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Focus on conservation and extraction of resources

- Gypsum gap
- Regional raw materials
- Recycling
- Recycling of geotextiles
- Dedusting
- Retaining structures
- Artificial intelligence
- Laser technology
- Roadheaders
- Nuclear waste repository
- Association work
- Decarbonisation

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The HBT Group has acquired a 50 % stake in the Germany-based company Advantec Tunnel & Mining Solutions. As a result, the Group now includes roadheading machines in its comprehensive range of mining equipment and can henceforth list tunnel construction within its field of activity.

https://hbt-group.com

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Mining • Maintenance & Repair • Laser technology • Artificial intelligence • Digitalisation

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Tunnelling • Mining • Geotechnics • Construction • Machinery • Legacy • Policy • Association work • Sustainability • Congress • CECE • bauma • Digitalization • Decarbonization

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Tunnelling • Tunnel renovation • Maintenance • Workplace safety • Ventilation • Personal tracking • Construction operation • Track laying • S-Bahn

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The HBT Group has acquired a 50% stake in the Germany-based company Advantec Tunnel & Mining Solutions. As a result, the Group now includes roadheading machines in its comprehensive range of mining equipment and can henceforth list tunnel construction within its field of activity. This creates a valuable synergy potential and presents a number of distinct advantages not only for both companies but also for customers in the mining and tunnelling markets. Projects currently underway serve to highlight the versatility of the tunnel digging roadheader (TDR) system.

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Mining • Underground mining • Trackless vehicles • Loading • Transport • Drive systems • Decarbonisation • Diesel • Electric • Hydrogen • Investment

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Mining • Radioactive waste • Repository mining • Modelling • Research

Special Topic

Closing the Gypsum Gap: The Role of Recycling in a Climate-Driven Future

Dipl.-Ing. Marco Pabstmann, Director Technics of Knauf Group North- and Central Europe

The gypsum industry is facing a significant challenge as the availability of FGD gypsum, a by-product of coal-fired power plants, is expected to decline rapidly due to climate policies. To ensure continued production, the industry must address this supply gap, with recycling playing a central role in the solution.

Recycling • Mining • Gypsum • Raw materials • Raw materials security • Research

For years, FGD gypsum has played a vital role in the industry. Produced from gases captured in emission control systems at coal-fired power plants, it is chemically identical to natural gypsum. This "technical gypsum" is especially pure and can be processed to high standards for use in building materials. Despite high demand, the production of FGD gypsum is steadily declining and will soon cease altogether.

To comply with the Paris Climate Agreement, European and OECD countries must phase out coal-fired power by 2030. The EU's Green Deal has identified coal phase-out as a key factor in achieving climate neutrality by 2030. As of today, 23 European countries have announced their commitment to phase out coal, with Germany targeting 2038 at the latest. However, the synthetic gypsum produced through other industrial processes is far from enough to compensate for the loss of FGD gypsum.

This transition is creating a significant shortfall in gypsum supply. In response, companies like Knauf are intensively researching alternatives, including gypsum as a by-product from sectors like lithium battery manufacturing and expanding recycling efforts. These efforts complement the increasing demand for natural gypsum mining, as recycling alone will not be able to fill the gap in the foreseeable future.

Gypsum is an exceptional material because it can be endlessly recycled, allowing it to be continuously reused for the same products. However, recovering usable gypsum from demolished buildings is complex. Contaminants such as metal, adhesives, and plastics – like screws and silicone – often compromise the material's purity and complicate recycling. The success of the recycling process depends on ensuring the gypsum is as pure as possible. Legal regulations also influence the amount of gypsum that can be recycled, and these vary between countries, impacting recycling efficiency.

Nevertheless, we must continue to improve recycling possibilities and increase the proportion of recyclable material. Our efforts focus on recovering gypsum from plasterboard waste and expanding the infrastructure needed for gypsum-based drywall recycling. A key objective is to minimize environmental impact by streamlining recycling processes, reducing transport distances, and lowering water consumption through improved planning. With a series of innovative projects, we're demonstrating how gypsum recycling can be successfully implemented.

For example, the Pakita project in Spain shows how gypsum waste can be recycled directly on construction sites. Machines separate gypsum from other components in old plasterboard, reducing transport distances and CO_2 emissions. Similarly, in the Netherlands, we're partnering with urban miner New Horizon to "harvest" plasterboard from renovated or remodelled buildings and feed it back into production. Intact boards are recycled, while damaged boards are repurposed to manufacture new products. A notable example from England is a take-back system, where we collaborate with service providers to collect plasterboard waste for recycling. As Northern Europe generally leads the way in incorporating up to 30% recycled gypsum in production, we are working intensively on the recycling of gypsum waste at our Scandinavian sites.

In Germany, Knauf established the Gypsum Recycling Competence Center to further drive circularity and environmental responsibility. It serves as a hub for research, knowledge-sharing, and advancing gypsum recycling techniques. It aims to create a closed-loop system where waste is reclaimed, recycled, and reintegrated into production, redefining the gypsum supply chain as a circular ecosystem.

Gypsum is essential for creating sustainable and affordable living and workspaces, making it crucial to address the looming supply gap. Despite progress in the field of recycling, the extraction of natural gypsum remains essential for securing the supply of raw materials. It is important to recognize that modern mining practices are designed to operate in harmony with nature and the local communities. Our production facilities are generally located close to the extraction areas, minimizing transport routes and reducing emissions.

The industry must balance mining with recycling, while continuing to innovate and prioritize environmental stewardship. Recycling is key to this strategy, and our ongoing work to improve infrastructure, recover more material, and optimize processes is critical to securing future supply. At the same time, collaboration across the industry and regulatory clarity are needed to fully unlock recycling's potential. By advancing technology, expanding recycling capacity, and fostering a circular approach, the gypsum industry can help meet future demand while reducing its environmental impact, contributing to a more sustainable future for all.

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Special Topic

Focus on Conservation and Extraction of Resources

Dipl.-Ing. Manfred König, Chief Editor, Publisher, GeoResources Verlag, Duisburg, Germany

Mining and raw materials are vital for industrial value creation, yet the mining industry is now coming under increasing attack because of its environmental impact. Despite the negative effects associated with it, mining, which is the primary method of producing anything, remains indispensable for us – whereas recycling and the circular economy, while rightly considered important, can never provide the complete answer. A more regionally based approach to raw materials production, combined with more sustainable solutions that incorporate technical innovations, can create a platform for meeting our resource requirements while at the same time keeping the environmental impact to a minimum.

Mining • Economy • Construction industry • Raw materials • Recycling • Supplier industry • Nimby • Future

Raw materials are the first element in every industrial value chain. Human life would be inconceivable without them. Houses, roads, tunnels, means of transport of all kinds and even entertainment media – none of these would exist without raw materials.

Raw materials – reality and public perception

Back in the old days people knew that without mining all is nothing. Miners and others too put this more succinctly:

'If you cannot grow it you have to mine it.'

People saw the mining industry as a source of employment. In the mining regions of Germany, as in the British Midlands, in the Americas and Africa, in Australia and Asia, fossil resources were drivers of technology and of economic growth. They provided reliable energy on the doorstep and enabled the manufacture of steel and concrete. Mining was the guarantee for a functioning industrial value chain.

Mining provided the focal point for all kinds of knowledge landscapes to develop: Georgius Agricola's *De re Metallica libri XII* had already become a scientific bestseller of international reputation by the 16th century, while Carlowitz (1645 – 1714), a mining administrator from Freiberg in Saxony, Germany, is recognised as having established the principle of sustainability and, it should not be forgotten, the world's oldest mining university (founded in 1765) is still a centre of learning in the Ore Mountains of south-eastern Germany.

Suddenly everything has changed

Mining is now being identified as a major cause of climate change. People here in Germany – and the daily news media in particular – have for many years taken the term 'mining' to mean the extraction of fossil raw materials. And as producers of CO_2, fossil fuels have been put on the environmental hit list. Professionals who should know better sometimes refer to the 'Post-mining Era' (Nachbergbauzeit) when in fact they are only talking about the end of regional coal mining.

'Mining is the exploration, development, extraction and processing of mineral resources – even if this simply means extracting salt from sea water.'

This definition comes from the famous Leoben Professor of Mining Günther B. Fettweis, who told it to me a few years before his death.

A Google search of the topic 'Everything is nothing without mining' soon serves up most of the arguments for and against. If you are honest, you will not be able to fully contest all these arguments and counter arguments. Yet neither are they all completely correct – no matter from which side of the argument you approach the subject. So, I should like here to try to put things into some kind of order. May I be forgiven for presenting this in a subjective way – but the facts as they are cannot be anything but subjective.

Public acceptance of primary production has fallen

Let us note: the public's readiness to accept the mining industry has declined, despite the latter's indispensable contribution to raw materials production. Agriculture and mining are the foundation of every civilisation, as shown by developments from the Stone Age and the use of flint tools, through the Copper and Bronze Ages to the Iron Age and our modern-day world. The importance of metals, and hence the vital role that mining has played, is clearly reflected in these phases of human civilisation whose names have become so familiar to all of us. No building and no technology of any kind is possible without raw materials; and people can never eat without sowing and harvesting first.

However, the growing demand for resources is a burden on the environment and the climate. This has created a dilemma: mining ensures our existence, our prosperity and our economic strength; agriculture ensures our global food supplies. At the same time, it is obvious that we have long been exceeding the carrying capacity of Mother Earth – the resulting climate change is now posing a real threat to humankind and the natural world and will ultimately jeopardise our economic systems too. 'Keep on with the same' is no longer an option.

How do we do things differently?

Abandon the mining industry – key to the solution?

However, is renouncing and condemning primary production as far as mining and even agriculture is concerned really such a brilliant idea? I think not. In each case it all comes down 'how' it is done. From a professional standpoint it is naturally the mining industry that I shall be considering here. According to Günther B. Fettweis, when it comes to mining we really need to take a close look at what mining products are. As surveys of this kind are often done by telephone I could do this in the following way:

- **Look up for a moment – what do you see?**
  A ceiling. What is it made of? Concrete. And what is concrete? Sand and gravel, limestone, water and iron. Right – and where do these materials come from? From gravel pits, stone quarries and metal mines.
- **Look straight ahead – what do you see?**
  A window. What is the window frame made from? Plastic. And the pane? Glass. Good. Now plastic is a mineral oil product, the frame is of aluminium and the pane is made from quartz (sand), feldspar and flux.

You can go on almost forever like this – looking down, looking right, looking left – and you can even look out of the window! With very few exceptions our man-made world consists of mineral raw materials, all of them obtained by means of mining in some form or another. And in the years ahead recycling and urban mining will also have an important role to play.

Germany – a resource-rich country?

We in Germany have had some outrageous luck. We have been richly endowed with coal and lignite. And shale gas is also very much part of the picture. While it is currently being imported from overseas it could just as well be extracted domestically and in so doing save 20 to 30% of the energy [1]. We also used to have access to large quantities of metals. However, metal mining is simply too expensive from today's perspective.

Almost all the raw materials that are needed by the construction industry can be obtained in Germany – and they are of the appropriate type and available in the quantities required. Natural stone, clays, gravel, sand, limestone, gypsum and salts – collectively referred-to as 'earth and stone' and industrial minerals – are all mined here and as such they protect supply chains and jobs, provide resource security with effective environmental monitoring and make for short transport distances, thereby reducing energy consumption. Germany still has around four thousand mines [2] ... and there is nothing wrong with that!

There are also various critical raw materials that can be mined here in Germany. It all comes down to the price on the world market, the available production technology and the need to secure supply chains. In fact, work has already started on the first new home based lithium and copper mines.

Supplier and service industry

In Germany we have an active and innovative supplier and service industry that as well as providing the domestic mining sector with machinery, equipment and mineral processing plant also supports the global mining industry by supplying durable and technologically advanced products and services, thereby helping it to operate more efficiently and in a more environmentally sustainable way at international level.

Recycling and the circular economy – opportunities and limitations

Mining is gradually being replaced by the circular economy – a captivating idea in a perfect world: all raw materials are simply re-used and we no longer need a mining industry!

The term 'circular economy' – now so frequently used by politicians and self-proclaimed raw material experts – suggests that natural resources can be endlessly recycled so that we can dispense with mining altogether. A growing number of people believe this and openly affirm it. But are things really as simple as this? The reality is in fact quite different.

One thing is certain: recycling (urban mining) is important and it will help us to reduce our raw materials consumption quite significantly both now and in the years to come. Recycling must be increasingly promoted and accelerated and legislation is needed to develop the opportunities available for the recycling and reprocessing of waste material. The miners – or should we say the processors – can then bring their industrial processes to bear in order to turn waste back into raw material.

Mining and recycling (urban mining) can be seen as part of the same story. To quote from the online circular economy platform Circulania [3]: 'Where possible, every supplier of primary raw materials should take responsibility for the secondary raw materials that result from his 'mineral competence'. Ideally this will create hybrid materials. Take the example of limestone and steel slag: the slag is limestone that has been in contact with steel. It therefore contains a small amount of 'impurities' in the form of iron, sulphur and/or phosphorus. It could be taken back to the lime works by the empty wagons and then processed for other purposes rather than using primary limestone'.

But recycling alone cannot replace the mining of raw materials:

- **In order to recycle raw materials it is essential to have waste products available.** If you want to build a house do you have to demolish another one first? Apart from the energy expenditure that is required, where then do we get the new living space that is clearly and urgently needed?
- **Technical feasibility:** The recycling of raw materials results in technical losses. These are based on the existing technology, on one hand, and also on the operating efficiency of the process, on the other. Were we to abandon growth altogether and simply avoid going backwards then we would have to find some way to offset these losses.
- **Backlog demand:** Living standards and therefore resource consumption have for centuries been distributed very unequally around the globe. If we do not want to block the aspirations of the world's growing middle-class then we will have to raise primary production levels accordingly.
- **Population growth:** The world's expanding population means that primary production cannot simply be put into cold storage. Even these 'new people' are entitled to a life that is worth living.
- **Disruptive technical developments:** One example of this is the transition to renewable energies. This has led to a huge increase in the demand for copper, cobalt, lithium and many other raw materials too. This cannot be met by recycling alone. After all, you cannot transform old gas pipes into copper wiring for electricity conduction. We have still to find that particular philosopher's stone.

Technical progress is creating new opportunities for sustainability

Renewable energies will become ever better at replacing fossil fuels. Hydrogen and its derivatives, storage batteries, hydroelectric power stations and the geothermal sector will provide buffer storage capacity and enable peak load balancing for heat and electricity supply systems. The circular economy and recycling will help make raw material supplies more sustainable and reduce resource consumption levels.

New and innovative techniques, such as the use of AI and new mining methods (e.g. bacterial leaching and mining robots), can and will greatly reduce the environmental impact of the mining industry. Take one example: AI can now be used to calculate hundreds of thousands of chemical compounds within a very short time. The compounds identified in this way can then be tested to determine their suitability as catalysts for chemical processes such as hydrogen generation and the manufacture of green fuel. Back in the day, how long did we have to wait for suitable catalyst technology for combustion engines?

Renewable energies, sensor technology, big data analytics and AI will all help to make mining more energy efficient, more safe and more commercially viable.

Can mining be made environmentally friendly?

If we really need the products of the mining industry we should be prepared to venture into regional mining projects in those areas that have the raw materials we need – whether this be in Germany, in Europe or elsewhere around the world. Regional raw materials extraction offers an environment-friendly and sustainable alternative to global supply chains. This will reduce the need for energy-intensive shipments around the world. Regional production can help alleviate supply-chain and delivery problems and in this respect can deliver economic benefits too. Let us not forget that Europe has put domestic raw materials production on the to-do list (4). We in Europe will not survive if we do not secure and safeguard our access to raw materials. This means not simply buying up raw materials from all around the world – the NIMBY approach – and refusing to take our own indigenous resource base into account. This concept could certainly be applied in Germany but it also holds good for every European and Western nation and indeed could work all over the world. We simply need to rethink our policy of depriving other cultures of their raw materials without ourselves being prepared to dig up our own raw materials.

In Germany the mining industry has developed highly advanced concepts for environmental protection and land recultivation. Even before initial approval is given for a new mining and mineral extraction project plans have to be submitted that set out in detail exactly what is to happen after the installation has been decommissioned. Old opencast mining sites are now being converted to other uses, for example as leisure and recreation areas, while some have also been restored to their original status (agricultural and forestry) or are renatured and transformed into nature reserves of exceptional quality.

I am convinced that regionally based raw materials extraction will experience an environment-friendly renaissance. Those whose eyes are open cannot fail to see the messages coming from German and European policy makers to the effect that real efforts are already being made in this area [5].

Transparency versus NIMBYism

As for those of us from the resource-producing, recycling and downstream industries, we have to be prepared to communicate more than ever before that a functional resource base is essential if we are to make a success of the energy transition. We have to be much better at convincing the public that regional raw material production and local recycling – no matter where you are in the world – are absolutely practicable while also being more energy efficient and more environment friendly. What is more, they provide economic opportunities and create jobs.

While this of course does not apply equally to all raw materials, those local deposits that can usefully be extracted should not be sacrificed to the NIMBYism that still widely prevails in various small-minded and egoistic circles. The right balance between personal freedom, the needs of society and the environment now has to be brought back into focus. Given the changes that lie ahead of us this means:

- Continuing with the regional mining and recycling of raw materials to the extent that this is feasible, necessary and environmentally sustainable.
- Accepting a degree of transitional damage to the environment as a result of the need for raw materials extraction.
- Balancing the rate at which the energy and heat transition is implemented across regions and over time so that industry and private citizens can keep up and jobs and property are not jeopardised.
- Providing political support for the required measures by way of sound, plannable decision making.
- Taking account of climate change, reducing the threat to our environment and protecting the latter as the basis of our existence.

This will serve to debunk the one-sided attitudes that are all too prevalent in the daily debate. Our continued survival will depend on whether all these different interests can be taken into consideration and sensible compromises adopted. And at the same time we have to realise something:

A compromise only works when everyone involved gets hit equally hard.

In today's society this basic fact of life seems to have become increasingly sidelined. A sensible compromise means that everyone of us has to accept that there will be bitter pills to swallow. For the good of all – and the benefit of our environment.

List of sources and recommended reads:

[1] Press release from the KIT, Karlsruhe Institute of Technology, Karlsruhe.
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[2] Report on Germany's raw material situation in 2022. Federal Institute for Geosciences and Natural Resources (BGR), Hanover.
Online: https://www.bgr.bund.de/DE/Themen/Min_rohstoffe/Produkte/produkte_node.html

[3] A face-to-face talk with Claus Pels Leusden, co-founder of Circulania, The concept behind Circulania.
Online: www.circulania.com

[4] European Raw Materials Alliance (ERMA)
Online: https://eitrawmaterials.eu/finance-fundraising/european-raw-materials-alliance-erma

[5] Germany's natural riches – a documentary about Germany's raw materials on ZDF info – video recommendation
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Dipl.-Ing. Manfred König

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Special Topic

Holistic Life-cycle Management leads to more sustainable Construction of Retaining Structures against natural Hazards

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Holistic life-cycle management of retaining structures which protect against natural hazards increases sustainability and conserves resources without neglecting the safety of infrastructure, residential areas and human life.

Geotechnics • Natural hazards • Maintenance • Retaining structures • New construction • Inspection • Conservation of resources • Sustainability • Durability • Service life • Safety

Introduction

The construction of structures protecting against natural hazards has been ongoing in Germany and Europe for the past six decades. They provide important protection for infrastructure [1], residential areas and human life. By definition, these are structures which protect against natural hazards, such as:

- Rockfall
- Block impact
- Ice impact
- Landslides
- Avalanches
- Debris flow
- Hazards in underground cavities intended for permanent use

At the time of construction, the retaining structure is not subjected to any loading. As the systems underwent development from simple auxiliary constructions to specialised technical systems, requirements on their serviceability were introduced [2]. The European Directive and national regulations govern the quality and use of the systems. In recent years, there has also been an increased awareness of the need to maintain safety structures in good condition. Sustainable decision-making and construction have become a task for society as a whole, since the construction industry consumes considerable resources and also generates significant emissions.

Fig. 1: Structure inspection of rock netting at Veldenstein Castle in Bavaria in southern Germany

Safety through Inspection

Until now, cities, municipalities, road construction authorities and other owners have provided no clear or standardised regulations for the inspection and monitoring of safety structures against natural hazards. However, in order to guarantee their durability and safety, monitoring of the systems is very relevant (**Fig. 1**). Due to increasing damage to existing safety structures and high capital expenditure on new structures for protection against natural hazards, structural inspections and controls are becoming more and more important. In the past, such structures were often not included in existing registers of structures and protective structures, as their structure type is clearly different to that of civil-engineering structures such as bridges, tunnels, troughs and retaining structures, which fall under DIN 1076 [3, 4]. Even today, some systems are still not recorded in the register so that regular inspections and maintenance of the systems in accordance with DIN 1076 may be omitted.

In recent years, different concepts for the monitoring of safety structures have been introduced at a national level. Gröner and Leidenberger [5] have already focussed on structure inspection from the manufacturer's point of view. System manufacturers and also authorities, such as the Bavarian State Construction Administration [6], have recently introduced a concept for the monitoring of safety structures. The programme comprises a recurring three-stage monitoring concept with observation, inspection, and testing; each stage increases in monitoring intensity. The position of 'expert for retaining structures' was thus introduced for the implementation of the monitoring concept and other engineering geological assessments. The requirements for this qualification include, in addition to study and job-specific conditions with relevant references in the field of georisks (expert reports and planning), participation in training as a rope access technician and participation in a course organised by the Bavarian State Construction Administration. The concept has recently been extended to other federal states. The inspections are intended to ensure the safety of infrastructure, residential areas and human life.

Conserving Resources through Inspection

An increase in resource-conserving thinking and the desire of cities and local authorities to become climate-neutral are also increasing the awareness of the benefits of structure inspection. The durability of the safety systems can be significantly improved by regular inspections. In the event of minor damage, for example, components can be replaced before major damage leads to the entire protection system having to be replaced. This requires experts with an understanding of the function of the individual components and their effect on the overall system. One source of suggestions for the assessment methodology is the manufacturer, and these proposals can serve as a guideline for structure inspection [7]. The current target service life of the safety structures is around 50 years. Regular inspections can guarantee and possibly extend the service life.

When the structure is inspected (**Fig. 1**), damage can be categorised by the experts according to the function of the components. If, for example, a supporting cable of a rockfall-protection fence has been damaged or has failed during a rockfall event, the component must be replaced because the overall function of the structure is impaired as a result. If it is not replaced, further rockfall can lead to greater damage and total failure of the system. This would result in a considerable safety risk and increased costs for replacement of the whole system, which would also have a negative impact on sustainability.

During structure inspection, "self-designed" structures built by gardening and landscaping companies from the 1970s and 1980s are also frequently encountered. Due to a lack of maintenance and servicing, many of the old structures are so badly damaged that they are no longer functional. Some of these structures, however, still have well-preserved supports, for example, so that they do not have to be completely replaced. Instead, the netting can be renewed (**Fig. 2**). This reduces repair costs and conserves resources. In such cases, it is also helpful if the structures have been recorded in the register of structures or protective structures after completion of construction. The entry includes structure plans with specific details of the retaining systems and anchor lengths, which help the experts to assess the condition of the system and the measures required.

Long Service Life of Retaining Structures

Sustainable Planning and Construction

However, the concept of sustainability should not just begin with the inspection of the structure, but should start with the construction of new safety structures. The longevity of the systems and the balance sheet of emissions during production and installation should be considered in the planning phase, because of their relevance when systems are selected in municipalities with the goal of climate neutrality. With the help of detailed geotechnical appraisals and realistic risk evaluations, anchor lengths and structure dimensions can be designed to be as small as possible while maintaining the required safety level; they are thus planned and executed as resource-efficiently as possible for the intended service life. In particular, a reduction in the use of conventional concrete and the use of climate-friendly concretes and cements play a key role in reducing CO_2-balance. The required level of safety and a long service life can only be guaranteed if the workmanship is technically flawless. Independent construction supervision on behalf of the client during the construction of the safety structures plays a decisive role in ensuring the quality of permanent safety systems. For cost reasons, during the construction

Fig. 2: Refurbishment of the structure – supports from the 1980s with new netting

Fig. 3: Netting fully integrated into the tree trunk

Fig. 4: Fallen foundation of a former palisade wall

phase there is often only self-monitoring by suppliers and contractors and/or monitoring by an inadequately competent local construction supervisor. The consequence is that construction defects are only discovered late or not at all. This subsequently leads to significant follow-up costs for the rectification of defects and major damage, which are only discovered, for example, during later structure inspections or when damage occurs.

Furthermore, maintenance and inspection concepts should be developed during the planning and development phase which regulate the inspections during the operating phase for the entire life cycle. Supplementary systems for remote monitoring of the safety structures such as GUARD from Geobrugg [8] can also be used for this purpose. Such systems can record not only impact events, but also rope forces that allow conclusions to be drawn about the degree of filling of rockfall protection fences. If additional data such as corrosion, temperature and humidity are documented, they allow conclusions to be drawn about the progression of component corrosion and help to better schedule inspection intervals. As early as in the planning phase, the use of monitoring systems should be adapted to local boundary conditions such as event frequency and intensity, and to the objects to be protected.

Sustainable Care and Maintenance

Other important factors for the durability of the systems are the regular clearing of vegetation and maintenance of the structure. Successful structure inspection requires unrestricted access to the structure. This is only possible if ingrowing vegetation has been pruned in good time (**Fig. 2**). Vegetation, especially woody plants, is able to integrate a covering net completely into its trunk (**Fig. 3**). Without pruning, the flexibility and thus the functionality of the system are considerably restricted. Windthrow from trees which have established themselves can also cause damage to safety structures. Where a covering net is in close contact with the surface, growth of woody plants leads to further loosening due to root pressure, especially on rocky slopes. In the case of soil slopes, however, grass and shrubs can also have a positive effect on the slope surface and stability, but damage to the mesh cannot be ruled out.

Recycling when Structures require Replacement

However, if the replacement of safety structures is unavoidable, an attempt should be made to remove the existing, outdated structures from the embankments/slopes. Dismantling not only promotes the durability of the new systems, but also enables material that is no longer required to be recycled. The safety structures are made mainly of steel, which can be returned to the cycle via scrap dealers and recoverers. Regulations on the conservation of natural resources and the protection of people and the environment were already set out in the Circular Economy Act of 2012. If old structures remain in place, rusting components can also come into contact with new, ZnAl-coated system components and cause contact corrosion. This can significantly reduce the durability of the new systems.

In the past, short anchoring lengths were often selected for old rockfall protection structures so that, for example, support foundations for interception fences with damaged or dismantled mesh panels are at risk of falling (**Fig. 4**). These often remain in the terrain when new replacement structures are built, and are not removed for cost reasons. However, progressive erosion exposes the foundations and short anchors, further increasing the risk of falling.

Effects on Infrastructure

The effect on the existing infrastructure should also not be neglected. The protective structures are generally erected to protect road and rail traffic and local residents. The construction work involved – whether new construction, replacement construction or renovation – is associated with road closures. Affected residents and users of the infrastructure therefore have to accept detours and be prepared for further inconveniences such as dust and noise. Structure inspections can reduce the impact on infrastructure if minor defects are rectified

Special Topic

more quickly. Often, only short closures – or none at all – are required here, whereas significantly longer construction times and more serious impacts on traffic are to be expected when a replacement is required.

Conclusion

For the sustainable use of retaining structures, a concept for their entire scheduled life cycle is essential. It starts with good, detailed planning and extends to the independent monitoring of production, an inspection and maintenance concept, and the resulting continuous or regular inspections, right through to any repairs required.

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Special Topic

Collaboration leads to groundbreaking Recycling of Geotextiles

Gijs Groen, Solmax, Hengelo, The Netherlands

In a pylon project in the Netherlands a good collaboration between the project partners enabled the development of a recycling method for geotextiles under temporary site access roads.

Geotechnics • Sustainability • Geosynthetics • Geotextile • Temporary roads • Recycling • Innovation • Collaboration

Solmax, TenneT, and SWITCH (a consortium consisting of Strukton, Mobilis, and Oosterhof Holman) have collaborated to successfully recycled geotextiles used in the construction of new high-voltage pylons in the Netherlands. This partnership marks a significant advancement in sustainable construction and waste management in geotextiles.

About the Project

The pylon project in the Netherlands used 500,000 m^2 (598,000 yd^2) of MIRAFI® HMi geotextile as a separation and stabilization layer beneath temporary access roads during the SWITCH project's installation of high-voltage pylons. This material choice reduced the amount of sand needed by 50 % compared to using only a separation layer without a stabilization geotextile, and decreased the environmental and community impact by minimizing transportation trips.

After the installation of the high-voltage pylons, the challenge was to recycle material used in the contruction of the temporary access roads. The geotextile in particular proved to be challenging to recycle as it was contaminated with soil and sand particles. No existing process could efficiently handle the high soil content. Through collaborative effort and innovative thinking, a process was developed that could clean and recycle the geotextile, transforming it into polypropylene pellets for reuse in Solmax production, thus supporting a circular economy model.

Collaborative Development Process

The collaboration's success hinged on integrating various technical innovations spearheaded by each partner, characterized by an open exchange of ideas and continuous adaptation of methodologies. Solmax took the lead in developing a specialized process to clean and recycle the geotextile. This process involved multiple stages of cleaning to ensure the removal of soil particles without damaging the integrity of the geotextile fibers.

Fig. 1: Disassembling the temporary access road constructed for the SWITCH project

Fig. 2: MIRAFI Geolon HMi-5 geotextile reclaimed after project completion

Simultaneously, SWITCH focused on the logistical aspects, devising methods for efficiently collecting and transporting the used geotextile from the field to Solmax's partner recycling facility (**Figs. 1 and 2**). This involved careful planning to minimize any additional environmental impact during the transport phase.

The technical challenge was particularly daunting due to the nature of the geotextile's contamination. Soil particles embedded in the fabric posed a significant hurdle. Through a series of pilot-scale trials, the team developed a method that involved agitation and sedimentation techniques to dislodge and separate the soil from the geotextile fibers effectively (**Fig. 3**). Once the material was sufficiently clean, it was processed into polypropylene granules, suitable for reintroduction into the production cycle of new geosynthetic materials (**Fig. 4**).

Conclusions

Servaes Huvenaars, Project Manager at TenneT, highlighted the broader implications of this collaboration:

Special Topic

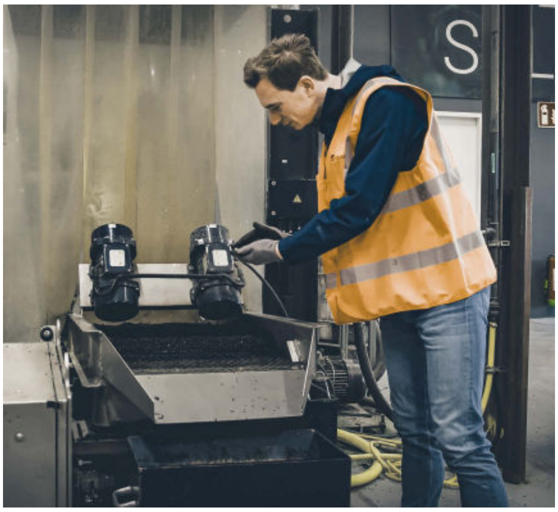

Fig. 3: Transformation of recycled geotextile into pellets for reuse

Fig. 4: Pellets prepared from recycled geotextile, ready for integration into new geosynthetic products

"*The fact that we are now recycling the geotextile from the 380 kV connection Vierverlaten-Eemshaven for the first time is partly thanks to the efforts of the collaborating parties. This can only be achieved with a lot of mutual trust. We have now demonstrated that the geotextile can be recycled. There is no reason not to do this more often in other TenneT projects. The potential spin-off is even greater, as recycling of geotextile can also be applied in other construction projects. This makes the market interesting for other producers as well. It just goes to show that the result can be greater than the sum of its parts.*"

Edwin Veldman, part of the SWITCH project management team, emphasized the social impact: "*Strukton aims to positively contribute to sustainable changes in our society. By collaborating with TenneT and Solmax to explore solutions for this non-digestible waste mountain, we have made an impact on our future and that of our children. I am convinced that we will come to see this as a sustainable solution throughout the construction industry, and I am already involved in various projects to raise awareness about recycling.*"

The successful partnership set a new benchmark for recycling geotextiles, proving that with trust and commitment, sustainable solutions are achievable. The project has the potential to inspire further sustainable practices: We share a great responsibility to develop solutions that minimize our environmental and community impacts. Fostering collaboration and transparency among diverse partners is critical for creating better, more sustainable infrastructure. This project is a prime example of the power of collaboration. Despite significant challenges, the commitment from all partners led to a groundbreaking solution. The lessons learned from this experience will undoubtedly benefit future projects."

This collaboration between Solmax, TenneT, and SWITCH not only addressed a specific environmental challenge but also laid a foundation for future recycling initiatives that reduces waste by demonstrating the significant environmental advancements that can be achieved through combining diverse expertise and perspectives.

Gijs Groen

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Special Topic

Shaping the Future: How AI and Laser Technology revolutionize Mining Repairs

Nikolaus Fecht for GeoResources , Interview with Amit Varma, Braintoy Inc., Calgary, Canada, and Max Zimmermann, Fraunhofer Institute for Laser Technology ILT, Aachen, Germany

In an exclusive interview, Amit Varma from Braintoy and Max Zimmermann from the Fraunhofer Institute for Laser Technology ILT reveal insights into the AI-SLAM project: Germans and Canadians have teamed up in a joint project to revolutionize repair processes in the mining industry. Using new algorithms from the field of artificial intelligence, typical wear parts such as rock crusher teeth, drill bits or ripper teeth are laser repaired and coated with a protective coating in a semi-automated process.

Mining • Maintenance & Repair • Laser technology • Artificial intelligence • Digitalisation

Fig. 1: The AI tool developed as part of the AI-SLAM project speeds up the laser coating and repair of components with complex geometries (pictured: a blade tooth)
Photo: Apollo Machine and Welding Ltd., Canada

Niko Fecht: Mr. Varma, what inspired you to initiate the project?

Amit Varma: The Canadian mining industry is massive because it is a big country with vast natural resources. There are a lot of equipment and machines, for example, ground-engaging machines, rock-crushing machines with millions of commodity parts which have to be repaired and re-coated (**Figs. 1 + 2**). And it takes highly experienced machining operators to be able to do that.

Imagine a shop which has to coat a few thousand parts every month. It is impossible for such shops to hire enough experienced laser machining operators. We want to use AI to help such operators consistently do their job better and faster (**Fig. 3**). It was my biggest motivation while approaching this project. Only by simplifying the complex tasks of each operator can the process be scaled to high volumes.

Niko Fecht: Mr. Zimmermann, please describe the role of the Fraunhofer ILT within the project.

Max Zimmermann: With its numerous parameters, the Laser Material Deposition (LMD) process is complex and difficult to master due to the constantly changing manufacturing and processing tasks. The Fraunhofer ILT has more than 35 years of experience and expertise in this field. We are now trying to digitalize the LMD process and our know-how. To do this, we are teaching an AI what constitutes good and bad machining. It should then be able to support the operator in designing the process.

Niko Fecht: And how your expertise contributes to addressing the challenges?

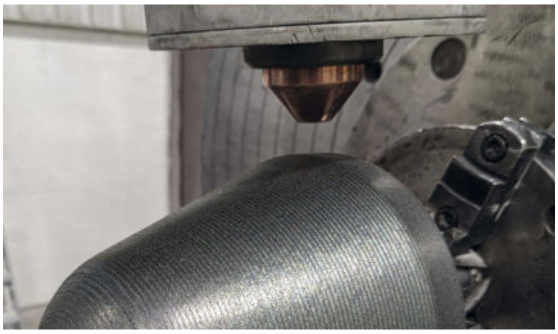

Fig. 2: Wear parts like this stone crusher tooth with an outer diameter of about 140 mm are restored with the LMD process. Thanks to AI, the processes for repairing irregular surfaces shall be optimized.
Photo: Apollo Machine and Welding Ltd., Canada

Max Zimmermann: We run the LMD processes and collect data such that an AI can read it. But in principle the AI does not know what it sees. And that is the point where the Fraunhofer ILT comes in with one question, "what can you see inside the process to be able to digitalize it?"

Amit Varma: Think of it this way – Max and Gentry, our project members, are intelligent operators with many years of training and experience in knowing what is good, and what is bad from a process point of view. Now, what we are doing is like creating a "Max bot" or a "Gentry bot". It is like digitalizing the brain of a highly experienced operator and putting it in a machine.

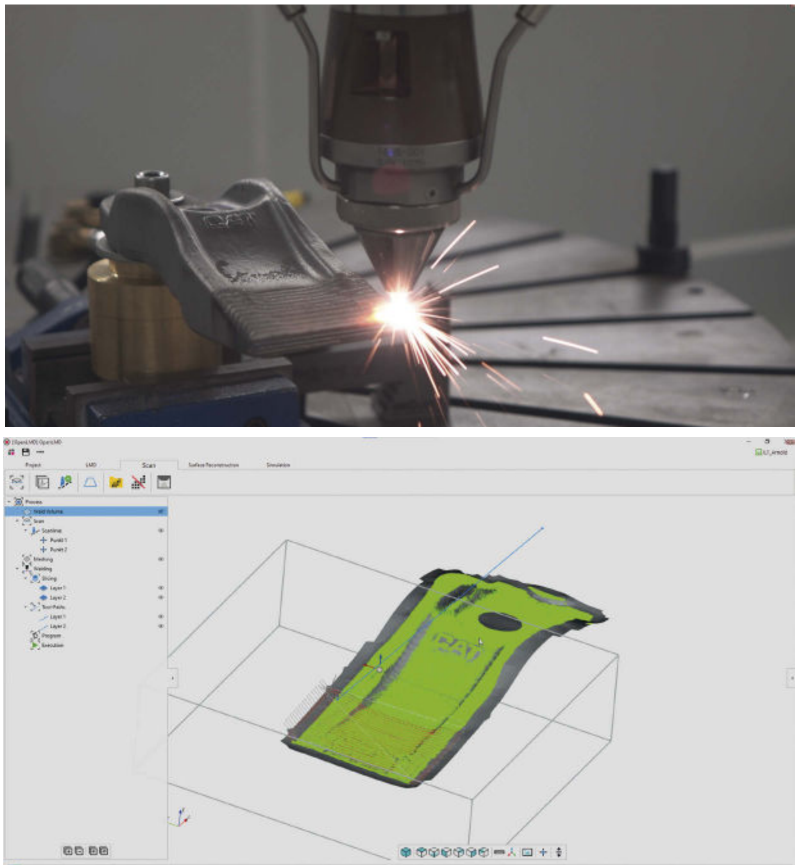

Fig. 3: The AI-driven LMD process simplifies the operator's role in coating excavator teeth.
Screenshot: Fraunhofer ILT, Aachen, Germany

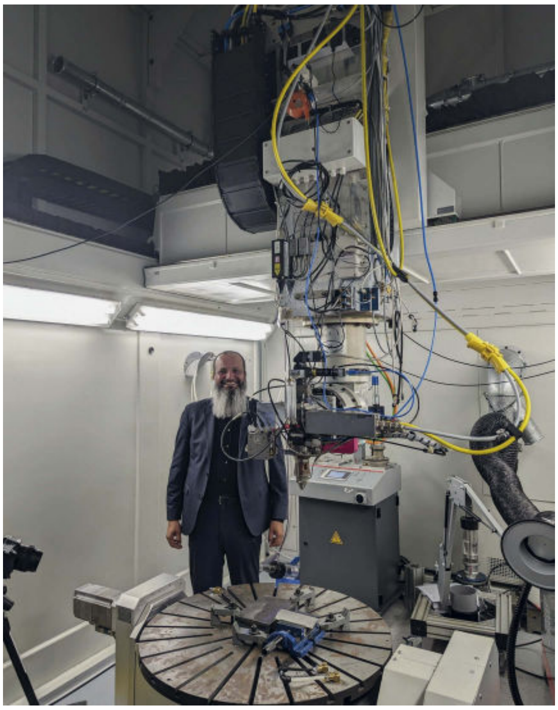

Fig. 4: Braintoy co-founder Amit Varma in front of the AI-SLAM machine: "The AI process recommends what parameters to set for a perfect repair or coating. It then adjusts them every second to make the process perfect."
photo: Fraunhofer ILT, Aachen, Germany

Niko Fecht: What are the main objectives you are pursuing with a project in the context of the mining industry? And what specific challenges are you addressing?

Max Zimmermann: We streamline the LMD process. We use the OpenARMS software from our project partner BCT as base program. The AI is also integrated in OpenARMS. With the OpenARMS software, the operator will later only need one software to program the best parameters for the LMD system using the integrated AI. This makes the LMD process more efficient, easier and more cost effective for the industry.

Niko Fecht: Mr. Varma, how does the multimodal platform mlOS from Braintoy support the machine learning operations in the optimization of the laser coating process?

Amit Varma: Imagine that I have to teach you how to ride a bicycle. The first thing that you will do is learn the know-how to sit on the bicycle, where to turn the handle, and how much to push the foot pedal. Those are the initial parameters to ride a bicycle. But as you begin to ride the bicycle, those parameters have to change rapidly in real-time to be able to continue to balance the bicycle while riding it. The AI does exactly that. It first recommends what parameters the machine operator has to set. It then adjusts these parameters every second so that the coating turns out in the best possible way every time (**Fig. 4**).

Niko Fecht: How does your platform come into play here?

Amit Varma: Braintoy mlOS is the only technology in the world which can ingest any data type and run it in the same universal pipeline. It is able to create many models within seconds, rank them, and revise those models again and again. It's easy for anyone to create a model, however, to repeat it in production is a very difficult task. And that is what mlOS does perfectly – it does it like a model factory.

Niko Fecht: What types of data do you utilize in the AI-SLAM project?

Amit Varma: The three types of data used are:

- Computer vision data comprising images and videos,
- Tabular data organized in rows and columns, and
- Time series data arranged in a sequence over time.

Niko Fecht: How does Fraunhofer ILT contribute to the development and application of AI in this project – especially in predicting microstructural defects?

Max Zimmermann: That is the fourth dimension of data – the microstructure images. The view of the microstructure is really difficult to understand, so that is total research. We have to label the data, to train the

AI properly, and send the labeled data to the Braintoy mlOS platform, so that it can extract and predict the information out of the microstructure data.

Niko Fecht: How does a real time AI algorithm improve laser deposition?

Amit Varma: The purpose of AI-SLAM (**Fig. 5**) is to prevent errors during the LMD process: the AI classifies errors in real time and tells the operator what to do. In other words, the machine gets a "brain" that explains how to avoid defects.

Max Zimmermann: The real-time and total quality assurance is the key. If you find a defect after setting the right parameters, you can pinpoint and fix it locally, a major benefit for materials and 3D build.

Niko Fecht: Mr. Varma, how do you handle defect prediction and correction?

Amit Varma: The data is tagged according to defect classes. Machine learning algorithms recommend parameters that avoid defects. The Fraunhofer ILT's LMD expertise was crucial here, as it combines software and process expertise to create an effective solution.

Niko Fecht: How do you select and adapt AI models within the project?

Amit Varma: We have a technique to evaluate the models featuring model explainability within the Braintoy mlOS platform. This unique feature allows us to understand precisely what the model predicts and why, which is groundbreaking since no other technology offers this. The mlOS platform enforces strict model governance and explainability.

German-Canadian AI Collaboration

In this collaboration, key participants include: the Fraunhofer Institute for Laser Technology ILT in Aachen, Germany, software developer BCT from Dortmund, Germany, the National Research Council of Canada, McGill University in Montreal, Braintoy in Calgary, Canada, and Apollo Machine and Welding from Alberta, Canada. They stand at the forefront of the project. The AI-SLAM project aims to harness Artificial Intelligence for optimizing industrial production across various sectors. The project leverages extensive process data and machine learning to improve efficiency in processes such as Laser Material Deposition (LMD), with a focus on enhancing repair and coating processes. The program is funded on the German side by the Federal Ministry of Education and Research BMBF and on the Canadian side by the National Research Council of Canada NRC.

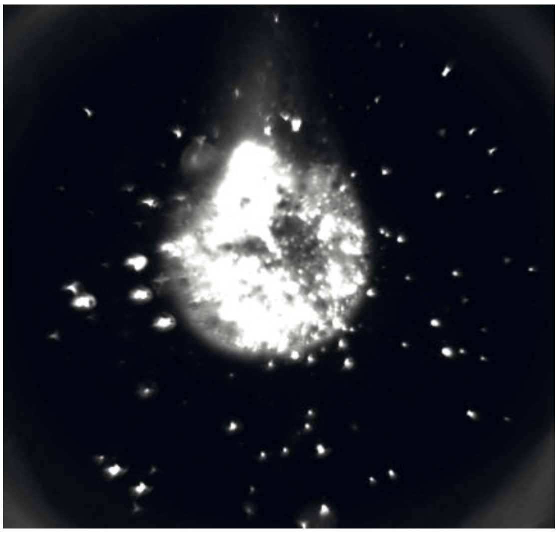

Fig. 5: Coaxial weld pool image from laser metal deposition in the AI-SLAM project
Image: Fraunhofer ILT, Aachen, Germany

Niko Fecht: How did the Fraunhofer ILT manage to standardize data, preprocessing and model generation?

Max Zimmermann: At the beginning, we created a detailed flow chart describing the data transfer and the pipeline. Since the beginning of 2022, our understanding of the data and its management has improved considerably. The flexibility of Braintoy's mlOS platform plays a crucial role in handling the dynamic and diverse structure of the data.

Niko Fecht: What results do you anticipate by the project's completion in March 2025?

Amit Varma: By the end, we expect to have a realtime process that recommends optimal parameters for correcting defects aiming for a scenario where defects can be preemptively avoided. This will be deployable by any machine operator globally, integrating BCT's OpenARMS and Braintoy's mlOS software for consistently improved LMD operations.

Niko Fecht: Have you reached any milestones so far?

Insights into the Canadian Mining Industry

The Canadian mining industry is a significant contributor to the national and global economy, supporting 665,000 jobs and adding CAD 125 billion (approximately EUR 84.94 bn) to Canada's GDP in 2021. Key products include gold, iron, steel, aluminum, iron ore, and critical resources like potash, uranium, nickel, with Canada being a leading global producer.

Fig. 6: A German-Canadian team in collaboration with multiple partners, is developing an easy-to-use tool in the AI-SLAM project: It swiftly identifies defects in laser repairs and coatings on parts for the mining industry.
Photo: Fraunhofer ILT, Aachen, Germany.

Amit Varma: Yes, the preliminary models are already deployed. This year's focus is on incorporating more sensors. Additionally, we're developing a recommendation engine for operators, similar to how Netflix recommends movies that you may like. These, we believe, will fulfill the project's objectives.

Niko Fecht: Mr. Zimmermann, how do you see the project impacting laser coating technology and future applications?

Max Zimmermann: The project streamlines the LMD process, making it automatic from tool path planning to execution. You scan the surface, set the parameters, and just start the process. This efficiency improvement is significant for both current users and new companies, by effectively lowering the barriers to entering LMD technology (**Fig. 6**).

Niko Fecht: What are the next steps for the project?

Amit Varma: We're implementing decision fusion, where multiple models vote on the best outcome, ensuring the most accurate decisions for the LMD process.

Niko Fecht: How would you describe the collaborative nature of your project and its openness to working with other partners?

Amit Varma: It is a multi-partner relationship supported by the Canadian and German governments. But we would also like to work with other interested parties, because we don't want to keep the project a secret.

Interested parties can find out more at the Fraunhofer ILT booth at Formnext 2024 in Frankfurt am Main from November 19 to 22, 2024, where updates will be presented, among other things.

Niko Fecht: Thank you Mr. Varma and Mr. Zimmermann for the interesting interview. I wish you all the best for your interesting work.

Amit Varma

Co-founder Braintoy Inc., Calgary, Canada: "We are trying to collaborate with others because we are not in the business of keeping it a secret. A collaboration with additional partners would be good for the project."

Contact: amit@braintoy.ai

Max Zimmermann

project manager in the Laser Metal Deposition (LMD) department of Fraunhofer ILT, Aachen, Germany: "We are digitalizing the LMD process and our know-how to make it easier and more cost-effective to operate in industry."

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Special Topic

Voluntary Actions contribute to a greater Good

The GeoResources team in an interview with Antonio Nieto, President of the CECE

The GeoResources Team interviewed Antonie Nietom, topical President of CECE – Committee for European Construction Equipment. The President provided insights into the motivation behind the voluntary work and the major current challenges for the construction and mining machinery industry. Reducing carbon emissions and leveraging digital technologies in connection with good European legislation are critical priorities.

Tunnelling • Mining • Geotechnics • Construction • Machinery • Legacy • Policy • Association work • Sustainability • Congress • CECE • bauma • Digitalization • Decarbonization

GeoResoures Team / Katrin Brummermann: Hello Mr Nieto, thank you very much for taking the time for this interview. GeoResources deals with topics related to the subsurface, particularly in the geotechnical, tunnelling, mining and energy sectors. Construction and mining machinery naturally play an important role here, as do current challenges such as digitalisation and decarbonisation and the associated technical developments and legal regulations. We have been in contact with the VDMA for years, but of course we also keep an eye on the whole of Europe and the international market. You have been Honorary President of the CECE since the beginning of this year. This is the association for "European Construction Equipment", in which the German association VDMA is represented alongside many other national European associations. You were previously Vice President of the CECE for two years, so you are no longer a newcomer.

I would like to start with a personal question for you. What motivates you for the certainly time-consuming additional voluntary work in the CECE and the national Spanish association ANMOPYC? Your full-time work as Managing Director of Putzmeister Iberica S.A. and the international underground business unit is certainly also challenging and fulfilling.

Jose Antonio Nieto: Certainly, it takes time, maybe more than I thought but it is worth to invest on it. For many years the CECE presidency was led by earth moving machinery companies, which is surely the largest sector of construction machinery. I am glad and proud to bring to CECE the concrete equipment technology as President, since I think it is good to give some visibility to other construction machinery like concrete pumps.

The CECE Presidency also helps with the social aspect and often enables to get to know new people, form friendships, and enhance social ties.

Finally, it provides a sense of purpose and fulfilment, knowing that one's actions are contributing to a greater good.

GeoResources: How do you work with the UK-based JCB Vice President Tim Burnhope and the CECE team and how do you divide up the various tasks?

Jose Antonio Nieto: We had an introductory meeting to get to know each other and establish some connections and now we have to create some tasks to distribute the work. Since Tim comes from the earth moving sector I mentioned before, I believe we can form a great duo and organize our collaboration for the benefit of all the members of CECE.

GeoResources: But now I would like to talk specifically about the content of your work as President of CECE. At your introduction at the beginning of the year, you formulated your mission as President: "My mission as CECE President is continuing with this legacy, as well as pushing for and supporting current key topics for our industry." You mention current legislative processes first. Is the reason why dialogue with politicians is so important to you that major transformations are currently underway in politics and in the industry and that a decisive course is being set for the future?

Antonio Nieto, President of the CECE

Special Topic

Jose Antonio Nieto: We are currently experiencing a time of significant change, with politics regularly making pivotal choices and decisions that will shape the future. It is essential for both industry and politics to maintain ongoing communication in order to foster mutual understanding and collaboration, thereby facilitating more effective support for one another. The main mission of CECE is indeed to inform policymakers of the impact their choices have on companies, employees, and overall prosperity. In an ever more complex world of decarbonization, sustainability and digitalization, some of the information we bring to policymakers come from our cross-checking of different regulations and how some laws contradict other objectives. In this key moment of change in Brussels, we have been also playing the democratic game by listing our main requests in a Manifesto for the European Elections and the next European Commission [1]. I am only President for two years, but the horizon is longer, we are talking about setting now the goals for the EU we want in 2030.

GeoResources: Sustainability has three pillars: environment, economy, and social issues. How do you classify the overarching topics of decarbonization and digitalization, which are important to you, within the overarching topic of sustainability?

Jose Antonio Nieto: Reducing carbon emissions and leveraging digital technologies are critical priorities for both the CECE and mining industries. All the three elements of sustainability have to be taken together. The most common mistake of certain politicians is to take economic sustainability for granted and focus entirely on the environment. I join my predecessors CECE Presidents in calling for policymakers to focus on these three dimensions jointly. If that were not the case, the risk is what we start to see, which is a loss of competitiveness of European manufacturing on the global markets. When it comes to digitalisation, I believe it plays an essential role as an enabler of many sustainable business models and of the overall transition to a carbon-neutral economy. CECE has been describing the digital transition and its tools as contributors to decarbonised machinery at the same level as alternative energies.

GeoResources: Do the sectors represented by the CECE have enough time to focus on these important issues in the current difficult economic climate? Or are the topics of decarbonization and digitalization perhaps the key to improving the situation?

Jose Antonio Nieto: The current economic climate is turning to a less positive perspective, but we come from several years of growth and we still are at very high absolute numbers on the European market. In addition, I strongly believe that in mature markets like Europe, it's innovation that improves productivity and working conditions, which creates the competitive advantage. Decarbonization and digitalization represent opportunities for driving positive change, enhancing productivity, health, environmental sustainability, and working conditions, among other benefits.

GeoResources: With regard to securing raw materials in Europe and the corresponding political developments, you recently strengthened the mining machinery and equipment division in your association. This also fits in with GeoResources' motivation and strategy. We see interesting synergies for both the construction and mining industries, particularly in the technical area, between the two sectors and therefore their markets. What specific actions do you have in the pipeline at CECE for the strengthened mining sector?

Jose Antonio Nieto: We focus on guidance on responding to the Critical Raw Materials Act (CRMA), including recommendations for engaging in dialogue with the Commission and collaborating with European trade associations such as Euromines, Eurometaux, and EIT Raw Materials to exchange information on raw materials-related issues.

GeoResources: As a woman in the construction sector – I am a civil engineer specializing in geotechnics, tunnelling, and construction materials – I am also interested in the topic of skilled personnel. Do you see a great need for skilled labour in the STEM sector and therefore in the construction and mining industry in the future? How important are equal rights for women and men and the attractiveness of relevant training and degree programs in this context? Do you see a need for action?

Jose Antonio Nieto: The Women in Mining campaign has been active internationally for some time, highlighting the ongoing efforts needed to make the construction sector more appealing to women. There is a clear need for more skilled workers, necessitating the exploration of new perspectives and approaches. One day, it should indeed become the new normal for women to participate in the construction sector.

GeoResources: You have a "home advantage" at the CECE Congress in Madrid in October. Can you give our readers reasons why it will be worthwhile attending the congress even if you are traveling further afield?

Jose Antonio Nieto: Well, a CECE Congress is always a great chance to network with the leading figures in the industry, with outstanding speakers addressing current topics and in a pleasant atmosphere of culture and fun. We will tackle the high-level political topic of the future of industry in Europe and how our economies need to re-industrialise in a sustainable way to secure prosperity. Our economic forum on the last day of the Congress will have a full focus on South America as a key continent for the mining and extractive industries and Europe's need to diversify its supply of raw materials.

GeoResources: And let's look ahead to next year when you will also be chairing the CECE. How will you use bauma in Munich in April for the work of the CECE? The key topics for the exhibiting companies and the target groups of trade fair visitors are certainly extremely attractive for CECE.

Jose Antonio Nieto: I am already looking forward to bauma 2025. My personal commitment to the mining industry will be central also in Munich in next April since CECE is going to be involved directly in the bauma Forum programme for the mining day. Bauma is a key international partner of CECE and I believe that this exhibition will be again the best showcase possible of the innovative and ground-breaking nature of the construction equipment industry. Like always, we plan to take advantage of the exhibition to have our internal meetings since everyone may be there and to host politicians and public officials at the trade grounds to see first-hand the industry that CECE represents.

GeoResources: Mr Nieto, thank you for taking the time to do this interview and for the interesting information for our readers. We wish you all the best for the rest of your CECE presidency.

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About Jose Antonio Nieto

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On-site Safety and Health Protection with Ventilation Support and Personal Tracking for a Rail Upgrade Project in the Berlin North–South S-Bahn Tunnel

Patrick Schneider, M.Sc., CFT GmbH – Compact Filter Technic, Marl, Germany

The infrastructure of the North–South S-Bahn Tunnel in Berlin, which carries 760 trains a day and is one of the most important lifelines of the public transport network, was extensively modernised in early 2023 in an operation that was completed in a mere six weeks. During the renovation project the 280-strong tunnel workforce was protected by an elaborate ventilation and tracking system devised by the Marl-based CFT company.

Tunnelling • Tunnel renovation • Maintenance • Workplace safety • Ventilation • Personal tracking • Construction operation • Track laying • S-Bahn

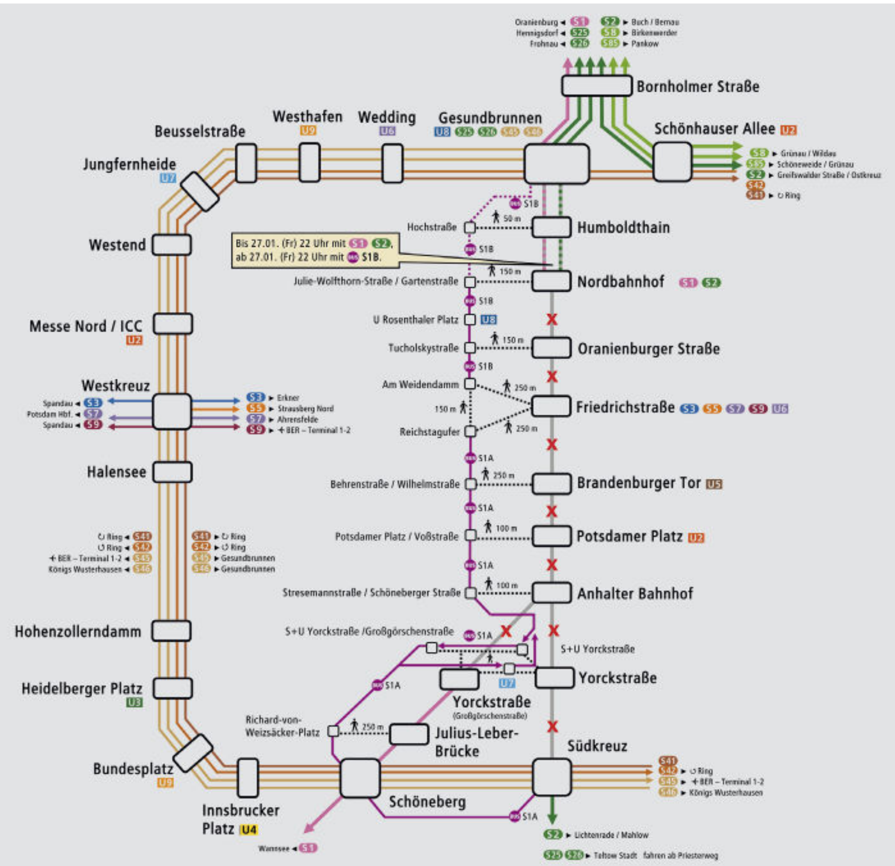

Fig. 1: Line closure in the North–South S-Bahn tunnel in Berlin

1 Background to the Modernisation Project in the North–South Tunnel of the Berlin S-Bahn

The North–South S-Bahn Tunnel, which was built in the 1930s, carries four S-Bahn tracks and serves around 100,000 travelling passengers a day, making it one of the most frequented lines in Berlin. The route was completely closed from 6th January to 17th February 2023 to allow various maintenance and renewal measures to be completed in two phases (**Fig. 1**). The modernisation programme included the replacement of two sets of points and 9.1 km of rail track, corrections to the track geometry, track stabilisation and maintenance work, the milling of 18.4 km of rail and other repairs. The track laying operation meant that in addition to two new battery locomotives a number of diesel-powered units would also be operating in the tunnel, including locomotives, BAMOWAG track cars, excavators and a rail-mounted milling machine. This required various ventilation measures to be put in place for safety and health protection purposes. The intrusion into the ballast bed during the points replacement and track correction work also called for the additional use of high-performance dust extraction equipment so that the dust released from the ballast material could be removed from the air and thereby prevented from entering the city atmosphere.

2 Workplace Health and Safety Measures

The use of diesel-powered vehicles for the refurbishment work inevitably meant the release of harmful exhaust emissions. These would contain gases hazardous to health, such as nitrogen monoxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO) and carbon dioxide (CO_2), along with diesel soot particles (elemental carbon). Where diesel motor exhaust gases are present in the workplace environment the requirements of TRGS 554 (Technical Rule for Hazardous Substances – Diesel motor exhaust gases) must be observed for occupational health and safety purposes [1]. Compliance with these requirements implies meeting the standards laid down in the Ordinance on Hazardous Substances (GefStoffV) [2] and in the Ordinance on Preventive Occupational Health Care (ArbMedV) [3].

When managing complex construction projects in an intra-urban tunnel, where many different activities have to be carried out and the overall site includes several stations and stopping points, it is vital that health and safety protection is factored into the overall planning process right from the start. The engineering firms participating in the project (Michalski Engineering, PBVI GmbH and PUS GmbH) therefore involved the Safety and Occupational Health Coordinator (SiGeKo) at an early stage and developed a suitable work schedule that would incorporate both the technical and the organisational safeguards and protective measures. In order to create an efficient workflow the plan provided for an air separator designed to split the tunnel into two distinct ventilation zones, thereby making for a more efficient deployment of the two construction sectors with their entirely independent ventilation regimes. The planning phase also had to make provisions for protecting travellers who would still be using the intermediate levels of the stations involved. The solution was to provide a continuous exchange of air by setting up 43 individual ventilating fans below ground that would draw in fresh air via a pre-allocated station/stop and move it through the tunnel towards the north and south portal. All the tunnel's emergency exits were therefore made airtight so that the airflow could be routed in a controlled way and no air could be exhausted or drawn in at these points. Here maximum priority was given to maintaining the functional integrity of these exits so that evacuation would still be possible in the event of a fire, for example.

As well as dealing with hazardous substances from the exhaust gases of diesel-powered railway vehicles the planning process also had to target hazardous particles such as the dust generated when removing and replacing the ballast. The requirements laid down in TRGS 559 (Technical Rule for Hazardous Substances – Quartz dust) [4] were implemented by using CFT dry dedusters to separate out the quartziferous dust (total air volume of the dust extraction plant 9,000 m^3/min) and by the additional wetting of the old and new ballast. These actions were combined with other measures, including the use of air screens and air doors to partition off the working sectors, so that particulate levels in the working areas could first be kept to a minimum and then any remaining hazardous material captured before the air was filtered and released into the city atmosphere.

These technical and organisational protection measures enabled much of the project work to be completed safely within the track possession period.

3 Extensive Execution Planning

The execution planning process was initially divided into the following sub-areas:

- Detail plans for the installation and positioning of all the required plant and equipment, such as fans, dedusters and measuring instruments, in accordance with the proposed ventilation concept
- Detail plans for the air screens, air doors and airtight seals for the emergency exits so that the flow of air could be directed through the workplace in a controlled manner
- Detail plans for the energy supply system, including the sub-main distribution, cable runs, conductor cross sections and earthing
- Detail plans for the ballast wetting operation, including provisions for the water supply and the removal of the return water
- Logistics planning for all road and rail transport arrangements
- Network concept for the integration of all measuring instruments and fans so that the ventilation system could be regulated from a central control room
- Detail plans for a personal tracking system that was to be embedded in the network
- Applications to the authorities in respect of land-use authorisations and traffic regulations.

The locations proposed for the dedusters, fans and measuring instruments were first identified and recorded during various tunnel inspections. This was followed by graphic drawings showing the main components installed in the tunnel, including all the dedusting units, the special exhaust air system at the Potsdamer Platz station and its associated ducts and exhaust stack. All constructional measures were carried out by CFT's own engineering design department. In addition, measures had to be put in place to ensure that the boundary lines for bringing in the track-bound pieces of equipment were strictly observed and graphically verified during the construction phase.

Detail plans for the power supply to all the ventilation units were drawn up in parallel with the planning for the machine installation and positioning process. It was initially planned to use the electrical current provided at the supply cabinets installed in the North–South S-Bahn Tunnel. However, as the existing cabinets were not capable of supplying power to equipment with an installed electric capacity of around 2.1 MW additional arrangements had to be put in place to provide the power that was required. Diesel generators were subsequently brought in and set up in three areas where there were no residential buildings located immediately above the tunnel. This was not an option for the station serving the Oranienburger Strasse, however, due to the immediate proximity of residential housing. The solution in this case lay in the temporary deployment of a site transformer fed from the municipal power supply, this also forming part of the scope of supplies. Given the need to coordinate arrangements with the various agencies involved, such as DB Energie, the local power supplier and the respective district authorities, the detail planning work required for the power supply system

Fig. 2: Two-way excavator positioning a fan unit during the preparation phase.

Fig. 3: Section of ducting for the active venting of waste air via a discharge stack at Potsdamer Platz station

therefore became a crucial part of the execution planning process, one of the factors here being the civil engineering work associated with the supply of electrical power to the current transformer.

Another key issue for the execution planning was to arrange for the wetting of the old and new ballast in those areas where the points were to be replaced, this to be executed using state-of-the-art technology. The water for the wetting operation was fed into the tunnel via hoses laid through an emergency exit close to the set of points being replaced. The used spray water then had to be collected and pumped via another set of hoses out through three emergency exits and into a number of waste-water tanks set up at ground level. The planning required for this operation therefore involved the layout of the pumps and hose system and applications in respect of land-use authorisations for the pumps and water tanks to be set up close to the emergency exits.

Given the deployment of the various fan units and instruments needed to monitor air quality along the 6 km section of tunnel, the building specification called for a central control room to direct the fan operations and provide access to all the measuring devices. The execution plans therefore included the setting-up of a temporary network capable of integrating and interlinking the different operating units and systems. In view of the length of the construction site it was decided to use fibre optic cables for this purpose.

Logistics plans for transporting all the plants and equipment into the tunnel and then withdrawing them again were prepared in parallel with the technical planning work. An important factor to be considered here was that there was only limited storage space available at the transshipment point. The logistics regime therefore provided for the materials to be delivered by truck to the transshipment point right on time and the schedules for the onward transport by rail were synchronised with these deliveries. For complex construction projects of this kind a well-thought-out logistics plan is the key to ensuring that all the site equipment is assembled and removed on schedule (**Fig. 2**).

4 Two-phase Construction Project

The North–South-Tunnel forms part of the S-Bahn line that runs between the Gesundbrunnen and Südkreuz stations in the centre of Berlin (**Fig. 1**). The 6 km-long tunnel begins at the portal to the north of Nordbahnhof station, runs through a number of S-Bahn stations (Nordbahnhof, Oranienburger Strasse, Friedrichstrasse, Brandenburger Tor, Potsdamer Platz (**Fig. 3**) and Anhalter Bahnhof) before exiting at the portal to the south of Anhalter Bahnhof.

The renovation work was divided into two phases and was carried out accordingly. During construction phase 1 the Nordbahnhof remained in operation, while in phase 2 the tunnel was completely shut.

The two work phases are presented in general detail in Sections 4.1 and 4.2, while the following Sections 5, 6 and 7 deal individually with the dust control measures, which involved the use of dedusters and ballast wetting machines, and also describe the instruments employed to monitor occupational exposure limits and the zone-based personal tracking system.

4.1 Work Phase 1

The main focus of work phase 1 was the replacement of two sets of points between the Anhalter Bahnhof and the Potsdamer Platz station and a track geometry correction to be carried out in the area of Oranienburger Strasse. This phase therefore featured a dust-laden working environment resulting from the disturbance of the ballast bed. In order to allow a second construction team to work in parallel an air separator was set up at the Anhalter Bahnhof and fresh air was directed out from this point towards the north and the south. This arrangement meant that rail replacement work could also be undertaken south of Anhalter Bahnhof at the same time as the points were being renewed to the north of it. In order that a third construction team could also operate in the tunnel it was decided that the air from the points replacement zone between Anhalter Bahnhof and Potsdamer Platz station, which despite having been filtered through the dedusters was still contaminated by exhaust gases from the engines of the track laying machines, should be discharged into the atmosphere via a stack. This meant that north of Potsdamer Platz station fresh air could be drawn into another working zone where track adjustments were being made close to Oranienburger Strasse. Ventilation systems of this kind can only be put in place in tunnels where additional options exist for fresh air to be supplied (for example via railway station entrances) and where construction teams can operate in parallel without having to work in the waste air flow of a team upstream of them.

4.2 Work Phase 2

Work phase 2 was mainly characterised by track milling and rail replacement operations. The aforementioned air separator was relocated to Potsdamer Platz station, from where fresh air could be directed towards the north and the south tunnel portal. During work phase 2 the tunnel was ventilated by a regular air exchange without the use of dust extraction equipment (**Fig. 4**).

Fig. 4: Korfmann AL 12-550 axial fans sitting on the platform at Anhalter Bahnhof

5 Dust Control with Dedusters and Ballast Wetting

During work phase 1 the track bedding material also had to be replaced when the two sets of points were being renewed and this meant disturbing the ballast bed. The track correction work involved the lowering of the existing track. To achieve this the rails were withdrawn in 15 m sections and excess ballast was removed using a two-way excavator. This operation also meant disturbing the ballast bed.

When a rail track has been in operation for many years friction between the ballast gravel stones causes large quantities of fine-grained material to build up within the bed and this is released as dust when the bedding is disturbed. Any disturbance of the ballast bed, especially within rail tunnels, therefore calls for dust control measures to be put in place to protect the health and safety of the workforce. The project plan provided for a combined state-of-the-art solution involving the wetting of the old ballast and the deployment of dry-type dedusters to protect the workers from exposure to dust.

Before commencing this part of the operation, i.e. prior to any intrusion into the ballast bed, the working area was wetted with a specific quantity of clean water. In this case the water was applied to the ballast using a mobile wetting car operating with a constant flow of water and at a constant speed of travel, thereby ensuring that a uniform wetting rate was maintained. The clean water for the wetting process was sourced from a surface hydrant and delivered into the tunnel via hoses laid through a nearby emergency exit. Wetting the old ballast is especially effective at binding visible dust particles and so is able to minimise the respirable dust fraction. As current regulations prohibit the water applied to the ballast bed from being released into the drains and subsequently discharged into the sewage system special measures were taken to provide for a controlled collection process. The return water was therefore sucked into pumps set up on the tunnel floor and then transferred into water tanks for safe and proper disposal.

The ventilation system provided for the tunnel air to be moved by axial fans to two dry dedusters mounted on rail cars. The dust-laden working areas were partitioned off from the rest of the tunnel by air separators to enable the fine dust to be captured systematically (**Fig. 5**). The continuous movement of the air towards the dedusters created an effective and uninterrupted dust removal regime and this counteracted any accumulation of particulates in the working areas. The waste air from the construction site, with its content of fine dust, was then cleaned by CFT dedusting equipment to produce a residual dust content of ≤ 0.05 mg/m^3 and, ultimately, released into the city atmosphere. In the points replacement area this was achieved by way of an active discharge via a vent stack, while in the track ad-

Fig. 5: Air separators seal off the dusty working zones from the rest of the tunnel.

Fig. 6: CFT dry dedusters with a Korfmann axial fan for cleaning dust-laden waste air from the worksite

justment area passive venting was the preferred method (**Fig. 6**). The dedusters were equipped with differential pressure sensors and if a failure of the compact filter elements caused the pressure differences to exceed a certain threshold an automatic cleaning process would be triggered with compressed air pulses being delivered in a counter-current process. The dust captured from the compact filter elements was subsequently removed from the extractors using a specially developed discharge system with a cellular wheel sluice. A fully automated process was then used to transfer it into Big Bags. The dedusting equipment was therefore able to operate maintenance-free for long periods of time, thereby providing an uninterrupted service long term.

When used in combination with various organisational measures, such as the temporal and spatial separation of the working activities and the specific allocation of men and machines to a particular working area, the proposed ventilation concept ultimately succeeded in meeting all the health and safety requirements and ensured that the track shutdown period was used most efficiently.

6 Measuring Instruments for Monitoring Occupational Exposure Limits

Various statutory regulations have to be observed to protect the safety and health of the workforce. This means that employers are legally obligated to ensure that they fully comply with the requirements of the Working Conditions Act (ArbSchG) [5], the Building Site Regulations (BaustellV) [6], the Rules pertaining to Hazardous Substances [7] and the Social Accident Insurance Stipulations [8]. According to § 7 of the GefStoffV [2] the employer is required to identify and assess the level of exposure to hazardous substances. Any activity involving the use of hazardous materials may only be commenced after a risk assessment has been carried out and the necessary safeguards put in place. The employer also has to ensure that occupational exposure limits for hazardous substances, as defined in TRGS 900 (Technical Rules for Hazardous Substances – Occupational exposure limit values) are being complied with [9]. One of the ways to achieve this is by taking workplace measurements. According to TRGS 402 (Technical Rules for Hazardous Substances, identification and assessment of the risks from activities involving hazardous substances: inhalation exposure) [10] workplace measurement means determining by measurement the degree of inhalation exposure affecting individual workers.

A combined deployment of fixed and portable measuring instruments has now become established practice for work in railway tunnels. It is now state-of-the-art for concentrations of the gaseous substances CO, CO_2, NO and NO_2 to be permanently monitored and recorded in working areas using fixed measuring devices. As well as measuring these hazardous gases fixed equipment is also used to monitor O_2 concentration levels as well as average airflow velocities.

In this particular case the air quality and air speed inside the tunnel were recorded at 15 stationary measurement points. At those workplaces with dust-laden environments, for example in those areas where the points were being replaced and the track geometry corrected, continuous optical dust measurements were also taken using direct-reading devices. As well as providing a permanent record of events these measurement data also played a vital role in the regulation and control of the ventilation system.

In addition to the fixed measuring equipment installed on site, body-worn gas detectors for direct personal protection were also kept available at the equipment holding area adjacent to the control room. These warning devices were fitted with sensors for the detection of CO, CO_2, NO, NO_2 and O_2. The site regulations stated that each work team had to deploy at least one body-worn gas detector and that prior to each deployment this device had to be inspected by CFT in accordance with the manufacturer’s instructions.

7 Zonal Person Tracking

In discussions between the client and the Berlin Fire Service on the overall management of the project the latter stipulated that in view of the spatial reach of the project the client had to be kept meaningfully notified at all times of the number of persons present in the tunnel. In the event of a fire the Fire Service would therefore be in a position to deploy their rescue teams in a targeted way and with the safety of the emergency crews very much to the fore.

Given the large number of potential movements in and out of the tunnel via the stairways of the six stations involved and via the 22 emergency exits and three tunnel portals an analogue-based roll call would not have provided the solution that was needed. Plans had already been made at this time to set up a network system to maintain central control of the ventilation plant and provide central access to all the measuring instruments installed in the tunnel. This same system had been used by CFT for a number of years for the targeted and efficient control and regulation of ventilation equipment of this kind. In this process the data collected at the measuring points were transmitted via a network system to an operator terminal. This terminal can provide a central display of the air quality and air speed prevailing at all the measuring stations. The network not only incorporates the different measuring instruments but also all the frequency inverters needed for controlling the speed of the ventilating fans. The operator terminal therefore serves as a central control point where frequency modifications can be made to regulate the tunnel fans. This terminal station can be in the form of a mobile telephone, a tablet computer, a PC or – in the case of more complex projects – a full-on control room.

The solution to the tracking problem therefore could only come from a fully automated system that could capture and log the inward and outward movements of individual workers via all the available entrances and exits. One of the objectives of the ongoing planning exercise was therefore to expand the existing network by including technology that was specially developed for this purpose.

Data protection was to play a central role in this planning work. The technology required to specify and identify which particular worker was wearing the transponder being located in a certain section of tunnel was therefore not put into practice here. In consultation with Michalski Engineering, a project-specific solution to the personal tracking issue was subsequently developed in collaboration with RS safetec GmbH (former RK safetec), Bregenz, Austria, a long-term associate of CFT.

Directional antennas were set up at all the tunnel entry and exit points and integrated into the network. According to site regulations each worker was required to carry a transponder with active BLE (Bluetooth Low Energy) technology. The transponders were distributed from the equipment holding area next to the CFT control room (**Figs. 7a and 7b**). The directional antennas were then able to track the movements of the transponders and persons moving within the tunnel could be counted in and out in a fully automated and reliable way. An ongoing analysis of this body of data provided information on the number of persons present in the tunnel. Because of the spatial reach of the working site and the structural conditions present within it, these including single-track sections and isolated storage sidings, the tunnel was also divided into zones each a maximum of 500 m in length. As well as displaying the total number of persons present in the tunnel the control room could then also produce a zonal picture of the headcount. In the event of a search and rescue operation being required the Berlin Fire Service could therefore dispatch emergency personnel to individual parts of the tunnel in a target-oriented way.

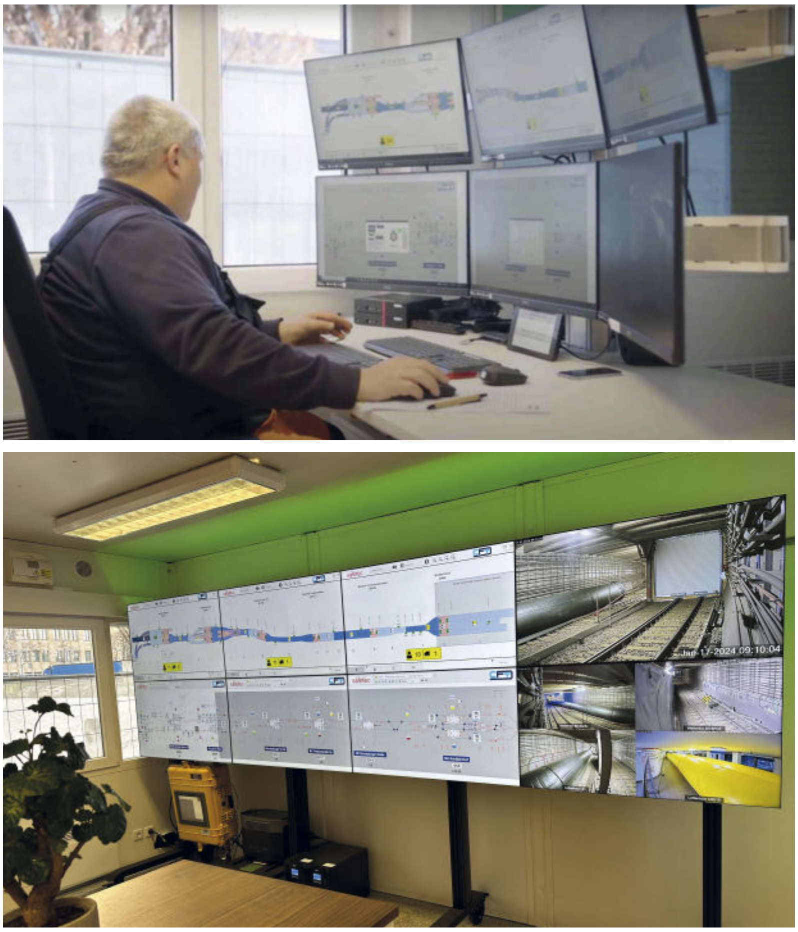

Fig. 7: The central control room with its data display screens is able to send commands to the on-site fans and monitor the personal tracking system.

8 Conclusions

An extensive infrastructure upgrade has been successfully completed in a very short period of time in the North–South-Tunnel of the Berlin S-Bahn. A well-thought-out ventilation regime was put in place to ensure that a safe working environment was maintained during each of the working phases. Embedding a fully automated personal tracking system within the existing data network proved to be a very effective and technologically advanced response to the Berlin Fire Service's safety requests. The North–South-Tunnel of the Berlin S-Bahn system was upgraded on schedule during a six-week track possession and was then restored to full operation as a vital part of the city's public transport network.

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Advantec Roadheaders make a valuable Addition to the HBT Portfolio

Efficient Roadheading for the Mining and Tunnelling Sectors

HBT GmbH, Lünen, Deutschland

The HBT Group has acquired a 50% stake in the Germany-based company Advantec Tunnel & Mining Solutions. As a result, the Group now includes roadheading machines in its comprehensive range of mining equipment and can henceforth list tunnel construction within its field of activity. This creates a valuable synergy potential and presents a number of distinct advantages not only for both companies but also for customers in the mining and tunnelling markets. Projects currently underway serve to highlight the versatility of the tunnel digging roadheader (TDR) system.

Mining • Tunnelling • Roadheading machines • Mergers & Acquisitions • Suppliers

Fig. 1: Structural symmetry keeps vibration levels down when the machine is cutting and loading.
(left: view of the transverse cutting head, right: the loading apron with its gathering arms and central conveyor)

Symmetry as a Design Instrument ensures Stability

Structural symmetry is a key characteristic of the TDR range of roadheading machines produced by Advantec Tunnel & Mining Solutions, Werne, Germany (**Fig. 1**). This feature has not been introduced for visual or aesthetic reasons. These machines can achieve a cutting performance of up to 400 kW and can operate at compressive strengths of more than 110 MPa. Their unique design concept means that the forward feed of the cutting tool is delivered from the centre of the unit. This has a significant impact on operating performance: the force with which the feed unit works the rock is maintained at a high and consistent level. This helps to minimise machine vibration and twist, even under the toughest conditions – such as when cutting very hard rock – with the result that the TDR series achieves a much longer service life.

Advantec: A Mining and Tunnelling Specialist

Tunnel digging roadheader (TDR) machines make up the main product group of the Advantec Tunnel & Mining Solutions division (TMS). Advantec's other business lines include the development and production of durable, high-grade hydraulic cylinders and hydraulic power systems (Advantec Hydraulics) and the worldwide industrial servicing of hydraulic systems and mining machines (Advantec Industrial Service).

HBT's Stake in Advantec

Advantec's Tunnel & Mining Solutions division has been 50% owned by the HBT Group since mid-2023, thereby further extending the Group's already significant mining technology portfolio. Advantec has been associated with HBT for some time through collaboration across several levels.

HBT Automation (formerly EXPROTEC) is also collaborating with Advantec in running a number of ongoing projects. These include the delivery of complete energy supply and control systems for the TDR machines.

Access to a new (Global) Market – Tunnel Construction

From HBT's perspective the decision to invest in Advantec TMS was based not just on the need to expand the company's mining equipment range by the addition of roadheading machines and the synergy effect that this would create. As these machines are used not only in the mining industry but also in infrastructure tunnel construction projects HBT will now have access to this hugely important market that is projected as having tremendous growth potential in countries such as India, the USA, Australia and Turkey.

One of the reasons for the widespread use of roadheading machines in tunnel construction is that this technology offers a very cost-effective and flexible solution for soft to medium-hard rock. The deployment of full-face tunnelling machines involves much greater cost and effort for installing and setting up the equip-

Fig. 2: The TDR 100 has a cutting performance of 300 kW (option to upgrade to 400 kW). The cutting arm feed is 600 mm. Various attachments can be fitted, such as the roofbolt drilling and setting device shown here.

ment and as a result such an investment only pays off when building tunnels of a sufficient length.

Some of the significant advantages that roadheading machines have to offer over conventional drilling+blasting methods include a reduced strata break-up, zero environmental impact from detonation shock waves and various benefits in respect of underground ventilation and workplace safety. This technology is therefore ideally suited to tunnel construction projects in urban environments and when working beneath buildings.

Focus on: The TDR Product Range

The Advantec range of roadheading machines has its origins in the technology that was taken over from Westfalia Becorit back in 1998. While leaving the basic design concept unchanged the company has opted for an ongoing process of machine development and improvement. The roadheader product line not only boasts the latest state-of-the-art technology but also leads the field as far as performance, durability and ease of use are concerned.

Fig. 3: Every TDR machine – from the smallest to the largest – has been developed from the ground up to cope with the highest stresses that arise in the harsh underground environment. Here a close-up of the cutting head.

Four basic Models in the 20-t to 140-t Range

The product line comprises four basic models that can be identified by their operating weight:

- TDR 20
- TDR 55
- TDR 100
- TDR 140

Here by way of example is a brief review of the TDR 100: this 100-t class machine can deliver an impressive cutting performance of 300 kW (with the option of a 400 kW upgrade). The cutting arm has a feed of 600 mm and is also designed for intrusion cutting. It can do this from a fixed standing position without having to be moved (**Fig. 2**).

The TDR 100 delivers power with precision irrespective of the operating environment. This even includes the most challenging geological conditions where the compressive rock strength exceeds 110 MPa. TDR 100 customers therefore have a machine that can cut through rock and operate at feed rates in ways that would hardly be possible with equipment from other manufacturers.

Rugged Construction – the latest Automation

Every TDR machine – from the smallest to the largest – has been developed from the ground up to cope with the highest stresses that arise in the harsh underground environment. The hydraulic systems have been developed and manufactured in-house and their reliability is on a par with mechanical drive components such as the TDR's bevel-helical gearbox.

The semi-automated cutting cycle follows a logical automation and control concept and is also designed for 'heavy duty' operations. The same applies to the latest generation of cutting heads (**Fig. 3**).

High Performance, high Availability

The impressive cutting performance contributes just as much to the TDR's efficiency as the fact that the machine maintains a high level of availability even under adverse operating conditions. Most of this is down to the highly wear-resistant components that are built into the debris clearance system. These can easily be replaced when required and the entire conveyor installation has been designed to compensate for the short-duration stoppages that can arise along the downstream transport circuit (the loading system acts as a bunker). This helps to maintain a continuous material flow (**Fig. 4**).

A closer look at the water spray system fitted to the cutter head shows that the design team have planned down to the last detail and have also ensured that resources are utilised responsibly. This system works so effectively that it significantly reduces water consumption while at the same time efficiently suppressing dust production (**Fig. 5**).

Each Machine built to Customer Specifications

Years of acquired know-how underpin the Advantec design engineers' ability to adapt each machine to the individual requirements of the user and the application in question. The machines are built to order and there is a huge range of design options available to choose from.

A Global Reach – a single Production Centre

TDR machines are in action all over the world – and the Advantec servicing division is there too (**Fig. 6**). This means that customers have access to on-site service and support almost everywhere. This global footprint has become even more close-knit as a result of Advantec's deeper cooperation with the HBT Group, which also has a global reach.

The relocation of Advantec TMS to the Westfalia Campus in Lünen (North Rhine-Westphalia), which is also the new home of the HBT Group, will enable both companies to develop further synergies in the years ahead – not only in design & engineering but in the production field too.

Fig. 4: The entire TDR conveyor system has been designed to compensate for short-duration stoppages along the downstream conveyor line (the loading system can act as a bunker).

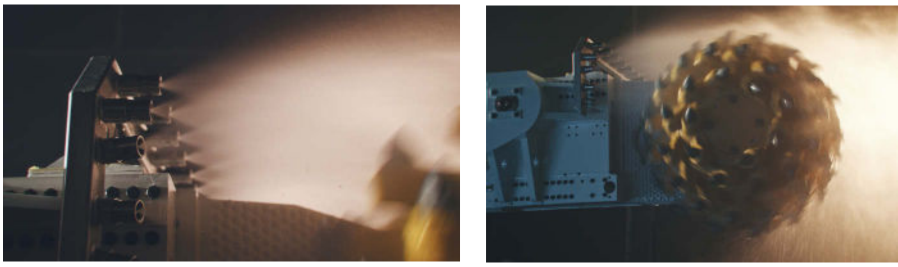

Fig. 5: The highly effective water spray system (water curtain sprays) shown in action at the cutting head. This has been designed to reduce water consumption and efficiently suppress dust production.

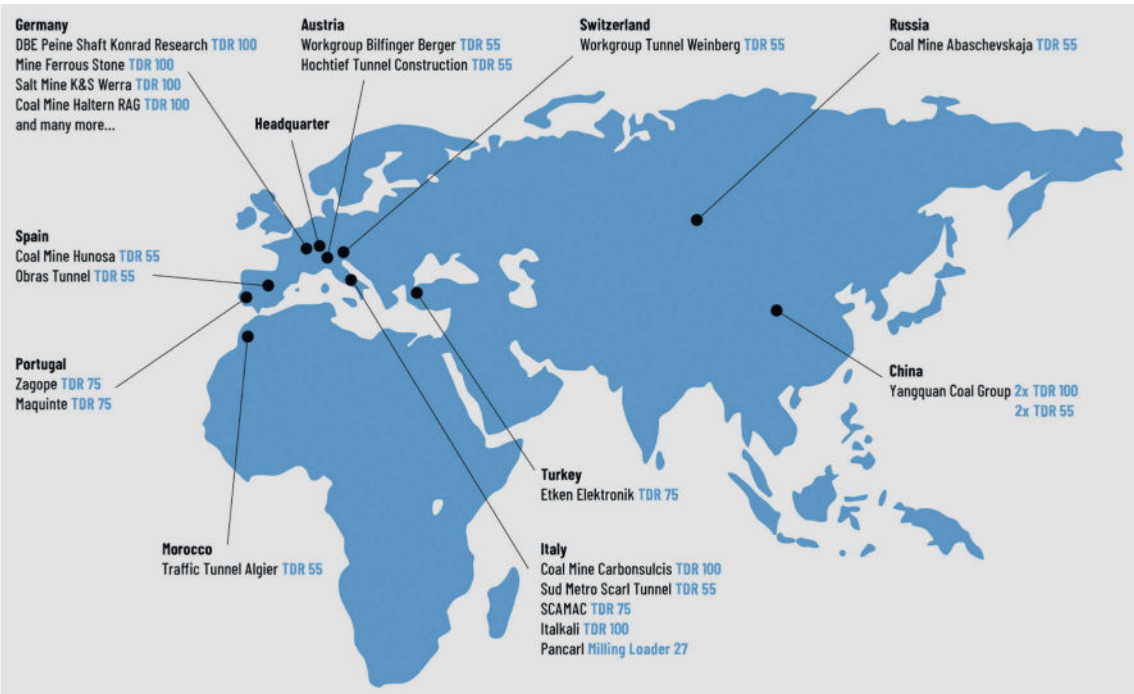

Fig. 6: Advantec TDR machines are operating in all kinds of mining and tunnelling projects around the world

Special Topic

Remanufacturing: new from old

After many years of service, when Advantec roadheaders reach the end of their (first) useful life, they are still far from being classified as 'scrap iron'. This is where Advantec is able to provide a general overhaul and renovation service. This operation is not restricted to the company's own products – for mining and tunnelling machines from other manufacturers can also be refurbished and adapted to customer preferences. This provides users with an opportunity to avail themselves of the latest technology and design options – all based around their 'old' machines.

Current and future Projects

A look at the list of both reference and ongoing projects shows the wide range of applications open to Advantec roadheading machines. Current examples include phosphate mining operations in Morocco and Egypt and a number of coal mines in Poland, Kazakhstan, China, India and Australia. India's largest coal producer Coal India Limited is planning to increase underground production to 100 Mt by 2028 and to achieve this target will be deploying Advantec roadheaders as well as equipment supplied by HBT.

Advantec is also involved in several civil engineering and tunnel construction operations in Australia. Here, as in other projects, the cooperation and know-how exchange taking place within the HBT Group has already proved to be a valuable asset – for example, when deploying drilling units supplied by the Australian company Waratah, which is also part of the HBT Group.

HBT Group

The HBT Group is an international alliance of top-performing midsized companies that have joined forces to create a fully integrated provider of end-to-end solutions for the mining and tunnelling sectors. Having affiliated brand names such as HBT, Hauhinco, Breuer Motors, Advantec and Pempek has enabled the Group to specialise in high-performance longwall face systems, roadheading machines, room and pillar equipment, electric motors and advanced solutions for automation and control technology. The HBT Group has its head office at Lünen in North Rhine-Westphalia.

Contact: https://hbt-group.com

Effective Dust Control in Mining means substantial Cost Savings

ScrapeTec Trading GmbH, Kamp-Lintfort, Germany

Effective dust control in mining and material handling is essential for cost savings, operational efficiency and worker safety. ScrapeTec provide innovative, contact-free dust suppression systems like DustScrape and AirScrape, which significantly reduce dust emissions, material spillage and explosion risks at conveyor transfer points. These durable systems minimize maintenance needs, enhance belt longevity and reduce environmental impact while delivering substantial savings.

Mining • Quarrying • Conveying • Dedusting • Explosion prevention • Cost efficiency • Product news

Specialists from ScrapeTec work together to offer dependable solutions for specific problems at the transfer points of conveyor systems in many industries where dust and material spillage are concerns, including in mining and quarrying.

"The risk of explosions caused by dust emissions on conveyor belts is an ongoing problem that engineers around the world are trying to prevent. ScrapeTec experts developed a new dust control system about six years ago that is proving to be highly effective – not only for preventing dust formation and material spill but also to minimize the risk of explosion at critical sections along the conveyor route and transfer points and for more efficient belt-cleaning," explains Torsten Koth, Sales and Distribution Manager for ScrapeTec – specialists in the development of dust suppression systems for diverse industries. ScrapeTec products, which are engineered in Germany to pristine quality and environmental standards, are proving to offer even greater operational cost savings in materials handling than anticipated at the launch of the range.

Apart from the benefit of cost savings, DustScrape and AirScrape dust suppression systems are highly effective in minimizing exposure of workers to environmental pollution, which is a major problem caused by fugitive dust in dry bulk handling (**Fig. 1**). Although conventional dust prevention side-seals do reduce conveyor problems in the short-term, these components quickly deteriorate as a result of friction and can also damage the conveyor belt during extended periods of use.

Contact-free Conveyor Belt Skirting System

The success of the combination of the DustScrape and AirScrape **contact-free** conveyor belt skirting system lies in the effective energy-efficient dust suppression. This compact and easy to install skirting adheres to most new dust prevention guides and can prevent health and safety issues on site. This advanced system also minimizes product loss by effectively preventing material from escaping into the surrounding environment. As a result, users benefit from substantial savings of energy, housekeeping and maintenance costs, without the need for the collection of material spills.

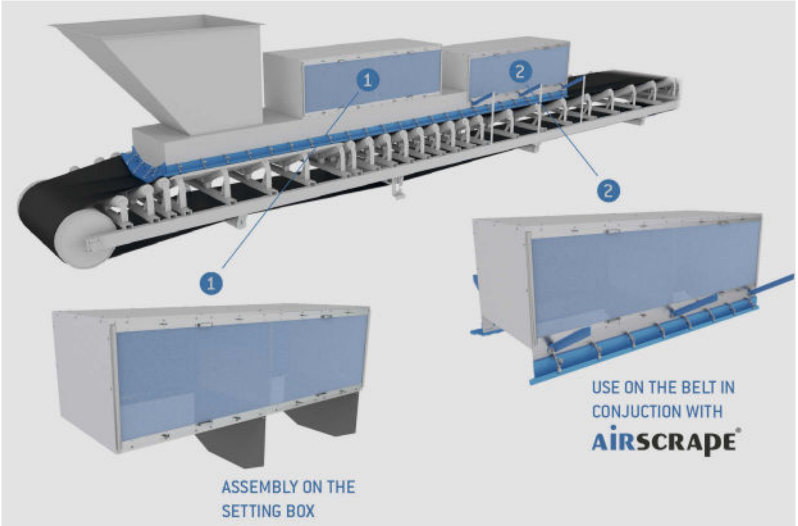

Fig. 1: Scheme: highly effective against dust formation

Less Material Loss

According to Koth: "In a recent installation we were able to solve many production problems for a customer who was losing almost 5% of materials on conveyor belts as a result of dust and material spillage."

DustScrape consists of a durable filtering cloth that is installed above the conveyor belt. This cloth retains

Fig. 2: System working for a customer

dust particles created by conveyed materials while remaining permeable to circulating air. This long-lasting filter cloth, which has cleaning and dust-releasing properties, is available in a range of grades (including anti-static features) for specific applications – for example for surface or underground mining. The dust retaining filter cloth, which is manufactured in rolls, can be extended to any required length and is suitable for any conveyor belt width.

Easy Application

The DustScrape dust emission prevention system comprises a filter cloth, support arches and skirts, arms to hold the system above the belt and a rubber curtain to eliminate further dust development – all sized to specific requirements. This system is easy to install and can be retrofitted to existing conveyors for continuous operation and for extended periods.

The contact-free AirScrape conveyor belt skirting system is a highly effective side-seal that lies contact-less over the conveyor belt and creates negative air pressure on the belt due to its specially designed blade structure. Because this system hovers freely above the conveyor belt, skirt friction and belt damage are eliminated and the service life of every component of the conveyor is extended. Conventional skirting is pressed against the conveyor belt to keep dust and material in the middle of the belt, but after a certain period belt and skirting wear can be so severe that material and dust begin to escape. Material spillages at transfer points have to be removed and regular maintenance is needed at the belt skirting and transfer points.

Designed for long-term use in harsh Conditions

Studies show that even five years after installation, and with continuous use in harsh conditions, the AirScrape system exhibits practically no signs of wear. This durable system consists of non-flammable and anti-static polyurethane materials and blades made from stainless steel. FDA-approved materials are also available for specific conveyor handling applications.

The SureSupport system works in conjunction with DustScrape and AirScrape to deliver support and stability to the belt at transfer points. Other advantages of this system include quick and simple installation, as well as reduced maintenance time and costs.

The PrimeTracker ensures that the belt is always correctly aligned during operation, thus eliminating problems with belt mistracking. The TailScrape system enhances the performance of the AirScrape by sealing the transfer tail in the rear area and also uses the Venturi effect to prevent dust generation and material spills. The intelligent blade structure on the bottom of the system creates negative pressure in the conveying area, thus preventing any escape of materials. Dust is kept in the material flow by the intake air stream.

Thorsten Koth

is specialist in dry bulk handling, dust and spillage control, conveying transfer points.

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Special Topic

Situation Update on Drive Systems for Trackless Loading and Transporting Equipment in Underground Mining

Dipl.-Ing. Karl-Heinz Wennmohs, M & R Consulting Mining & Rock Excavation, Witten, Germany

Trackless loading and transport equipment for the deep mining industry has to become more environment-friendly and in this way contribute to the decarbonisation process. It is still not clear as to how future driveline technologies will develop from diesel powered units to alternative systems. This paper aims to take stock of the situation and will examine future development prospects, opportunities and risks from a manufacturer and an operator perspective.

Mining • Underground mining • Trackless vehicles • Loading • Transport • Drive systems • Decarbonisation • Diesel • Electric • Hydrogen • Investment

Fig. 1: GHH MK-42 dump truck fitted with the latest diesel technology in Tier 3 and Tier 4 final version with Stage V upgrades
Picture: GHH Solid as a Rock

When drawing up their operational plans many equipment operators and manufacturers now attach a high priority to switching away from diesel motors – still the dominant drive technology for trackless loaders and transport vehicles in underground mines – and towards more sustainable systems. The aim of the planning brief is to ensure the decarbonisation of the underground environment in as timely a manner as possible. The period that has been set to achieve this objective cannot be precisely defined for a variety of reasons. One of these is a lack of impulse on the part of the mining companies to make investments in mines that operate diesel technology, as the latter – though it may well be cutting-edge stuff – is nevertheless set to be phased out (**Fig. 1**).

Add to this the lack of willingness on the part of manufacturers to create production lines and supply chains for new vehicle drive technologies. Such a situation can lead to risks for manufacturers, as the existing portfolio of loaders and transport equipment will still be manufactured and marketed and will still be needed to ensure the economic success of the company. Ramping up production with new drive systems is something that cannot be done in a short time as even the market – apart from a few exceptional cases – is not ready for it. This means that a smooth transition from conventional drive systems by running down the existing production lines and powering up the new technology cannot be fully planned for and is only partly achievable in the near term.

It is also impossible to predict at the present time just what kind of solutions will be chosen for the 'new' drive technology.

Fig. 2: Paus PMK 12000 dump truck
Picture: Hermann Paus GmbH

History, Status and Development of Trackless Vehicles in the Deep Mining Industry

Though the picture is somewhat blurred, it has been estimated that there were in the region of 22,000 trackless loading and transport vehicles operating in the deep mining industry worldwide in 2022. About 65% of this figure were mobile loaders, i.e. LHDs fitted with various types of drive system (**Fig. 2**). Most of these units were still powered by diesel engines. They came in a range of sizes and some were fitted with diesel engines that were not state-of-the-art in terms of emissions technology.

Electric powered LHD loaders with power supply cables have been in use for something like 50 years. The load-dependent cable drum control system has undergone a number of modifications in recent times (**Fig. 3**).

Fig. 3: GHH LF 19EB LHD loader with cable drum
Picture: GHH Solid as a Rock

Fig. 4: Epiroc MT 42 SG dump truck
Picture: Epiroc

Fig. 5: GIA/Epiroc KIRUNA ELECTRIC dump truck
Picture: Epiroc

and these improvements have significantly prolonged the lifetime of the power supply cables. [2]

Dump trucks, which make up around 35% of the total fleet, are for the most part diesel powered (**Fig. 4**). Many of these vehicles are still running with the older type of diesel motor. There are very few electrically powered dump trucks in service equipped with trolley-wire and/or conventional battery systems, while the first series-produced dump trucks with new-generation batteries are now being introduced on to the market.[2]

Nearly all the manufacturers have gone for battery-type electrification for their latest model developments. This particular machine stock has seen a replacement demand of between 2,500 and 3,000 units a year. Such a market potential is set to increase assuming an annual growth rate in this market segment of 2 to 3% up to the year 2040.

The switch from diesel to electric motors is not a new development, as electric LHDs with cable drums and dump trucks with trolley-wire systems have been used by the mining industry for decades.

While for the first electric powered LHDs, which were introduced around 1970 [1], the conversion – simply put – involved replacing the combustion motor with an electric one, along with switching elements and cable drum, the first dump trucks to feature a trolley-wire system were fitted with an electric motor on each axle. One such example is the electric powered Kiruna truck with its pair of electric motors (**Fig. 5**). This machine was developed from the diesel driven Kiruna Truck that had only one driven axle.

For reasons of cost the manufacturers reverted to using existing standard components for the drive systems as the market was too small for a redesign and any such investment would not have paid off. These systems laid the foundations for electric drive technology that in some respects is still being used on the models of today.

The different types of LHD loaders and dump trucks currently available from the manufacturers are variously equipped with electric motors. When an electric motor is being fitted to a diesel powered machine it generally retains the same drive train with its gearbox and axles. The electric power is then delivered via a cable or battery system.

The performance of mine loaders and trucks is now being boosted by fitting two electric motors for the drive mode. Here each axle is driven by its own motor and the drive train will have fewer components than the diesel version. The advantages of having an electric motor at each axle can be used to good effect when it comes to braking efficiency and power control.

Another option is to fit four wheel traction motors (**Fig. 6**). This technology offers the best solution from a drive point of view and the drive train that would normally be required can be dispensed with. An important factor to be considered here is that the motor units must be very well protected as they will be installed in an exposed position. Machines using this type of motor drive technology should be provided with a motor control system.

As well as the cable-fed and the battery powered units there is also a hybrid version of the mine loader available. In this case the diesel motor is used to drive a generator that then supplies power to the machine's electric motors (**Fig. 7**). The developers of this system were perhaps taking a long-term perspective in believing that with this type of drive arrangement the diesel motor could at some later stage of the manufacturing process be replaced by an eco-friendly drive unit. This technology will also be applied as a medium-term solution for dump trucks.

All electric drive trains also require several electric motors to power the cooling and hydraulic systems.

Decision criteria for diesel-free systems at brownfield and greenfield project sites

The plans that mines are now making for diesel-free transport operations, particularly when it comes to brownfield projects, are now contingent on the economic viability of the new machines. Capital investment, operating costs and the potential performance gains resulting from higher travel speeds are all being factored into the equation. The following decision-making criteria are just some of the factors to be taken into account when planning such a fundamental operational transition [1]:

- **Emission-free operations**
  Reducing or completely eliminating diesel motor emissions brings a decisive improvement to the working conditions below ground. The development of the latest generation of diesel motors for today's state-of-the-art vehicles has been a major step in this direction (**Fig. 8**).
- **Lower energy costs**
  Because of the substantial difference in efficiency, electrically powered vehicles require less energy. However, a major factor in this assessment is how, and at what cost, is the electrical current produced. [2]
- **Reduced heat emission**
  Higher efficiency means that less heat is generated and this has a positive impact on the mine climate. The cooling system for the hydraulics and the liquid cooling required for the motors also generate heat that is released into the surrounding air.
- **Higher power output** (**Fig. 9**)
  If the diesel motor on a given class of loader or dump truck is replaced by one or several electric motors it is then possible to fit higher-powered units that have a greater amount of power in reserve, particularly when operating at full load. This advantage is especially felt on uphill runs where higher travel speeds can be reached. Higher speeds mean a greater transport capacity and hence reduced costs.
- **Lower noise levels**
  Electric motors generate less noise than combustion engines. Safety regulations in many countries indicate that in future most of the vehicles sold will have to be fitted with driver's cabs. As these offer a high level of protection, depending on their design, the driver's workspace will henceforth be very well protected from noise and vibration, especially on machines equipped with electric motors (**Fig. 10**).
- **Savings on maintenance and repair**
  This aspect is now being increasingly highlighted as a positive characteristic of electrically powered vehicles. It is certainly correct to point out that these machines require fewer components for their drive

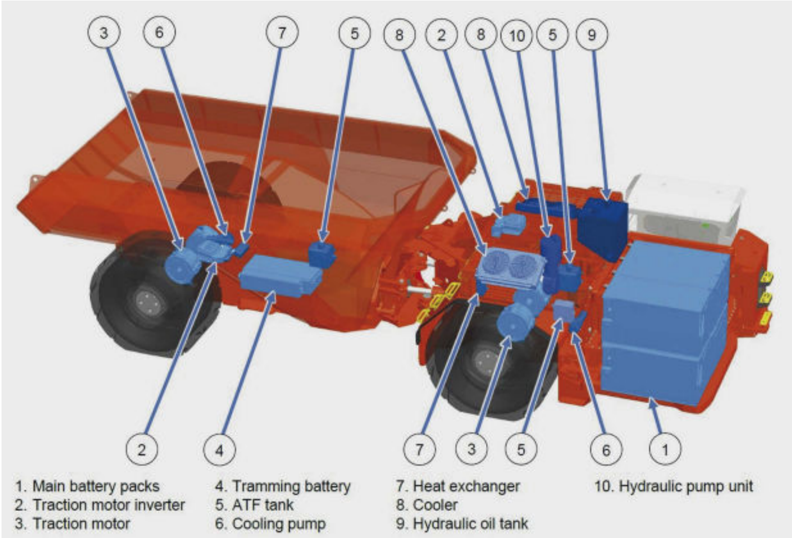

Fig. 6: Sandvik TH665 B dump truck with four wheel traction motors
Picture: Sandvik

Fig. 7: Komatsu WX 22H LHD loader with hybrid drive
Picture: Komatsu

Fig. 8: Service truck with the latest diesel technology – Paus Uni 50 LP-IH (Idler Handler)
Picture: Hermann Paus GmbH

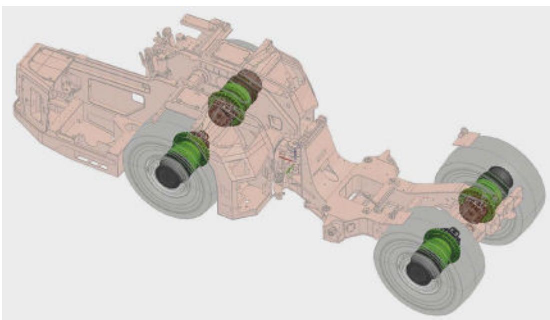

Fig. 9: Sandvik battery powered dump truck with traction motors
Picture: Sandvik

Special Topic

Fig. 10: Sandvik TH665 B dump truck with battery changeover system
Picture: Sandvik

system. However, any electrical assembly is subject to malfunctions and repairs and/or replacement can be an expensive business. A key factor here is to ensure that skilled personnel are available to carry out work of this kind.

- **Reduction in ventilation and air-conditioning costs**
  The prescribed volume of fresh air required per diesel-kilowatt is a significant cost factor for mine operators. If the diesel consumption can be reduced or even avoided altogether huge energy costs can be offset by savings on ventilation output.
- **Savings on the profile dimensions of the mine workings**
  Electrification and the elimination of diesel power can significantly reduce the airflow requirement. In theory, the cross sections of the mine openings can be optimised to match the size of the machines being deployed without the expense of having to maintain a high air velocity. Considerations of this kind will be incorporated into the future mine planning process. Savings made on tunnel drivages and other excavations will help reduce costs.

Most mines are based around brownfield projects where electrical installations already exist, these having been planned to supply power to any electrical equipment on site [1]. The conversion from diesel to electric power was not foreseen when the underground electric network was being laid out. For many mines the transition all comes down to cost. The total budget for new machinery and the extra cost of retrofitting the electrical installations cannot be met by every mine. Capital investment of this magnitude cannot easily be realised, especially when it comes to production faces that are located some distance from the shafts and ramps.

Advocates of battery technology will favour the use of battery powered loaders and dump trucks for these distant workplaces – on the grounds that batteries can be charged at places that are far away from the deployment point. This saves on the huge costs that would be incurred for retrofitting the electrical equipment in the production areas. Finally, the power supply network at the battery charging point must be fit for purpose and allowance has to be made for the fact that a battery pack weighing several tonnes may have to travel back and forth if the charging station is not located within the operational range of the machine in question (**Fig. 11**).

When it comes to greenfield projects the investment required to set up an electric powered system of loaders and mine trucks is part of the overall budget for the new mine and is tied into the profitability analysis. News bulletins announcing projects of this kind are followed with interest by the wider public as this means that something fundamental is being done for the workforce and for the environment.

Only time will tell just how sound and how successful are the decisions that have been and will be taken in this area.

Summary and outlook

The market for mine loaders and transport vehicles will continue to grow at a steady rate.

Yet while press announcements often highlight the introduction of electrically powered vehicles, the market is still mainly buying machines fitted with diesel

Fig. 11: Epiroc Scooptram ST 18 SG loader
Picture: Epiroc

motors. The equipment being sold in the years 2021 and 2022 shows that the breakthrough to a sustainable decarbonisation has still not happened.

The market leaders on the supply side of the sector have been promoting a range of innovations aimed at ensuring diesel-free vehicle operations and when it comes to the new developments battery powered solutions with a changeover system seem to be the industry's preferred choice.

Further improvements have also been made to cable-based solutions for LHDs and the maximum transport capacity has now been set at 25 t (**Fig. 12**). Battery powered LHDs can now haul up to 18 t, while the hybrid version can manage 22 t. Some types of battery powered dump trucks have now been designed for a transport capacity of as much as 65 t.

One well-known manufacturer has developed a 'fast-charging system' for its range of loaders (**Fig. 13**). This technology allows the battery to be charged in a very short time – less than 20 minutes. This does away with the need to swap batteries, an operation that also takes a certain amount of time. This fast-charging system requires a charging station of sufficient capacity along with the electrical output to match.

The mining sector still operates electric powered dump trucks fitted with the trolley-wire system, though relatively few vehicles of this type are now in use. There are no indications at present of any further developments in this technology.

Hydrogen is now being openly discussed as 'the' possible solution for all kinds of applications. However, hydrogen in its pure form is not generally available but must be produced by electrolysis, for example, and this requires electrical energy. In this process, therefore, the price of energy is a key factor. New methods of hydrogen production are currently being developed.

With a hydrogen motor driving a generator, or operating directly through a fuel cell, electrical energy can be generated to provide the driving force needed to power mobile equipment. The technical possibilities of this technology are now being tested. When using molecular hydrogen it must be remembered that the highest safety standards must be met when refuelling. Moreover, in view of the high operating pressures of up to 700 bar the tank itself must have a suitable wall thickness for the amount of energy required and must also be installed in a secure position on the vehicle. The liquefaction of hydrogen at –253 °C also enables a high energy density to be achieved. However, the vehicle tank and the filling equipment must be isolated accordingly.

It has become important for the mining industry to take the necessary steps to introduce electric motor technology in order to improve working conditions below ground and at the same time to help protect the environment. When deciding on actions of this kind it is vital that the required electrical power is available in the form of sustainable energy. Diesel and gas powered generators should not be employed, whether below ground or above it, to supply the current needed by the electric LHDs and dump trucks.

It is still hard to present a clear picture of how this market will develop between now and 2040 (**Fig. 14**). An optimistic assessment of market trends suggests that sales of trackless vehicles may eventually grow by around 3% a year and that the quota of electric machines sold each year could increase to some 50% by 2040.

Fig. 12: Toro LH 625 IE LHD loader with supply cable
Picture: Sandvik

Fig. 13: Caterpillar R 2900 XE LHD loader with battery unit
Picture: Caterpillar

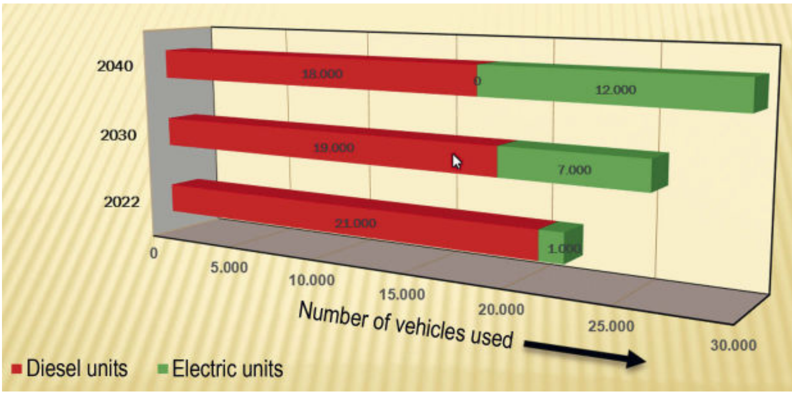

Fig. 14: Projected sales share of electric LHD loaders and dump trucks in the period to 2040
Source: M&R Mining & Rock excavation

Special Topic

The solutions being developed both now and in the years ahead will help drive the decarbonisation of the underground mining environment. The crucial factor here will be the technology choices available and whether these prove to be workable, sustainable and economically viable.

Source material

This article is based on a publication by the author that was presented at the 11th Colloquium on 'Materials Handling in Mining' held at Clausthal University of Technology on 31.1.2024.

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Practical Model Approach for Relationship between POLLUX Emplacement Position and the Spatial Thermal Radiation in Dry Salt Grit Backfill

Ibrahim Alsalamin, Louis Schaarschmidt, Prof. Dr.-Ing. Helmut Mischo, TU Bergakademie Freiberg (TUBAF), Freiberg, Germany

Germany's nuclear waste repository research focuses on storing high-level radioactive waste in salt formations using POLLUX containers, designed to withstand temperatures up to 200 °C. Recent studies at TUBAF suggest that adjusting the container's position within a trench in the host rock could enhance heat transfer, potentially reducing surface interim storage times and optimizing underground space. Further modeling and scaling are planned to validate these findings and explore their implications for repository design.

Mining • Radioactive waste • Repository mining • Modelling • Research

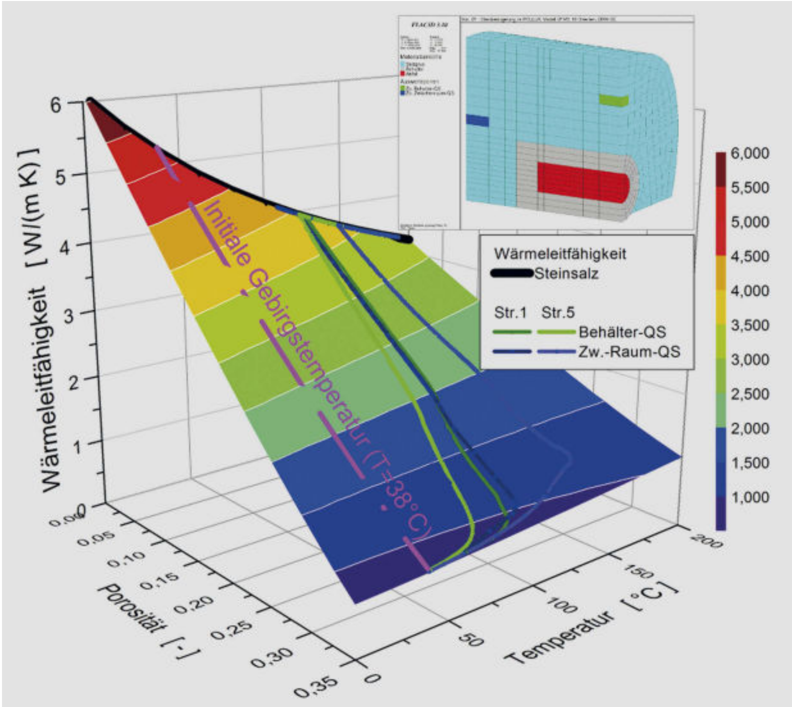

Fig. 1: The relation between thermal conductivity depending on the porosity and the temperature [1]

1 Introduction and Motivation

High-level waste (HLW) repositories are underground facilities designed to safely isolate radioactive waste from the biosphere for an extended time period, up to one million years [2]. The objective is to ensure that the radioactive decay of the isotopes within the waste occur in a safe geological environment down to a level where they finally pose only minimal risk to humans and the environment. Germany's high-level radioactive waste only makes up about 5% of the total radioactive waste volume, but is accounting for 99% of the radiation heat [3]. Germany expects to store 1,900 large containers of high-level waste, equivalent to around 28,100 cubic meters by 2080 [4].

The safe management of HLW has been a constant challenge for the global nuclear energy sector. There are numerous varieties of containers, e. g. CASTOR containers are dual-purpose casks with a cylindrical shape and utilized for intermediate storage and transport on surface, while smaller containers, like the POLLUX for instance, are specifically engineered for the underground final waste disposal of spent fuel elements [5, 6]. **Figure 1** shows the relationship between an increasing backfill density, thus decreasing permeability, the thermal conductivity and the heat dissipation over time within the backfill body in the direct vicinity of the HLW container. It highlights that it is generally desired to have heat transmission into the backfill but shows that this is not up to a desirable level in the beginning due to high backfill-porosity. Porosity will decrease over time with increasing compaction, i. e. due to convergence. Therefore, the idea is to optimize positioning of the POLLUX to utilize the early stage of disposal and the occurring heat transmission to optimize the overall HAW repository design.

The spatial distribution of heat around the container is affected by the varying heat conductivity capabilities of the backfill and solid rock. This led to the hypothesis, that the heat dissipation towards the host rock will be higher by increasing the contact area of the POLLUX container with the host rock. In order to assess this, TUBAF conducted a Master Thesis research project with down-scaled in-situ experiments in the "Glückauf" rock salt mine in Sondershausen (Glückauf Sondershausen Entwicklungs- und Sicherungsgesellschaft mbH (GSES), Thuringia).

TUBAF is operating an underground research site there with two full-scale and fully instrumented backfill bodies, that are continuously monitored for several parameters. These two backfill bodies and the adjacent test site, which where predominantly used for BMUV-funded GESAV and SAVER project series, in which the

Fig. 2: Heating setup showing the miniature POLLUX (left) and heating controller

characteristics of matrix-stabilized backfill are investigated, were also used to host the practical testing of the heat test setup. The laboratory test was carried out in the TUBAF laboratory facilities in Freiberg (Saxony) and aimed to minimize the influence of variable factors that could impact the results, while the in-situ tests are providing a research environment with a higher proximity to reality.

The development and installation of the POLLUX-dummy and the emplacement position within the host rock requires a research installation consisting of a heating system designed to replicate the conditions of a POLLUX container in real-life situations and a logging system to log all the data acquired from the temperature sensors. This integrated system underwent two types of pre-testing: the first involved assessing the accuracy of the sensor readings, while the second focused on examining the distribution of heat along the cylinder.

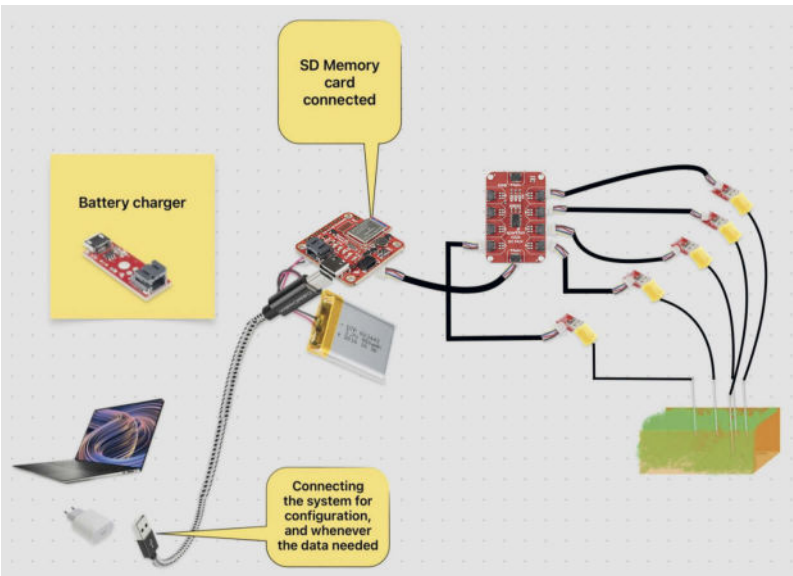

Fig. 3: Logging system setup

2 Experimental Approach

The investigation of the hypothesis of increased heat dissipation depending on an optimized position of the container within the drift and, thus an increased contact surface area, has been defined as the major task within the Master's thesis. This comprises both the design and implementation of an experimental setup and the development of a model to simulate this. The general idea was to design a miniature model of a POLLUX container, that contained a heat source to simulate the thermal radiation caused by residual heat of the nuclear waste within the container.

The heating setup (**Fig. 2**) consists of a solid aluminum cylinder that contains the heating bullet with sufficient output on the inside. The temperature inside was monitored with a built-in sensor to ensure constant heating with a stable temperature. Furthermore, one sensor was always kept in direct contact with the surface of the cylinder to track and regulate the surface temperature.

Throughout all the conducted experiments, an external temperature controller connected to an external sensor was used to regulate the temperature of the cylinder, while an internal temperature sensor controller provided a control circuit. It was decided to use the external sensor for regulation, since for the experiment and future application the surface temperature of the container is of higher relevance due to direct contact with the host rock and backfill material. The controllers and other electrical components of this setup were encased within a durable electrical enclosure in order to meet the necessary safety regulations for an application within a mining environment.

The logging system is comprised of a Sparkfun Open Log Artemis (OLA) microcontroller, which can either be powered by a direct current (DC) battery or a universal serial bus (USB) with a type C cable. The latter can be connected to a computer for real-time data logging or to a power pack. In order to prevent a data loss during the test trials, a micro-SD card is inserted into the micro controller to save the data obtained from the sensors. Additionally, a multiplexer is utilized to connect the sensors to the microcontroller through an amplifier for each sensor. The system components are connected by using QWIIC cables from Sparkfun. All applied sensors are thermocouple type K sensors that can measure temperatures up to 400 °C (**Fig. 3**)

2.1 Pre-Tests

Since no pre-calibrated sensors for the application in rock salt backfill materials have been available, Thermocouple Type-K (temperature measuring probes) were ordered without any specific calibration. In order to check the suitability of the sensors, it was necessary to do a receiving inspection to assess how much they deviate from each other and if their quality is sufficient for the experiments. Therefore, several pre-tests had to be carried out.

2.1.1 Logging System Water Pre-Test

This test aims to compare measurements among all sensors at a specific temperature in order to obtain basic information about accuracy and standard deviation, if any are present. It was expected that all sensors would show readings within a ± 1.5 °C difference. To achieve this objective, water was used as a liquid environment to obtain uniform and consistent results. The water was initially heated up to a defined temperature, then the sensors were allowed to cool down to the ambient temperature (**Fig. 4**). This entire procedure was repeated three times to ensure the accuracy and reliability of the measurements across different temperature ranges.

Fig. 4: Logging system water pre-test. The tube contains the hot water and the cover holds the sensors while logging the readings.

2.1.2 Heat Distribution 3-Dots Pre-Test

This test aims towards the evaluation of the heat distribution along the surface of the cylinder. The examination used three sensors, two of which were connected to the logging system, and one directly connected to the external temperature controller. Moreover, each trial was conducted at a marked line along the cylinder. Finally, the test was conducted twice, with the sensors arranged linearly for the first and in a triangular formation for the second trial. **Fig. 5** shows the linear arrangement along a section of the cylinder circumference.

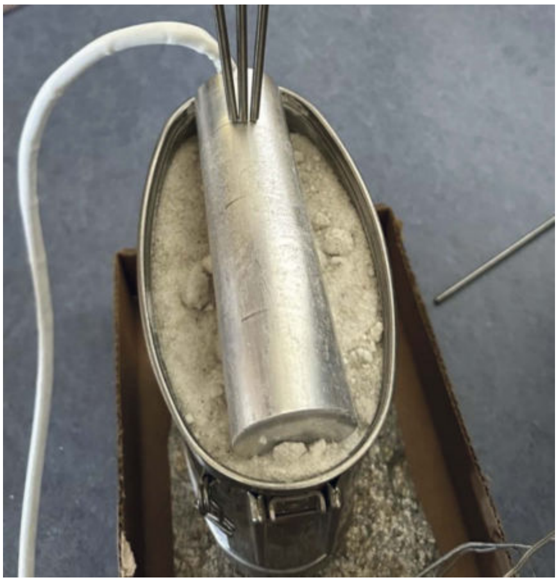

Fig. 5: Heat Distribution 3-Dots Pre-Test. Linear-arranged sensors trail

2.1.3 Beta Model Experiment

This model was created to evaluate the functionality and integration between the logging and heating systems, as well as functionality of the components within each system. The beta model is essentially a box of plywood that was filled with dry salt grit, which is the same material that acts as preferred backfill material in the current emplacement design. The POLLUX model was heated up and the logging system visualized the temperature increase for each sensor in real-time on a connected laptop (**Fig. 6**).

Fig. 6: Beta model setup showing the heating setup and the logging system connected while performing the test

2.2 Pre-Test Result Discussion

2.2.1 Logging System Water Pre-Test

In the first trial, the highest temperature registered amongst all sensors was 85 °C, which then declined to 74 °C in the second trial due to a relatively rapid cooling down of the hot water as a result of the relatively low ambient room temperature. Decrease in temperature persisted in the third trial, ultimately reaching 66 °C. **Table 1** contains the retrieved data.

Each of the sensors displays either identical or closely aligned accuracy measurements when placed in both

Special Topic

Table 1: Logging system water pre-test results in hot water and room temperature

Water Pre-Test Results						
[°C]	Trial 1		Trial 2		Trial 3	
Sensor	Hot water 1	Room temperature 1	Hot water 2	Room temperature 2	Hot water 3	Room temperature 3
1	83	21.5	70	23	64	23.5
2	84	21.5	71	23	64	23.5
3	83	21	71.5	22	64	23
4	82	21	71	22	64.5	23
5	82	21.4	71.5	22	64.25	23
E	85	24	74	24	66	24

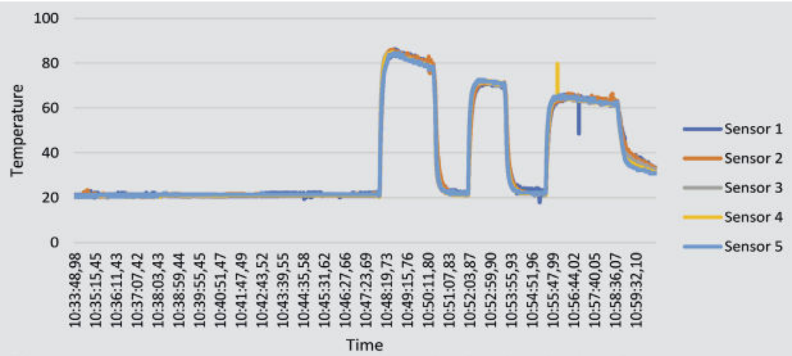

Fig. 7: Logging system water test full results presented in a chart

the hot water environment and the room temperature setting (**Fig. 7**). However, it should be noted that sensor E demonstrated marginally elevated readings. In order to maintain a proper and qualified test set-up, it is worth mentioning that this sensor is connected to the external temperature controller and is therefore not connected to the amplifiers like the rest of the sensors, as this could lead to marginally different readings by the controller. It is essential to highlight that the monitored data originating from Sensor E are logged since it is just included in the control circuit. Al the other sensors are connected to the logging system. The outcomes derived from this preliminary test ensure the precision and accuracy of the readings provided by the sensors as well as affirming the suitability of the system for application within the experiments.

2.2.2 Heat Distribution 3-Dots Pre-Test

For this pre-test, the inner temperature of the miniature POLLUX dummy cylinder was set to 260 °C. The actual temperature was meanwhile monitored with the internal sensor and fluctuated between 258 °C and 263 °C. The readings were taken simultaneously. Thus, the distinction among the sensors in each trial is the precise location from which the reading was obtained. In the first measurement location along the cylinder, the readings display a difference of up to 4 °C in each trial, also with a maximum average difference of up to 4 °C between the trials (**Table 2**).

Table 2: Heat distribution 3-dots pre-test results in linear-arranged sensors Linear Arranged Sensors

Linear Arranged Sensors			
Sensor / [°C]	Trial 1	Trial 2	Trial 3
1	170	170	165
2	167	168	166
E	170	166	163
Average	169	168	165

Table 3: Heat distribution 3-dots pre-test results in triangle-arranged sensors

Triangle Arranged Sensors			
Sensor / [°C]	Trial 1	Trial 2	Trial 3
1	182	186	182
2	186	190	185
E	185	188	182
Average	184	188	183

In the triangle test, the readings display a difference of up to 4 °C in each trial, with a maximum average difference of 5 °C between the trials (**Table 3**). The outcomes derived from this pre-test can ensure that the distribution of heat along the solid aluminum cylinder is nearly uniform and dependable within the expected ranges for this type of set-up and sensors, thereby proving the applicability for the desired experiments.

2.2.3 Beta Model

Fig. 9 shows the sensor data in the chart for a heating duration of 45 minutes (**Fig. 8**). The purpose of this model was to get an idea of the time required for the cylinder to reach a temperature of 200 °C in an experimental environment. Sensor 1 has direct contact with the surface of the cylinder. The chart below indicates that sensor 1 took approximately 30 minutes to reach a temperature of 200 °C. Moreover, it underlines the fact, that the 3D heat distribution within the backfill body declines with the distance to the heat source.

2.3 In-Situ Experiment

Based on the results of the laboratory pre-tests, in-situ experiments were conducted in the "Glückauf" rock salt underground mine to simulate the real-life conditions that will be met in a possible future repository. The setup was placed into one of the test drifts that are operated by TUBAF for the GESAV and SAVER research projects, which are funded by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). These drifts are permanently monitored for their air temperature and moisture.

To simulate a miniature test drift, a rectangular trench with high quality finishing was created on the drift's (**Figs. 10 and 11**). The trench had dimensions of 66 cm x 16 cm x 10 cm. Afterwards, the miniature POLLUX heating cylinder was placed on the bottom and the trench was filled with salt grit up to the rim after the sensors were put in place in a defined distance to the cylinder. Subsequently, the heating cycle was started and the logging commenced.

Overall, 3 heating cycles, each continuing at least for 8 days, have been executed. With each cycle, the POLLUX cylinder has been lowered deeper into the trench bottom to increase the contact surface between the host rock and the cylinder. This was done in order to investigate the initial hypothesis and yield the anticipated expectation that with an increasing trench depth also an increasing heat transmission into the host rock can be observed and quantified.

The selected trench depths were equal to 0%, 15% and 30% of the POLLUX cylinder diameter. It was capped at 30%. **Fig. 12** illustrates the placement and entrenchment depth for each phase.

Some difficulties arose from fixing the sensors in the exact same position for each repetition of the test.

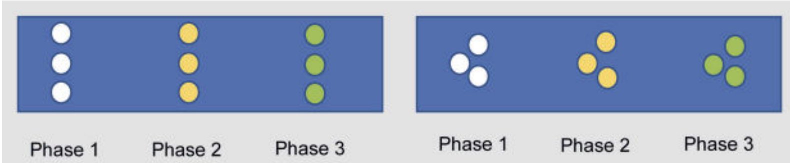

Fig. 8: Pre-testing with linear (left) and triangle (right) positioning of the sensors

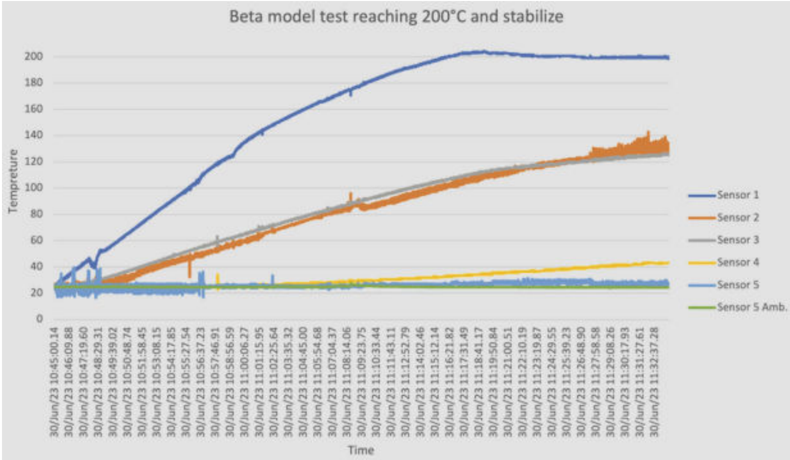

Fig. 9: Beta model test chart results over 45 minutes of operation

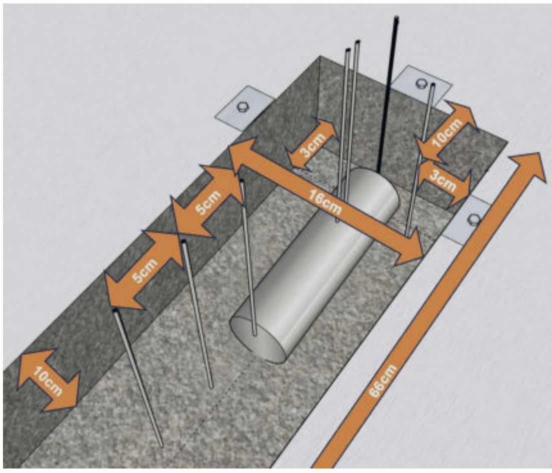

Fig. 10: In-situ experiment model showing the sensors' placement position and model dimensions

Fig. 11: Creation of trench by professional

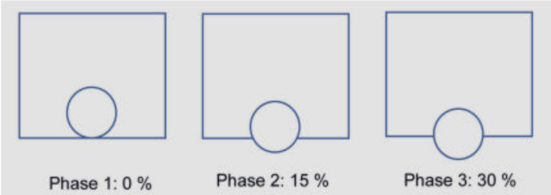

Fig. 12: Different entrenchment depths used in the underground test site

Due to this inaccuracy of the three-dimensional set-up, the results were not completely perspicuous. Still, it was possible to prove an influence of depth regarding heat transmission, but not for all 3 phases. With the expectation to receive more concise results the whole setup was transferred to the TUBAF laboratory in Freiberg.

2.4 Laboratory Experiment

The primary objective of this experiment was to achieve more concise results compared to the underground experiment. In order to achieve this, it involves the integration of a holder for the sensors within the test set-up, which would ensure consistent positioning of the sensors throughout each stage of testing. In order to conduct this experiment, the floor of the artificial drift was constructed using pre-mixed concrete. The whole test set-up held a volume of 10.7 dm^3 with a qualified salt backfill of the void space. In order to simulate a dense host rock environment, the walls consisted of lawn edgingstones. The sensor holder was then securely attached to the top of the model with an aluminum frame guaranteeing accurate sensor tip positions in each stage at a height of 4 cm above the concrete floor.

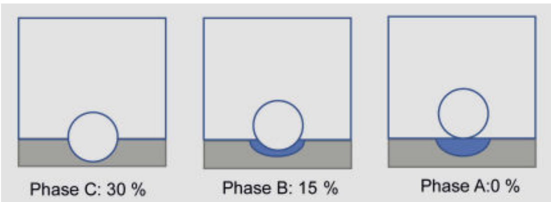

Fig. 13: Trench concrete casts for laboratory tests

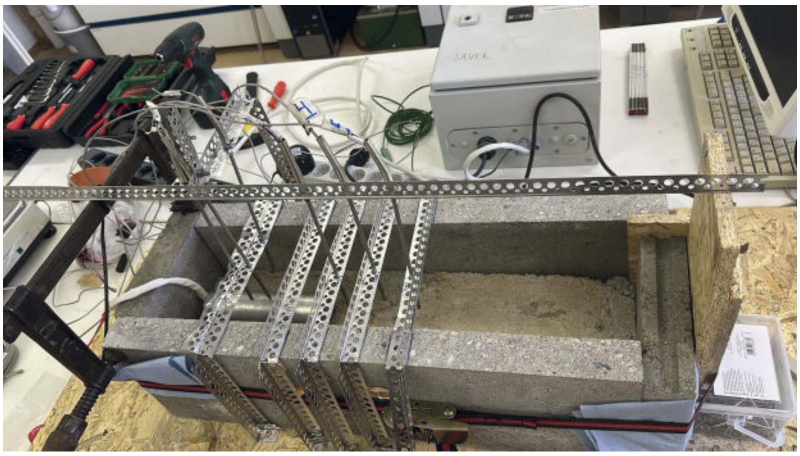

Fig. 14: Laboratory experiment model showing the sensor placement position and model dimensions (before backfill was filled)

Compare to the in-situ test, the three phases of the test have been executed in reverse order in the laboratory experiments for the reason that it is easier to pour concrete with a trench shape for the floor, and fill the trench for the next test with concrete than chisel the trench consecutively deeper into the concrete floor. The following **Fig. 13** will illustrate the process.

The experiment started with phase C, which accounted for 30% of the cylinder's diameter entrenched in the floor. Following the completion of phase C, it was imperative to allow for a period of cooling overnight to bring the test set-up and especially the concrete foundation back down to the ambient laboratory temperature. Subsequently, the salt backfill was carefully removed, and any remaining salt was extracted using an industrial vacuum cleaner to eliminate any residues and avoid damaging the trench surface. The purpose of this was to prepare the trench for the addition of another layer of pre-mixed concrete, which was necessary to achieve the desired depth of 15% of the cylinder's diameter for phase B. Once the concrete layer was poured, additional waiting time was allocated for sufficient curing of the new concrete layer (**Fig. 14**). This step was essential before proceeding to the next phase. The same procedure was repeated for phase A. The laboratory test was conducted three times, once for each phase, with each session lasting approximately three and a half hours of heating, and approximately ten hours for cooling down. Data was recorded for both heating and cooling down in every phase, in order to get a deeper understanding of the 3D heat transmission scheme between the floor and the cylinder as well as the backfill.

3 Results and Discussion of the In-Situ and Laboratory Experiments

3.1 In-Situ Experiment in the Underground Test Drift

Due to inaccurate sensor placement, readings from phase 2 have been excluded from the test assessment. The sensors 2, 3, and 4 recorded higher readings in Phase 1 compared to Phase 3. Specifically, sensor 2 had an average reading of 98 °C in Phase 1, whereas in Phase 3, it was only 75 °C. Similarly, sensor 3 exhibited an average reading of 166 °C in Phase 1, while in Phase 3, it was 95 °C. Likewise, sensor 4 displayed an average reading of 70 °C in Phase 1. Meanwhile, in Phase 3, it was 60 °C. Sensor 1, which monitored the temperature of the cylinder surface, recorded consistent readings. Sensor 5 showed nearly identical readings across all phases, likely due to the distance to the POLLUX and heat flowing into the host rock before reaching sensor 5. The comparison with Phase 2 did not reveal significant variations. (**Fig.15**)

The inaccuracy of the sensor positions throughout all phases, the broad particle size distribution of the backfill material, the inconsistency of the operating procedure and times, and the electrical instability are all factors that demanded the execution of another experiment with a more consistent setup and less possible influences caused by accuracy of positioning. Despite the above-mentioned challenges, it could be proven that the difference between 0% (Phase 1) and 30% trench depth (Phase 3) was clearly visible.

3.2 Laboratory Experiment

The outcomes of this experiment exhibit a greater level of consistency compared to the in-situ experiment. Upon examining the results, it becomes evident that sensors 2 and 3 recorded considerably higher readings during Phase A as compared to Phase C. As explained earlier, in the laboratory test the phases were reversed, meaning Phase C had the deepest trench whereas Phase A had no trench. Sensor 2 registered an average reading of 126 °C during Phase A, in contrast to 94 °C during Phase C. Similarly, sensor 3 displayed an average reading of 80 °C during Phase A, in contrast to 65 °C during Phase C (**Fig. 16**). The reading of sensor 4 was consistent, with an average reading of 41 °C, which is likely caused due to the distance to the POLLUX dummy and the considerably shorter heating period of 3 hours in the laboratory experiment compared to the underground trials with a heating period of around 8 full days. The comparable shorter heating period in the lab is sufficient, since the initial heat transmission is the most important phase. It is arguable that the heat transmission rate would change over time but due to the in-situ test, the long-term 3D-heat transmission into the rock is known, and shows that the heat transfer continues to go into the host rock rather than the backfill (Sensor 5 stays almost consistent between phase A and C with 43 °C to 44 °C; **Fig.15**).

Sensor 1 was utilized to monitor the temperature at the cylinder surface, which was reading 4 °C more in Phase C compared to Phase A. This is probably caused by minor changes in sensor positioning, since the surface temperature was kept consistent around all phases. Sensor 5 showed almost identical readings across the phases, while sensor 5 ambient sensor measuring ambient lab temperature) exhibited a 2 °C increase during Phase C, which is likely caused by ambient temperature changes due to the outside weather. Furthermore, upon analyzing the results, it becomes apparent that the sensors required more time during Phase C to reach a specified degree compared to Phase A, which proves the hypothesis that trench depth affects the 3D heat dissipation.

From the recorded logs of the cooling phase, Sensor 1 was reading a temperature of 98 °C in Phase A, while in Phase C, the temperature was recorded as 87 °C after one hour. Sensor 2 was reading 83 °C in Phase A, while in Phase C, the temperature was recorded as 71 °C after one hour. Similarly, sensor 3 read 64 °C in Phase A, while it read 57 °C after one hour in

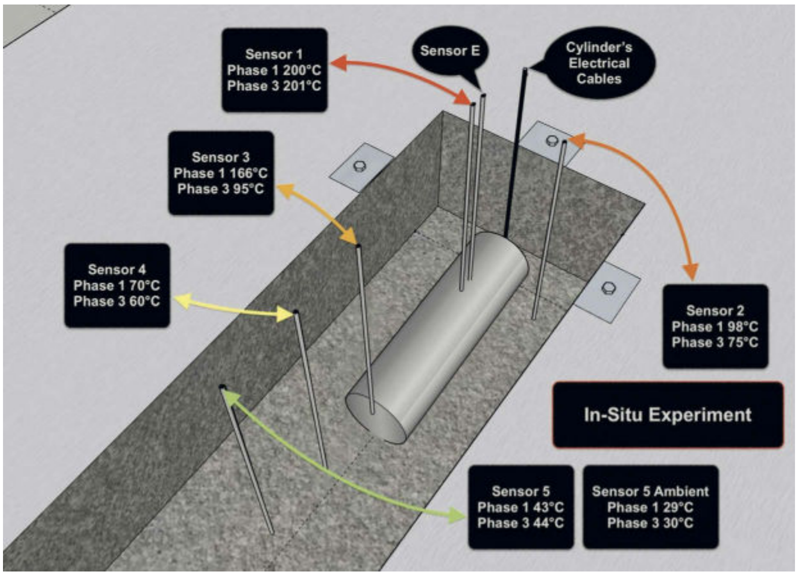

Fig. 15: In-situ experiment sensors' readings comparison between Phases 1 and 3 after eight days of operating

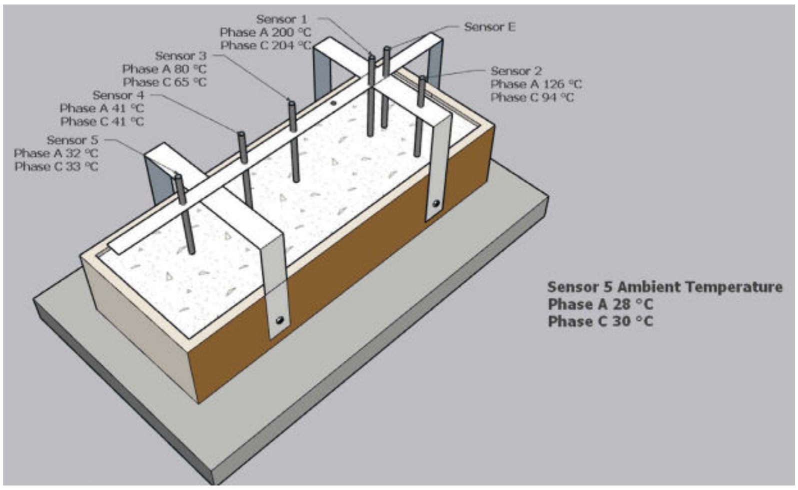

Fig. 16: Laboratory experiment sensors' readings comparison between Phases A and C after three hours of operating

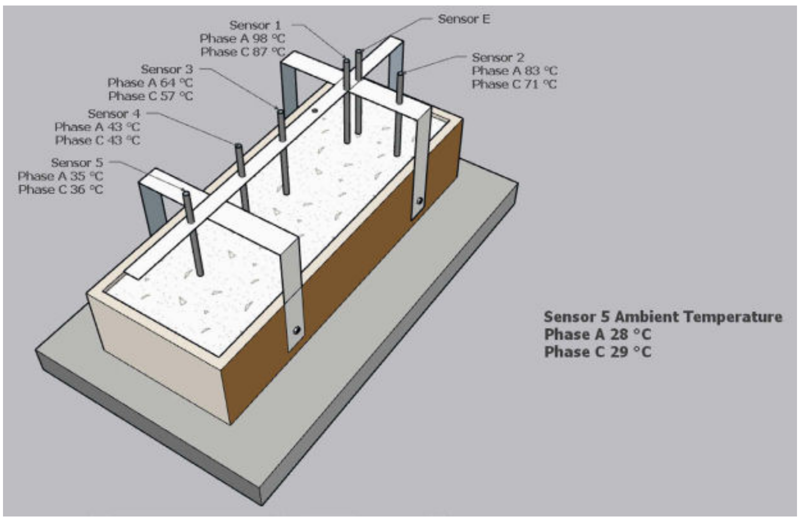

Fig. 17: Laboratory experiment sensors' readings comparison between Phases A and C after one hour of cooling down

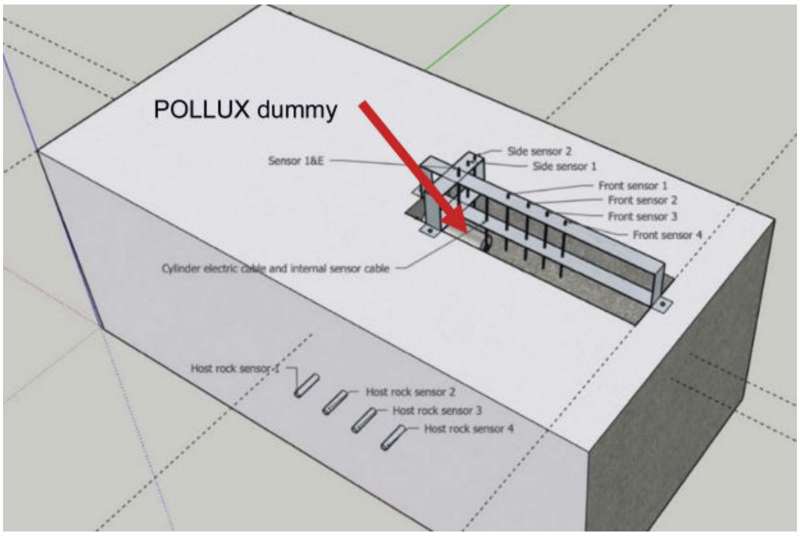

Fig. 18: 3D-visulization of recommended model for future research

Phase C (**Fig. 17**). However, it is vital to consider the starting temperature when cooling down commences, as it varies in some sensors across the phases, and to consider the ambient temperature. Upon examination, it becomes evident that Phase C shows significantly faster cooling down in comparison to Phase A. This suggests that heat dissipation in Phase C is superior since the contact surface of the dummy with the concrete is bigger due the trench depth of 30%. This underlines the hypothesis that cooling is accelerated with increasing trench depth within the emplacement drift. The sensor data from Phase C suggests that the heat dissipation is favored towards the concrete bed (which would be the host rock in real-life) instead of the backfill. If heat transmission into the backfill would be favored with increasing depth, Phase C would show higher readings after the 1 h cooling down period than in Phase A after 1 hour.

The concrete thermal conductivity, the limited duration of the testing period, and the electrical instabilities encountered have all exercised an impact on the results. On the contrary, a narrow particle size distribution of the backfill, the capability to examine the laboratory and the simultaneous monitoring of real-time data effectively reduces the range of variable factors.

4 Conclusions

Upon collecting and analyzing data from both experiments, the results can be summarized as following: The deeper the POLLUX dummy cylinder was placed within the host rock formation in the trench, the higher was the thermal dissipation towards the host rock as opposed to dissipation through the backfill. This can be explained by the thermal conductivity of the host rock being higher than the one of the salt backfill material. The thermal conductivity of rock salt is around 6 W/(mK) [7], which corresponds to the data within the in-situ experiment. Conversely, the first laboratory experiment utilized pre-mixed concrete with a thermal conductivity range of 2-3 W/(mK) [8]. In the future, it is expected to receive validating data sets by applying rock salt bricks instead of concrete.

5 Recommendations and Further Research

The currently prepared next experiment campaign will utilize a double connection thermocouple sensor instead of the existing separate sensors (1 and E). This would optimize the integration between the logging system and the heating setup. Upgrading to higher-quality temperature sensors and amplifiers enhances the accuracy and reliability of the data collected. Furthermore, incorporating an additional set of sensors at various distances within the floor and strategically placing other sensors on the same side as sensor 2 at different distances would provide further comprehensive data insights (**Fig. 18**). Improving the sensor holder could ensure more secure and precise positioning of the sensors, enhancing their overall stability. Moreover, maximizing the floor size is being considered, as a larger floor area provides better thermal conductivity, allowing heat from the cylinder to dissipate more effectively. Replacing the cast concrete floor with a better thermal conductive material, like rock salt, will increase heat transfer towards the host rock. These recommendations collectively aim to enhance the accuracy, efficiency, and overall quality of future research outcomes.

The setup recommendations are planned to be implemented again in an underground test trial. Using the TUBAF test sites at the "Glückauf" mine in Sondershausen ensures constant temperature and moisture conditions as well as realistic convergence values. **Fig. 18** shows the envisioned setup for future tests. It is planned to position the trench into a rock salt block of 1 m width and 2 m overall length and position the heat sensors accordingly around the model. Moreover, the fixation of the sensors is supposed to be even more accurate and stable. The top of the backfilled trench will be covered with a plate to minimize heat dissolvement into the air. The plate is not included in the figure above, so the POLLUX dummy at the floor of the trench can be seen. With the proposed setup it should be possible to increase the proximity to reality. In general, an improved 3D-pattern of additional sensors covering the complete surrounding of the POLLUX dummy container is favorable.

After carrying out the next in-situ-testing phase, additional data evaluation and verification on a laboratory scale will be conducted. It is intended by TUBAF to make the retrieved data accessible to the salt repository research community and stakeholders via a cloud-hosted database. The retrieved data can be used, e.g. for thermo-mechanical modelling to determine spatial heat distribution around the POLLUX container depending on its positioning within the floor of the future waste disposal drift. This would lay the foundation to optimize container positioning which possibly impacts overall repository size and interim-storage times.

6 Abstract

In order to store high-level radioactive waste underground, the German repository concept considers clay, crystalline and salt formations as suitable host rock materials. The current research projects of the Chair for Underground Mining Methods at TUBAF (Technical University Bergakademie Freiberg) in nuclear waste repositories mainly focus on storage within salt formations in the form of horizontal drift disposal. In this scenario, the high-level radioactive waste, for example, is supposed to be packed into specifically designed containers like the POLLUX containers and then transported and emplaced underground. POLLUX containers are cylindrical shaped, made out of cast steel alloys, weigh approximately 65 tons and have a length of 5.5 m and a diameter of up to 2 m. The maximum current temperature limit for the containers to be placed in repositories in salt formations was set to a maximum of 200 °C. The emplacement at such a high temperature level leads to the question if there are optimization possibilities for waste handling, the storage and the long-term emplacement of such high temperature level waste. Especially, a better understanding of the heat transmission from the container into the host rock might lead both towards possibly shorter surface interim storage times as well as faster cooling of the containers within the disposal drift. With the experiments for this research project, it has been shown that the positioning depth of the POLLUX container within a trench cut into the floor of the host rock within the disposal drift can affect the spatial distribution of heat into the surrounding rock due to an increase contact surface of the container towards the host rock. Thus, the initial cooling of the container by heat transmission can possibly be increased, allowing to direct more heat towards the host rock below instead of the surrounding backfill. Still, heat will be transferred into the surrounding salt grit backfill which would yield the desired increased compaction rate while providing optimization possibilities regarding HAW repository design. By transferring more heat towards the area below the drift, the three-dimensional heat field overlapping between storage drifts could possibly be reduced, which would result in higher storage capacities due to an increased overall disposal container capacity or less required total underground area. In order to validate the results, further upscaling and modelling is desired to be carried out in the near future.

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