sibanye Gold) indicated that processing 1.3 billion tons of tailings at a million tons a month will take a long time. In order for that process to be sustainable there needs to be economic return and benefit. How the water is taken and treated and how it is charged for and so on requires a discussion around the sustainability of the solution that is put in place. The reality is that illegal mining is very widely spread and the miners have become blatant, ruthless and above the law because there is no criminal offence associated with illegal mining activity. An interdisciplinary working group is needed to support the mining industry in order to curtail the scourge. Illegal mining represents a micro economy that is growing and that pays well.

**Dr Shingirai Mutanga** (MISTRA) suggested that there is an urgent need for urban planning that took into account societal needs and those of people living in vulnerable places. This and the area of small-scale mining requires more discussion.

**Mr Andrew Barker** (Town Planning Consultant) informed delegates that when talking about sustainability, rehabilitation and community engagement, the Integrated Development Plan (IDP), which is the municipal business plan, is one of the most interesting opportunities for formal engagement between the mining company, local authorities and communities and should be structured into a budget process of the local authority. The challenge is that IDPs and budgets are short-term programmes while the rehabilitation initiatives are decades long. He enquired whether there are similar processes or mechanisms throughout the world that allow for a mining company's social labour plan to be incorporated within municipal plans, recognised and therefore 'legalised' as part of the future city development.

**Dr Willson Mutagwaba** (NTL Consulting, Tanzania) commented that, in the context of this conference, small-scale mining needs to be looked at in terms of the danger it causes to the remediation and rehabilitation of mining sites, which is evident in several SADC countries. Once the sites are rehabilitated and handed back to the government the area is seen as a new resource for small-scale mining.

**Dr Nils Hoth** (TU Bergakademie Freiberg) commented that the idea of re-mining tailings is interesting. It is understood that the tailings are processed for gold and almost nothing is removed from the tailings material, which is dumped again, this time in the new facility to store the re-mined tailings. He asked Mr Grant Stuart whether the dolomites increase the pH levels and what his thoughts are about pyrite, which is the driver of AMD.

**Mr Grant Stuart** responded that it is acknowledged that the pyrite and sulphide in the ore is the cause of AMD. Part of the process is to float the pyrite and take out the iron sulphide. There is a process looking at the viability of putting in a sulphuric acid plant to take out the uranium. This will mean that the uranium, gold and pyrite will be taken out of the material. The regulators are of the firm opinion that the new facility must be lined, but this comes at huge expense and an alternative option has been put on the table.

**Prof Christian Wolkersdorfer** pointed out that he had done a calculation with regard to what will happen to the dolomite if there is acidic water, which shows that the dolomite will buffer the AMD to a pH of 6.5 to 7.5, beyond which no more dolomite will be dissolved.

**Mr Andrew Barker** referred to the Chamber of Mines' proposed study commenting that putting surface material back underground would be criminal as it had been brought from under the ground at great expense and effort, and should be used until there is no further use for it. It is necessary to look for opportunities instead of focussing on the problems. Opportunities have been found to restructure Johannesburg in terms of land development through the release of land by land reclamation. There is a huge opportunity to restructure one of the largest megatropolis' of the world environmentally, socially and economically. No other city has this opportunity. There are numerous examples in Johannesburg of work that has been done, land that has been released and socio-economic benefits that have been realised. A positive approach should be taken and it is important to recognise that it can be done, has been done and will continue to be done.

## OFFICIAL OPENING DINNER

### Keynote Address: Is Sustainable Post-Closure Development Achievable?

(Mr Pieter Scholtz, Aurecon, Lead Sustainability and Mine Closure, South Africa)

There is a myth that mine closure is the same as environmental rehabilitation. This is false. Environmental rehabilitation is a part of mine closure. Another myth is that mines just don't care. From working with many senior executives of large mining houses in SA, every one of them without exception has a moral compass that obliges them to do environmental rehabilitation right. The question then is about why is there failure to do so.

Several facts need to be taken into consideration when talking about sustainability, namely:

- There are a little more than 6 000 abandoned mines in SA.
- There is not a single blueprint or case study that can be used to show how best to achieve sustainability in mine closure. Although some mines that have closed got the environmental rehabilitation almost right, some created initiatives around sustainability for the communities and some developed helpful systems about how to decommission, demolish and dispose of the infrastructure, but the integration of all the aspects of mine closure to achieve sustainability has not been done.

As a point of interest, Australia has 53 000 abandoned mines and there are a few examples of sustainable solutions post-closure.

The last mining houses that had the resources, capacity and the capabilities to close mines chose to sell their assets to junior mining houses that could coerce a few more years' worth of mining from the mines. Financially, this is a very good system. The problem is that these junior mining houses do not have the capability or the resources to successfully close these mines. Reasons why mine closure is complex are:

- It is extremely difficult to plan for closure very far in advance (30 years or so).
- As closure becomes imminent, the good employees are lost as they are able to find alternative employment.
- There is no blueprint to follow.
- Mine closure is not a key performance indicator (KPI) of senior executives in the industry.

- Various departments have different approaches and focus areas and tend to operate in silos.
- There is insufficient financial provision for mine closure. Mines' liabilities have typically increased between 30% and 300% making it difficult (or impossible) to make up the shortfall if a mine is within 5 to 10 years from closure.
- Very lenient legislation and the enforcement thereof. Closure used to be governed by the Mineral and Petroleum Resources Development Act (MPRDA) and was a 'tick-box exercise'. Closure plans were ignored and financial liability was thumb-sucked.

Because the previous legislation was insufficient, the National Environmental Management Act's (NEMA) financial provisioning regulations were put in place. This legislation requires mining companies to plan for closure in a lot more detail. The Act was written by the Department of Environmental Affairs (DEA), but is enforced by the DMR. Safety mechanisms are built into the regulations, one of which is that the CEO of the mining company must sign-off and take responsibility for the annual rehabilitation plan, final closure and rehabilitation plan and the risk assessment report. In addition, the legislation requires mining companies to publish these plans and reports on their websites. If the company is not compliant, the CEO can be imprisoned. Mine closure will therefore have to become a key performance indicator (KPI) of senior executives in the mining industry. If the DMR fails to enforce the legislation, interested and affected parties around the mines have access to the plans and will ensure compliance through the courts.

Because the legislation obliges companies to plan in so much detail and to calculate financial provisioning from first principles and requires auditing by an accredited auditing company, they will know what their closure liability will be and can plan accordingly. The new legislation will force sustainability thinking because the only way that the liability can be reduced in a legally compliant way would be to get rid of some of the costs associated with closure and transform these into sustainable solutions post-closure that can be taken over by the communities in the area or sold to other businesses. However, this has not yet been done and remains a dream.

Just imagine that a mining company could take its water issue (often the largest component of the liability because the new legislation makes the company liable to treat and manage the risk of water

pollution once the mine has closed, for eternity) and transform this liability into a water solution that the communities can own, that produces drinking and agricultural water at a lower cost than water utilities and reduces current operating costs. Such a solution would be sustainable, is possible and its implementation is currently being planned. Mine closure needs to be thought of not as closure but as asset transformation.

Just imagine that liability can be reduced by taking the existing infrastructure and incorporating it into the State Owned Enterprises (SOEs) in the area and into a local municipality. Furthermore, just imagine that by doing this, some of the housing shortages in the area can be addressed, that there is government support to do this and that this can be done without further costs. All this can be done. It only requires a new way of thinking about mine closure.

Actual sustainability post-closure has not yet been achieved, but it can be achieved. All the ingredients are there and only need to be integrated in the right way. Getting sustainability right and reducing liability will require a change of mind set and a different approach. The new legislation is not a burden, but the tool that can unlock actual sustainability and restore some of the trust that has been lost between the different stakeholders in the mining industry. The task of achieving sustainability is extremely difficult but it can be done. It only requires the will to make it work.

## SESSION TWO: THE CHALLENGE OF MINING LEGACY SITES

(Facilitator: Prof May Hermanus, Executive Director, CSIR, South Africa)

### Environmental Health Impacts of Mining in Africa

(Prof Theophilus Clavell Davies, Department of  
Geology, University of Nigeria, Nsukka, Nigeria)

In 1987, the United Nations Environmental Protection Agency warned about the severity and destructiveness of mining waste. Africa ranks first or second in quantity of world reserves of numerous mineral deposits and gold is Africa's main mining resource.

In answering the question about why the environmental impacts of mining are so severe for Africa, it is necessary to consider the unique characteristics of Africa's surface environment. Its climate has caused geochemical reactions to be taken to extremes and this has caused the dispersal of nutritional and toxic elements in a way that results in large areas of element excess as well as element deficiency, impinging on the health of most of the population, which still lives in rural areas and depends directly on the land for basic requirements of food and water.

Some of the observations captured in the recently concluded project, which covered 17 countries (29 experimental sites) in sub-Saharan Africa include:

- Heavy metal precipitation, both during and after mining, presents a high health risk to the people who consume the contaminated agricultural products.
- Trace metal poisoning. In 2010, hundreds of children in Zamfara, Nigeria, died from severe lead poisoning associated with gold ore processing and thousands more continue to be severely poisoned by exposure to pervasive lead dust.
- AMD formation, arguably the world's most significant mining environmental challenge.
- Arsenic released through coal mining and processing of metal sulphide ores as well as through weathering, erosion and transportation can be found in high concentrations in both surface water and groundwater.
- Mercury causes damage to the nervous system even at relatively low levels of exposure.
- Platinum mining impacts on the environment through water pollution, dust emission and production of solid waste.
- Uranium mining waste retains nearly 85% of the original radioactivity that lasts for thousands of years. The majority of mine residue areas in South Africa are radioactive because the Witwatersrand

gold-bearing ores contain almost ten times the amount of uranium than gold. The estimated 1.6 million people who live in informal and formal settlements on or in close proximity to tailings are particularly vulnerable. Health risks associated with high levels include kidney damage and disease, neurological problems and cancer, as well as birth defects and developmental delays in babies.

- Radiological toxicity. Several possible health effects are associated with human exposure to radiation from uranium.
- Mine dust emissions resulting in air pollution
- Mine workers are afflicted by silicosis and coal worker's pneumoconiosis.

Despite massive environmental contamination from uranium mining in Witwatersrand, no epidemiological studies have been undertaken so far. There is failure to diagnose obvious uranium exposure problems in pregnant women and children in particular, because the relevant experts are not incorporated into the teams that are investigating the effects of uranium exposure. This also applies to other harmful elements.

So far, no independent epidemiological research on the effects of radioactivity on public health has been performed in the Niger region, which supplies around 7.5 % of world's uranium. Much more epidemiological data are necessary in order to be able to make correlations with the distribution of potentially harmful elements for mining.

The following solutions to minimising environmental health impact are proposed:

- A nexus approach, incorporating a basket of experts in research teams, would go a long way to reaching more tangible conclusions about the environmental health impacts of mining in Africa.
- A collection of pertinent geochemical data and the Africa Geochemical Database. Radioactivity maps of rocks, soils and groundwater are urgently needed for southern Africa. Despite the many possible sources of radon within the country and the potential health hazards, there is a problem of data availability and a need for direct quantification of radon concentrations and exposure.
- Improvement of mine wastewater treatment and control techniques. Environmentally responsible practices, especially relating to water, have become central to the viability and acceptance of a modern mining operation.

- The use of plants to stabilise metals in soils.
- The useful application of tailings.
- The production of evidence-based policy briefs, which present the findings and recommendations of a research project to a non-specialised audience and are a vehicle for providing policy advice.

### Mining Legacies and Sustainability: Reflections on a Quarter of a Century spent looking at Abandoned Mines in South Africa

*(Dr Henk Coetzee, Specialist Scientist, Council for Geoscience, South Africa)*

There is a huge contrast in sites between what is seen in the field and the horror story of 6 000 abandoned mines.

Simplistic models are often used, but environmental impacts have to be looked at in a larger, broader context. Most of these result from the interaction of the deposit type, host rock and characteristics, the mining methods and the receiving environment. Conventionally, it is said that AMD is formed when sulphide minerals oxidise in an aqueous system in a mining environment. The processes that bring the ingredients together are as much a part of AMD generation as the ingredients themselves. How the ingredients are put together determines the impact. In the Mpumalanga Highveld environment, mining has created a new water table with new flow vectors allowing oxygen and water to mix with sulphides, resulting in AMD which then seeps to the surface. However, in a different environment, water flowing through a mine produces a good quality (potable) discharge.

Sustainability is about more than just environmental protection and rehabilitation. It should move from survival sustainability (not the desirable end state) through to rehabilitated mine sites being able to maintain quality of life and eventually improve quality of life ecologically, socially and economically. One definition of sustainability has to do with reducing existing environmental impacts, reclaiming mine sites for value-added reuse, investing in robust remediation solutions requiring no or limited active after care, ensuring long-term availability of information and knowledge to support institutional control and public awareness. Reducing environmental impacts with appropriate effort to a socially accepted and reasonable level does not always mean restoring to pre-mining conditions. Objectives, targets and metrics for success are essential. Social acceptance requires talking to people and agreeing on objectives and targets, as well as involvement of important stakeholders at all

levels of the process. A shared understanding can be developed more easily if all stakeholders work from a shared information base.

In terms of what is a reasonable level of rehabilitation, a basic point for SA is Section 24 of the Constitution of the Republic of South Africa, which deals with everyone's rights in relation to the protection of the environment, but does not mention the important aspect of capacity to solve serious problems.

The City of Johannesburg is a very good example of sustainable rehabilitation after a mining project. In this case, the economic development that accompanied mining continued after the closure of mines and this is an important consideration in respect of sustainability. The first reports of AMD in the Witwatersrand go back to 1903. Problems were acknowledged well after the peak of gold production and the serious efforts to address the problems came after mining revenue had peaked.

A consideration is that many mine rehabilitation projects fail because they rely on technological choices which cannot be sustained without continued and expensive inputs, and that the simplest solutions seem to be the best ones. Some experimental work (at pilot scale) is being done on abandoned mines, such as:

- The use of acid mine drainage and coal fly ash as a backfill that deals with AMD generation, spontaneous combustion and subsidence.
- Passive treatment using natural processes and materials to treat mine water in a gravity-driven system
- A simple alternative to pumping and treating water after it has flowed into underground mines is to prevent it from entering the mines in the first place.
- The use of discharge adits to drain underground mines to low-lying areas, minimising pumping during operations and eliminating pumping after closure.

Robust remediation solutions are needed by learning from nature and it is important to work towards systems that do not divert resources from other social needs. Mine rehabilitation should be used as a vehicle for education, training and skills development, particularly to develop a future generation that is able to take over and carry on with this work. The lack of information on historical mine sites (from the start of mining through the mining era) is a serious stumbling block in addressing mining legacies. It is essential that the information generated today remains available for future generations, and that work on finding sustainable solutions

to abandoned mines is done in multidisciplinary, transdisciplinary and interdisciplinary teams.

**The Legacy of Mining: Perspectives on Past Practice and Future Options - A Community-Centred View from South Africa**

*(Mr David van Wyk, Lead Researcher, Bench Marks Foundation, South Africa)*

Given climate change and the planetary challenges, it is important to reduce levels of consumption and slow down development and growth. Human economic growth is cancerous, destroying the planet and the conditions for life. Solutions can be found to AMD and to the uranium and radiation problem and so forth, but the possibilities of finding solutions will run out because the impact will be too vast unless growth is slowed down. It is necessary to begin to look at different models of development and engaging with the environment.

The Bench Marks Foundation has a community monitoring school and works in about 33 mine affected communities in SA alone and in mine impacted communities throughout SADC. Monitors have been trained to write about their experience with mining, understand the legislative environment they work in, have a basic understanding of the impact of mining, engage with power (big corporations and government), and to use their cell phones in order to communicate and share experiences with each other and learn from each other. Information is shared through the internet with people living in informal settlements.

The Chamber of Mines indicates that about 250 mining companies control more than 95% of the output of minerals in SA. The mining industry in this country is highly concentrated and monopolised, and therefore very powerful. In order to begin to deal with the challenges of mining and the problems associated with mining from the perspective of a community, it is necessary to bring information to the community to get information from the community and assist the community to find their voice to be able to interact with government and corporations. Communities must be able to ask politicians difficult questions. The identity of people in Africa is closely associated with the land. A government governs for its people and not for anything else, and needs to listen to and understand its people. Power should be disseminated down to the lowest levels instead of being concentrated in board rooms and parliament. The Foundation wants to create an independent fund that communities can draw from in order to employ experts to work with them and for communities to be able to deal knowledgeably with big corporations.

Mining creates far more jobs outside of Africa than within Africa. Most of SA's mining wealth has left the country and most of the jobs created from mining have gone to Europe. With the decline of industrial mining, especially in gold mining, the country has experienced large scale retrenchments, massive unemployment and growing inequality. In the Foundation's opinion, the life of mining in South Africa is coming to an end and the country needs to move beyond mining. After mine closure, the costs of the mine increase tremendously, but this cost is externalised to society and the solutions have to come out of the tax system and mine closure funds. As minerals are depleted so mines are abandoned and parts of Johannesburg (particularly the mining belt in the south) are reverting back to an informal settlement, as when mining started on the Witwatersrand in the late 1800s. Readings with regard to uranium and so on are at frightening levels and there are high concentrations of children suffering from cerebral palsy, as is found on the copper belt in Zambia.

As formal mines decline, so informal mining will increase. Many of the 6 000 abandoned, ownerless and derelict mines are occupied by informal miners. In Gauteng alone there are 34 000 'illegal', micro and survivalist miners, or Zama Zamas, eking out a marginal existence from artisanal mining. It is estimated that about 400 000 people are dependent on these small-scale mining activities. A solution to the problem of 'illegal mining' needs to be found. The Bench Marks Foundation is engaging with Zama Zamas along Main Reef Road in the Johannesburg area and building a trusting relationship with them. The Foundation believes that the Zama Zamas should be organised into small legal business entities as co-operatives, supported financially by the state and given education and training to do mining in a much safer way. There should be clusters of small operations and each cluster should be assigned an engineer, a geologist, a health and safety officer and whatever else is required to make their operations safe. There should be a central buying agency belonging to the state that buys all the small-scale miners' gold. This would eliminate the gangs and syndicates that take the gold off the miners. Formal supply chains should be created around the small-scale operations, with involvement from nearby communities.

It was essential to pay attention to the situation with regard to 'illegal mining'. Unless micro and survival mining activities are regulated and brought under control, there will be war and conflict over minerals (as is the case in the DRC) and this country will quickly move into an utterly failed state. The Bench Marks Foundation wants to create an independent

problem solving service that will mediate between communities and mining companies in order to resolve some of the intractable problems faced by mining companies when engaging with communities in order to create a situation where communities, small-scale miners and large corporations can co-exist.

**Panel Debate: The Challenge of Mining Legacy**  
(Moderator: Prof May Hermanus, Executive Director, CSIR, South Africa)

**Panellists:**

**Mr Marius Keet**, Acting Provincial Head, Department of Water and Sanitation (DWS), SA

**Mr David van Wyk**, Lead Researcher, Bench Marks Foundation, SA

**Dr Henk Coetzee**, Specialist Scientist, Council for Geoscience, SA

**Prof Theophilus Clavell Davies**, Department of Geology, University of Nigeria, Nsukka, Nigeria.

**Prof Hermanus** asked the panellists to give their reflections and suggestions about what can be done to address the legacy of mining in SA, in the short-term and the medium- to long-term.

**Mr Keet** explained that most mining activities are focussed in the northern parts of the country where water resources are scarce and the demand for water is growing. Currently, there are 1 654 operational mines in South Africa and only 518 are licenced. The country's mining legacy dates back to when mining began in the 1800s and over the years there has been a lack of environmental legislation to deal with the resultant challenges. Mines disappear once mineral reserves are depleted. Mine water treatment and waste disposal come at a high cost. The sustainability of conventional mine water treatment plants is a concern, particularly when mines close, because people rely on this water for potable use. In addition, there is a lack of regional approaches towards management of mine water. The perception that treated mine water (and waste water) cannot be sold as potable will have to change. The challenge relating to the mining legacy that has to be resolved in the short-term has to do with regulation and the need for a 'one-stop-shop' that addresses a basket of environmental issues (mining, water, air pollution). The problems have to be approached as opportunities and become resources.

**Mr David van Wyk** emphasised that creating an informed citizenry in South Africa is of utmost importance. Only an informed population can engage with and ask questions about the issues that are associated with mining in a meaningful way, and

organise the right solutions to those problems. In the long-term, it will be necessary to deal with the serious environmental issues in this country and in so doing, change the current consumer culture to one that is more oriented towards living with the planet rather than at the cost of the planet.

**Dr Henk Coetzee** remarked that communication is key and that many problems are because role players are talking past each other and working in silos. It is fair to believe that CEOs are serious about doing the right thing when it comes to mine rehabilitation, but they speak to other CEOs. Consultants work out what they can do around the problem but are limited to the financial support that the CEOs approve. Regulators have their own conversations and communities talk among themselves. Each group resists listening to the other groups. The conversation about the problems, such as uranium, must be opened up in order to work towards solutions as opposed to everybody taking up defensive positions, through a well-facilitated dialogue process.

**Prof Theophilus Davies** was of the view that more effort and resources must be put into studying the geochemistry of the surface environment of Africa under the Africa Geochemical Database project. This will be helpful to the medical profession in terms of diagnosing diseases of unknown aetiology. It is suspected that many diseases have a geochemical co-factor. More effort and resources are needed to improve the knowledge of rehabilitation techniques that will transform the abandoned mines and tailings dams into assets.

## QUESTIONS AND ANSWERS

**Mr Andrew Barker** (Town Planning Consultant) commented that Mr Keet's point about the need to look for opportunities rather than focus on the problems is critical. Prof Harold Annegarn (Cape Peninsula University of Technology) led a long-term dust monitoring programme in Johannesburg and it is interesting to see how the monitoring has resulted in the mining taking action to reduce the incidences. These successes need to be reflected. He asked for clarity about what is meant by '6 000 abandoned mines'.

**Prof Theophilus Davies** responded that progress has been made in tackling the dust emission related to mining in SA and its abatement, and some working groups continue to address this question. Dust related illnesses remain among the 10 most common causes of death in Africa. The fact that conditions such as silicosis are still prevalent despite the efforts indicates that more has to be done to abate the dust from mining activity.

**Dr Henk Coetzee** explained that the figure of 6 000 was derived from work done in about 2005. This figure has remained reasonably constant since then. However, the focus should not be on the number because the database of abandoned mines is being updated constantly. The Council of Geoscience has a database of mineral deposits and occurrences. To qualify for the abandoned mines database, a mine needs to be a deposit not an occurrence and there needs to be evidence that it has been mined in the past and was not being mined when last updated. The operation can be any size. Coal mines and the Witwatersrand gold mines tend to be larger mines. There is a process that will do a risk assessment of all of the mines listed on the database.

**Dr Willson Mutagwaba** (NTL Consulting, Tanzania) made the following points:

- The environmental health impacts of mercury are important as small-scale mining is increasing all over the continent and globally. There is a lot of evidence that mercury is becoming a major issue and we know that measures are being taken, but it is a major issue that has to be dealt with.
- Tanzania has examples of successful co-operatives but not so in small-scale mining. Many things have been tried, but it has been realised that by the nature of small-scale mining, co-operatives do not work.

**Prof Theophilus Davies** indicated that a dedicated team is looking at environmental health impacts of mercury, which is important mainly because it is a nuisance in small-scale gold mining.

**Mr David van Wyk** pointed out that mercury is new to mining in Africa and that health problems relating to the use of mercury in mining will not be eliminated unless the supplies to African small-scale mines are stopped. He added that Zama Zamas have organised themselves very efficiently. At the moment, they are involved in micro and survival mining even though it occurs on a very large scale, because the income is very small. Co-operatives seem to work quite well in Zimbabwe.

**Dr Moagaba Mathiba** (University of Botswana) enquired whether abandoned mines are prioritised in terms of the risks they pose.

**Dr Henk Coetzee** responded that a limited risk assessment on abandoned mines has been done. About 12 years ago, a risk assessment was put together based on what commodity was mined. An in-depth assessment of a small subset of the mines was done and anomalies of high and low risks were found. A reasonably low level risk assessment aimed at having data on as many sites as possible. Much of the data has to do with immediate physical risk. There is a programme to seal as many of the high risk shafts as possible. Formalising the opening of shafts where there are illegal miners would help solve the risk.

**Dr Salima Valiani** (MISTRA) mentioned that MISTRA decided to look at the question of the future of mining in SA using these approaches and the report should be published in mid-2018. She asked the panel what research question they think would bring together multidisciplinary and transdisciplinary research approaches, and whether such a question would be about solving existing (mining related) problems or about preventing them from recurring. She asked them to share their thoughts on the future of mining in SA, given the topic of this conference.

**Mr David van Wyk** responded that mining in SA will move towards smaller-scale mining as industrial mining declines. Smaller-scale to medium operations will be the future. Planning for the future needs to start now.

**Dr Henk Coetzee** commented that huge problems have to be solved and technical solutions implemented within a social framework. It is necessary to go about mining (where there is potential for development using mineral wealth) in such a way that it does not create problems for the future.

**Prof Theophilus Davies** pointed out that researchers are typically not good at doing multidisciplinary and transdisciplinary research. Research teams are

not being constituted well enough to be able to adequately address the wide variety of disciplines involved in researching the problems relating to abandoned mines. Doing it properly requires that every aspect of a project (the project design and the field research team, assembling of the data and so on) is multidisciplinary and transdisciplinary. There should be a battery of behavioural specialists in all the phases of the project work.

**Mr Marius Keet** was of the view that mining is here to stay for a long time. There is much potential to reclaim the tailings in facilities that are scattered across the country (particularly as a means to get to the source of the pollution instead of treating the symptoms) even if it is done by small-scale mining. A recent map shows the future development of mines in the upper part of the Vaal River system, which is the hub of the country. Mine owners, especially coal mine owners, talk of mining for another 50 to 100 years and beyond.

**Prof Harold Annegarn** (Cape Peninsula University of Technology) asked how security on the tailings relating to the small-scale mining of steel and plastic that occurs on the dumps could be dealt with, given the Bench Marks Foundation's community-based approach to small-scale mining. The mines are aware of the security problem but the reality is that fencing and pipes are being stolen. The failure of security has been attributed to the moral probity of the managers.

**Mr David van Wyk** responded that the Foundation would like to assist whoever is involved with the tailings around Soweto to engage the community to help solve the problem. For example, if a community co-operative or small enterprise does the fencing they will look after the fencing. They regard it as an imposition if it does not belong to them. The mine management, especially the Corporate Social Responsibility Officers need to do more to engage with communities as to how to involve them in the solution. There is much scope for involving small enterprises from the communities in solving these problems.

**Mr Gerald Mturi** (Tanzania Chamber of Mines and Energy) asked whether the Bench Marks Foundation has conducted a study about how much formalising the Zama Zamas would cost.

**Mr David van Wyk** responded that Zama Zamas were, like the taxi industry, entirely self-funded and black owned. These two industries ought to get more support from the state in order to make their operations safer, more meaningful and help the people live a more dignified life. This needs to be

addressed. Not enough attention is paid to Small, Micro and Medium Enterprises (SMMEs) in SA and most fail.

**Prof May Hermanus** asked Mr Marius Keet's view on how water licencing can address the problem of the mines being licensed individually as opposed to looking at the combined effect of concentrations of mines in certain areas.

**Mr Marius Keet** indicated that it is unfortunate that every mine owner has to have a water use licence. The challenge is how to do it smarter and avoid working in silos (every mine company does its own water treatment and own studies). The regulators should put forward an approach that integrates treatment systems and provides for one regional works instead of each mine having its own system. This would be in the licence conditions of each mine. Challenges within a certain region will be shared by all the licences in that region. Licence conditions ought to deal with the reality that water does not see boundaries of any sort.

## SESSION THREE: REMEDIATION EXPERIENCES I

(Facilitator:

Prof Theophilus Clavell Davies, Department of Geology, University of Nigeria, Nsukka, Nigeria)

### Remediating Mining Legacy Sites: Case Study China (Prof Qingshan Zhu, Institute of Process Engineering, Chinese Academy of Sciences, China)

The minerals in China (coal, iron ore) are low grade, which means that more waste material is produced, but China also has a large population and huge mineral consumption. Gangue and tailings occupy 4 million hectares of land, increasing by 40 000 hectares each year, limiting agricultural land.

The Chinese government issued the Land Reclamation Provision in 1988 and started to invest in research. Almost no land had been reclaimed prior to this. The Land Management Act of 1998 legislated land remediation for all damaged land and to further implement the Act, regulations on land reclamation and land reclamation monitoring were issued. The national strategy on land reclamation requires that all land affected by mining activity must be remediated and with costs carried by those responsible for damaging the land. Licence requirements for new mines stipulate a government approved land reclamation plan and establishment of a reclamation fund. In the case of closed mines, government initiates the land reclamation plans and establishes the reclamation fund.

China has 9 000 large mines and 260 000 medium and small mines producing over 7 billion tons of mining gangue and over 10 billion tons of tailings stored in over 3 000 tailings ponds. In the area of 100 000 hectares of land are reclaimed every year, increasing the availability of land for agriculture. Mining legacy sites become mine parks (used for environmental education), expansive forests or green spaces and photovoltaic power generation sites.

Five billion tons of coal gangue occupies about 13 700 hectares of land. Several technologies utilise almost 70% of the coal gangue, for making construction materials and filling materials for roads and white pigment from kaolinite, and for thermal power generation.

Ten billion tons of iron ore tailings are stored in over 2 000 tailings dams. Utilisation of the tailings is low value and most of the tailings remain unused, but new technology is being developed in order to recover iron ore concentrate. A pilot plant has produced good results, recovering 93% of the ore concentrate. A larger project, implemented with

Anshan Steel, processed 28.5 million tons of tailings to produce 6.2 million tons of primary iron ore concentrate, and after roasting-magnetic separation, 2.5 million tons of iron ore concentrate were produced.

### Case Study Germany: Uranium Mining (Dr Michael Paul, Division Head, WISMUT GmbH, Germany)

Dr Michael Paul presented some of his experiences of the past 27 years in relation to the rehabilitation of the uranium industry in the former East Germany, which until 1990 was one of the major uranium producers. As the mining of uranium in East Germany was part of the defence sector there was very little concern about the environment. The production philosophy was rigorous and irresponsible from an operational point of view. When the Berlin Wall came down in 1990 a political decision was taken to halt uranium mining, but no preparation had been made for mine closure. The Federal Government of Germany became the sole owner of the uranium mining company called WISMUT, and this meant remediation activities are paid for by German taxpayers. WISMUT is mandated to decommission and remediate mining legacy sites in East Germany involving the full scope of environmental remediation of 9 operational mines and 2 processing plants covering 3 700 hectares of contaminated mine land and almost one billion tons of radioactive residue, as well as addressing the stigmatisation of the regions affected by uranium mining.

There was very little potential for after use of the mining sites due to severe contamination. Underground mines were closed and immediately flooded. Safekeeping of solid mine waste, especially tailings, as well as proper effluent management had to be guaranteed and environmental monitoring and maintenance had to be taken care of. To date, almost 90% of the physical remedial work has been completed and radiological remediation objectives have been achieved, significantly mitigating the residual contaminant transfer into environment. The remediated sites provide unique examples of the after use of former uranium mining areas. However, active aftercare measures that are required, mainly with regard to water management and treatment, were not anticipated at the onset of the project.

The lessons learnt from this project have to do with the following issues:

- **Sustainability principles:** The definition of sustainability, 'to reduce existing environmental impacts to a socially accepted and reasonable level', only relates to legacy mine sites, which are being reclaimed with tax payers' money. It is increasingly problematic to ensure the long-term availability of information and know-how to support institutional control and public awareness.
- **Technical planning and supervision:** Site characterisation and a site-wide conceptual model used to develop remediation approaches were of primary importance. A 'one-size-fits' all approach could not be used. Strict on-site construction supervision with adequate quality assurance and quality controls are crucial.
- **Significant focus on the overall decision-making process:** Although this seems trivial, the entire project could fail unless cognisance is taken of changes that affect remediation criteria and ways to measure them during implementation.
- **Understanding and overcoming key bottlenecks:** Bottlenecks tend to relate to responsibility and financing, permits and procurement processes.
- **Key assets:** A master plan is needed to guide the dismantling of infrastructure and a stable workforce at operator and management level needs to be maintained, and there must be adaption to changing skill-sets and training requirements.
- **Water management:** This is of key relevance for mine closure projects and a crucial prerequisite for proper and project implementation. A holistic approach to water management is necessary.
- **Mine flooding:** Implementation must be understood as a site-specific learning process.
- **Water treatment:** This requires adaption due to changes in flow rates and composition, as well as increasing demands regarding the cleaning performance. This proved to be the biggest long-term burden related to mine remediation.
- **Gaining value from mine water:** Uranium is still being recovered from one of the underground mines, but it is no longer economical. There is some potential for recovery of metals and rare elements, but there are key obstacles to full-scale implementation. The potential for recovery of geothermal energy is very limited.
- **Gaining value from former mine land or tailings reprocessing:** The main after-use is for reforestation and others include small-scale business and recreation. Nevertheless, the activities are unable to compensate for the aftercare costs. Tailings reprocessing is not considered because the tailings remain hazardous.

- **Stakeholder involvement:** Complex environmental rehabilitation projects can only be managed by pro-active involvement of stakeholders. Early and consistent stakeholder consultation is key to the success of the overall process.

As a result of its vast experience in the rehabilitation of uranium mines, WISMUT is able to offer the following to the international mining community:

- Internationally accepted benchmarking project for mine closure and remediation of radioactive waste
- Proven and standardised technologies and workflows
- State-of-the-art approaches to Environmental Impact Assessments (EIAs), monitoring, data and know-how management
- Well documented case histories
- Multitude of knowledge sharing activities.

Balancing ecological, economic and social interests is necessary for sustainable remediation solutions. The key success factors of the WISMUT programme are:

- Strong and decisive political motivation
- Retaining valuable skills
- Immediate and stable funding
- Recognition of non-technical factors

Long-term surveillance and monitoring activities have to continue for decades into the future in order to ensure sustainability of remediation results.

### **Case Study Germany: Hard Coal Mining in the Ruhr Area**

*(Dr Boris Dombrowski, DMT GmbH & Co. KG, Germany)*

DMT is a core brand of the TÜV NORD GROUP and RAG is the company responsible for the coal mining activities in the Ruhr area. In 2007, the German government decided to stop subsidies for coal mining by 2018. A result of this decision, RAG split into two companies, but RAG retained the hard coal mining activities. RAG-Stiftung, a foundation, was established in 2007 and tasked with the socially acceptable closure of hard coal mining activities by the end of 2018, building up the foundation's assets, launching of EVONIK Industries on the capital market, financing perpetual mine management and supporting education, science, and culture in the mining region.

The technical activities to remedy the historical damage done post-closure in 2018 are:

- Remediation of historical damages and consequences, and monitoring subsidence and compensation of related damages.
- Current activities are focussed on mine closure, water management, minimising the environmental impact and developing a concept for minimising the perpetual costs.
- To develop ideas for further use of the mining areas and installations, and develop the land.

About Euros 220 million per year are required to finance the perpetual obligations and used for mine water management (65% of the total cost), groundwater purification and polder measures (to mitigate the subsiding of the ground surface to form lakes due to mining activities). In order to reduce the high cost of water management, a concept for future mine water management in the Ruhr area sets the following targets:

- Conversion to well operations, where the underground pumping stations are replaced by submersible pumps operated from above ground
  - Reduction of pumping stations in the whole region, by using existing underground water pathways (interconnectivities)
  - Raising the mine water level as high as possible
  - Reduction of environmental impact.
- These issues have to do with modelling the mine water flow and reactive mass transport.

Box model, mine water management simulation software, is a forecasting tool that considers special aspects of water flow in mine areas in order to assist decision-making. It provides the possibility to calculate thousands of situations (randomly generated) and is used to predict rising mine water levels and the geochemistry of flooding water quality, as well as to identify uncertainty considerations, and provide sensitivity analyses and safety assessments. It is fast (in calculation time) and cheap. The 'box model concept' is a very powerful tool to simulate mine flooding even in very large coal mine regions where many individual mines are involved, such as the Ruhr area of Germany.

## SESSION FOUR: REMEDIATION EXPERIENCES II

(Facilitator:

**Prof Christian Wolkersdorfer, SARChI Chair, Tshwane University of Technology, South Africa)**

**Remediating Mining Legacy Sites: International Experiences and Lessons Learned by the International Atomic Energy Agency (IAEA)**  
(Dr Horst Monken-Fernandes, Engineer, IAEA, Vienna)

(Presentation via Skype)

The remediation of uranium mining legacy sites is in the context of the broad activities developed for environmental remediation and takes into consideration safety (health) issues, technological aspects, managerial strategies, and elements of costs and financing. In some cases psychological matters are relevant and public opinion is becoming an increasingly important driver of the entire process. The International Atomic Energy Agency (IAEA) expects member states to have proper infrastructure (regulatory, managerial and human resources) in place as well as technologies for managing their radioactive legacies and resolving all related issues in a timely, safe and cost-effective manner. The IAEA does not provide financial resources to member states, but provides support in respect of capacity building and procurement of equipment.

Remediation is thought about in the scope of ongoing and future operations. The integration of

remediation in the overall lifecycle management of the installation is being increasingly promoted in ongoing operations. The objective is to avoid the need for future extensive remediation work. Successful remediation of existing sites depends primarily on good planning, resources, availability of technical and scientific knowledge and capability to assess long-term performance of the remediation project, and good communication with relevant stakeholders.

The IAEA supports best practices in uranium mining through its Department of Nuclear Energy, which focusses on the nuclear fuel cycle and waste technology. The waste and environmental safety section of the IAEA's Department of Safety and Security takes care of the environmental remediation of uranium mining legacy sites. Assistance provided by the member states is co-ordinated by the Department of Technical Cooperation.

The Technical Cooperation Programme is the main mechanism through which the IAEA delivers services to its member states. The IAEA assists to build, strengthen and maintain capacities in the safe, peaceful and secure use of nuclear technology in support of sustainable socio-economic development,

using both specialised technical and development competencies and focussing on a wide range of technical issues. All member states are eligible for support, but the focus is on the needs and priorities of less developed countries. The programme is operational in four geographic regions: Africa, Asia and the Pacific, Europe and Latin America and the Caribbean. The capacities of technically advanced countries can be used to address the needs of less advanced countries. The programme also supports a diverse portfolio of national, regional as well as inter-regional projects.

The Co-ordination Group on Uranium Legacy Sites comprises national and international stakeholders, and provides a forum for information exchange, supports project planning and implementation issues, addresses radioactive waste management issues and coordinates efforts to optimise resources.

The Regulatory Supervision of Legacy Sites has as its overall objective to promote effective and efficient regulatory supervision of legacy sites, consistent with the IAEA fundamental principles, safety standards and good international practices. This is to be achieved through the collection, collation and exchange of information on legacy sites, as well as through the generation of mutual support through presentations and discussions on how effective and efficient regulatory supervision can be implemented and maintained.

Environet is an international network dedicated to environmental management and the remediation of radiologically contaminated sites. The scope of Environet includes lifecycle management of active and future operations as well as legacy sites. Its objectives are to:

- Organise an expanded range of training and demonstration events
- Facilitate information exchange and experience sharing amongst organisations with advanced programmes
- Create a forum in which expert advice and technical guidance can be provided.

The IAEA has identified constraints to the implementation of environmental remediation programmes in terms of the fundamental requirements such as adequate legal and regulatory framework, adequate funding and access to appropriate technologies, and availability of trained personnel. Significant constraints relate to national policy and institutional infrastructure for liability and project management, and waste disposal routes and associated transportation systems.

The overall environmental remediation project lifecycle and critical steps that need to be implemented in any assistance provided to member states follow a specific sequence. Some of the steps are very time consuming and require sufficient time in order to be addressed adequately.

Lessons learnt by the IAEA in respect of remediating mining legacy sites are:

- For proper and efficient implementation of remediation works, governments need to establish national policies supported by a robust legal and regulatory framework.
- Provision of appropriate funding, properly qualified personnel and historical knowledge have the most effect on a remediation project.
- Enhanced state support of these activities is essential to the successful and sustainable implementation of IAEA technical assistance.
- Societal aspects can dramatically influence the implementation of remediation projects. It is therefore necessary to develop well-considered stakeholder involvement plans and appropriate communication programmes.
- The involvement of national counterparts and stakeholders needs to be well co-ordinated.
- A joint international effort is needed to assure the advancement on implementation of remediation of uranium mining legacy sites. These efforts need to be co-ordinated to make country specific support effective and sustainable.
- International organisations can make available examples of good practices and facilitate these efforts. Important points to be highlighted include:
  - The stimulation of cooperation, co-ordination, and co-funding of remediation activities
  - Sharing of information on past, ongoing and planned activities in order to maximise effectiveness and avoid redundancy
  - Exchange of information on best practices and experiences to avoid repeating historical mistakes
  - Provision of stable platforms with permanent membership for the elaboration of joint projects
  - Outlining specific needs to be funded and available regional solutions.

The key element for successful implementation of environmental remediation plans is to bring all the players together (implementers, regulators and technical and scientific institutions, as well as stakeholders).

**Remediating Mining Legacy Sites: Case Study Chile**  
(Dr Nils Hoth, TU Bergakademie Freiberg  
(University of Resources), Germany)

The case study addresses Chilean tailing bodies, investigating the structural understanding, the water behaviour and the option of selective recovery.

The interest in industrial strategic elements is due to the drastic rise in demand from the high tech industry. Although estimations differ and risks change, it is important to have a deep understanding of what the tailing bodies contain and to be able to adapt to varying situations. Tailing bodies are secondary mining bodies because the energy for milling is still invested.

Structural understanding of tailing bodies requires general characterisation of the tailings body by taking sampled profiles. Direct field measurements are very important to understand the layering behaviour and identify general aspects. In grain size analysis it is important to understand that there is agglomeration. Distribution of elements depends on grain size fractions. Mobility is important and can be characterised by sequential extraction. The main results of the structural understanding are:

- There is a layering inside the tailings body
- This layering is not related to large mineralogical differences but by grain size and spill technology effect
- Agglomeration (and rims) must be kept in mind in the normal flotation procedure

Geophysical investigations in terms of the structural understanding of tailings bodies showed that when looking at trench behaviour for instance, the 'roof tile structure' is important to understand in relation to selective re-mining.

In terms of selective re-mining of tailings bodies, a study looked at defining mining options on the basis of the material knowledge to figure out the pros and cons of the equipment choices. The different equipment choices can be mobile, hydraulic and continuous. The continuous equipment option (bucket wheel excavator and conveyor) was found to have some important pros compared to the other methods as it provides for the selective excavation of layers, high capacity and low operational costs, and long-term use of machinery.

Studies on another copper (Cu) heap leaching residual materials also showed aluminosilicates were attacked and rare-earth elements (REE) are mobilised. Residue of the heap leaching process is washed and dumped.

The project also did much work on the question of metal retention and reuse of mine water in relation to ionic separation, using onsite materials, such as zeolites and peat.

**Panel Discussion: Remediation Experiences**  
(Moderator: Prof Christian Wolkersdorfer, Tshwane  
University of Technology, South Africa, Secretary-  
General, International Mine Water Association)

**Panelists:**

**Dr Michael Paul**, Division Head, WISMUT GmbH, Germany

**Dr Nils Hoth**, TU Bergakademie Freiberg, (University of Resources), Germany

**Dr Boris Dombrowski**, DMT GmbH & Co. KG, Germany

**Prof Qingshan Zhu**, Institute of Process Engineering, Chinese Academy of Sciences, China

**Dr Horst Monken-Fernandes**, Engineer, IAEA, Vienna.

**Prof Christian Wolkersdorfer** (Tshwane University of Technology) requested panelists to briefly state what to do and what not to do to remediate legacy mine sites based on their experience. Their responses were:

- It is a key issue to understand the setting in relation to an abandoned mine site.
- Give the tailings body a soul and try to understand it.
- The most important thing in flooding mines is to develop a highly sophisticated flow model and transport unit model.
- Technology is the most important factor in remediation.
- Understand the problem well and have appropriate infrastructure in place that allows for the remediation plan to be implemented.

**Prof Christian Wolkersdorfer** asked Dr Nils Hoth what advice he would give to people who are new to the field of mine remediation about what they should focus on and which investigation must be done first.

**Dr Nils Hoth** responded that when his students arrive at a site that he is already familiar with, he starts with simple investigations in order to gain a general understanding of the site and the materials, by looking for eluates of the materials for pH values and to understand that the eluates will give a good idea of whether there are differences in the material.

**Prof Christian Wolkersdorfer** asked Prof Qingshan Zhu's view of what the Chinese regulators should do

to ensure that the majority of the mine sites in China will be closed in a suitable way in future.

**Prof Qingshan Zhu** responded that the most important thing is for the regulators to ensure transparent law enforcement of the regulations. The Land Management Act of 1998 was not taken seriously and therefore companies failed to take action. More recently, however, the government had begun to take environmental issues seriously, starting with law enforcement.

**Prof Christian Walkersdorfer** asked Dr Horst Monken-Fernandes what, from his experience in remediation of uranium mining sites, the common problems on the abandoned uranium mining sites are and what someone who is going to remediate uranium mining sites should take into primary consideration.

**Dr Horst Monken-Fernandes** indicated that, unfortunately, although the IAEA supports member states it has not achieved as much as it would have liked to. Many cases where there has been little progress have to do with legacy sites where the responsible party no longer exists and countries are faced with problems that they do not have the appropriate resources to address. It is necessary to have a firm political decision from the country to take the remedial action into consideration and ensure that it correlates with the international community so that consistent lines of assistance can be established and supported by funding. Technology itself is not the key problem. Sometimes the issue can be resolved in a simple way. It is essential to have a good understanding in place between all stakeholders at national level in order to ensure national assistance and resources, with a well-established plan of action for the way forward.

**Prof Christian Walkersdorfer** asked Dr Michael Paul what he would have done differently if he had had the knowledge he has now, thinking back over his 26 years' experience in the remediation of uranium mine sites.

**Dr Michael Paul** responded that he would not have done much differently. One thing that was learnt was that mine flooding is a tough issue if there is not going to be any long-term active treatment. There was underestimation of the potential risks in terms of storage capacity and high water inflows as adverse effects of downstream water causes. There is a combination of solutions, technologies and approaches and each one comes with an individual risk that things could develop in a different way. It was a very hard lesson for a mining company which, during the time it was in operation, was not

dependent on asking the public for their opinion because it knew what had to be done, but lessons can be learnt from public opinion. If the remediation projects were done again, this very important lesson would be taken into account from the onset of each project.

**Prof Christian Walkersdorfer** mentioned that there is a view that hard coal mining could start up again in Germany in five to ten years' time and asked that if so, how problems such as those experienced in relation to abandoned mines could be avoided when starting a new mine.

**Dr Boris Dombrowski** was certain that hard coal mining would never happen again in Germany and that in ten years' time coal will no longer be burnt and transformed into energy in Germany because renewable energy would have taken over.

## QUESTIONS AND ANSWERS

**Mr Piet Smit** (Land Rehabilitation Society of Southern Africa) asked Dr Hoth whether in their respective case studies any drilling was done to look at the density differences in the layers and whether there was any core drilling.

**Dr Nils Hoth** responded that geo-electrics were used to understand the depth of the body and in one instance sounding was done in relation to this structure. Some drillings were investigated, but the research project was about showing the capabilities to study what is possible in principle and not to plan in detail the re-mining of the tailings body.

**Ms Mariette Liefverink** (Federation for a Sustainable Environment) explained that South Africa's National Nuclear Regulator was appointed in terms of the Act to protect the public, property and environment against nuclear damage. Tailing storage facilities in the gold fields are classified in terms of the Act as nuclear installations. All the legacy sites (abandoned but not ownerless) are unregulated. The National Nuclear Regulator interprets its mandate very narrowly and is affiliated to the IAEA. She requested that the IAEA should build capacity in the National Nuclear Regulator to be able to publish regulations to address these legacy sites.

**Dr Horst Monken-Fernandes** clarified that the IAEA affiliation is by member states and not individual organisations. If its members request support to address a specific issue, the IAEA will provide the support, but it does not have the possibility to approach a government, dictate or suggest what it should be doing. Civil society would have to address

the matter with the relevant government entities and the IAEA would be willing to provide assistance should there be an understanding that additional support might be necessary to address the issue at hand. This is the way that the system is organised.

**Mr Igor Klopčič** (Consultant) pointed out that the previous sessions had given the impression that profit can be the driver of remediation, but it was not mentioned that the money to remediate has to come from the mine closure fund. He asked the panellists whether profit can be a sole driver of mine site restoration.

**Dr Michael Paul** indicated that he is not aware of any abandoned site that has the potential of generating

more profit than burden. If a site has high potential for profit, it will not be abandoned. In the case of Germany, there was political pressure and political will, and funding was made available to do the right thing at the uranium mining sites. Even so, some cost drivers made the remediation projects extremely expensive.

**Prof Qingshan Zhu** remarked that in his experience, it is necessary to implement cheap technology and not spend excessive amounts on elaborate technology. Extending the lifetime of the tailing dams is also financially beneficial.

## **SESSION FIVE: UNDERGROUND PUMPED HYDRO ELECTRIC STORAGE (UPHES) TECHNOLOGY I**

**(Facilitator: Mr Ewald Erasmus, Director, Geotech, South Africa)**

### **UPHES Pre-feasibility: Case Study South Africa** *(Prof Frank Winde, Head of Mine Water Research Group, North-West University, South Africa)*

Prof Frank Winde presented the findings of a pre-feasibility study on implementing the underground pumped hydroelectric storage (UPHES) concept in the Far West Rand (FWR) goldfield. The consortium investigating the UPHES concept consists of research, mining and energy components under a multilateral MoU. UPHES is not a new idea. It was investigated in the late 1990s by Eskom and similar studies have confirmed viability of the concept elsewhere in the world.

The research group believes that putting pumped hydro storage underground using abandoned or closed mines is technically feasible in SA due to specific characteristics and that it is economically viable and affordable on an investor level as well as on a national economy level.

In some cases, deep level mining in SA takes place right below dolomitic karsts, which need to be protected because they contain water several times the volume of the Vaal Dam (supplying Johannesburg with water imported from Lesotho and elsewhere). Pumping and treating the current AMD (which is acidic mine water) is expensive and the quantity of acidic mine water could triple soon, depending on the lifespan of the remaining mines. SA has the deepest mines in the world and pumping costs will be significant, threatening their economic viability. The post-closure requirements imposed by the DMR

include post-closure development responsibilities. Recent legislation, the Mine Water Management Policy, holds mines liable for water they discharge, including AMD, a perpetual process involving indefinite costs to any mine. Sinking a fully equipped shaft in SA through hard rock costs in the area of R14 billion. This expensively generated asset needs to be preserved. In considering putting pumped hydro storage underground, it is important to take energy supply into account. Eskom was unable to meet peak demand between 2008 and 2016 and since then has had an oversupply of electricity and significant increases in the cost of electricity. In addition 'black start capacity' is limited. SA is a water scarce country with water deficits in Gauteng, the economic hub of the country, threatening industrial, mining and agricultural activity in the region. It is anticipated that putting pumped hydro storage underground will help address some of these issues.

The UPHES concept involves pumping water while electricity is cheap into an upper reservoir, increasing the potential energy of the water. When the electricity is expensive (during day-time on weekdays) the water flows back to the lower reservoir generating electricity through turbines and is sold to Eskom. A profit to run the system is derived from the price difference between electricity used for pumping and the significantly more expensive electricity generated. However, 20% more energy is needed to run the whole system than what can be generated. This system could therefore not be solely relied upon to provide all energy needed but is designed to complement other forms of energy

generation through temporal storage energy. The idea is to use part of the existing underground mine void as an upper reservoir on one or more levels, with a pressure pipe connecting to a lower reservoir, and pumps and turbines (separately positioned) that either pump or generate energy.

Two mine sites on the FWR were selected for the technical feasibility of UPHES. A calculation showed that two levels would suffice to store the water that would be needed for this concept. The amount of energy that can be generated in megawatt hours (MWh) depends, inter alia, on the shaft depth. This can be calculated considering height difference, density of water, gravitational pull and turbine efficiency. It is estimated that using existing underground tunnels as storage is significantly cheaper than storing water on the surface. Possible complementary add-ons to UPHES are harvesting geothermal energy from mine water and storing solar and wind power. Sibanye Gold Ltd. currently needs a total of ~500 MW per day, which could be produced by the modelled UPHES for eight hours per day.

In terms of the economic viability of UPHES, efficiency of 80% can currently be achieved (reduced by pumping ingress to 77%), implying that 23% more energy is used than generated. Nevertheless, the average electricity selling-buying profit margin per year at 8-hour operating mode is 257%. Business cases looking at the total revenue from selling peak electricity and water showed that the two mine sites could generate R1.145 million and R841 million per annum respectively. A potential geothermal component and grid services (power storage capacity provided to Eskom) could be added to bring in additional revenue. UPHES could thus provide monetary benefits for the mines, Eskom, government as well as communities.

The areas where research is needed and where there are risks and uncertainties have to do with:

- Geological aspects, such as seismic effects of frequent mass shifting, natural and mining-related seismicity, boundary pillar integrity/ stability, stability of void structures and water tightness of tunnels.
- Water-related aspects, such as karst feed flow fluctuations, silting of reservoirs, pressure and temperature induced calcite precipitation, contamination of bottom ingress and acidification.
- Engineering aspects, such as pressure pipe construction, suitable machinery, corrosion issues and drainage time from long tunnels.

- Economic aspects, such as future energy market in SA.
- Legal, administrative aspects, such as liability issues, sterilisation of mineral resources, regulatory uncertainty in terms of the status of UPHES and applicable fees.
- Socio-political aspects, such as the nationalisation debate, tensions between industry and government, and organised labour.

There is a need to conduct a pre-mortem and SWOT analysis that address the risks and uncertainties.

### **Implementing Pumped Hydro Energy Storage at an Open Pit Gold Mine: A Pilot Project from Australia** (Mr Simon Kidston, Executive Director, Genex Power Limited, Australia)

The site used for the project is Kidston Gold Mine, located in northern Queensland, where there is very good solar resource, one of the biggest gold mines in Australia and more than 100 years old. The mine closed in 2001 when the economic reserves were extracted. The owners at that time had to spend AUD 40 million doing the mine rehabilitation and maintained the site since closure. Genex Power acquired the site three years ago as an ideal platform to create a renewable energy hub. It is made up of 50 metre-high waste rock dumps and two enormous voids that will be developed into a very large and strategic pumped hydro energy storage project.

Genex Power's strategy is about creating a renewable energy hub by utilising all of the infrastructure left behind from the mine and positions the company and its shareholders in order to benefit from a structural transition happening in Australia (and other parts of the world) as the economy is decarbonised. Genex Power has managed to garner strong support from the federal, state and local government in Australia, mainly due to the strong social benefits of revitalising the mine.

The site is being developed in two stages:

- Stage one: The construction of the 50 MW Kidston solar project, a solar farm capable of generating 145 000 MWh of clean, renewable energy per year through half a million solar panels mounted on a tracking system to optimise the sun's energy. The stage one solar farm will be completed soon and be able to generate electricity into the grid. It is located on the tailing storage facility, which has proven to be the ideal location to build a solar farm. On-time and on-budget delivery of stage one is essential in order to secure the same funding partners for stage

two. The cash flows from stage one solar project will sustain the company and the site for at least 30 years into the future.

- Stage two: A large pumped storage hydro and solar expansion project involving 250 MW peak generator/energy storage fully integrated with 270 MW of large-scale solar. The solar energy will be used to power the pumps and make an integrated renewable energy hub, a very strategic asset in the context of the Australian energy market. Feasibility optimisation has been completed and the final stages to put the project into construction were underway. Pump storage hydro was chosen as the technology for energy storage for three main reasons, namely:
  - It is a very mature, proven technology, with more than 1 000 plants operating around the world.
  - It has a long economic life (at least 80 years) and low cost.
  - It is a 'giant water battery' that has the capability to store energy in a low cost, efficient way by virtue of having water at elevation.

Operation of the pumped hydro energy storage plant is based on a very simple business model that has to do with using power when the demand and prices for power is low to pump water from a lower reservoir to the upper reservoir through tunnels and turbines. When the demand and price for power is higher, the same water is released through tunnels and turbines to generate power that can be sold to the grid to derive revenue. The Genex Power project will be fully capable of operating in that way and is co-located with a large solar farm, which provides an intermittent solar resource that is made reliable and dispatchable through the operation of the hydro plant.

Feasibility optimisation was completed to a bankable standard in November 2016 and concluded that the best configuration of the project was 250 MW of capacity for a 6-hour generation capability. One of the key learnings of the feasibility was the importance of considering the impact of the system on the grid when in generation mode and pumping mode, and because pump storage relies on the charge between peak and non-peak electricity prices, it is necessary to choose the size of an asset that would not unduly push electricity prices either upward in pump mode or downwards in generation mode.

A joint venture between two large Australian companies has been appointed to do the detailed engineering design and construction work of the project. A small optimisation of the feasibility was

done because of the recognition that electricity markets in Australia are transforming and placing greater emphasis on the value of energy storage, 'black start' capabilities and synchronistic generation. The current key focus is to put in place the contracts to support the project finance, most importantly the long-term revenue off-take deal. The cost of the pumped hydro energy storage project is about AUD 330 million, and the cost of the solar is AUD 400 million, to be funded under one package because of the interdependency between them.

In transforming the mine site to a renewable energy generator, one of the advantages is the ability to use the infrastructure that was left behind by the mine. Having permits in place proved to be an important time, risk and cost saving advantage. The freehold in Australian law extinguishes native claims, which can delay the development of any sites. Because the site was drilled extensively by the previous owners, there is a huge wealth of information and studies about the geology, pitwall stability, fauna, flora and more, which have been utilised by Genex Power as a reference for the Kidston project.

As in many other countries, energy policy is very topical in Australia due to the growth in renewables, with high levels of penetration of wind energy in South Australia, supported by government through implementation of policies to stimulate the development of wind energy. However, two extreme weather events in 2016 that caused blackouts in South Australia alerted politicians to the importance of grid stability and energy reliability, as well as storage to complement the growth of renewable energy. Government is instigating a number of policies to specifically reward energy storage. The National Energy Guarantee mandates all generators of energy to have storage and reliable dispatchable energy. Government has been very supportive of this development primarily because it gives the abandoned mine a sustainable economic future and will contribute to energy storage and grid reliability, but also financially. The principle disadvantage of utilising the Kidston mine site for the project is the extreme remoteness of its location, which adds costs in terms of mobilisation of people and equipment and makes it difficult to retain staff. In addition, environmental constraints have to be dealt with.

The main lesson learnt in developing this project is the need to 'think outside the box' to identify opportunities for attractive commercial returns from otherwise unattractive assets. A significant pumped hydro energy storage development would be of great benefit to SA.

**UPHES Feasibility: Case Study Finland***(Mr Ernst Zeller, Regional Director, Pöyry Energy GmbH, Austria)*

The case study is from Pyhäsalmi Ore Mine in Finland where various consideration options of what to do after closure in two years' time are being considered. Pöyry Energy GmbH's client is investigating alternative possibilities of using the mine not only for energy storage, but also as a big data storage facility and for climate-related issues, because Finland's intention is to use existing mine infrastructure for the benefit of future generations. A feasibility project has been developed and the environmental permitting process is underway.

Pumped storage is a proven and most important current technology. The main pumped storage projects are in China followed by Japan and the US, and countries in Europe. Although batteries will play a dominant role in the future economy and development of energy storage, pumped storage is expected to find its role in energy storage capabilities primarily due to its efficiency, extended life time and relatively low operational costs. Increased effectiveness of renewables is expected to enhance the use of a wider variety of renewables in the future and bring them to the forefront of energy generation and storage. Combining the generation of wind, solar and hydro energy with pumped storage power plants (PSPP) will be necessary in order to deal with fluctuating energy generation. One of the benefits of PSPPs is that they can be installed close to the demand for energy (such as cities) reducing transmission costs.

Pyhäsalmi mine provides a 1 400 m shaft and well developed infrastructure both on the surface and underground. Its good location allows for balancing the Finnish power grid and its geology is very well investigated. PSPPs serve an important purpose in providing ancillary services outside of the market. Geotechnical conditions are one of the most important issues in developing PSPPs and have to be investigated in detail in order to establish the most favourable location for reservoirs and caverns. In considering the most appropriate location for the PSPP in the Pyhäsalmi ore mine, the use of 700 m as well as 1400 m elevations were investigated, taking into account the efficiency of different turbine technologies. The economic evaluation was done from a 'day-ahead market' perspective using the free market model with an energy forecast system for the next 30 years. The outcome of the generation benefit analysis suggests that the most feasible configuration is around 75 MW and six hours storage size. The feasibility study covered a wide range of options from 75 MW to 200 MW. The existing upper

reservoir would be widened and the shaft down to the lower reservoir would be used, and new caverns installed. The layout of final tunnels is optimised in respect to geological conditions and the existing tunnel system. Safety measures in the case of an accident in the power plant have been taken into account. Cycle efficiencies at rated operation point are around 80%, with losses occurring during the generation and the pumping processes. A transport study showed that the curves will have to be widened by about 1.5 m to allow for large equipment to be transported.

The current situation is that project feasibility has been developed through in-depth investigation and studies, considering all the possibilities that could occur during the construction phase and finances to undertake the project were being sought. If realised, this project is likely to be the PSPP with the highest head in the world.

**Close of Day***(Mr Ewald Erasmus, Director, Geotech, South Africa)*

Mr Ewald Erasmus presented the following take-home message from the conference thus far: All mines differ to such a degree that each one requires its own rehabilitation plan (encompassing all facets of rehabilitation), partly driven by circumstances outside the physical boundaries of the mine, such as local legislation, community needs and expectations, and stakeholders.

## SESSION SIX: TECHNOLOGICAL SOLUTIONS: UNDERGROUND PUMPED HYDRO-ENERGY STORAGE (UPHES) TECHNOLOGY II

(Facilitator: Dr Klaus Krüger, Head of Plant & Product Safety and Innovation Management, Voith Hydro Holding GmbH & Co. KG, Germany)

### UPHES Feasibility: EFZN Case Study from German Ore Mines

(Prof Uwe Düsterloh, Clausthal University of Technology, Germany)

The presentation provided an overview of geomechanical aspects of research funded by the German Federal Ministry for Economic Affairs and Energy and conducted by the Institute of Waste Disposal Technologies and Geomechanics to estimate the feasibility of underground pumped hydro-energy storage plants using abandoned mines. The Energy Research Centre of Lower Saxony (EFZN) coordinated and guided the interdisciplinary research executed by eight participating organisations.

Within the framework of the Kyoto Protocol and supplementary agreements, Germany had committed itself to becoming a greenhouse gas-neutral country by 2050. To reach this status, no fossil or nuclear energy carriers should be used, no biomass crops should be cultivated for energy-generating purposes, and there should be no carbon capture and storage. Germany has decided to shut down its nuclear power plants in 2022. This priority created the need for a bio-renewable energy supply from hydropower, wind power, photovoltaics, biomass and household waste.

Much of the renewable-based electricity is generated by wind and photovoltaic power. The use of both these resources has increased significantly over the past decade. The supply of electricity derived from hydropower remains relatively constant, since the relatively small size of Germany and the population density make it difficult to establish hydropower plants. The intermittent nature of wind power, solar power and hydropower necessitated the development of temporary energy storage, and underground pumped hydro-energy storage (UPHES) technology was identified as eminently suitable with respect to both storage capacity and release time. If UPHES technology is used, the large impact of conventional pumped heat electrical storage (PHES) on the landscape could be avoided. This regulated energy could be created by, for example, compressed air energy storage, classical hydro-pump systems, batteries, hydrogen production or by an UPHES system.

Germany's current energy storage capacity based on pump storage and Compressed Air Energy Storage

(CAES) amounts to approximately 10 000 MW. By replacing conventional power plants with renewable energy, it is estimated that energy storage could be increased to 85 000 MW to deal with fluctuating demand.

The Institute of Waste Disposal Technologies and Geomechanics investigated the feasibility of UPHES at Bad Grund ore mine with respect to the load-bearing behaviour of rock mass, taking the site-specific boundary conditions into account, indicating the static stability of such a system. Prof Düsterloh elaborated on the operational procedure followed, including empirical and analytical, as well as numerical investigations.

In summary, the findings of the geomechanical research on the project indicate that UPHES plants are generally feasible and that their feasibility is significantly affected by site-specific boundary conditions. Although the content of geomechanical investigations for a UPHES plant is generally not particularly innovative, additional benefit could be delivered by addressing questions and demands through the economical, technical, electrical, ecological, geological, judicial and rock mechanical aspects of a UPHES plant.

Realising an entire UPHES plant is still only at the conceptual stage due to its complexity and the high-risk capital demands. To bring a UPHES plant to life, a pilot site-specific project would be required for evaluation purposes.

### UPHES Feasibility: Case Study from German Hard Coal Mines

(Prof Andre Niemann, University of Duisburg-Essen, Germany)

Prof Niemann introduced the findings of a study on the feasibility of establishing UPHES in former hard coal mining environments. The first phase of the study involved the development of an implementation concept. The project was supported by the German Federal Government and the Regional Government of North Rhine-Westphalia. Experts from several disciplines, including hydropower engineering, mining, geological, geotechnical, water and energy, collaborated in the research conducted at the Prosper-Haniel mine in the Ruhr area of Germany.

The Vianden pumped hydroelectric storage (PHS) project in Luxembourg is a classic example of an established and reliable surface pumped storage system that has been in use for the past 100 years, but conventional storage systems such as the one at Vianden are becoming increasingly difficult to establish. Suitable hilltop sites are difficult to find, since society no longer condones the use of surface space for this purpose. This situation creates the need to develop new storage options, but there are divided opinions on this matter. Some people believe that no extra storage capacity is required, which gives rise to uncertainty with respect to the way forward.

Many years ago, a decision was made to phase out the Prosper-Haniel hard coal mine and close it down in 2018. In 2010, an investigation commenced to determine how the existing infrastructure could be used after closure. Many ideas were considered to transform the post-mining landscape through energy transition options.

The end of hard coal mining in Germany came at the time that the country was working to reduce its carbon dioxide emissions by replacing fossil fuel with renewable energy sources such as wind and solar. A key challenge is to find ways to store energy for later use. One solution is to use a pumped energy storage system. Existing pump storage systems make use of hills or mountains for the necessary difference in altitude, but a deep coal mine such as Prosper-Haniel would also work.

The Prosper-Haniel mine in Germany's Ruhr region was analysed for its potential to become a follow-up facility as an underground pumped hydroelectrical storage project. The Ruhr coal basin has been extensively mined and explored underground during the past 200 years, and a wealth of geological information and geotechnical experience in the handling of rocks is documented in reports and on maps. Although the geology of the research area is complex and complicates the placement of pumped storage, the mining operators are confident that, with their wealth of knowledge and mining experience, it is possible to find the most suitable site in the deep ground for a UPHES facility.

The existing infrastructure at the Prosper-Haniel mine offers many tunnels and even at the depth of 1 200m, a 30 km tunnel system is available at no cost that could be adapted to a pump-storage scheme. Only four exit tunnels from the deep ground to the surface would be used. Other existing tunnels would not be used, as it is easier, safer and more reliable to construct new tunnels and the investment risk is much lower. Since the mine is still in operation, it is

easy to access in order to validate the geology and maps and take samples in the deep ground. The miners are extremely helpful in finding solutions to research questions.

Two caverns would be required, with their orientation based on geological conditions and taking restrictions into consideration. One cavern would be for the turbomachinery and the other for electrical generators and energy transformers.

Classical PHS systems have both reservoirs on the surface, whereas at least one of the reservoirs of an underground PHS (UPHS) system would be below the surface. The lower reservoir, a tunnel of 15.5 km, would form a storage ring with a volume of 600 000 m<sup>3</sup>. The upper reservoir could be established on the existing mine site, which is ecologically acceptable. The concept development provides a 200 MW power generation for four hours. The total capacity will be 853 MWh each cycle.

The main results of the first phase are the technical and economic feasibility of using the existing mine infrastructure for the potential development of a pumped-storage facility in a densely populated area with high energy demand. The area offers a well-developed existing grid infrastructure. The innovative location is a technical highlight, which is proving to be a unique selling point worldwide.

The social and non-monetary findings of the study include the readiness of the region for efficient energy production and storage. A UPHEs project would make a significant contribution towards a sustainable post-mining landscape that would have economic effects within the Ruhr area. The ecological impacts of a UPHEs system are minor compared to conventional PHES. The results of a study of public acceptance indicate positive acceptance of renewable energy and the future use of mining areas for cultural or local recreational purposes areas, and for industry, business or energy supply. A UPHEs system is more publicly acceptable than classical energy storage concepts. The technology leadership that would be involved and the contribution of mining knowledge also provide an international perspective.

The second phase of the project (2016–2018) involves project management, networking and public relations. Government is interested in supporting the implementation of a UPHEs project, but requested the identification of measures and estimation of costs for securing the options. The Federal Ministry of Economic Affairs and Energy requires a pilot project, but only if the business case is close to being successful.

The project has been running for seven years, during which time the media have been very supportive. After an article on the project was published in the Wall Street Journal early in 2017, many countries requested more information. There is worldwide interest in this new energy-storage concept.

**Harvesting Geothermal Heat from Mine Water:  
A Pilot Project from Germany**  
*(Dr Nils Penczek, Ruhr University Bochum, Germany)*

The aim of the Ruhr Mine Water (Grubenwasser-Ruhr) project was to develop innovative and efficient concepts for using the geothermal heating energy in mine water in the Ruhr area. Geothermal energy presents an alternative to the use of fossil fuels such as oil and gas.

The Ruhr area is the biggest metropolitan region in Germany with a population of more than 5.5 million. Mining in the area dates back to the 15th century, but all hard coal mines are due to be closed in 2018. At their peak, the mines employed approximately 400 000 miners, but only a few thousand miners are still left.

The project is supported by the German Federal Ministry for Economic Affairs and Energy. The project commenced in 2016 with a budget of more than one million Euros for the first three years and is divided into three phases: (1) Concept phase (2016–2019), (2) Implementation phase (2019–2022) and (3) Monitoring phase (2022–2025).

The four partners taking part in the project are:

- Chair of Energy Systems and Energy Economics at Ruhr University Bochum, which is responsible for management and coordination of the project
- Ruhrkohle AG (RAG) coal mining corporation, which is responsible for controlling the water drainage system
- DMT, a global consortium providing interdisciplinary services, which is responsible for water management
- Eimer Project Consulting, a project consulting company that is responsible for managing shareholders and stakeholders and assisting with development programmes.

The technical objective of the project is to connect all heat consumers to a single low-energy network, distributing the warm mine water to consumers with low energy loss. A heat pump will raise the temperature for individual customer requirements.

The mine water temperature varies between 15°C and 30°C in different shafts. Approximately 90 million cubic metres of mine water would be available each year; if just five degrees of the temperature of this quantity of water is used, it would generate approximately 500 GWh of thermal energy. It would be a waste of energy not to use the mine water.

Successful pilot projects for harvesting mine water heat are active at the Auguste Victoria mine in Marl, the Zollverein mine in Essen and the Robert Müser mine in Bochum. The information gathered in these projects has assisted in formulating the proposal for initial investigation in the Ruhr Mine Water project.

Mine shafts have been identified close to potential mine water heat consumers and categorised according to accessibility and the availability of infrastructure. Category I comprises drainage shafts, which offer the highest thermal potential; heat exchange takes place on the surface with raised mine water. Category II comprises shafts with drainage preparations; a closed loop system with an underground heat exchanger would be required to harvest the mine water heat. Category III comprises shafts with limited access; water will be harvested with a ground probe in a closed loop system. Category IV comprises sealed shafts that could be re-opened depending on consumer demand.

The energy concept includes a central heating system and a decentralised heating system. The central heating system would connect consumers to the network by means of pipes, and the water temperature would be more than 65°C. At a central point, the heating systems would be kept in a container and energy technologies such as CHP (combined heat and power), a heat pump or gas technology would be used to raise the mine water temperature. If additional input is required, the heating system would need a natural gas container (for gas technology). The disadvantage of the central heating system is that less than 30% of the heat from the mine water can be used. This system would be used by city utilities and in older buildings where higher temperatures are required.

The decentralised heating system is much simpler. Consumers would be connected to a network with temperatures lower than 30°C, and energy technology (in the form of a heat pump) would be installed in each building. Each individual consumer could decide to heat, or not to heat, without any effect on other buildings. This system would enable consumers to change the cycle of the heat pump to either heat or cool the water. The greatest advantage of the decentralised heating system is that the

temperature of the mine water could be raised by at least 70%. This system would be installed in new buildings, for example.

Hot spots for potential projects have been identified in the Ruhr area. In Essen, a category II shaft at the Zeche Amalie mine is situated in the middle of a reconstructed urban district including business and office buildings as well as dwellings. The main goal of this project would be to utilise a thermal energy mix of mine water and other renewable energy.

A category I shaft at the Robert Muser mine in Bochum is close to a commercial expansion area and a school building. Only mine water would be used in this project. In new commercial buildings a passive heating system would be used for depots and warehouses, while heat pumps would be used for offices and sanitary rooms. The main goal of the project would be the comparison of the centralised system with the decentralised system.

In Aden, a category I shaft at Haus Aden mine has been identified for reutilisation. Approximately 200 new buildings are planned, including business and commercial buildings as well as dwellings. This project aims to supply the network with approximately 20°C. A heat pump would be installed in each building and the consumer could decide whether to use heating or cooling, without any effect on other buildings. The project requires close cooperation with the city utilities and urban planners. The main aim of the project in the specific area is to demonstrate that carbon dioxide could potentially be reduced by approximately 1 050 tons per annum compared with using fossil energy systems.

### UPHES Panel Debate

*(Facilitator: Prof Frank Winde, Head of Mine Water Research Group, North-West University, South Africa)*

#### Panellists:

**Dr Nils Penczek**, Ruhr University Bochum, Germany

**Prof Andre Niemann**, University of Duisburg-Essen, Germany

**Mr Ernst Zeller**, Regional Director, Pöyry, Austria

**Prof Uwe Düsterloh**, Clausthal University of Technology, Germany

**Mr Simon Kidston**, Executive Director, Genex, Australia

**Prof Frank Winde** asked the panellists to suggest how the UPHES concept could be successfully implemented. The following ideas were suggested:

- The best driving force is money, a business case and a suitable site. Site-checking is always required. The business case and investments should then be discussed. Funds could perhaps also be made available to restore the ecology damaged by the mining activities.
- It is important to get support from government and to set up a legal framework to enable private investment. Considerable funding is available worldwide, but private investors only spend money when suitable framework conditions are in place, including the political circumstances and the tax and tariff systems of the country.
- In Australia there is strong acceptance from both the government and local community of the idea of reworking old mines to make them sustainable in product assets. Such acceptance is critical for any project. As many countries implement more renewable energy systems, the focus on energy storage will become more prominent. The implementation of storage to make the energy reliable and dispatchable will also drive the economics.
- Suitable people must be sourced to establish a plant, and it is crucial to connect all stakeholders as soon as possible.
- UPHES is generally feasible; the technique is available and consumer needs have been researched against the background of profit, which is important for industry.
- Everyone has a responsibility towards the next generation and the environment, and government should drive the technique in the future.

### QUESTIONS AND ANSWERS

**Dr Klaus Krüger** (Voith Hydro Holding GmbH & Co. KG) observed that the pumped storage facility at a plant in Germany was above the 'legal maximum' level for ground water, which meant that there would be no conflict between the ground water level and the pumped storage project. In South Africa, the cheapest way to deal with abandoned mines is to flood them completely. Acid drainage from the mine is only treated if it reaches the surface. This approach would be incompatible with a parallel pumped storage system. If a pumped storage system were installed, the whole mine would have to be kept dry and the pump station would have to generate additional income to compensate for the cost of bringing the acid mine water to the surface for treatment.

**Prof Frank Winde** explained that the mines included in his presentation would be flooded mainly by good quality water from the overlying dolomitic aquifer.

Some 90% of this clean water will be captured, leaving 10% that can be polluted by migrating through the mine (10 MI/d). By daily blending the polluted 10 MI with the 1 000 MI of clean water that is circulated, the dilution by factor of 100 reduces all pollutants to levels of potable water standards. The 100 MI of ingress per day would still have to be pumped out (90% from a shallow depth at relatively low costs). The energy needed for this is only a fraction of the energy generated by daily dropping the 1 000 MI over the entire shaft depth. The additional energy needed for pumping out the ingress reduces the overall efficiency from 80% to 77%, still allowing the generation of healthy profits under current market conditions. In addition, this reduction in efficiency will be overcompensated by selling the clean excess water. It is not correct to assume that flooding a mine is the cheapest option. Currently billions of Rand are spent on pumping and treating AMD from flooded mines in and around Johannesburg. This needs to be done as long as people are living in the area and thus places a large and indefinite financial burden on future generations.

**Dr Felix Toteu** (UNESCO, Nairobi) expressed concern about the notion that finance drives the rehabilitation of environmental damage from mining activities. He emphasised that rehabilitation is a moral, ethical, environmental and social responsibility. Whatever the main driver for rehabilitation, it is essential to ensure the sustainability of the environment and the community on conclusion of a project.

**Prof Frank Winde** responded that rehabilitation after mine closure requires money. In his experience, most mining companies do take responsibility for rehabilitating the environment after closure. Government-funded projects require only a single investment. The Ruhr area recognised that long-term commitment to rehabilitation was required, and a large fund was established for that purpose that yields approximately €220 million per annum. How such yields can be sustained under conditions of an uncertain stock market and a low-interest environment remains to be seen. Instead of relying on external funding to sustain long-term rehabilitation, it would be best for a site to keep generating income, which is the ultimate aim of using closed mines for UPHES projects.

**Dr Henk Coetzee** (Council for Geoscience) expressed concern about seismic effects on rock stability and the seismicity of daily mass rock shifting.

**Prof Uwe Dusterloh** replied that the stationary stress situation induced by excavation and loading related to operations was equivalent to only 1% of the stress produced by an earthquake and would not affect

the safety of a UPHES system. In the event of the flooding of openings between rock masses, internal pressure would be created in these openings, which would stabilise the rock mass similar to reinforcing such openings. Withdrawing the water from the openings would increase the stress on the rock mass, which is a dynamic effect. This effect has not yet been investigated on hard rock. Much research has been done regarding rock salt, and the results show possible effects on the rock mass and the size of the induced stresses. Prof Uwe Dusterloh commented that, in general, he was not concerned about the seismic effects.

**Mr Simon Kidston** commented that, in the context of the project in which he was involved to explore the development of two open-cast mines, the stress in the rocks had been considered because the weight of the water fluctuates as the water passes from one reservoir to another. Rock strength is a critical issue that needs to be determined in the feasibility study.

**Prof Andre Niemann** added that the geology of the site is of great importance. In his experience, individual site investigation and risk assessment must be performed as a first step, which takes time. Maps, geological behaviour and other knowledge provided by mining activity should be taken into consideration to determine the risk factors. Mining companies should be required to submit a first post-mining plan to government ten to 15 years before the closure of a mine.

**Dr Henk Coetzee** asked whether saving costs by using abandoned or closed mines for renewable energy purposes would be the optimal solution for the energy grid from an investment perspective, or whether it would be better to invest in drilling a new shaft at the most suitable location for a pumped-storage facility where the risks were likely to be lower.

**Prof Frank Winde** believed that drilling a new shaft that would be better suited for the same purpose would not make much difference. An important advantage of using existing shafts is the utilisation of synergies that would result in overall winning solutions.

**Mr Simon Kidston** observed that investors consider the risks and possible returns before deciding whether to invest in a project. By demonstrating that the risks could be lowered and returns created while utilising the existing infrastructure would contribute to achieving the objectives of investors.

**Mr Ross Wilson** (BBE Group) asked whether there had been any studies to establish whether the use

of hydropower would be the best option for storing electrical energy for the grid compared to other competing energy storage technologies.

**Mr Simon Kidston** commented that all the various technologies for storing energy had been carefully investigated, and pumped storage had been chosen primarily for economic reasons because the technology is mature and low cost. For large-scale applications, pumped storage is undoubtedly the most efficient way to store power, but if the installation of power at a domestic distributed level were considered, batteries would be used instead. In comparing capital costs, the initial installation cost of pumped storage would be 15 times cheaper than batteries (at the current cost of batteries), and when taking the different lifespans of the two technologies into account. If the price of batteries were to decrease over time, the advantages of using pumped storage might diminish.

**Prof Frank Winde** added that more renewable energy techniques are being developed, the implications of which are that more storage capabilities would be required. All technically feasible possibilities should be investigated.

**Prof Andre Niemann** commented that in Germany a storage strategy is being discussed, which should be provided by government and agreed on with society. Investors need reliability, and government should pave the way towards a future energy system for it to be successful.

**Mr David van Wyk** (Bench Marks Foundation) commented that land is available that could be used for solar energy, which would act as an exclusion barrier, preventing people from building informal housing in that area. Community participation is critical. He was also concerned about people building on land where tailings have been re-mined and moved to another site, since radon levels at such sites are problematic. It would be advisable to develop radon legislation in South Africa. Such areas could also be used as solar farms. Another advantage of using abandoned mine sites is that these sites very often have electricity substations that could be linked to the national grid. If these abandoned sites and existing infrastructure are not used, such substations are often stripped by copper thieves and others, and a huge investment in the electricity supply is lost. Mr van Wyk emphasised the importance of the community investing in such projects in order to create a sense of ownership and participate in the benefits.

**Prof Frank Winde** commented that if abandoned mines are not converted into something useful, they

would become a liability. The use of abandoned mines and their available infrastructure could be considered as turning liabilities into assets.

**Mr Igor Klopčič** (Consultant) referred to a suggestion from the past that abandoned underground mines could be used as water storage facilities. Considering future global warming, water would become Africa's 'gold'. He suggested revisiting the possibility of storing water in underground mines for use in agriculture, industry and possibly for drinking. Complete flooding of mines is not envisaged, but controlled flooding of gold mines, which supports the point that uncontrolled flooding of gold mines is probably one of the worst options.

**Prof Frank Winde** explained that the karst aquifers that yield water for the mines have perhaps a 1 000 times more capacity than all the shafts combined. If the karst aquifers could be preserved, it would be more important than having 1 000 cubic metres of additional water storage. Storing water in disused mines would also be hazardous. Even if the first flush idea were applied, where water quality will gradually improve over time, this would not mean that the decanting water would be pristine. In addition, some of this water might pollute the thousands of millions of cubic metres of water contained in the karst aquifer. Prof Winde did not believe that this water storage option would be viable.

**Prof Christian Wolkersdorfer** (Tshwane University of Technology) referred to Mr Ernst Zeller's work at Pyhäsalmi mine in Finland on severely polluted mine water with, for example, a sulphate concentration of 13 to 15 grams per litre. He referred to Mr Zeller's presentation on day two of the conference that suggests that the lowest part of the mine must always be kept dry to ensure access to the turbines. Consequently, highly polluted mine water would have to be pumped up 1 400 metres for treatment whilst the system is running. He asked who would cover the costs of the pumping and mine water treatment.

**Mr Ernst Zeller** (Pöyry Energy GmbH) answered the question from a socio-economic perspective. He commented that the mine owner had benefited financially from the mine in the past and is responsible for developing various possibilities for future mine closure. The mine owner and government are required to develop and present options to deal with unemployment as a result of mine closure. The costs and benefits have to be weighed up and the legal framework provided for operating the system. Since it is an isolated/ closed system, it would not cover the waste water, which would have to be treated. This would involve costs that must be weighed against the benefits of a pumped storage

system and of employment and the social effect on the area. Government should then decide which approach to take. It would be unacceptable to flood the mine due to acid pollution of the water.

In response to Prof Christian Wolkersdorfer's question on how damage would be avoided when acidic water flows through pump systems and turbines, **Mr Simon Kidston** explained that where water from two open pits was used, the water had been sourced from a nearby dam and river system. The initial quality of the water was very good. Over time, sulphide levels in the pits increased, but did not present major challenges with respect to the performance of the turbines.

**Dr Shan Holmes** (Real Search) suggested that the development of financial models surrounding UPHES systems should be seriously considered. She asked what progress had been made in this regard and what the 'mix of finances' entailed. Without adequate funding, these systems could not be implemented.

**Mr Simon Kidston** responded that much work had been done to develop a financial model for pumped storage. This complex model is further complicated by the difficulty of accurately forecasting future energy prices. Genex Power Ltd. had partnered with a major energy user that would operate the asset in a way that would suit their portfolio. Once the contract has been secured, the project finance would be a very simple exercise.

**Dr Henk Coetzee** (Council for Geoscience) noted that some people still recommend relying on coal or nuclear power to meet future energy needs, but the potential problems need to be pointed out. It has been determined that a pumped storage system is not needed next to a solar power system. Some mines in the western Bushveld propose supplementing their energy supply through wind farms on the coast, which is feasible because of the availability of the energy grid. Where an energy grid is available, this level of optimisation could also be considered because energy storage next to the power station would not be required.

**Mr Ernst Zeller** commented that, given anticipated future temperature increases due to global warming, when new technologies or new energy systems are considered, it is everybody's responsibility to decrease the emission of carbon dioxide levels immediately, disqualifying the use of coal for energy generation. Possibilities and socio-economic responsibilities would have to be seriously considered, because everybody would be affected.

**Mr Phil Tanner** (Land Rehabilitation Society) had previously been involved with mine closure issues in South Africa for a number of years. He asked whether it would be sustainable for water containing high levels of pyritic material to be pumped up and down a gold mine that would continue generating acid mine water. Similar concerns would apply to the Australian situation where the water quality was initially good, but now contained increased sulphur levels. He asked whether the situation was expected to stabilise, or whether precipitation issues affecting equipment in the medium to long term would have to be dealt with.

**Mr Igor Klopčič** commented that water storage in closed gold mines should use a haulage system rather than a stopping system, which would contain dust and much pyrite. By using a haulage system, acid mine drainage issues could be completely avoided.

**Prof Frank Winde** responded that, according to geologists, below a critical depth stopes close naturally and are sealed off through expansion due to gigantic pressure of the overlying rock column.

**Mr Igor Klopčič** also commented that South Africa has some of the deepest mines in the world, up to a depth of four kilometres. He suggested the option of storing radioactive waste very carefully in such deep mines. Any such business proposal would require careful examination.

**Mr Phil Tanner** commented that he had dealt with a much simpler, technically feasible concept that could use 40–60% of existing coal mine water for irrigating appropriate agricultural crops. The results of Water Research Commission research projects over the past 25 years support the technical feasibility, but there has been no implementation yet. He asked how new technology displaying significant promise could be implemented.

**Mr Simon Kidston** explained that in Australia, blackouts caused by wind in certain areas had intensified government's focus on finding solutions to the problem. The project had engaged with the political environment from the start and was strongly supported at all levels of government. They had also worked hard at gaining the support of the media, to the point where the project is well known in Australia and has become self-perpetuating.

**SESSION SEVEN: OTHER INNOVATIVE APPROACHES****(Facilitator: Dr Henk Coetzee, Specialist Scientist, Council for Geoscience, South Africa)****Geothermal Acid Mine Drainage Treatment***(Dr Thakane Ntholi, Council for Geoscience, South Africa)*

Dr Thakane Ntholi thanked the conference organisers for the opportunity and privilege to present the work she had done as part of her PhD research. She had researched the possibility of using geothermal energy as a power source for the PUMP (Passive Underground Mine-water Purification) model she had designed for in-situ remediation of acid mine water (AMW), particularly in the Witwatersrand gold mines.

South Africa has a long and deep history of gold mining. Some mines are as deep as four kilometres below the surface. The interconnectivity of mines within a goldfield poses a challenge. If a mine starts to fill up with AMW that is not pumped out, the water would flood the mine and move on to the next mine, increasing the pumping pressure for the owner of the next mine. If the second connected mine does not pump out the water, that mine would also flood and the AMW would move to the next interconnected mine. This challenge highlights the need for an integrated remediation system that includes all the interconnected mines, resulting in the development of the PUMP system.

Dr Thakane Ntholi's approach had been to develop an in-situ remediation system, mainly to reduce the costs of continuous water pumping from the mines to a treatment station. The possibility of using the mines as water storage facilities was then investigated, since it would be ideal to prevent water loss due to evaporation.

The PUMP geo-engineering system is based on mimicry of natural processes, hydrothermal vent systems, taking place under the sea. By adding some engineering to the natural process, the PUMP's efficiency is increased. The system is reliant on the functioning of sulphate-reducing bacteria and powered by geothermal energy harvested from below the mines, and would be installed in mines of between three and four kilometres deep. To develop a geothermal system, two wells must be drilled from the deepest part of the mine to an extended depth of approximately four kilometres to generate geothermal energy that would be harvested from the rocks below. The system allows the mine to be flooded in a planned flooding approach, and AMW from the controlled flooded mine would then be pumped down the injection well. This water is the geothermal fluid that will circulate to harvest the heat

pumped up the production well to a binary power plant where organic fluids are used to generate power. The residual water would then return to a reaction chamber in the mine containing sulphate-reducing bacteria, where the sulphate in AMW would be reduced to sulphide. The sulphide would then react with metals that would precipitate in metal sulphides. The precipitate formed in the process would be controlled. This reaction has a positive impact on metal acidity, reducing the acidity of the water in general. The ensuing water, once it has been treated, could then either be pumped to the surface for alternative uses such as agriculture or further purification for potable use, or it could be allowed to flow back into the mines, which would contribute to the dilution factor. If such dilution continues over time, an underground reservoir of water could be created that is self-purified through the system.

Temperatures ranging between 90°C and 120°C at a depth of eight kilometres had been confirmed based on physical and thermal rock properties of the Witwatersrand basin. These temperatures are sufficient for harvesting geothermal energy. The Witwatersrand basin can be classified as a potential reservoir of low-enthalpy geothermal energy (with in-situ temperatures of below 150°C). By using systems such as the Organic Rankine Cycle system and improved technology, electricity can also be produced by harvesting low-enthalpy geothermal energy. Calculations indicate that approximately 59.6 MW of geothermal heat could be extracted from a one square kilometre reservoir at a depth of eight kilometres, which would be sufficient to drive a PUMP system for 20 years.

The model must be refined, and the output of geothermal energy tested, which would require a pilot study site for the PUMP system. The PUMP system has the potential to offer a multifaceted solution, but there has been only limited interest due to uncertain economic feasibility.

**Recovery and Reprocessing of Mine Tailings: Experiences from Germany***(Prof Tobias Elwert, Clausthal University of Technology, Germany)*

Prof Tobias Elwert shared some experiences and findings of a national research project dealing with the re-mining and reprocessing of two tailings ponds. The reprocessing of sulphidic tailings from mineral processing has gained a lot of attention in the last

decade. The research project is funded by the German Federal Ministry of Education and Research, and some local companies are also cooperating with the university. The overall goal of the project is to develop a re-mining and reprocessing concept.

The Bollrich tailings pond that was investigated was used between 1938 and 1989 and contains the tailings from the mineral processing plants of the Rammelsberg deposit (about four million metric tons), which used flotation processing. The shale-hosted sedimentary exhalative ore was mainly mined for its unusually high content of valuable sulphidic minerals and trace metals. Furthermore, barite was temporarily recovered.

The project has been divided into sub-tasks, starting with the sampling and characterisation of tailings material, which includes mineralogical investigation, and deposit and geomechanical aspects. A re-mining concept must be developed that would include adapted mining technology and techniques, and optimised machinery. The final step would be to develop the reprocessing concept, which involves the investigation of mineral processing flow sheets; for some of the outputs of these flow sheets, metallurgical processes would be required. The project requires close cooperation with local companies from the mining industry for assistance with the business model, and with local authorities for compliance. From a legal point of view, the project is very complicated, and both economic and ecological calculations would have to be applied.

At the beginning of 2016, a company collected samples from the bottom of the pond and modelled the deposit in chemical and mineralogical terms. The most important contents of the tailing pond are, in descending order, shale, mixed carbonate, barite, pyrite and sphalerite, galena as well as chalcopyrite. The tailings material shows little alteration below the surface layer but is still heavily inter-grown despite the small average particle size. The composition of the material is characterised as generally homogeneous. The main deviations in the chemical properties are caused by variations in barite concentrations. During early mining activities, in particular, barite was not won by flotation, resulting in higher barite concentrations in the lower tailings. The main deviations in the physical properties were caused by changes of the inlet points during the operation and changes in comminution over decades.

The motivations for the project are twofold. On the one hand, the tailings pond contains several minerals and trace elements that have experienced large increases in both price and demand such as barite,

indium, cobalt and gallium. The latter three as well as lead, zinc and copper are not mined in Germany and recovery could reduce import dependency. On the other hand, the tailings pond has high acid mine drainage potential and considerable amounts of toxic heavy metals. Although the tailings dam is stable now and further investigations are necessary, the old-fashioned tailings dam set-up as well as the presence of a karst nearby pose the risk of dam failure. A village is closely situated to the tailings pond and such collapse would be catastrophic and might result in extremely high follow-up costs. The recovery of material from the tailings pond or removal of potentially harmful materials could considerably reduce long-term costs.

The project investigated the reprocessing of tailings material at laboratory scale. It could be shown that barite can be recovered by flotation, but only approximately 40% of the barite can be recovered in a quality suitable for the market. Sulphides can be floated and subsequently leached, but flotation suffers from low selectivity. The reasons for the low selectivity are mainly fine intergrowth and particle sizes. So far, complete desulphurisation could not be achieved through flotation. Further comminution seems unfeasible.

The overall planning for re-processing revealed that several different aspects must be taken into account, leading to higher decision complexity than in most profit-driven primary raw material projects. These include technical issues such as the mining of clayish material with unknown underground stability, special permits and licenses due to overlaps in environmental, mining and waste disposal regulations, follow-up cost mitigation, public acceptance, and the development of an intelligent and sustainable mineral processing route.

The overall goals for process development at the Bollrich tailings pond include probable sanitation. Residue reduction is therefore a priority, because the old tailings ponds would have to be redeposited in a safer location, which would be costly. In situ mining and deposition at the Bollrich location is not possible. Removal of the material from the tailings pond would have to be conducted layer by layer to secure the dam's stability.

The project reached several conclusions regarding reprocessing. Currently there are many investigations on the reprocessing of tailings, but reprocessing should not only be value carrier driven. Value contents are usually comparatively low, but might reach economic or strategic relevance in the future, especially in Europe. Profit remains the main motivation for reprocessing, and to a lesser extent,

avoiding costs. Reprocessing efforts need to take a longer-term perspective, and sanitation or other follow-up cost compensations should be considered.

The project reached several conclusions for current tailings management. The mining industry should place more emphasis on anticipating and monitoring potential problems and future value potentials. It would be helpful if different residues could be separated and stored separately. The externalisation of follow-up costs must be prevented to enforce a more sustainable mining approach.

### Resource Extraction from Mine Waste Water

*(Mr Hans-Jürgen Friedrich, Fraunhofer Institute for Ceramic Technologies and Systems, Germany)*

The Fraunhofer Society is the largest non-profit research organisation in Germany, acting on behalf of the German Federal Ministry of Education and Research. The society employs approximately 23 000 people in approximately 70 institutes, covering most branches of modern science and technology. Its work focuses on applied science in eight business fields, including environmental process technologies, energy, ceramic materials and technical diagnostics. The activities include the design of processes and systems for processing.

Water quality changes and becomes polluted with dissolved minerals when exposed to soil or rock. Typical water treatment processes include leaching, solving and often oxidation. Lignite and bituminous coal mining as well as the mining of sulphidic ores around the world result in acidic waters containing high concentrations of sulphate and heavy metals, which often render the water unsuitable for further use if allowed to flow into receiving water systems.

The typical environmental impacts of mining on water quality include:

- Coal mining: water contamination by sulphate emissions, iron, aluminium and manganese
- Bituminous coal or uranium ore mining: radium contamination
- Potash mining and coal mining: salting (sodium chloride), for example in the German Ruhr area
- Ore mining: pollution of heavy metals, metalloids, radionuclides and sulphates
- Bore hole mining (for oil, gas and geothermics): pollution of radionuclides, heavy metals, hydrocarbons, as well as increased salt load.

State-of-the-art mine water treatment includes well-established and widely used precipitation processes (liming), biotechnical processes (sulphate

reduction), pressure-driven membrane processes that can produce potable water, ion exchange and other in-situ processes (mostly through the reduction of contaminants). All these methods have both advantages and drawbacks, but none of them allow for the extraction of value or the possibility of selectively removing the main contaminants such as sulphuric acid at sufficient reaction velocity for large-scale application.

Electrochemical separation of sulphates and heavy metals entails membrane electrolysis that enables the removal of sulphate ions (the main contaminant) and conversion into useful products such as fertiliser (ammonium sulphate). For the removal of heavy metals, the Rodosan process (an electrochemical sulphate separation process) has been developed. The Rodosan process can also be applied to treat wastewater with elevated chloride concentrations so as to produce products such as chlorine and chlorate. The process has been tested with water from different mines containing a wide range of hydrochemistries and concentration values. Pilot testing achieved sulphate reduction of 50–70%. The results indicate that fertilisers produced from mine water are of similar quality to commercial products, and no heavy metal contamination has been detected.

Critical challenges experienced during the development of the Rodosan process include problems with highly mineralised water in the beginning, causing blockages of cells and piping by heavy calcium carbonate scaling. The problem was solved by optimised regeneration processes for the cells and modification of the internal cell design.

Electrochemical separation of sulphate and heavy metals remains affordable. Proper selection of the electrolysis set point is crucial for energy demand and process stability. A separation process that combines electrolysis and electrodialysis could be used in cases of water with a high salt content, if the aim is potable water.

The Rodosan process has been modified to also enable the separation of toxic heavy metals and radionuclides from mine water, deep geothermal water and formation water. Heavy metals in the water contribute to scaling, and the treatment of geothermal brines or formation water proved to be a promising method to avoid this problem. Some interesting concentrations of valuable materials in brines include sodium chloride, potassium chloride, copper, zinc, lithium, indium, manganese and more. The value of dissolved metals and salt could exceed the value of extracted thermal power.

The current target is to maximise benefits by combining electrochemical water treatment, energy generation and storage, and agriculture. This would enable the production of purified water, possibly drinking water, agriculture and service water, hydrogen and fertilisers, for example.

Electrochemical membrane processes are of interest for the treatment of different types of mine water. The positive features of the system include its ability to selectively separate contaminants and convert these into valuable products. The processes are robust enough to manage water containing high levels of calcium carbonate. Efficient application requires the careful selection of process parameters.

## QUESTIONS AND ANSWERS

In response to a question on whether there was any possibility of parts of the machine becoming contaminated by radionuclides, Mr Hans-Jürgen Friedrich responded that the goal is to treat the water above ground. A reactor would be installed containing a water treatment system that would rid the brine of radionuclide contaminants. The reactor accumulates the contaminants, and the subsequent treatment would separate various products, for example, lead. The process is simple and easy to manage.

## SESSION Eight: MINING LEGACY: LEGAL AND SOCIAL ASPECTS (Facilitator: Dr Shan Holmes, Consultant, Real Search, South Africa)

### Transforming Artisanal and Small-Scale Mining in Africa through Research and Training

*(Dr Felix Toteu, United Nations Educational, Scientific and Cultural Organisation, Nairobi Office, Kenya)*

Dr Toteu, coordinator of the Earth Science Programme for Africa, gave a presentation on the environmental and health impacts of abandoned mines in sub-Saharan African countries, which is implemented by United Nations Educational, Scientific and Cultural Organisation (UNESCO) and the Swedish International Development and Cooperation Agency.

Artisanal and small-scale mining (ASM) is flourishing in Africa, but governments are not anticipating the possible future impacts. In this context, the project was launched with the following objectives:

- To understand how abandoned mines negatively affect ecosystems and the health of adjacent communities
- To identify through experimentation the most appropriate rehabilitation technologies and remedial actions for sites contaminated by trace metals from mining
- To use science-based evidence to influence policies on issues of abandoned mines.

UNESCO operates at 29 experimental sites in 17 African countries, and more than 100 scientists from various fields (earth, life, medical and socio-economic fields) are involved in the projects.

At a mining site in Kédougou in Senegal, mercury amalgamation for gold has been performed for ten years. Tests have been conducted in the Kédougou area to detect mercury concentrations in human hair, and the results are becoming alarming. In Zimbabwe, geochemical and health data spatial maps for three Pumped Hydroelectric Storage (PHES) sites indicate that, in the eastern areas where arsenic and silver levels are high, there is higher prevalence of disease. These results emphasise the importance of data collection.

Throughout Africa, ASM has various facets, and has increased dramatically since 1990. In West Africa, ASM is many people's livelihood. ASM produces more than 35 different minerals, with more emphasis on high-value low-volume minerals such as gold, coltan (a metallic ore) and precious and semi-precious gemstones, including diamonds. In Ghana, ASM for gold is contributing significantly towards the country's economy. The African Minerals Development Centre determined that approximately 12 million ASM operators were active in Africa in 2015, supporting a further 60-100 million direct dependents, as well as six million service providers with a further 30-35 million dependents. The Tanzanian Minerals Commission determined that in 2015, two million ASM operators were active in Tanzania, 28% of whom were female. In Nigeria, ASM mining accounted for 90% of solid mineral production in 2015. In Rwanda, ASM is the only form of mining activity.

Artisanal small-scale mining raises the following serious concerns:

- Significant harm to the health and safety of miners, their communities and the local environment, including mercury abuse
- Contribution to the pollution of water supplies and degradation of agricultural land
- Significant contribution to deforestation, habitat fragmentation and land-use conflicts
- Large influxes of 'ASM migrants', often accompanied by an increase in crime, prostitution and sexually transmitted diseases including Acquired Immune Deficiency Syndrome (AIDS), drug and alcohol abuse and disruption of local culture
- Potentially fuelling local and large-scale conflicts, destabilisations and wars.

The impact of ASM was investigated to determine its potential impact on achieving the Sustainable Development Goals (SDGs) in African countries. Thirteen of the 17 SDGs are impacted by ASM, and in some cases the impacts are high.

There are widely differing opinions on ASM, but millions of Africans in rural areas are involved and depend on ASM for their livelihood. ASM presents great challenge for governments, UNESCO and other agencies and cannot be ignored.

UNESCO is approaching the ASM challenge from a research and training perspective, considering that more than 60% of its 29 funded projects in Africa deal with ASM. Many African governments are in the process of formalising ASM. The delegates to a UNESCO workshop in Tanzania in 2015 concluded that ASM in Africa needs strong research and training input as an integral part of the formalisation process. A working group was established to investigate ways in which UNESCO could contribute, resulting in a publication in *Geoscientist* (April 2017) expressing UNESCO's opinion regarding the gaps in training and research in artisanal mining.

During the past decade, African governments have been incorporating the ASM sector into revised mining legislation and regulations, giving rise to the need for training government officials at national, provincial and district levels to understand and manage the ASM sector. Some training is provided in Africa, but most of the training is linked to bigger mining projects that generally receive external funds. After such projects end, sustainability problems tend to arise. There is a lack of government support and strategy for ownership after projects close.

UNESCO facilitated a survey in 2016 to map African institutions offering ASM training. In South Africa, three institutions offer ASM training, whilst Zimbabwe, Tanzania, Ghana and Malawi each have one institution offering ASM training. In other African countries, very few institutions offer a curriculum on ASM. Globally, schools for mining engineers focus only on skills development for large-scale mining.

It has been concluded that the following would have to be done to maximise the usefulness of ASM:

- There is a need to change behaviour through education.
- Governments should develop robust policies for research-based training in areas that enhance the ability of ASM to maximise the benefits and address the challenges.
- It is critical for governments to take the necessary political and financial steps to invest in research and training. Sustainability and ownership result when training is included in the national education system and becomes part of normal training for mining engineers and technicians. Lessons can be learnt from the success of agriculture in many African countries as a result of government investment in agricultural training, especially in schools for agricultural engineers and agricultural technical vocational schools.
- Governments should support mining schools in establishing ASM departments to develop dedicated curricula for ASM. Such commitment would encourage the private sector, international organisations and donors to support the initiative.

UNESCO plans to implement a four-year pilot training experience in four countries. This would give the hosting universities sufficient time to prepare for full ownership and inclusion of the training in national education systems. Training will be offered on or off campus in vocational training centres as annexes of the hosting university, to full-time students, ASM champions, ASM operators and in order to encourage youth employment.

### **Mining-affected Communities: Risks, Expectations and Opportunities**

*(Ms Mariette Liefferink, CEO, Federation for a Sustainable Environment, South Africa)*

The Federation for a Sustainable Environment is an organisation constituted by community-based organisations, national and international non-profit organisations, as well as conservancies. The federation focuses on the realisation of Section 24 of the Constitution of the Republic of South Africa, which stipulates the right of people to an environment that is not harmful to health and

well-being; to have the environment protected for the benefit of present and future generations through reasonable legislative and other measures that prevent pollution and ecological degradation, promote conservation, and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

Ms Mariette Liefferink thanked the conference organisers for including civil society, thereby displaying commitment to the principle in South Africa's National Development Plan that active citizenry is required for democracy to flourish and to hold politicians and business accountable. This also shows commitment to the principle in the National Environmental Management Act, the over-arching environmental legislation in South Africa, that decisions must take local, ordinary and traditional knowledge into consideration, and not only scientific knowledge.

The presentation focuses on the West Rand Goldfields and the results of 130 years of mining. It addresses, inter alia, the risks to communities living close to radioactive mine residue areas and their dependency on contaminated rivers and wetlands.

The legacy of mining intersects with human rights and cannot be separated. The human rights to dignity, life, water of sufficient quality and quantity, access to information, the right to administrative justice and security of tenure, must be taken into consideration and addressed. Ms Liefferink had written a booklet entitled *Rehabilitation of Mine Contaminated Ecosystems*, outlining measures to turn environmental hazards into job generators. The poorest communities often live adjacent to the richest mines. A large percentage of people living in communities affected by mining are unemployed. On the West Rand, a significant unemployment rate of 36% prevails. Information has been obtained from approximately 50 000 completed questionnaires gathered over ten years. These questionnaires contain information regarding community concerns and proposed objectives that communities would like implemented. Ms Liefferink had facilitated meetings with mining-affected communities and Gold Fields, a progressive mining company that realises the value of win-win solutions that would benefit all parties and appreciates that face-to-face meetings with communities de-escalate hostility and conflict into cooperation and partnership. Tours are conducted with multidisciplinary, interdisciplinary and transdisciplinary research groups, including national and international organisations, research groups and universities. The objective of these activities is to encourage paradigm shifts from win-lose to win-win

situations, focusing on how to clean up after mine closures and how to deliver value to communities impacted by mining activities. Mining waste and contaminated ecosystems can provide benefits to mining-affected communities through the extraction of metals. Such an approach would moreover reduce rehabilitation costs for mines.

In terms of ecological risk, the US Environmental Protection Agency considers that mining waste rates second only to global warming and stratospheric ozone depletion because of the often irreversible and profound impacts on ecosystems. Climate change would exacerbate the impacts of mining waste on ecosystems and communities, presenting both opportunities and challenges.

South Africa's economic growth has been based on the externalisation of cost model, which is no longer sustainable. Arguments in favour of the financial viability of a mine include development cost, capital expenditure, operational cost and the profit during the mine's lifetime. Post-closure costs and impacts that accrue rapidly after mine closure are often not reflected on the balance sheet. From a social perspective, the historic mining legacy displays a power asymmetry in which coercive power has been applied, resulting in disenfranchised and mistrusting communities. However, mining communities are no longer uneducated with respect to their environmental rights and how to exercise these rights, resulting in communities demanding greater transparency through access to social and labour plans, legally binding environmental programme reports and water-use licences. Not only has there been a failure of duty of care by some mining companies, but also systemic failure of duty by the state to enforce compliance with legislation.

Ms Mariette Liefferink referred to research by Prof Tracy-Lynn Humby (University of the Witwatersrand), for example, to illustrate her views. The Blyvooruitzicht Gold Mining Company (BGMC) has been an outstanding mine, yielding large quantities of gold, silver, uranium and other mineral commodities. In 2013 it requested closure, and on 24 November 2017 it was assumed that final liquidation was granted. The mine left in its wake un-rehabilitated footprints of reclaimed tailings storage facilities without retainer walls, functional toe paddocks, penstocks or onramps, containing residual radioactive toxic metals and no management for toxic and radioactive dust fall-out. Communities were left unenriched and disrupted. BGMC also left behind total liabilities of over R891 million. An amount of R43 million is held in trust for rehabilitation, which is completely inadequate to address not only the current impacts, but also the unforeseen, latent

and residual impacts. BGMC has not complied with its legally binding environmental management programme report stating that, "The site would be left ecologically and geophysically stable and would not pose an economic, social or environmental liability to the local community and the state, now or in the future".

Lessons have been learnt from the Witwatersrand goldfields legacy, with specific reference to the West Rand. Mining communities are characterised by widespread poverty and are in desperate need of employment. Communities must be empowered to consider medium- and long-term benefits after mine closure. Land that is left unfit for use after mine closure compromises livelihood opportunities and future sustainable use of the land by communities.

The Tweelopiespruit on the West Rand is one of the rivers that received acid mine drainage and neutralised acid mine drainage and flows into the Krugersdorp Game Reserve. The river received a hazard classification of Class V due to its acute toxicity. The aquatic biota has not been restored, even after the implementation of neutralisation of acid mine water in 2012. The river still contains precipitated metals. The Hippo dam in the game reserve also contains precipitated metals, since it is fed by water from the Tweelopiespruit and two hippopotami bulls were covered in sludge documented in a photograph taken in 2010/2011.

Tudor Dam, located in Krugersdorp (Mogale City municipal area), as was recorded by the National Nuclear Regulator in 2009, contains radioactivity in the soil of between 10 000 and 100 000 becquerels per kilogram, far exceeding the regulatory limit of 500. Communities live on the banks of the dam, and in the wetlands downstream. There are no warning signs or fences, indicating a failure of duty of care by the state. A Water Research Commission (WRC) report of 2016 reported a uranium concentration of 16mg/l uranium within the Robinson Lake. The results of remobilisation of uranium from a contaminated sediment by acidic water which resulted in the NNR declaring the lake a radiation area.

Open pits also contain acid mine water, and the Council for Geoscience has estimated that these pits contribute 30% to acid mine drainage. On the West Rand, Central Rand and East Rand, acid mine water is treated by neutralisation or lime dosing that adjusts the pH. In this process, metals contained in the water do not disappear, but change to a different state of oxidation, from soluble to solid. Neutralisation renders the water unfit for any use. The solid metals are disposed of into open pits or shafts and can

be mobilised or solubilised under certain plausible environmental conditions. Legislation for the long-term treatment of acid mine drainage is expected to be implemented in 2020 or 2021.

There are more than 1 000 sinkholes on the West Rand. The de-watering of mining compartments has contributed to the formation of sinkholes. During wind spells, significant dust fallout is experienced from un-vegetated tailings storage facilities. The National Nuclear Regulator (NNR) determined that the principal pathway for radioactivity is through inhalation, ingestion and deposition of radioactive dust on crops.

It is believed that the best practicable environmental option is to reclaim tailings facilities and deposit the residues in a centralised storage facility. The management of the reclamation operations is often poor, causing spillages on to agricultural land and leaving behind footprints containing radioactive residues and toxic metals, without remediation efforts. Pipeline spillages also occur.

Acid mine water is currently used for reclamation by means of hydraulic mining. If not properly managed, this could result in an exacerbation of acid mine water, because it introduces air and water into anaerobic tailings. A particular concern is that some mining companies only extract the profitable parts of a mine dump and do not plough back any benefits into the remediation of the entire mining area.

According to Prof Dorothy Tang (Massachusetts Institute of Technology and University of Hong Kong), 1.6 million people in South Africa live in informal settlements on mine residue areas. The Gauteng Department of Agriculture and Rural Development identified 380 radioactive mine residue deposits in a 2011 report. In Mogale City, the Tudor Shaft informal settlement community of 1 800 people has lived on highly radioactive land since 1997. Residents adjacent to tailings storage facilities use storm water run-off from the tailing storage facilities for recreational purposes. The site has been well researched, and it is hoped that the current litigation process in this regard will soon be resolved.

Ms Lieferrink briefly discussed the potential to use local communities for metal reclamation from contaminated wetlands and ecosystems. A report by Dr Henk Coetzee (Council for Geoscience) indicated the potential for recovering such metals. Many nearby wetlands contain elevated levels of metals such as nickel, copper, arsenic and uranium. A report by Prof Henk Bouwer (North-West University) indicated that certain birds that breed in the Orange

River system feed in the Vaal River system, and their eggs contain elevated levels of a broad spectrum of metals, demonstrating the potential to recover metals from these ecosystems.

The 2014 Environmental Impact Association regulations, Appendix 5, regarding mine closures are applicable. The 2015 regulations on financial provisions for mining are currently under review. The NNR has proposed the following action plan to address the rehabilitation of mining legacy sites:

- Improve NNR regulations to align with international best practice for remediation
- Establish an authorisation process
- Establish criteria for the release of remediated land, other than exclusion and exemption criteria
- Develop a skills plan for the training and development of newly appointed staff in the area of remediation
- Establish contacts and cooperative agreements with other governmental departments on both vertical and horizontal levels.

The NNR proposed developing a position paper to establish remediation criteria and requirements. Funding remains a challenge, but R10 billion is currently available in rehabilitation trust funds. The Minister of Mineral Resources is the competent authority to release funding to address current rehabilitation challenges, instead of waiting until a mine has closed or been abandoned. In 2002, Anglo American released a statement that it is unacceptable for mining companies to leave gaping holes in the ground, polluted rivers, and unenriched and disrupted communities when they close.

Sand dump 20 in Randfontein was recorded in the Guinness Book of Records as the largest worldwide. It took approximately 12 years to completely re-mine it to ground level. Ms Liefferink and the alumni and academics of the University of Siegen in Germany planted the first *Ziziphus mucronata* (Buffalo thorn) indigenous trees at the site in November 2017. This is achievable if mining companies remove entire tailings storage facilities, deposit the residue in better-engineered tailings storage facilities and rehabilitate the entire area to a state of sustainable land use, with sustainable resources such as water.

### Panel Debate: Social and Legal Aspects of Mine Closure

(Moderator: Dr Henk Coetzee, Specialist Scientist, Council for Geoscience, South Africa)

#### Panellists:

**Ms Mariette Liefferink**, CEO, Federation for a Sustainable Environment, South Africa

**Dr Shan Holmes**, Consultant, Real Search, South Africa

**Dr Felix Toteu**, UNESCO, Nairobi, Kenya

**Dr Henk Coetzee** asked panellists to suggest one thing they would like to see changed for the better.

- **Ms Liefferink** emphasised that when mining operations cease, the land should be left in a sustainable condition for communities and future generations.
- **Dr Holmes** recommended closer collaboration among many government departments and joint efforts of the public sector to spend taxpayers' money wisely to enhance rehabilitation efforts.
- **Dr Felix Toteu** would like to see communities close to mine sites living safely and sustainably after mine site rehabilitation.
- **Dr Henk Coetzee** would like to see collaboration based on a shared body of reliable and verified information and knowledge, and decisions based on sound science.

**Prof Harold Annegarn** (Cape Peninsula University) commented that some people promote only sustainable solutions, some people want radical change from the status quo to something completely new and different, while others suggest some radically new geo-hydrochemistry solutions. He suggested that the word 'sustainable' should be substituted with the word 'transformation' in rehabilitation efforts, since it would liberate thinking in approaching problems.

**Dr Wilson Mutagwaba** (MTL Consulting Co. Ltd) was pleased that UNESCO was involved in addressing issues of artisanal and small-scale mining, but advised that organisations under the UN umbrella should join forces to develop solutions to address the challenges. There is a tendency to group together artisanal and small-scale mining, whereas these are two separate groups. In training miners in the two groups, the programmes and curricula developed would not be able to address the unique problems of each group unless a distinction is made between them. Recognising and addressing the differences between the two groups would make the UNESCO programme much more useful.

**Dr Felix Toteu** confirmed that many UN agencies try to stick to their own mandates. No single entity

would be able to resolve the issues of unregulated artisanal mining. UNESCO, as an agency for research and education, specifically attempts to address the challenge from an educational perspective. UNESCO's role is to ensure that all aspects are addressed in the formalisation process. The root of the problem is probably a lack of education. Artisanal miners try to build small businesses from their mining efforts, while businessmen want to invest but often lack knowledge of how the sector operates. By implementing training, hosted by universities with good-quality curricula, artisanal miners could benefit greatly. Universities were suggested for such training to ensure sustainability.

**Dr Andrew Parsons** (Gold Fields) commented that NGOs and many other organisations are working on possible solutions. The International Institute for Environment and Development operates in countries such as Ghana, Tanzania and Madagascar, doing outstanding practical work on site with artisanal miners. It is doubtful whether artisanal miners have the time to attend a university course, since their subsistence depends on their mining activities. It is important to work in a consultative manner with artisanal miners to understand what they need and work with the information obtained. Much of the artisanal mining activity is illegal, and business and governments should avoid endorsing illegal activity. In South Africa, Zama Zama operations are associated with organised crime, creating a level of complexity that should not be ignored. Rigorous enforcement of the law would need to be coupled with assistance to those prepared to work within the law.

A delegate asked Dr Felix Toteu how the responsible use of mercury could be addressed, taking into consideration the negative effects of mercury, as well as the fact that artisanal mining contributes greatly towards sustaining families in Africa.

**Dr Felix Toteu** referred to the existing international agreement resulting from the Minamata Convention on Mercury, involving many countries. The aim of the convention is to protect the environment from anthropogenic emissions and releases of mercury and mercury components, and the agreement stipulates guidelines for countries towards achieving the objective. Scientists will have to contribute to achieving the objective, and UNESCO's role is to assist scientists in their quest for solutions.

**Ms Mariette Liefferink** commented that her organisation had been part of the South African Human Rights Commission's advisory committee on unregulated artisanal mining. Mining companies often close or abandon mines without rehabilitating the

environment properly, which creates opportunities for unlawful mining. Children and women work with men to leach gold. They often use sewerage pipes to obtain water and then apply mercury amalgamation to extract residual gold. The South African Human Rights Commission has produced a document recommending the regulation of artisanal mining.

**Dr Felix Toteu** concurred that in South Africa, artisanal miners take over the residue of large-scale mining and use mercury wherever they can, posing a problem when large-scale mines do not rehabilitate the environment after closure.

**Ms Barbara Chuene** (Mintek) commented that Mintek had been working with small-scale miners from Limpopo to the Western Cape, as well as from other countries, in providing them with skills, supporting them with technical knowledge and understanding of mining, and legalising them. A research group in the small-scale mining division of Mintek investigated chlorine as a possible alternative to mercury, but it did not result in good yields. The research was continuing, and institutions were invited to work with Mintek to find an alternative to the use of mercury. South Africa had succeeded in formalising artisanal mining. Mintek had adopted the Department of Mineral Resources' definition of a small-scale miner, which does not include Zama Zamas, whose mining operations are illegal. Small-scale miners are defined as rural-based miners operating next to light deposits throughout the country. South Africa is the only country in the world that offers formal qualifications in small-scale mining, and these qualifications are endorsed by the Mining Qualifications Authority. Universities or any other accredited institution can assist in training small-scale miners. Some South African universities have attempted to train small-scale miners, but there was not much interest in the course and it was discontinued. In Mintek's experience, most of their trainees are involved with projects and wish to improve their skills. Ms Chuene had not seen the recommendations of the South African Human Rights Commission to which Ms Liefferink referred, which highlights the fact that organisations and institutions work in silos. Ms Chuene emphasised the importance of working together to find the best solutions.

**Mr Ewald Erasmus** (Geotech) pointed out that effectively all the safety features in abandoned subsurface mines like shaft pillars, stope pillars and roof pillars were mined out before abandoning a mine. What is left is the absolute minimum safety features which is targeted by the Zama Zamas. No government support, either in training Zama Zamas or supplying technical expertise in the form of

geologists, rock mechanics or engineers is feasible especially the latter group will just declare the mine unsafe. To even contemplate legalising Zama Zama mining in the deep underground Wits gold mines is simply immoral as besides endangering the lives of Zama Zamas, it also places an unnecessary burden on rescue teams in the inevitable case of a mining disaster. Governments should rather target structured surface mining, like for alluvial diamonds as a much safer work creation option for Zama Zamas.

**Dr Henk Coetzee** commented that Mr David van Wyk had raised an important distinction between 'ghost miners' and Zama Zamas. Ghost miners join legally employed miners at an operating shaft and then wander off from the main operations, operating underground with the support of workers from the mine making some extra money on the side. Zama Zamas work under dangerous conditions, but their knowledge of mining operations and safety is commonly underestimated, since many of them have previously been employed by mines.

**Dr Felix Toteu** commented that Mintek's efforts are in line with what UNESCO is trying to achieve. Mintek's research to find an alternative to the use of mercury is the 'missing research component' to which he previously referred. UNESCO does not suggest that small-scale miners should attend courses at a university, but research takes place at universities, and good research results in good training. In the past, many governments have invested in technical and vocational training in rural areas, which transformed agriculture in many parts of Africa. A similar approach could be taken to providing training in small-scale mining. Technical and vocational training would fulfil an important role in training and promoting new knowledge regarding artisanal mining in rural areas.

**Dr Shan Holmes** commented that there is a significant opportunity to teach artisanal miners not only to practise mining more efficiently and safely, but possibly to become part of the closure and rehabilitation programme of mines. This is a complex situation to deal with and requires a multimodal approach. There are many other ways to address the largely symptomatic problems created by the lack of proper mine closure.

**Ms Mariette Liefverink** commended the encouragement of formal mining companies to develop not only mining skills, but also other skills to enable miners to live sustainably after mine closure, and not resort to unlawful mining.

**Mr Igor Klopčič** (Consultant) expressed the view that if there were general agreement that mines that discontinue operations as formal entities should not flood their underground operations, there would be an explosion of ghost mining. Illegal miners educate themselves and are very good at finding the best ore. Their safety record is probably better than that of big companies. It is unlikely to be expensive or take much time to improve the safety skills of artisanal and small-scale miners, and the efforts should be intensified.

**SESSION NINE: LESSONS LEARNED AND CONFERENCE RESOLUTION****(Facilitator: Prof Frank Winde, Head of Mine Water Research Group, North-West University, South Africa)****Wrap-up of Conference***(Prof Frank Winde, Head of Mine Water Research Group, North-West University, South Africa)*

Prof Frank Winde commented that it has been a great privilege for him to have the opportunity to structure the conference. His aim was to create awareness of existing problems and provide a platform for discussions and questions.

Coming to terms with exhausted mines that have been formally closed or abandoned, as well as legacy sites will become increasingly important in future. Globally, legislation governing these processes is only ten to 20 years old. Many mining companies are only now starting to plan for closure in order to comply with stricter regulations. The process will require increased levels of competence, which will have to be provided by a new generation of students that have been trained in post-mining rehabilitation, remediation and the sustainable use of abandoned sites, offering huge opportunities for universities to develop dedicated course modules in these fields.

The conference highlighted possible plans to turn liabilities into assets. Harnessing the entrepreneurial spirit and ingenuity of artisanal and illegal miners to generate their own income could possibly be regarded as an asset rather than a liability. Many delegates have commented that the conference has been very informative, interesting and worthwhile, especially learning about severe problems experienced in other countries and realising that what works in one country would not necessarily be feasible in another.

Although the Chinese economy is often portrayed as reckless, with disregard for environmental concerns, they have ingenious ways of dealing with legacy sites. It should be borne in mind that many South African mines are now Chinese-owned. If one of these mines, with the required resources, could be convinced to create an example in South Africa, it could possibly be used as a reference project for mines in China and might be a first step towards implementing some of the new ideas available.

Despite all parties concerned generally wanting the same outcome – namely properly rehabilitated land, the safety of people and preferably income from closed or abandoned mine sites – it has proved difficult to realise because of the lack of trust-based honest communication – especially

between mines and affected communities. It is of the utmost importance to recognise, involve and train competent representatives of communities, thereby cultivating mutual respect. Human interaction and effective communication are as important as technical knowledge and economic might, since mining operations and rehabilitation often directly impact not only on the environment but also on people's lives.

Many concrete and fascinating ideas have been suggested during the conference. A very exciting and encouraging one is that of turning closed mines into underground hydro-energy storage facilities (UPHES). Based on a significant body of researching the concept German delegates support the assessment that conditions in South Africa are particularly favourable to further explore the installation of a world's first UPHES in the country.

Prof Frank Winde concluded by encouraging ongoing communication not only among the various international research teams exploring the concept worldwide but also between competing operations, regulators and affected communities based on honesty, respect and sound science.

**Presentation and Endorsement of Conference Statement***(Dr Siyavuya Bulani, Senior Liaison Officer, ASSAf)*

Dr Siyavuya Bulani thanked Prof Frank Winde for structuring and coordinating the conference, and for drafting the Conference Statement with the assistance of colleagues.

Having deliberated on the sustainable use of abandoned mines in the SADC region, the delegates of the Science-Business-Society Dialogue Conference released the following statement:

1. In view of the future expansion of mining for sustaining a growing and rapidly urbanising world population with its ever-increasing use of mineral resources, new ways need to be found to avoid adverse ecological and economic impacts which are still all too often associated with closed and abandoned mines around the world. This is particularly true for countries in the Global South where most of the future mining is likely to take place.

2. Impacts of mining legacy sites on local communities are generally most severe in resource-restricted economies. This is especially true for countries heavily relying on the extractive sector while lacking resources for adequate remediation, as case studies from sub-Saharan Africa illustrate. As affordability frequently limits the extent to which remediation strategies are adopted, innovative approaches and more cost-effective alternatives are required. A number of promising examples were presented at the conference warranting follow-up studies and pilot projects.

3. Given the extremely long time scale of post-closure impacts – especially on frequently scarce water resources – it is generally more cost-effective to avoid the formation of legacy sites in the first place than attempt remediation later on. Combined with pro-active mine planning that keeps the desired after-use in mind right from the start, mine voids and other assets can be prevented from turning into liabilities relatively cost-effectively.

4. Exploring the underground pumped hydroelectric storage (UPHES) concept in different countries illustrates the multitude of factors impacting on their feasibility. General consensus exists that the concept, in principle, is technically feasible even under very challenging conditions. However, its economic viability is affected by a complex interplay of governmental policy, energy tariffs, market structure, ownership models, and geographical and other factors. Following on the successful conversion of the Kidston gold mine in Australia into a pump storage scheme on the surface, it is recommended to utilise favourable conditions in the SADC region for the transformation of mining infrastructure for energy storage and other opportunities.

5. It is also agreed that any successful measure aimed at ensuring sustainable after-use of closed mines can only be successful if all stakeholders (i.e. mining communities, civil society, the mining industry, science, engineering and policymakers) work together towards reconciling potentially conflicting interests to find a solution. Early and broad public participation, good communication, transparency, respect and honesty are key ingredients for succeeding with this difficult task.

6. One of the key issues in the SADC context is that all mining stakeholders, for example researchers, consultants, regulators and the mining industry, need continuous improvement of their understanding of complex post-mining legacy issues.

The delegates agree that focal points of future research are, inter alia:

- a. Finding ways for reliable long-term preservation of knowledge, data and expertise as the basis for resilient and adoptive post-closure site management.
- b. The internalisation of social and environmental post-closure costs in planning and approving of mining operations to secure sufficient funds for structured closure and remediation.
- c. Innovative technologies, including affordable low-tech and low-energy solutions, aimed at preventing legacy sites and transforming potential liabilities into future assets.
- d. Health, safety and capacity building of workers involved in remediation.
- e. Financing and/or enabling reference projects to gain experience in implementing innovative technologies.
- f. Continuous exchange of experience in the field.

#### **Vote of Thanks**

*(Prof Volker ter Meulen, Immediate Past-President, Leopoldina)*

Prof Volker ter Meulen expressed his gratitude for the organisation of such an important conference. In particular he thanked Dr Siyavuya Bulani and Mr Stanley Maphosa from ASSAf, Prof Frank Winde and other organising committee members. He also thanked the German Ministry of Science and Education for the financial support of the conference.

On behalf of ASSAf, Mr Stanley Maphosa, Liaison Manager, thanked Prof Volker ter Meulen for his vote of thanks, presenters for their powerful and engaging presentations, and delegates for their attendance and valuable contributions to the Science–Business–Society Dialogue Conference. He also thanked the ASSAf leaders, Profs Brenda Wingfield and Dan Kgwadi, members of the organising committee, facilitators and staff at the conference venue.

**APPENDIX A: LIST OF ACRONYMS**

<b>AIDS</b>	Acquired Immune Deficiency Syndrome	<b>LARSSA</b>	Land Rehabilitation Society of Southern Africa
<b>AMD</b>	Acid Mine Drainage	<b>MIASA</b>	Mining Industry Association of Southern Africa
<b>AMW</b>	Acid Mine Water	<b>MISTRA</b>	Mapungubwe Institute for Strategic Reflection
<b>ASM</b>	Artisanal Small-scale Mining	<b>MoU</b>	Memorandum of Understanding
<b>ASSAf</b>	Academy of Science of South Africa	<b>MPRDA</b>	Mineral and Petroleum Resources Development Act
<b>AUD</b>	Australian Dollars	<b>MW</b>	Megawatt
<b>BGMC</b>	Blyvooruitzicht Gold Mining Company	<b>MWh</b>	Megawatt hours
<b>BRICS</b>	Brazil, Russia, India, China, South Africa	<b>NEMA</b>	National Environmental Management Act
<b>CAES</b>	Compressed Air Energy Storage	<b>NGO</b>	Non-governmental organisation
<b>CCS</b>	Carbon Capture and Storage	<b>NNR</b>	National Nuclear Regulator
<b>CGULS</b>	Co-ordination Group on Uranium Legacy Sites	<b>NWU</b>	North-West University
<b>COIDA</b>	Compensation for Occupational Injuries and Diseases Act	<b>PHES</b>	Pumped Hydroelectric Storage
<b>CSIR</b>	Council for Scientific and Industrial Research	<b>PSPP</b>	Pumped Storage Power Plants
<b>DEA</b>	Department of Environmental Affairs	<b>PUMP</b>	Passive Underground Mine-water Purification
<b>DMR</b>	Department of Mineral Resources	<b>R&amp;D</b>	Research and Development
<b>DRC</b>	Democratic Republic of Congo	<b>REE</b>	Rare-earth elements
<b>DST</b>	Department of Science and Technology	<b>RSLS</b>	Regulatory Supervision of Legacy Sites
<b>dti</b>	Department of Trade and Industry	<b>SA</b>	South Africa
<b>DWS</b>	Department of Water and Sanitation	<b>SADC</b>	Southern African Development Community
<b>EFZN</b>	Energy Research Centre of Lower Saxony	<b>SDG</b>	Sustainable Development Goal
<b>EIA</b>	Environmental Impact Assessment	<b>SMME</b>	Small, Micro and Medium Enterprise
<b>FWR</b>	Far West Rand	<b>SOE</b>	State Owned Enterprise
<b>GDP</b>	Gross Domestic Product	<b>TUT</b>	Tshwane University of Technology
<b>GWh</b>	Gigawatt hours	<b>UN</b>	United Nations
<b>GW-Ruhr</b>	Grubenwasser-Ruhr project	<b>UNESCO</b>	United Nations Educational, Scientific and Cultural Organisation
<b>HSRC</b>	Human Sciences Research Council	<b>UPHES</b>	Underground Pumped Hydro Electric Storage
<b>IAEA</b>	International Atomic Energy Agency	<b>US</b>	United States of America
<b>ICMM</b>	International Council on Mining and Metals	<b>WRTRP</b>	West Rand Tailing Retreatment Project
<b>IDP</b>	Integrated Development Plan		
<b>IPR</b>	Intellectual Property Rights		
<b>KPI</b>	Key Performance Indicator		

## APPENDIX B: LIST OF ATTENDEES

SURNAME	NAME	TITLE	INSTITUTION/COMPANY
Annegarn	Harold	Prof	Cape Peninsula University of Technology
Arp	Reinhardt	Mr	WWF
Banks	Norman	Mr	Southern Mapping
Baker	Julian	Mr	Mine Metallurgical Managers Association
Barker	Andrew	Mr	Town Planning Consultant
Botha	Andries	Mr	Southern Mapping
Breytenbach	Mia	Mrs	Mining Weekly
Bulani	Siyavuya	Dr	ASSAf
Chuene	Barbara	Ms	Mintek
Coetzee	Henk	Dr	Council for Geoscience
Coleman	Candice	Ms	DST
Davies	Theophilus Clavell	Prof	University of Nigeria
Diab	Roseanne	Prof	ASSAf
De Klerk	Arno	Dr	CSIR
Diehl	Christiane	Dr	Leopoldina
Dombrowski	Boris	Dr	DMT GmbH & Co. KG
Duesterlo	Uwe	Prof	Clausthal University of Technology
Elwert	Tobias	Prof	Clausthal University of Technology
Erasmus	Ewald	Mr	Geotechnical Environmental Specialists
Erasmus	Heather	Ms	Write Connection (Scribe)
Ewert	Thomas	Mr	University of Duisburg-Essen
Friedrich	Hans-Juergen	Mr	Fraunhofer Institute for Ceramic Technologies and Systems IKTS
Geissler	Anja	Ms	Leopoldina
Gevers	Christian	Mr	Centre for Mineral Resources, Southern African - German Chamber of Commerce and Industry
Godsell	Bobby	Mr	National Planning Commission
Govindsamy	Seshen	Mr	Southern Mapping
Henyane	Danoline	Ms	HSRC
Hermanus	May	Prof	CSIR Natural Resources and the Environment
Holmes	Shan	Dr	Real Search, Environment Management & Development
Hoth	Nils	Dr	TU Bergakademie Freiberg, Institut fuer Bergbau und Spezialtiefbau
Kalele	Phyllis	Ms	ASSAf
Keet	Marius	Mr	DWS
Kgwadi	Dan	Prof	NWU

<b>SURNAME</b>	<b>NAME</b>	<b>TITLE</b>	<b>INSTITUTION/COMPANY</b>
Kidston	Simon	Mr	Genex Power Limited
Klopcic	Igor	Mr	Consultant
Krueger	Klaus	Dr	Voith Hydro Holding GmbH & Co. KG
Kumar	Manesh	Dr	Global Young Academy
Kwesu	Isaac	Mr	Chamber of Mines of Zimbabwe
Lesufi	Nikisi	Mr	Environment and Health, Chamber of Mines of South Africa
Liefferink	Mariette	Ms	Federation for a Sustainable Environment
Lohmeier	Stephanie	Dr	University of Duisburg-Essen
Mabena	Vusi	Mr	Mining Industry Association of Southern Africa
Mandiwana	Marvin	Ms	ASSAf
Maphosa	Stanley	Mr	ASSAf
Marais	Rina	Ms	Write Connection (Scribe)
Mack	Richard	Mr	Anglo Ashanti, South Africa
Matine	Obete Francisco	Mr	Ministry of Mineral Resources and Energy
Mathiba	Moagabo	Dr	University of Botswana
Mbhiza	Kholani	Mr	ASSAf
Mjimba	Nqangi	Mr	Technology Innovation Agency
Moima	Mohato Cyril	Mr	Ministry of Mining, Lesotho
Monken Fernandes	Horst Richard Sebastian	Mr	IAEA (via Skype)
Mphusu	Haile	Mr	Gem Diamonds, Botswana
Mturi	Gerald	Mr	Tanzania Chamber of Mines and Energy
Mureriwa	Nyasha	Ms	Southern Mapping
Mutagwaba	Willson	Dr	NTL Consulting, Tanzania
Mutanga	Shingirirai	Dr	MISTRA
Nanyaro	Asifa	Dr	Tanzanian Academy of Sciences
Ngure	Veronica	Dr	Department of Biological and Biomedical Sciences Technology, Laikipia University
Niemann	Andre	Prof	University of Duisburg-Essen
Nkosi	Nomfundo	Ms	ASSAf
Ntholi	Thakane	Dr	Council for Geoscience
Oellermann	Bernd	Mr	South African National Department of Trade and Industry
Parsons	Andrew	Dr	Gold Fields
Paul	Michael	Dr	WISMUT GmbH
Penczek	Nils	Dr	Ruhr University Bochum, Energy Systems and Energy Economics
Radebe	Thabo	Mr	DST

<b>SURNAME</b>	<b>NAME</b>	<b>TITLE</b>	<b>INSTITUTION/COMPANY</b>
Wilson	Ross	Mr	BBE Group Geotechnical Environment
Scholtz	Pieter	Mr	Aurecon
Stuart	Grant	Mr	Sibanye Gold
Sikazwe	Osbert	Dr	Zambia Academy of Sciences
Simpson	Llanley	Mr	DST
Smit	Piet	Mr	Land Rehabilitation Society of Southern Africa (LARSSA)
Tanner	Phil	Dr	LARSSA
Taylor	Mark	Mr	DesSoft: Engineering design documentation
Ter Meulen	Volker	Prof	Leopoldina
Titus	Rian	Dr	Delta-H
Toteu	Felix	Dr	UNESCO Africa, Earth Science and Ecology
Tsenoli	Kopano	Mr	Ministry of Communication, Science & Technology Lesotho
Tshitangoni	Mpho	Dr	Land Remediation, Department of Environmental Affairs
Tumagole	Benevolut	Mrs	City of Tshwane
Unite	Jeannette	Ms	Unite Studio
Valiani	Salimah	Dr	MISTRA
Van Wyk	David	Mr	Bench Marks Foundation
Wagener	Henriette	Ms	ASSAf
Whacha	Knowledge	Mr	Group R Mining and Exploration (Pty) Ltd, Botswana
Winde	Frank	Prof	North-West University
Wingfield	Brenda	Prof	University of Pretoria
Witthuser	Kai	Dr	Delta Water Systems Modelling
Wolkersdorfer	Christian	Prof	Tshwane University of Technology
Wrigley	Charlene	Ms	Gold Fields
Zarske	Rene	Mr	Centre for Mineral Resources, Southern African - German Chamber of Commerce and Industry
Zeller	Ernst	Mr	Pöyry Energy GmbH
Zhu	Qingshan	Prof	Institute of Process Engineering, Chinese Academy of Sciences

## NOTES

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