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CONSTRUCTION MATERIALS AND BACKFILL IN
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Tunnelling • Australia • Major project • HSE • Dedusting
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In-situ Bioextraction of Industry Metals from deep Ore Deposits to secure EU Resource Supply

Romy Matthies, Horst Hejny, Knut Hirsch, René Kahnt, Horst Märten and David Barrie Johnson

The Biomore research programme brings together 22 European and non-European partners from industry and research. The project aims at developing an environmentally-friendly method for the extraction of technology metals from poorly accessible, i.e. deep ore deposits. To this end, the metals are extracted by combining deep drilling, fracturing and in-situ biolaching. The pregnant leach solution is further processed at the surface. GeoResources interviewed the project manager on important aspects of the project.

Mining • Raw materials • Research • In-situ extraction • Bioleaching • Environment

MINING – INTERVIEW

Responsible Mining Business participates in Solutions to the World’s big Problems

Frank Leschhorn

BHP is the world’s largest mining house led by CEO Andrew Mackenzie. Read about Andrew Mackenzie’s multidisciplinary approach in mining business to participate in solutions to the world’s big problems – population growth, poverty, economic inequity and jobs for young people.

Mining • Tradition • Innovation • Responsibility • Economy • Environment • Education

MINING

No nuclear Power – no Disposal Facility?

Jörg Feinhalts, Duncan Kemp and Anastasia Savidou

Even if countries have no nuclear power programme they often produce radioactive waste, e.g. from medical, industrial and research facilities, and have to responsibly deal with low amounts of the waste. This article discusses the challenge and different concepts for safe and affordable disposal solutions.

Mining • Radioactive waste • Waste disposal • Storage • HSE • Costs

Imprint

GeoResources Zeitschrift
GeoResources Journal
2. Year. Journal for Mining, Tunnelling, Geotechnics and Equipment
Date of publication: 31 May, 2017
ISSN | Online 2364-8430 • Print 2364-8422
Publication:
GeoResources appears 4 times per year in German (GeoResources Zeitschrift) and 4 times in English (GeoResources Journal). GeoResources is released as online issues on the GeoResources Portal (www.geo-resources.net). Additional GeoResources Journals are available as printed copies.

Purchase Price:
Online issues are free of charge. Printed issues in one language for 100 €/a, the combined English and German package for 150 €/a. Student discount 50 %, incl. shipping costs, shipping envelope, VAT in Germany included.

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Makossa Druck und Medien GmbH, Gelsenkirchen

Publisher:
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Cover:
G.E.O.S. as a midsize engineering company with roots going back to 1872 provides services for evaluation and sustainable exploitation of all kinds of georesources as minerals, water and deep geothermal energy. This includes mine planning, geotechnical and processing engineering, environmental consultancy and geoinformatics. Beside others, G.E.O.S. has specialized on 3-D geological modelling, mineral deposits, geothermal reservoirs, hydro-geological systems, geodynamics, geochemistry and in-situ leaching, mine water prognosis, logistic processes and prognosis of energy consumption.

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Today's mining has changed considerably from previous generations. Technological developments have improved exploration and mining operations. Also, today's mining operations have come to be more sensitive to the communities in which they are situated and the environment in which they operate. Thus, while modern mining needs to be profitable, it should operate with environmental integrity, be considerate of social concerns and be supported by effective government systems. At the same time, mining companies face operational challenges. For example, the ore content of mineral resources decreases, the ore mineralogy becomes more complex, the depth and size of mining operations increase, the amount of energy needed to extract the valued commodity increases, and the amount of waste spirals. Nowadays, the concept of "sustainable mining", to be able to provide resources for future generations economically and using environmentally sound and socially accepted practices, has become a major global challenge.

At the same time, the world's population is forecasted to surge from currently 7,500 million to 11,000 million people by the end of the century. With the growth of both, global population and prosperity, especially in developing countries, the prospect of much higher resource consumption levels is far beyond what is likely sustainable. According to the report by UN-EP's International Resource Panel, by the year 2050, human beings could devour an estimated 140 billion tonnes of minerals, ores, fossil fuels and biomass per year – three times the current consumption rate. The question then arises as to how to provide mineral and energy resources for a growing world population. Such a global challenge will only be solved through very important changes, in the way the mining sector engages with society, uses energy, protects the environment, educates professionals and pursues innovations. And in our global business of resources, we will also need greater exchange of technical information and knowledge. Hence, the mining sector needs to embrace five revolutions in the 21st century:

1. **Social revolution:** The lack of broad societal acceptance of mining in Europe will shift mining operations to resource-rich developing nations, but with the environmental impacts also being shifted from Europe to other continents and to government systems that are ill-equipped to deal with resource extraction. Conflicts between the mining industry and other stakeholders, in particular local communities, will continue, unless the social revolution of mining will continue to pursue initiatives like the Extractive Industries Transparency Initiative (EITI), Global Reporting Initiative (GRI), or Fairtrade. These initiatives could ensure that companies establish and maintain a social license to operate.

2. **Energy revolution:** Mining companies face increased pressure to reduce energy consumption and CO₂ emissions. Such pressures will lead to much greater investment in decentralised renewable energy and energy efficient processes in the mining sector.

3. **Environmental revolution:** The mine of the future will have to be increasingly quiet, out of sight and hardly visible, green and clean. It has to have an insignificant environmental footprint, and it will only bring to the surface the primary resources required by an increasingly circular economy. Mining will have to be like keyhole surgery – getting the same resource with a much smaller footprint. Also, the rehabilitation of mine sites will need to become more innovative and considered of the long-term needs and expectations of all stakeholders.

4. **Education revolution:** The education of mining professionals needs to be multidisciplinary, embedded in international curricula and relying on modern blended learning concepts like serious gaming.
as well as virtual reality labs and experiments. To participate in the Fourth Industrial Revolution (Industrie 4.0), technology like robotics, automation and self-learning tools needs to be integrated into university teaching activities. We will also need internationally educated professionals that are culturally aware and know the expectations of society. Training will have to be extended to resource-rich developing nations that will require capacity building of local professionals.

5. Technology revolution: Innovation is the key to the survival of any industry. Thus, there is a clear business case for: in-situ/leach mining; biomining; automated, containerised and modular mining, operating in a switch-on/switch-off mode; ore pre-concentration; new comminution technologies; sensor-based sorting; real-time data processing; self-learning mines and mineral processing plants. Industry must find new solutions and establish more innovative operations, if they want to gain trust and confidence from the public, acquire the social licence to operate, promote shareholder value and be profitable in a networked global society. The reality is that companies must innovate or die.

The mine of the future will be different to that of today. There is reason for optimism that the required revolutions in mining are possible. Such optimism is based on the fact that the mining sector has a phenomenal ability to achieve progress and change. However, only a combined effort by all stakeholders (education and training organisations, government agencies, mining companies, mining contractors, equipment suppliers, community groups, media) will result in a bright future of mining in the 21st century.

Welcome and Glückauf!

Bernd Lottermoser

Univ.-Prof. Dr. Bernd Lottermoser

is chair in Sustainable Resource Extraction and Director of the Institute of Mineral Resources Engineering (MRE) at the RWTH Aachen University in Germany. The MRE emerged in 2015 from the mining institutes BBK1 and BBK3. Mining Engineering was established in 1880 as one of the first institutes at RWTH Aachen University.

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Mining in Europe – Aachen International Mining Symposia (AIMS), June 2017

The Aachen International Mining Symposia (AIMS) have a long standing tradition. For the last 20 years, the Institute has been organising this international conference by selecting particular topics covering aspects of the production of mineral raw materials. You are welcome to the next conference on 7-8 June 2017.

www.aims.rwth-aachen.de
New Tire Product Lines for Construction and Mining Vehicles

GeoResources interviewed Christian Luther, Continental Commercial Specialty Tires, Hannover, Germany

The GeoResources team interviewed Christian Luther, Product Line Manager Earthmover Tires at Continental Commercial Specialty Tires about the new Tire Product Lines for Construction and Mining Vehicles.

GeoResources: Mr Luther (Fig. 1), here at the GeoResources offices we read that you are producing innovative tires for construction and mining machinery (Figs. 2+3). Clearly this is of interest to our international readers in the geotechnics, tunnelling and mining sectors. Thus we really appreciate the fact that you have found the time to respond to our questions.

Your new developments are tailor-made solutions for different vehicles and applications. Which general advantages do they offer to your customers?

Christian Luther: For us at Continental the customer is always our main focus. We have therefore developed our earthmoving tires specifically for the individual vehicle types and their use. This can partly be seen in the name of the products. The DrillMaster (Fig. 4) is ideally suited for drill rigs, the ScoopMaster (Fig. 5) for underground loaders and scoops. Depending on the application and requirements, we have also chosen the design of the tires: some products are based on the proven V-ply design with high carcass strength and stability (Fig. 6). Others are all-steel radial tires (Fig. 7) and extremely durable, even on long transport routes underground. In this way, we offer our customers exactly the tire they need for their own individual construction project, in the sand or gravel pit, the quarry or underground.

At the same time, we are complementing our tires with holistic solutions from a single source. Additionally, we bundle our knowledge and experience in the automotive and rubber sectors and offer, in addition to tires, industrial hoses (Fig. 8) and drive belts as well as various telematics solutions and services. In this way, we contribute to safe, efficient, clean and comfortable mobility in the construction and mining industries.

Fig. 2: Earthmoving (EM)

With a broad portfolio of Earthmover tires, Continental is further expanding its Commercial Specialty tires portfolio.

Fig. 1: Christian Luther, Product Line Manager Earthmover Tires

Source of the figures: Continental
GeoResources: What are the essential differences between the EM Master and the RDT Master and which are the innovations that really matter?

Christian Luther: The EM Master is ideally suited for articulated dump trucks (ADT), loaders and bulldozers, which are traditionally used for earthmoving (EM). The vehicles are used for transporting large quantities of bulk materials or aggregates under extreme conditions. We have two versions of the EM master: the EM master E3/L3 with a normal tread depth and a greater distance between the profile blocks (Fig. 9) and the E4/L4 with a larger block size, a smaller distance between the blocks and a larger tread depth (Fig. 10). The E3/L3 offers excellent self-cleaning properties, good traction and very good maneuverability even on muddy surfaces. The open tread design and a standard tread depth of 100 percent ensure better cooling properties. As a result, the heat development is minimized, resulting in a long service life. In comparison, the E4/L4 offers high carcass protection and excellent cutting resistance, which reduces the risk of tire damage and therefore downtime. The smaller tread block spacing results in smooth running, even on hard surfaces. Due to its high tread wear volume, the tire also offers an excellent service life.

The RDT master (Fig. 11), on the other hand, was developed for rigid dump trucks. These transport heavy loads over long distances in rough terrain. The special tread design with a deep tread depth and a wide and flat tread radius offers high loading capacity and cutting resistance. The angled tread edges, in addition to the open shoulder design, facilitate high lateral stability which results in better driving behaviour. Maximum traction is guaranteed even on winding terrain and while driving at high speeds. Moreover, the open tread design results in excellent self-cleaning characteristics.

GeoResources: Depending on the field of application there are undoubtedly overlaps between tires for mining and construction machinery, for instance between earth moving in construction and opencast mining or between tunnelling and underground mining?

Christian Luther: Definitely. In underground operations, people drill. A lot. This is why our DrillMaster is equipped with a highly cut-resistant carcass which
protects the tire from freshly blasted rocks. Whether the drilling rig is used to break salt or to produce a cavity in the ground at full pressure, which later serves as a tunnel, does not matter – the requirements for our tires remain the same.

The same applies to our ContiEarth portfolio, which consists of EM and RDT master. Let us compare an example of a gravel plant with a construction site. From the gravel pit, building materials such as gravel and sand are extracted, which are then used for construction works, for example, when building the foundation for streets or buildings. What counts here is durability and traction on stony, uneven ground as well as cut resistance and a lower heat-buildup.

GeoResources: How do you get to know your customers’ requirements and receive practical suggestions for your development activities? How do you test new special developments on site prior to introducing them to the market? Does your cooperation with Caterpillar help in this respect?

Christian Luther: An important principle of our work is that products are always developed very close to the customer. This is the only way to develop a tailor-made offer and deliver the accustomed premium quality to our customers. The analysis of the customer requirements is mainly done by the Field Intelligence department. Our engineers travel to customers around the world who may, for example, be vehicle and machine manufacturers, but also mine operators. The biggest challenge for us is that the influential factors in mining operations are highly diverse. One mine scarcely ever resembles another. Nevertheless, products can be specially developed for these applications. Therefore, it is highly important to get to know the customer’s site to find out why tires currently in use are dismantled and exchanged. In this way, we derive the customers’ needs and potential for improvement. As soon as the tires are developed and produced, the acid tests follow: the tires are tested on the spot with the same customer groups with which we have already carried out the analysis.

GeoResources: Improving the operational efficiency of your customers is a further objective that matters to you. This is why you integrate sensors and supply accessories. What is your contribution to Mining 4.0 and BIM and how do you participate in the specialist discussion?

Christian Luther: The aim of BIM in the construction sector and Mining 4.0 in mining is to optimize processes from planning to the actual extraction of raw materials or implementation of construction projects. The goal is to increase efficiency while saving resources and thus the environment. Especially for our customers

GeoResources: New Tire Product Lines for Construction and Mining Vehicles
in the earthmoving segment, the safety of the vehicle or machine and driver is also particularly important. We contribute by delivering all tires of our ContiEarth range as iTires with an integrated sensor (Fig. 12). The sensor constantly monitors the tire pressure as well as the tire temperature and transmits the information in real time to the ContiPressureCheck system (Fig. 13). Using additional components, the data can either be displayed on a handheld tool (Fig. 14), or in the driver’s cab (Fig. 15).

**GeoResources:** How do you ensure prompt availability internationally – especially with regard to repair and maintenance? It’s no secret that mining is often carried out in remote areas that are not easily accessible.

**Christian Luther:** Especially in mining, maintenance is an enormously important topic. Galleries and shafts are difficult to access and the vehicles and machines have to be serviced and – if necessary – repaired underground. Thus, strong, local partners are extremely important. We maintain a good network of local tire dealers and service providers, who in such cases are quickly and conveniently at the end customer’s site.

**GeoResources:** You first presented the new tire series in autumn last year at the MINExpo in Las Vegas. What response did you receive and how has demand developed?

**Christian Luther:** In Las Vegas the response of our customers was very good. We were already able to win new customers and sign cooperation agreements. Since the introduction of the tires, demand has also developed well, especially in North America and Europe.

**GeoResources:** Have you already received initial feedback from your customers? How satisfied are they with your new products and services? Has it already been possible to register increases in operational efficiency?

**Christian Luther:** The feedback from our customers is very good. Thanks to the built-in CPC sensor, they do not need to check the air pressure manually. This saves them valuable time right from the start. We are already taking repeat orders from our customers, and that, we feel, speaks for itself.

**GeoResources:** What do you see as the greatest challenges in the mining and construction sector for the future?

**Christian Luther:** The ongoing optimization of processes will remain one of the biggest challenges in the future. For us, therefore, a central task will be to expand our range of intelligent tire and tire management systems in the earthmoving sector in the coming years. This enables us to support our customers, reduce costs, save resources and increase efficiency.

**GeoResources:** We should like to thank you for your input and wish you every success with your products and future innovations.

**Christian Luther** is Product Line Manager Earthmover Tires at Continental Commercial Specialty Tires. The graduate engineer has been working for Continental since 2002. After completing his technical training with a degree in mechanical engineering, specializing in production technology, he worked for Continental in the field of special tires at various stations, most recently as a global key account manager for Original Equipment OTR and UG Mining. In 2015 he assumed responsibility for the product line Earthmover.

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Foundation Piling for the New Champlain Bridge Corridor Project in Canada
Amr Aly and Nick Papas, Bauer Foundations Canada Inc., Canada

About the Project
The Champlain Bridge crossing is one of the busiest bridge crossings in North America, with up to 50 million vehicle crossings per year. The current bridge has been in service since 1962, and extensive wear and prolonged road salt exposure has brought the bridge into line for replacement. Currently, the new Champlain Bridge in Montreal is one of the largest infrastructure projects in Eastern Canada. It will be a signature feature of the St. Lawrence waterway when complete. The project was conceived in keeping with sustainable development practices, and utilizes innovative ideas in modern engineering and urban integration. The new bridge will be designed for a service lifespan of 125 years. The project is financed by the federal government of Canada.

Scope of the Foundation Works
Bauer Foundations Canada was contracted by “Signature on the St Lawrence Construction” (SSLC), a consortium of companies that includes SNC Lavalin, Dragados & Flatiron, to carry out the foundation piling for the New Champlain Bridge over the St Lawrence River and the highway and ramps bridges feeding into the main bridge.

Bauer’s scope was 200 concrete piles of sizes 1,300 and 2,000 mm for the two main bridges, the New Champlain Bridge over St Lawrence and Nun’s Island Bridge. All concrete piles were permanently cased to top of competent rock, with the large diameter casings being rotated into place using a rotary casing drive adapter. 190 piles were drilled from land or jetties and 10 piles

Fig. 1: Pouring a marine pile using 2 pumps
Source of figures: Bauer Group
were marine piles drilled offshore from a barge in the St. Lawrence (Fig. 1). Caisson lengths ranged from 9 to 26 m in depth.

**Equipment**

Two rigs were initially mobilized to the job; a Bauer BG 28 and a BG 40 (Fig. 2). The original BG 40 on site was later replaced by a brand new Bauer PremiumLine BG 39 in January 2016 (Fig. 3). This drilling rig was ideal for a site such as this, with tight working areas but a requirement for high torque rock drilling and casing drive capability through various soil layers, including hard limestone bedrock.

**Geotechnical and Drilling Conditions**

The drilling site covers a wide area. However, in general, the geological setting was quite consistent across the site and is typical of the Island of Montreal and Nun's Island. As per geotechnical investigation and Bauer's own drilling records, the ground conditions mainly consist of:

- Fill with varying thickness installed by client to construct the jetties (up to 5 m)
- Overburden, loose to very dense comprised of sand, silt with occasional cobbles and boulders (3 to 6 m)
- Glacial till, sandy silt/silty sand dense to very dense (2 to 4 m)
- Fractured rock, clay shale to mud shale (1 to 4 m)
- Bedrock, black calcareous shale (over 100 MPa strength)

The average groundwater depth was about 6.5 m below ground surface, generally in the fill characterizing the St. Lawrence River bank. Occasional hard intrusive dykes and sills were encountered within the till during drilling. As per project requirements, a permanent casing was installed to the top of the competent rock. All piles were socketed in rock between 5 to 11 m.

**Piling Operations**

Piling operations started at the Main Span Tower (MST) on October 2015 (Fig. 4). The full piling scope was completed by July 2016. The work proceeded with two crews per day on rotating 10 hour shifts. Bauer implemented day and night shift rotations to meet the aggressive schedule proposed by the client. Drill crews worked through adverse weather conditions between October and December 2015, completing the structure safely, within the quality targets and ahead of schedule (Fig. 5).

Kelly drilling of the caissons and installation of permanent casing were done simultaneously using modified casing drive adapters and the Bauer rigs’ dual rotary drive system. Due to the presence of water in all of the soils adjacent to or on the St. Lawrence Seaway (Fig. 6), all holes were drilled under water, with concrete being placed with tremie pipe.

One of the technical challenges was meeting the strict cleaning criteria at the pile toe. The thickness of
sediment or loose, disturbed material prior to placing concrete was not to exceed 15 mm for more than 50 % of the shaft area and maximum of 40 mm for the rest of the shaft. After standard machine cleaning with a cleaning bucket, an air lifting procedure was used to clean the bottom of the pile. Air lifting was followed by rigorous down-the-hole camera inspection to verify the cleaning and the seal at the fractured rock/competent rock interface. Due to a comprehensive and in depth quality control program, the pile toe cleaning and inspection would typically last only a few hours per pile.

The project had strict safety, quality and environmental challenges (e.g. working in environmentally sensitive areas, offshore piles, noise restrictions etc.). It also required considerable planning and close coordination with the client and was quite successful.

Marine Piles Construction

Working from a floating barge in the middle of the St. Lawrence to install the 2,000 mm diameter piles was especially challenging (Figs. 1+6). Some of these challenges were:

▶ A limited availability of barge surface area spoil disposal and a congested work area
▶ Stringent, unachievable specifications, allowing only 3 hours between final camera inspection and start of concrete placement
▶ Supply and quality of water used in air lifting
▶ Disposal of residual water from air lifting
▶ Concrete placement in the middle of the river
▶ Disposal of excess concrete after placement
▶ Restricted Navigation of barges due to shallow area just to the south of the piles, limiting approach to piles to north side only.

To meet these challenges detailed planning and coordination with different parties involved was undertaken and the following measures were implemented:

▶ Drilling barge geometry was adapted to allow for safe and efficient drilling.
▶ The stability of the barges was checked and adjusted for all possible construction scenarios and contingencies.
▶ Equipment layout on barge and sequencing of construction were revised few times to meet stability and navigability requirements.
It was agreed with the client to change the concrete placement start from 3 hours following final camera inspection to 24 hours.

Whenever possible, river water was used, while having fresh, clear city water containers on standby in case the river water was too turbid to allow inspection.

Risk assessment was carried out with the client to ensure contingency measures were in place before start of construction.

Bauer crews were briefed about risks and contingency plans prior start.

Concrete mix was adjusted, extending its acceptance to 4 hours and adjusting air to account for the long pumping path across the river.

Two concrete pumps were used for reach and sometimes an intermediate barge with a line pump.

All operations not directly involved in drilling or placement of concrete, such as welding of teeth to casings or repair of tools, were moved off barge to shore to provide more space on barges.

**Conclusion**

The project was completed with no Lost-Time incidents (LTI), meeting the project quality standards and on schedule (Fig. 7).
**Introduction**


Structural fire protection for road tunnels with an inner shell consisting of in situ concrete is regulated in the ZTV-ING [1] Part 5, Section 1, Item 10.3. Accordingly, sufficient fire protection can generally be safeguarded by means of structural measures in the form of a minimum inner shell thickness of 35 cm, a nominal size for the concrete covering of the reinforcement at the exposed side of 6 cm and an inner shell executed with concrete with the addition of polypropylene fibres (PP fibres). The application of PP fibres has been anchored in the ZTV-ING for new tunnels since 2012. The demands on the mix and quality assurance during execution are contained in Appendix 8 of ZTV-ING Part 5 Section 1. This stipulates the application of authorised PP fibres with a content of 2 kg per cubic metre inner shell concrete, a fibre length of 6 mm and a fibre diameter of 0.016 to 0.020 mm. Should the prescribed content and the geometry of the PP fibres not be adhered to, then fire tests must be carried out to prove suitability. These structural measures are devised to minimise spalling and secure a temperature of less than 300 °C for the exposed reinforcement.

In cases of exception, structural fire protection must be verified by theoretical means. For the fire protection design, a corresponding temperature-time curve, also known as the ZTV-ING curve, is defined (Fig. 1). For tunnel structures, in the case of which possible damage of the tunnel structure resulting from the effects of fire can culminate in major secondary damage, e.g. tunnels with shallow overburden beneath water courses, special requirements must be posed on structural fire protection. Generally speaking, the full fire phase reflecting the fire curve from 25 to 55 min is needed for the verification process. Then the applied fire curve would correspond to the EBA Curve (Fig. 1). The ZTV-ING does not specify the case of exception and the necessary verification method.

Structural fire protection for rail tunnels is regulated in the Ril 853 [2] and the EBA-Ril [3]. Proof of structural fire protection is either to be obtained through major fire tests or theoretical verifications. The fire exposure presented in the EBA Curve (Fig. 1) must be applied.

In the case of major fire tests, the marginal conditions relating to the geometry, the load state and the concrete composition are to be presented as close to reality as possible. Proof of structural fire protection must be shown according to Ril 853 either through major fire tests or by calculation. Towards this end, theoretical proof must be provided within the scope of an accidental design situation using the Advanced Calculation Method of the DIN EN 1992-1-2 [4].

The determining damage resulting from the fire exposure on reinforced concrete structures is reflected by major fire tests or theoretical verifications. The fire exposure presented in the EBA Curve (Fig. 1) must be applied.

In the case of major fire tests, the marginal conditions relating to the geometry, the load state and the concrete composition are to be presented as close to reality as possible. Proof of structural fire protection must be shown according to Ril 853 either through major fire tests or by calculation. Towards this end, theoretical proof must be provided within the scope of an accidental design situation using the Advanced Calculation Method of the DIN EN 1992-1-2 [4].

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Concrete spalling with corresponding effects on stability. In this connection, possible spalling must be taken into account during theoretical verification in keeping with Ril 853. Towards this end, a systematised method is provided in Ril 853, which relates to the project-specific available factors of influence. These factors of influence are moisture content, permeability, type of aggregate, concrete compressive strength, static degree of exploitation, thermal expansion of the concrete and the addition of polypropylene fibres (PP fibres). The determining factor of influence is the addition of PP fibres, which can be shown to lead to a substantial reduction in spalling.

**Spalling Behaviour of PP Fibre Concrete**

Up till now numerous major fire tests with varying fire loads, test body geometries, concrete recipes and stress states have been executed to investigate fire and spalling behaviour of PP fibre concrete. The marginal conditions and the results of selected ongoing fire tests are presented in Table 1.

This compilation indicates that average spalling amounts to ≤ 10 mm if a suitable recipe for PP fibre concrete is used. Restricting the maximum grain diameter exerts a positive influence on reducing the spalling depth, something which can be substantiated by the lower expansion difference between cement and aggregate. Compared with the test results, the method in keeping with Ril 853 with theoretical estimation of the spalling depth by application of the corresponding marginal conditions results in more conservative values of up to 90 mm.

**Computational Verification in the Case of Fire for representative Tunnel Cross-sections**

**Calculation Process**

The calculations are carried out with the Advanced Calculation Method of the DIN EN 1992-1-2 [4] by means of the Sofistik Company’s TALPA software module on an elastically bedded beam model. During verification with the Advanced Calculation Method in a first step the time-related temperature distribution in the structural element is established on the basis of fire exposure by dint of a thermal analysis. During the subsequent mechanical analysis the resultant constraints from the temperature distribution of the thermal analysis are superimposed with the decisive design load cases (cold dimensioning) and the stress resultants calculated by means of an iterative, non-linear method. In the calculations the non-linear, temperature-related material properties of the reinforced concrete are applied in keeping with Ril 853 [2] with reference to DIN 1054 [5] as 1.1.

The fire exposure is applied in the vault above the carriageway. The invert is protected against fire exposure by the carriageway structure. In the non-linear calculation the reinforcement is derived from proofs in the limit state of the bearing capacity and the serviceability. The concrete covering at the perimeter affected by fire is presupposed.

**Selected Tunnel Cross-sections and Boundary Conditions**

Representative tunnel cross-sections for a rail and road tunnel are considered for the calculations:

- For the rail tunnel a single-track tunnel cross-section is selected (Fig. 2). The tunnel has a water-pressure tight circular profile. High external, mechanical effects, in particular high water pressure as well as high rock stiffness are taken into account. High pressure normal forces and comparably slight bending moments in the concrete cross-section result from these marginal conditions.

- A bi-directional tunnel is chosen for the road tunnel (Fig. 3). The tunnel is provided with groundwater relief measures in the form of underground water drainage thus eliminating water pressure on the inner shell. In addition, low rock stiffness is taken into consideration. Low pressure normal forces

---

**Table 1: Marginal conditions and results of selected major fire tests**

<table>
<thead>
<tr>
<th>Project</th>
<th>Actual concrete quality [N/mm²]</th>
<th>Fibre content and geometry [kg/mm³]</th>
<th>Fire curve</th>
<th>Average spalling [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner shell</td>
<td>approx. 50</td>
<td>2 (2.8 dtex/6 mm)</td>
<td>ZTV-IX</td>
<td>2</td>
</tr>
<tr>
<td>Segmental tunnel</td>
<td>approx. 72</td>
<td>1.4 (1.7 dtex/6 mm, HPR)</td>
<td>EBA</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>approx. 65 – 70</td>
<td>1.2 (1.7 dtex/6 mm, HPR)</td>
<td>EBA</td>
<td>10</td>
</tr>
<tr>
<td>Rectangular frame</td>
<td>approx. 74 (maximum grain size 8 mm)</td>
<td>2 (2.8 dtex/3 mm)</td>
<td>EBA</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>approx. 77 (maximum grain size 16 mm)</td>
<td>2 (2.8 dtex/3 mm)</td>
<td>EBA</td>
<td>18</td>
</tr>
</tbody>
</table>

Fig. 2: Representative cross-section of a rail tunnel [7]
and comparatively high bending moments in the concrete cross-section result from these marginal conditions.

Via the selected tunnel cross-sections and marginal conditions the possible scope of cross-sectional utilisation – i.e. in the one case, high compressive and low bending stress and on the other, low compressive and high bending stress – is taken into account in conjunction with the possible effects on the theoretical proofs in the case of fire.

**Calculation Results for the Rail Tunnel**

The selected static boundary conditions for the rail tunnel are summarised in Table 2. Determining the stress resultants and dimensioning in “cold state” were executed for the following load case combinations (LFK):

- LFK 1: dead weight (EG)
- LFK 2: dead weight (EG) + water pressure (W)
- LFK 3: Dead weight (EG) + rock pressure subject to uplift (G) + water pressure (W)

In Figure 4 the courses of the characteristic normal force $N_K$ and the bending moment $M_K$ in cold state for the load case combination dead weight (EG) + rock pressure subject to uplift (G) + water pressure (W) are presented. The theoretical proof of the fire load was undertaken for the cited load case combinations plus the fire exposure of the EBA Curve.

The Figs. 5+6 display the course of the dimensioning normal force $N_{ed}$ and the dimensioning bending moment $M_{ed}$ in the roof from the start of the fire until the cooled down state is restored (approx. 5,000 min after the fire started). The theoretical proofs for the fire case were undertaken for the entire time period, without additional reinforcement being needed for this purpose.

**Fig. 4:** Calculation example for a rail tunnel – characteristic normal force $N_i$ in kN (otl) and bending moment $M_i$ in kNm (otr) for load case combination LFK EG+G+W
The maximum constrained stress resultants occur in the period of up to roughly 200 min after the fire begins. Owing to the high rock stiffness and bedding, the outcome is a correspondingly large obstruction affecting thermal expansion and in turn, a high constrained normal force. The course of the constrained bending moment involving alteration to the sign can be explained as follows. The maximum constrained bending moment possesses a negative sign, caused by the constrained pressure stresses on the inner side and the lever arm to the system line. As time progresses the temperature further penetrates the cross-section. Combined with the temperature-related reduction of the concrete compressive stresses in the exposed perimeter area, the main focus of the constrained compressive stresses lies behind the system line in the half of the cross-section at the earth side as from a point in time of roughly 600 min after the fire starts. This brings about a change in the sign of the bending moment.

### Calculation Results for the Road Tunnel

The selected static boundary conditions for the road tunnel are summed up in Table 3. The determining of stress resultants and dimensioning in “cold state” were carried out for the following load case combinations (LFK):
- LFK 1: dead weight (EG)
- LFK 2: dead weight (EG) + rock pressure (G)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete thickness vault [cm]</td>
<td>40</td>
</tr>
<tr>
<td>Concrete thickness invert [cm]</td>
<td>varying, max. 65</td>
</tr>
<tr>
<td>Concrete quality</td>
<td>C 30/37, quartzitic aggregate, PP fibres</td>
</tr>
<tr>
<td>Reinforcing steel</td>
<td>B 500A</td>
</tr>
<tr>
<td>Rock overburden [m]</td>
<td>approx. 10</td>
</tr>
<tr>
<td>Max. rock pressure (application full overburden) [kN/m²]</td>
<td>200</td>
</tr>
<tr>
<td>E-module of the rock (mudstone) E [MN/m²]</td>
<td>100</td>
</tr>
<tr>
<td>External radius R [m]</td>
<td>approx. 5.5</td>
</tr>
<tr>
<td>Radial bedding module kₚ = E/R [MN/m³]</td>
<td>18</td>
</tr>
<tr>
<td>Fire exposure</td>
<td>ZTV-ING curve</td>
</tr>
</tbody>
</table>

---

Fig. 5: Calculation example of a rail tunnel – chronological normal force force Nₚ for the cross-sectional point roof

Fig. 6: Calculation example rail tunnel – chronological bending moment course Mₚ for the cross-sectional point roof

Fig. 7: Calculation example road tunnel – characteristic normal force Nₑ in kN (otl) and bending moment Mₑ in kNm (otr) for load case combination LFK EG+G

Table 3: Static boundary conditions of the road tunnel
In Fig. 7, the courses of the characteristic normal force $N_K$ and the bending moment $M_K$ in cold state for the load case combination dead weight (EG) + rock pressure (G) are shown. The theoretical proof of the case of fire was carried out for the cited load case combination plus the fire exposure in the ZTV-ING curve.

The Figs. 8+9 display the course of the dimensioning normal force $N_{ed}$ and the dimensioning bending moment $M_{ed}$ in the roof from the start of the fire until it regains a cooled state (approx. 5,000 min after start of fire). The theoretical proofs of the case of fire for the road tunnel could also be conducted for the entire time period without additional reinforcement being required in this connection.

**Conclusion**

When PP fibre concrete is applied, the theoretical proof of the case of fire by means of the Advanced Calculation Method of the DIN EN 1992-1-2 [4] is not relevant for dimensioning the selected representative tunnel cross-sections.

In the case of the proofs, it was assumed that negligible concrete spalling occurred in the case of fire. Especially given project-specific demands on the recipe for the PP fibre concrete – for instance, the need for self-compacting concrete, high-grade concrete quality and/or in the event of fluctuations from standardised PP fibre types and contents – sufficient fire resistance should be verified by means of fire tests.

If a highly ductile reinforcing steel B 500 B is applied, the steel regains its original strength while it is cooling down. However, the temperature-related damage affecting the concrete is irreversible. Redevelopment work may become necessary on the concrete covering in order to ensure that the tunnel bearing structure acquires full safety for the permanent dimensioning situation following the fire. Corresponding measures have to be determined specifically for the project concerned depending on the extent of damage.

**References**


Gaskets for Sealing Segments in the Boßler Tunnel and innovative Developments

Christian Braun, Product Manager Tunnelling, Datwyler Sealing Technologies Deutschland GmbH, Waltershausen, Germany

Motivation

Until today the Datwyler Group has furnished some 650 tunnel projects throughout the world with tailor-made sealing solutions. These include very complex major projects such as the Gotthard Base Tunnel, which is fitted with special silicone seals for fire protection doors catering for complete tightness in the tunnel and fulfilling the high fire protection requirements. Further projects include tunnel structures for the Moscow and Singapore metro networks, tunnels in Sochi on the Black Sea in Russia within the scope of the 2014 Winter Olympics as well as the upgrading of the German ICE route from Erfurt to Leipzig. Ongoing tunnel projects are located for example in Los Angeles in the USA, Nice in France, Doha in Qatar, Riad in the Kingdom of Saudi Arabia as well as in Germany in the shape of the Boßler Tunnel (Fig. 1).

The Datwyler Group profits from the experience harnessed during these projects to advance further developments. This report deals with the innovative development of sealing gaskets for segmental tunnels in order to master tricky, ever-changing geological marginal conditions and reduce the efforts for installing the gaskets. Innovating developments and their advantages as well as their application in the Boßler Tunnel in Germany and further tunnel projects are explained.

“DatBalance” Sealing System for tricky and alternating Geology

Design and Mode of Functioning

The more complex a tunnel project is, the more varied the geologies and the surface structures are along the tunnel route. This has to be observed when the tunnel tubes are produced. Frequently construction tolerances originate between the individual segments (Fig. 2) when tunnel tubes are created, i.e. when the individual concrete segments are set together. As a result of con-
Construction tolerances during the production of tunnel tubes, in some cases there is an offset between the individual segments, which causes restoring loads of varying size in the EDPM profiles thus leading to reduced tightness.

The Sealing Technologies Division of the Datwyler Group developed an innovative patented solution for changing marginal conditions and different offset conditions within a defined offset range of up to 20 mm prompted by the tricky marginal conditions prevailing in the Bößler Tunnel and the resultant high demands posed on the gasket frame. As Fig. 3 shows areas of varying hardness are arranged in such a way in the two EPDM sealing profiles, which form the gasket frame that the restoring loads increase as the offset becomes larger. The restoring load-gap diagrams in Figs. 4 + 5 display the increase in the restoring load for the newly developed system compared with classical sealing profiles without varying hardness. The load-gap behaviour was established in pressure tests according to [1], in the case of which the profiles were pressed together to reach a minimum groove bottom distance. The varying hardness areas cater for higher pressure and in turn a better sealing effect as the profile covering decreased. The innovative system was proved to withstand higher water pressures.

The sealing system “DatBalance” for segments in tunnels was awarded with the Innovation Price Thur ingia 2014 in the category “Industry and Material”.

Initial Application in Bößler Tunnel on the new Stuttgart-Wendlingen-Ulm Rail Route

In January 2013, work began on the Bößler Tunnel, an important section on the Deutsche Bahn AG’s new Stuttgart-Wendlingen-Ulm rail route – better known in conjunction with the redevelopment of Stuttgart Central Station as the “Stuttgart 21” project [2, 3]. After completion, the roughly 8,800 m long Bößler Tunnel

![Image](image1.png)

**Fig. 3:** Patented sealing system “DatBalance” with varying hardness in the two sealing profiles

![Image](image2.png)

**Fig. 4:** Restoring load-path diagram for the sealing system “DatBalance” with varying hardness

![Image](image3.png)

**Fig. 5:** Restoring load-path diagram for classical gaskets without varying hardness
between Aichelberg and Mühlhausen will be the fifth longest in Germany. It is the longest tunnel on the 60 km long new rail route. The project was planned with two single-track tubes, largely built by mechanised means. The two tunnel tubes were driven from the Aichelberg portal on the rise with a tunnel boring machine (TBM) and from the Umpfental intermediate point of attack by means of the NATM (shotcreting). En route they pass the Alb Plateau and rise from approx. 400 m to roughly 800 m ASL.

The tunnel driving commenced in spring 2015. After a two-month long orientation phase to allow the machine to adapt to the specific rock conditions, since then roughly 500 tunnel metres have been driven per month. To this end, the TBM cutter wheel with 11.40 m diameter and 64 cutting tools has dug through various rocks with segments securing the tubes (Figs. 1, 2 and 6). Seven prefabricated concrete segments form a complete ring. They support themselves against the rock. The completed tunnel comprises roughly 4,000 of these rings and 28,000 segments, which provide ultimate safety for man and machine during the construction period and the tunnel’s service life.

For the first time, the patented new sealing profile system “DatBalance” is being applied in the Boßler Tunnel (Fig. 3), so that the requirements posed by the different mountain ranges with changing surface structures and geometries are fulfilled. Figs. 7 + 8 show how the segments are handled during production in the field factory and temporary storage. After the segments enter the tunnel (Fig. 9) they reach the point of installation (Fig. 10).
Anchored Seals

Design and Advantages

Conventional seals for segmental tunnels must be fixed with a contact adhesive in a prepared groove on the concrete segment and then pressed into position. This involves a great deal of time and labour. The so-called anchored gaskets produced by the Datwyler Group, which have been available for a number of years, contribute towards improving efficiency (Fig. 11). These anchored gaskets possess the following advantages:

▶ Substantial reduction of the work outlay
▶ Cutting down on adhesives, spraying technology and pressing frames
▶ Definite increase in process security and reduction of rectifications

Examples of Projects

A project in Moscow drew the attention of the Morgan Sindall’s Ridham Precast factory prompting it to use anchored gaskets for the first time for producing the segments for the Thames Water Lee Tunnel in London. Work started on the 6.9 km long tunnel in 2010 and it was commissioned in early 2016. The sealing profile inserted in the shuttering frame is anchored firmly in the concrete during the concreting phase (Figs. 12 + 13) and resulted in substantial savings [4].

Further tunnel projects with anchored gaskets include Blue Plains & Anacostia, Washington DC in the USA, the Rennes metro in France and the Doha metro in Qatar.
Conclusion and Outlook

Thanks to the good experiences, an increasing number of segmental tunnel projects throughout the world are plumping for anchored gaskets in order to enhance efficiency during production of the numerous segments (Fig. 14) and save costs. Furthermore, increasingly more complex tunnel projects call for gasket frames, which resist high water pressure and serve to overcome the greatest possible construction tolerances given a constant sealing performance. The findings obtained so far from the Boßler Tunnel appear to show that the innovative sealing system “DatBalance” can contribute towards mastering these challenges.

The future lies in the further development of the anchored gasket with larger profile geometries combined with swellable applications. Work is already forging ahead on the next generation of sealing systems.

References


Datwyler Group

The Datwyler Group is a focused industrial supplier occupying a leading position in global and regional market segments. The Group offers the client in the given markets real assets thanks to its leading technological role and custom-built solutions. In this connection, Datwyler concentrates on markets, which enable an increase in value and sustainable profitable growth. The Technical Components division is a high-service distributor in Europe for components and accessories in maintenance, electronics, automation and ICT. The Sealing Solutions division provides client-oriented sealing solutions for global market segments such as automotive, health care, civil engineering and consumer goods. With altogether more than 50 operative companies, outlets in more than 100 countries and around 7,000 members of staff, the Datwyler Group earns an annual turnover of around 1.2 billion CHF. The Group has been registered on the SIX Swiss Exchange since 1986.

Further details available from:
www.datwyler.com

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Fig. 14: Segments with anchored gaskets produced in series
1 Introduction

Large, protracted deformations of the excavated cavity are formed when tunnelling in squeezing rock. As a result, tunnel boring machines (TBMs) can jam or their cutter heads can block. A well-known example in this case is the drive involving a Gripper TBM when building the Gotthard Base Tunnel in Switzerland [1 to 4]. Further examples of TBMs jamming can be found in [5 to 7]. One possibility of preventing a TBM jamming is to execute an overbreak by means of the disc cutters fixed to the cutter head.

In the past, the selected size of the overbreak was established by reference values from accomplished projects. Extensive investigations were undertaken for tunnel boring machines with shield (TBM-S) and double shield machines (DSM), and criteria for design and dimensioning purposes developed [8 to 17]. These criteria or approaches cannot simply be applied for excavating with a Gripper TBM. In comparison with driving with a TBM-S or a DSM, in the case of which the stress deformation behaviour of the rock differs. This signifies that in the case of a Gripper TBM drive is first scheduled to be secured in the Gripper TBM’s back-up area by means of a shotcrete support. This area was established at a gap of 46.5 m from the face for the drives for the Gotthard Base Tunnel for example [4].

When the rock has to be supported unexpectedly, anchorage, shotcrete and support arches for example can be installed directly behind the cutter head in the case of drives involving a Gripper TBM in unstable rock. However, this leads to a clear reduction of the rate of advance thus exerting an influence on a Gripper TBM’s economy. This signifies that in the case of a scheduled drive with a Gripper TBM a relatively large or long area of excavated cavity exists in the rock, which is not supported by a lining and in which the rock can deform without being hampered. In this way, the stress deformation behaviour of the rock in case of an excavation with a Gripper TBM deviates most pronouncedly from the stress deformation behaviour of the rock in the case of a drive with a TBM-S or DSM [19].

In order to be in a position to analyse the stress deformation behaviour of the rock during a drive with a simple pretensioned Gripper TBM, a three-dimensional numerical calculation model was developed [19, 20]. Parameter studies were undertaken using this calculation model, in the case of which the physical parameters and the overburden height of the rock were varied. Diagrams were developed from the results of the parameter studies, by means of which the displacements occurring during a Gripper TBM drive are estimated and the risk of a Gripper TBM jamming can be predicted.

2 Three-dimensional numerical Calculation Model

The three-dimensional numerical model that was developed represents the complete construction cycle of an excavation using a simple pretensioned Gripper TBM. Fig. 1 shows the numerical calculation model with the individually modelled areas. The geometrical dimensions, the material characteristic values and the construction cycle correspond with those during a Gripper TBM excavation in individual sections of the Gotthard Base Tunnel [19, 20]. The model dimensions are shown in Fig. 2. A tunnel diameter of d = 9.5 m was assumed. On the basis of prior investigations and recommendations by the working group 1.6 “Numerics in Geotechnics” of the DGGT [29], a distance of 77 m, in other words eight times the diameter 8d, from the lateral model edge and a gap of 48 m, in other words five times the diameter 5d from the lower model edge were applied. The total length of the calculation model amounts to 230 m. The excavated section shown in the calculation model was set at 190 m.

Homogeneous rock behaviour was assumed for the depicted ground. For this purpose the physical characteristics of the ground were simulated by a linear-elastic ideal plastic constitutive equation with the flow criterion according to Mohr-Coulomb and non-associated...
flow rules. The steel structural parts of the Gripper TBM were depicted by a linear-elastic material behaviour as well as equivalent stiffnesses and equivalent weights applied in parts. The in situ concrete invert and the shotcrete for the necessary temporary support were also described by a linear-elastic material behaviour. In this connection, the elasticity module for the in situ concrete invert and the shotcrete were adjusted in keeping with construction progress for a predetermined rate of advance of 13 m/day in order to simulate the time-related setting of the concrete \cite{18, 19}. The compressive strength was correspondingly converted in the elasticity module (Fig. 3) according to \cite{22}. The shotcrete shell and the in situ concrete invert were taken into consideration with a Poisson ratio of $\mu = 0.2$ and a specific weight of $\gamma = 24 \text{ kN/m}^3$.

The individual driving phases such as the individual strokes, the implementation of the grippers and the relocating of the advancing gear are simulated in the spatial calculations. These calculations were undertaken in the form of a step-by-step analysis for the results which are presented here.

### 3 Parameter Studies

Extensive sensitivity studies were carried out using the previously described numerical model so that the theoretical stress deformation behaviour of the rock in the case of a mechanised tunnel drive with a Gripper TBM could be examined. Taking the isotropic material properties of the rock into consideration the rock characteristic values and the overburden height $h$ were varied in the sensitivity studies. Table 1 shows the individual parameters with the varied ranges. It should be observed that the lower parameters for the elasticity module of the rock $E_{\text{ro}}$ and the cohesion of the rock $c_{\text{ro}}$ represent borderline cases.

### 4 Calculation Results

The vertical displacements in the roof were defined as decisive for contemplating the displacements in the excavated cross-section as they exceeded the calculated values of the displacements in the wall and the invert. Fig. 4 shows the vertical displacements in the roof visualised for different sets of parameters. Towards this end the vertical displacements are shown depending on the
Two particular areas are decisive for a Gripper TBM jamming when driving with a Gripper TBM. First of all, there is the risk that the cutter head can block owing to major displacements; secondly the displacements in the unsupported area are so large that the back-up section can no longer be advanced.

In the proximity of the roof shield, roof displacements occur in the calculations for a “soft” rock as well given a shallow overburden height of 100 m in the case of the contemplated shear strengths of the rock, which are non-critical for the excavation and do not lead to the cutter head jamming. On the other hand, the risk of the cutter head jamming grows very quickly overproportionally given greater overburdens (Fig. 4).

A large proportion of the displacements occur in the area between the cutter head and the area where the temporary shotcrete support is installed. This factor can influence the back-up system being advanced. Roof distance to the face. The individual curves form the varied overburden heights h and the different elasticity moduli of the rock E. As the overburden height h increases and the elasticity module of the rock E decreases, the vertical displacements in the roof become greater as expected. The largest part of the vertical displacements in the roof ceases when the temporary shotcrete support is installed as the excavated area is secured once the temporary shotcrete support has been placed.

Table 1: Range of applied rock parameters with isotropic characteristics and overburden height

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific weight γrocks</td>
<td>[kN/m³]</td>
<td>26</td>
</tr>
<tr>
<td>Elasticity module Erocks</td>
<td>[MN/m²]</td>
<td>500 to 5,000</td>
</tr>
<tr>
<td>Poisson ratio μrocks</td>
<td>[-]</td>
<td>0.2</td>
</tr>
<tr>
<td>Angle of friction φrocks</td>
<td>[°]</td>
<td>25 to 40</td>
</tr>
<tr>
<td>Cohesion crocks</td>
<td>[MN/m²]</td>
<td>0.1 to 2.0</td>
</tr>
<tr>
<td>Overburden height hrocks</td>
<td>[m]</td>
<td>100 to 800</td>
</tr>
</tbody>
</table>

Table 1: Range of applied rock parameters with isotropic characteristics and overburden height

Fig. 4: Vertical displacements in the roof dependent on the distance to the face in the longitudinal direction of the tunnel for different overburden heights h and E-moduli E of the rock.
displacements occur here as in the case of the area of the cutter head for a "soft" rock given a shallow overburden height of 100 m in the case of the contemplated shear strengths of the rock, which are considered non-critical for the excavation. Here too, displacements are to be observed in the excavated area given greater overburdens, which must be assessed as critical for advancing the back-up system (Fig. 4).

In the presented results, on the one hand, the very great influences exerted by the overburden height \( h \) and the elasticity module of the rock \( E \) are evident, and on the other, the determining displacements occur in the area from the face to the one in which the temporary shotcrete support is installed. Once the temporary shotcrete support has been installed, the increase of the vertical displacements in the roof is only relatively slight. This can of course, be attributed to the fact that the rock is secured by the temporary shotcrete support thus hampering further displacements.

Fig. 5 serves to compare and analyse the influence of shear strengths and the elasticity module at the cutter head based on the results of the parameter studies. In this case, the overburden height is taken to be \( h_0 = 250 \) m. The elasticity module and the shear strengths of the rock were varied. The cohesion of the rock \( c_{r,\text{m}} \) is presented as it increases from left to right on the abscissa axis and the vertical displacements in the roof shown on the increase from top to bottom on the ordinate axis. The individual diagrams in each case represent the different variations of the rock’s angle of friction \( \phi_{\text{rock}} \) and the three curves form the different elasticity moduli of the rock \( E \). When considering the influence of cohesion on the vertical displacements it is obvious that as the cohesion increases the vertical displacements greatly decrease. If the rock possesses low cohesion, which attains a state of failure more rapidly, the plastic deformations are correspondingly large. As the cohesion grows the overall vertical displacements depend almost solely on the elastic properties of the rock so that the shear strengths exert merely a slight effect on the size of the displacements. The vertical displacements are still relatively large within the range of the extreme values of cohesion \( c_{r,\text{m}} \) from 0.1 to 0.5 MN/m\(^2\) as the shear strengths are slight and the rock, as previously described, attains a state of failure more rapidly. However, the vertical displacements in the case of cohesion greater than or equalling 0.5 MN/m\(^2\) are relatively slight and decrease only moderately given increasing cohesion.

The analyses relating to shear strengths also indicate that the angle of friction also exerts an influence on the amount of vertical displacement. However, this influence is less than the influence of cohesion. The influence of the angle of friction becomes negligibly small as from a cohesion greater than or equalling 0.5 MN/m\(^2\) and the plastic deformations become negligibly small on account of the angle of friction. As the cohesion in the 0.1 to 0.5 MN/m\(^2\) range relates to an extreme value and the values do not characterise stable

![Graph showing the influence of cohesion and shear strengths on vertical displacements in the roof](image)

**Fig. 5:** Vertical displacements in the roof in the cutter head area at the end of the roof shield depending on the cohesion of the rock for overburden and different angles of friction \( \phi \) and \( E \)-moduli \( E \).
In the case of the previously cited parameters. On the basis of the results of the parameter studies diagrams were developed by means of which it is possible to estimate the displacements, which occur when tunnelling with a Gripper TBM so that a prediction can be provided with regard to the risk of jamming when using a Gripper TBM in instance of the scope of a feasibility study.

The diagrams are in this case produced for the two decisive areas for three rock elasticity module alternatives. Section 5.1 shows the diagrams for the cutter head area. The cutter head area is in this case defined as the end of the roof shield according to Fig. 4. The diagrams for the back-up area are presented in Section 5.2. In this case the back-up area in keeping with Fig. 4 is defined as the point in the back-up section, where the temporary shotcrete support begins.

5.1 Cutter Head Area of the Gripper TBM at the End of the Roof Shield

Figs. 7 to 9 display the vertical displacements, which in accordance with Fig. 4 occur in the roof in the cutter head area at the end of the roof shield, increasing from top to bottom depending on the cohesion of the rock increasing from left to right. Fig. 7 shows the vertical displacements for an E-module of the rock of 500 MN/m², Fig. 8 for an E-module of 1,000 and Fig. 9 of 2,000 MN/m². Each image contains four diagrams for four different angles of friction. The four curves of the individual diagrams depict various overburden heights.

5.2 Back-Up Area of the Gripper TBM

Maximum displacements in the roof placed at the point, where the temporary shotcrete support begins, are depicted in Figs. 10 to 12 for the back-up area, in similar fashion to Figs. 7 to 9 explained in Section 5.1.

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Fig. 7: Vertical displacements in the rock in the cutter head area depending on the cohesion of the rock for E-module $E$ of $500 \text{ MN/m}^2$ and various angles of friction $\varphi$ and overburden heights $h$.

Fig. 8: Vertical displacements in the roof in the cutter head area depending on the cohesion of the rock for E-module $E$ of $1,000 \text{ MN/m}^2$ and various angles of friction $\varphi$ and overburden heights $h$.
6 Conclusion and Outlook

Jamming or blocking of the cutter head represents a high risk for the excavation when tunnelling with a TBM. The criteria and approaches developed for designing and dimensioning drives using a tunnel boring machine with shield and for double shield machines cannot be transposed for tunnelling with a Gripper TBM. As a result, in order to be able to analyse the rock’s stress deformation behaviour during a drive with a simple pretensioned Gripper TBM, three-dimensional numerical parameter studies were carried out. The physical parameters of the simulated rock and the overburden height were varied in these studies.

The results indicate that the overburden height, the elasticity module as well as the cohesion of the rock exert a decisive influence on the vertical displacement in the roof. This is, in turn, decisive for predicting the risk of a Gripper TBM jamming in the proximity of the cutter head and the back-up area.

Diagrams were developed from the results of the parameter studies, which facilitate the displacements while tunnelling with a Gripper TBM to be estimated and in turn, a forecast of the risk of a Gripper TBM jamming, for example, in the form of a feasibility study.

The results relate to idealistic models and calculation assumptions. Measurement technical verification is still lacking owing to the fact that the measurement data from projects are still incomplete. The influence of separation planes on the stress deformation behaviour of the rock while driving with a Gripper TBM has still to be analysed in further parameter studies through applying appropriate physical laws in the numerical calculation model.

7 References

Fig. 10: Vertical displacements in the roof in the back-up area depending on the cohesion of the rock for E-module E of 500 MN/m² and various angles of friction $\varphi$ and overburden heights $h$.

Fig. 11: Vertical displacements in the roof in the back-up area depending on the cohesion of the rock for E-module E of 1,000 MN/m² and various angles of friction $\varphi$ and overburden heights $h$. 

$$\gamma = 26 \text{ kN/m}^3$$  
$$\mu = 0.2$$  
$$d_1 = 15 \text{ cm}$$  
$$p_{\text{d}} = 60 \text{ MN/m}^2$$  

$E_{\text{rock}} = 500 \text{ MN/m}^2$ 

$E_{\text{rock}} = 1,000 \text{ MN/m}^2$
Fig. 12: Vertical displacements in the roof in the back-up area depending on the cohesion of the rock for E-module E of 2,000 MN/m² and various angles of friction $\varphi$ and overburden heights h.


Clean Air for Australian Highway and Tunnel Construction in the “WestConnex” major Project
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“WestConnex” Project
For years the population and the economy in the Australian federal state of New South Wales with its capital Sydney have been trying to come to terms with an overloaded infrastructure. The greatly overburdened ports and highways – triggered through increasing imports and a growing population – led to the government embarking on the “WestConnex” project involving investments of just under 17 billion AUD. The aim is to create long-term economic growth and substantially improve the infrastructure in the region around Sydney. The increase in capacity for the M4 and M5 motorways as laid down in the project plus linking these two motorways is intended to enhance connections between the city, the airport and the port (Fig. 1).

Implementing the Project
By implementing the project in three construction phases with a scheduled duration of eight years and a deadline for completion in 2023 around 10,000 jobs are to be established in various branches of the economy. The project is being executed by the CPB Samsung John Holland Joint Venture as well as the Leighton Dragados Samsung Joint Venture. The high investment costs are essentially to be retrieved through calculated economic benefits of 20 billion AUD. Nonetheless, due to the financial and ecological concerns of the local population, project planning took many years until it was ultimately approved.

The first two construction sections include upgrading the M4 motorway to four lanes per direction as well as tunnel excavations to widen the M5 motorway. In the third construction section two further tunnels with three lanes each way are to be driven in order to link the two motorways with one other.

Altogether about 50 roadheaders are in action within the scope of the project to produce a 33 km long continuous motorway – 14 km of which are on the surface and 19 km in tunnels (roughly at a depth of 50 m). Energy-efficient, economic and eco-friendly technologies are designed to assure that any disadvantages and disturbances that might occur are kept to a minimum and that the general public is constantly convinced of the benefits throughout the duration of the project.

The air quality on the construction sites and in their proximity is thus examined during the entire period of the project and made transparent for the population in published reports. This calls for professional and reliable dedusting during the construction measures.

Dedusting the Construction Sites
The company CFT GmbH Compact Filter Technic, Gladbeck, Germany was commissioned to provide low-noise and resource-efficient dedusting of the construction sites for the “WestConnex” major project to follow up on the “NorthConnex” tunnel project [1].

Dry-Type Dedusting Plants
On the first two construction sites, 35 dry-type dedusting plants made by CFT GmbH provide air for a comfortable and clean working environment while complying with the MAK values legally prescribed for workplace and environmental protection purposes. Due to the clean air on the construction sites, the protection
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Clean Air for Australian Highway and Tunnel Construction in the “WestConnex” major Project

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stations are designed to minimise noise. Altogether, Korfmann supplied 35 fans stations. Primarily, fans Type GAL (counter-rotating axial fans) are used. With a diameter of 1.40 m, installed power of 2 x 110 kW and the application of two inverse impellers, they produce very high pressures at a very high level of efficiency (up to more than 90%) (Fig. 3).

Dust Storage and Discharge Systems

DFT GmbH Deichmann Filter Technik produced the dust storage and discharge systems to go along with the CFT dedusting systems.

Conclusion

Thanks to their reliability and low-maintenance design, the products of CFT GmbH Compact Filter Technic, Korfmann Lufttechnik GmbH and DFT Deichmann Filter Technik are to be found not only in Australia but throughout the world in mining and tunnelling and industrial applications.

Reference


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Fig. 2: 3D presentation of a CFT dry-type dedusting system as well as Korfmann fan station and connecting duct
Source: CFT GmbH Compact Filter Technik

Fig. 3: Characteristics of the fans type GAL for the “WestConnex” major Project
Source: Korfmann Lufttechnik GmbH
In-situ Bioextraction of Industry Metals from deep Ore Deposits to secure EU Resource Supply

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Growing Demand for raw Materials worldwide

Economic growth is tied to an increasing demand for mineral resources. The demand of the European Union (EU) for industry metals accounts for 20 to 35 % of the demand worldwide. Only 3 % of this can be covered by European ore deposits. Furthermore, industries that rely heavily on the import of raw materials such as construction, chemicals, automobile and aviation industries create more than 30 million jobs within the EU. As a result, it is important to reduce the European dependence on raw material imports from overseas.

Significant reserves of strategic raw materials are available in Europe [1]. However, they often are located at depths below 1,000 m so that they cannot be exploited profitably by conventional mining. Thus, geoscientists and mining experts increasingly need to develop cost-saving extraction and processing methods.

Leaching methods have long been established for various processes in mining technology. Leaching has been used for centuries and become an essential method to secure resource supply and promote human development. This method is widely applied on ore and mine wastes (e.g. in-situ heap leaching). The kinetics of these purely chemical methods are increasingly enhanced by the application of microorganisms.

For their application on rock of low permeability, hydraulic pathways have to be created initially to increase the reactive surface and thus the effectiveness of the leaching process.

The Research Project

The Biomore research project [2] is funded by the European Commission with a budget of 8.6 million euros. The consortium composed of 22 European and non-European partners from industry and research are working over a 3 year period on the development of an in-situ bioleaching technology to extract copper from deep mineral ore deposits. With this project we aim to reduce the impacts of currently applied mining activities and examine the feasibility of this technology on an industrial scale.

In the process, the copper is mobilized from the mineral copper sulfides of the ore deposit with ferric iron in an acidic leach solution via oxidation (Fig. 1). The method was initially developed and optimized under laboratory conditions. Underground pilot-scale tests are now being undertaken on a 100 m³ copper-containing ore block at the Rudna Mine, KGHM Polska Miedź S.A. Models have been developed that describe the processes taking place and upscale the test results. The models also inform Biomore’s evaluations of the costs and environmental impacts of a future full-scale facility. The technology developed is also expected to be applicable to ore deposits containing critical technology minerals [3] such as rare earths, cobalt, germanium and gallium.

References

[1] //promine.gtk.fi/
Interview with Project Manager Dr. Horst Hejny

GeoResources talked to the Biomore Project Manager Dr. Horst Hejny to find out more about the project.

GeoResources: Dr. Hejny, which significant economic advantages do you believe are offered by in-situ bioextraction?

Horst Hejny: The project aims at reducing the European economy’s dependency on non-European resource supplies. At the same time, operation costs will be diminished by eliminating infrastructure commonly required for conventional mineral extraction techniques, greatly reducing energy consumption and waste generation. The reduction of the underground void space and stress that in traditional underground mining may lead to uncontrolled rock fracturing is greatly decreased or avoided. Furthermore, this new technology enables us to exploit previously inaccessible reserves thus decreasing Europe’s need to import mineral resources. In addition, an extensive risk analysis will accompany the development of the in-situ bioleaching plant. A further important part of the project relates to the environmental risk assessment which will inform risk assessments for operating at an industrial scale. It is understood that we continuously monitor the test unit in detail during the project. Also, any microorganisms applied for the bioleaching will subsequently be demobilised.

GeoResources: How do you and your project partners hope to prevent negative environmental impacts?

Horst Hejny: We are convinced that the Biomore technology will lead to lower environmental impacts than conventional mining methods since less mine waste such as tailings and waste rock are generated. Thus issues relating to mine waste deposition and storage are avoided, including surface and groundwater contamination. Further, there is no need for any underground infrastructure when applying the Biomore technique. Only a few facilities will have to be built on the surface. This leads to a decreased dust generation as well as a reduction in energy consumption and associated CO₂ emissions. In addition, an extensive risk analysis will accompany the development of the in-situ bioleaching plant. A further important part of the project relates to the environmental risk assessment which will inform risk assessments for operating at an industrial scale. It is understood that we continuously monitor the test unit in detail during the project. Also, any microorganisms applied for the bioleaching will subsequently be demobilised.

GeoResources: What is the difference between the research activities that are taking place within the Biomore project and a future pilot plant?

Horst Hejny: In the Biomore project the bioleaching process as such is being developed and evaluated economically as well as environmentally regarding its feasibility and chances of success. The current project will enable us to conclude whether it is conceivable that the process can be applied economically and environmentally. In case of a positive outcome, the next step for developing the technology would be the installation
of a pilot plant. For this purpose, a suitable deposit has to first be identified. Once legal approval has been obtained, the deposit will be accessed by deflected drilling and fracturing. All infrastructure including the bioreactor will be installed on the surface. The leaching solution will be injected into the ore body and thereafter extracted to the surface after leaching.

**GeoResources:** Do you foresee disadvantages or risks deriving from the proposed technology? How do you assess this technology when comparing it to fracking in the oil and gas industry?

**Horst Hejny:** Bioleaching is a widely applied method used in many countries – in Chile for example for the extraction of copper from copper sulfide minerals. To this end, technology metals are won from ore or mine waste by heap leaching.

The difference in the case of Biomore is that we aim to keep the microorganisms used to generate components of the leaching solution permanently in a bioreactor. They will thus not be injected with the leaching solution. Furthermore, we aim to extract technology metals in situ, this is directly from ore bodies at depths greater than 1,000 m. Consequently, neither overburden nor ore will have to be excavated and the processing steps in which the metal is separated from the matrix can be avoided. As a result, the environmental footprint of our mining method has less impact than traditional mining methods.

In order to apply this method in situ, the underground ore body must possess sufficient porosity and reactive surface to optimize the metal extraction. As of today, the term fracking is commonly associated with the oil and gas industry. There, various substances (e.g. foaming agents and stabilizers) that are commonly added to the fracking fluid to attain a certain consistency and stabilize the underground flow pathways are, however, suspected of causing groundwater contamination.

In the Biomore method, pressurized water is used to fracture the ore and additives are not expected to be required. If additives are applied at all in the Biomore method, then they will only include those that degrade entirely without causing harm to the environment. Thus, the associated risks are low. We therefore prefer applying the terms fracturing or channeling in this project to avoid confusion with the standard fracking method.

Finally, the risk of seismicity triggered by the fracturing process will be evaluated in detail applying geomechanical models.

**GeoResources:** Dr. Hejny, thank you for that interesting interview and your willingness to respond to our questions. We should like to wish you and your project partners great success in carrying out this socially significant research project. We should be delighted to be able to report on how work progresses and the outcome at some future time in GeoResources.

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**BIOMOre:** Research on future mining

Funded by the EU’s Horizon 2020 research and innovation program

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**Dr. Romy Matthies**  
obtained her Ph.D. in environmental geochemistry from Newcastle University (UK). She has mostly been engaged in mining related research and industry projects in Chile, Canada, Japan, Spain and the UK in the fields of acid mine drainage prediction, impact assessment and passive remediation. During the 12 years she spent overseas she attained fluency in English, Spanish, French and Portuguese. She is now heading the R&D division of the consultancy GUB Ingenieur AG in Germany.

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**Dr. Horst Hejny**  
qualified in the field of chemical technology. He is an experienced project manager with more than 30 years experience in mining and mineral management. Prior to the Biomore project he has coordinated various research and development projects. Since 2015, he has been engaged as Adjunct Professor at Lulea University in Sweden.

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In-situ Bioextraction of Industry Metals from deep Ore Deposits to secure EU Resource Supply

**GeoResources Journal** 2 | 2017
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Knut Ansgar Hirsch
heads the Profit Center DMT Marketing & Communications Consulting. For more than 10 years, he has developed and managed major international marketing and communication projects. Apart from the Biomore project, he has overseen work packages and tasks for projects such as NESMI, IAMTECH, IMPACTMIN, MERIDA or iDeepMon. His focus thereby lies on market development, marketing and communication strategies, PR work and business development.

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Dr. René Kahnt
After qualifying in the field of theoretical physics, Dr. Kahnt was initially involved in the restoration of former uranium mines as group leader responsible for system analysis/modelling with the Wismut GmbH. Since 2006, he has worked for the consultancy G.E.O.S. Ingenieurgesellschaft mbH, Freiberg. There, he heads the department for modelling and risk analysis concentrating on 3D and deposit modelling, hydrogeological modelling, process modelling, risk and decision analysis, deep geothermics as well as mineral oil and gas in addition to acting as an authorized representative of the company.

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Dr. Horst Märten
Horst Märten, a graduate physicist, was initially engaged in fundamental research at a number of international research organizations. Since 2005, he concentrates on various fields of applied research such as geophysical exploration, mining (e.g. in-situ extraction techniques), ore processing and metal recovery, environmental technology and monitoring. Since 2003, Dr. Märten has been the CEO of the consultancy Umwelt- und Ingenieurtechnik GmbH Dresden – a partner in the Biomore project. In parallel, he has since 2004 taken over the executive role of the Australian mining and prospecting Company Heathgate Resources (Vice-President Technology).

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Professor Barrie Johnson
Environmental biotechnology Professor at Bangor University (GB), Titles: BSc, PhD, DSc from the University of Wales, member of the Learned Society of Wales and the Royal Society (GB), academic career at Bangor University: lecturer, senior lecturer, reader and professor. In the Biomore project, he is in charge of work package 1, Biotechnology and Process Modelling.

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Dr.-Ing. Frank Leschhorn hold an interview with Andrew Mackenzie, the CEO of BHP, on 1 December 2016 in Melbourne, Australia. BHP launched the Think Big brand campaign in Australia on 15 May 2017 and changed the brand from BHP Billiton to BHP. This abbreviated simple expression of the organisation is used colloquially around the world and therefore also in this article.

Frank Leschhorn: How does it feel to lead the world’s largest mining house BHP with 65,000 employees and a turnover of about US$45 billion?

Andrew Mackenzie: BHP is a truly great company and it is a privilege to be the Chief Executive Officer. We have been granted the licence to operate some of the best ore bodies and some of the most distinctive oil and gas fields known on the planet. That means we play a critical role to supply the basic commodities that the world requires to grow, both in population and in wealth.

Growing up in a coal mining town north of Glasgow in Scotland, I didn’t sit back at the age of 15 and say, “I’d like to be CEO.” I was interested in geology and always imagined being a coal geologist working at the mines nearby. I was a geologist, and a chemist, then an engineer, and finally what I call an industrialist. I was scientifically curious. That same curiosity still gets me out of bed in the morning.

My scientific background has helped me be a good business leader. You can, for example, apply science to make hard decisions. Leading people requires know-how that comes from philosophy, psychology and neuropsychology about how the human mind works and how you motivate it to achieve a higher potential.

It has taught me to delve into the detail and then look at the big picture. I appreciate the beauty in simplicity. In science – to solve a problem, you make it simpler; it becomes solvable.

I am conscious of my responsibility as a leader of a resources company of BHP’s size that we must participate in solutions to the world’s big problems – population growth, poverty, economic inequity and jobs for young people. This is done not through business activity alone. It requires debate with companies, countries and their citizens and we must be brave in this debate.

Frank Leschhorn: Mining business is a multi-discipline task with inputs from geology, mining and processing technologies and marketing skills. Mining was always a long-term related business. You are one of the few CEOs with scientific and technical background. As a shareholder or an employee I tend to be happier with a leader who understands minerals better than someone with a legal or commercial background only. Short-term shareholder value is good for investors but not necessarily good for long-term investments. How is your opinion to this?

Andrew Mackenzie: It is a combination of these skills that make a company a great investment. BHP has been around since the 1880s. That has come from generations of scientists and geologists who find new ways to unlock the world’s resources and commercial men and women who enable their development. Investors only
succeed if the world will pay for the price of resource extraction and licence is only granted if society benefits.

BHP’s history shows that leaders balance science and commercial decision making for long term investment. For the most part over the decades we have got that balance right. We operate in an industry where production cycles, the lifetime of a mine, are measured in decades, generations. Our cycles of opportunity are that long.

Right now we have a roadmap for investor value creation based on opportunities that exist within the portfolio today – geological and commercial. These are opportunities for more productivity, the addition of low-cost capacity, organic growth and through exploration and technology.

Capital productivity is as important as operational productivity for us. Our capital allocation framework delivers balance sheet strength and investment discipline to enable our strategy and shareholder returns. We have the right assets in the right commodities with the financial capability to prosper.

Frank Leschhorn: BHP is a global player. How do you see your ethical responsibility? The Samarco incident in Brazil with a multi-billion lawsuit was surely a hurting event for you? Other companies have issues with bribery, especially in third world countries. Does the BHP management enforce the same technical, environmental and ethical standards in all countries? Are there any new consequences within BHP?

Andrew Mackenzie: Our starting point is our Charter and Code of Business Conduct. It guides us in our daily work, demonstrates how to practically apply values. Our values are global as are our expectations and capabilities including technical and environmental. They apply to everyone everywhere.

On Samarco, do not doubt my determination to do the right thing. The tragic loss of life, and the community and environment impacts have left a scar on our company. We have 41 programs to address the social, economic and environmental impacts and there are more than 3,000 people working to rebuild infrastructure and provide community and social services. We know recovery will take many years.

We commissioned an external investigation into the cause and have shared those findings with the industry and the public. I am determined that the experience and knowledge we have gained from this investigation is used to improve the safety of tailings dams through greater use of the world’s best science and engineering. Following the review we have strengthened management practices of our own dams.

We operate in an environment where being open and transparent is expected of us. Much of that is about how we, as a company, face out to the world and say: ‘This is who we are. This is what we do. This is what we will achieve.’ Transparency will satisfy the people who we deal with that we deserve the licence we have to operate all over the world.

Frank Leschhorn: When you took over the reign of BHP in 2013 the international minerals markets were in downturn due to a fundamental change of the Chinese economy. How did BHP adapt to the new normal after the end of unprecedented boom years?

Andrew Mackenzie: We saw the change, perhaps earlier than some in the industry. We reshaped our portfolio divesting over US$7 billion of assets at attractive prices, and successfully demerged South32, to focus on 12 core operated assets.

We have had a productivity agenda in place for many years that has saved US$10 billion in the past three years and we expect US$1.8 this financial year.

We are a simpler, more productive and more sustainable Company than we were in 2013. Importantly, we are well positioned to respond to changes in commodity markets, technology and changes in society expectations.

We also developed a clear and transparent capital allocation framework which will optimise shareholder value through the cycle. We have a strong balance sheet, strong margins and strong cashflow.

Frank Leschhorn: What is your comment about the widely used “peak” demand terms in the media for your main future products iron ore, copper, metallurgical coal and oil & gas? What are your expectations for the future of the minerals industry? What are BHP’s target resources in the coming years? Do they include the new darlings, the technology minerals?

Andrew Mackenzie: We invest in high quality projects to create long-term value and grow.

While we watch minerals development around the world, there is nothing yet that will deliver returns superior to the assets and strategy we have now.

The iron ore and metallurgical coal markets are currently well supplied and we do not expect to invest significantly more in these businesses at this time. Instead our capital will be focused on the commodities we believe will have attractive supply fundamentals.

We believe grade decline in copper and field decline in oil will constrain industry production and there will be a recovery in prices over the medium term. The potash industry has largely exhausted brownfield expansion options and new greenfield supply will be required.

Our diverse portfolio of growth options will allow us to select the markets in which we can create the most value. Over the next decade, our growth projects at Spence, Olympic Dam and Escondida will help us to embed BHP as one of the largest and lowest cost copper producers.

In Petroleum, the development of our Onshore US acreage, conventional projects like Mad Dog 2, and exploration opportunities such as our program in Trinidad and Tobago will build on our foundation as one of the most competitive independent producers in shale and offshore oil and gas. And on completion of
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Leschhorn:
the shafts, Jansen will be the potash industry’s most advanced option to bring on new greenfield supply.

Frank Leschhorn: Now a question which will interest our metallurgists. Could you please explain the benefits of the proposed heap-leaching process using saline water at BHP’s flagship copper, gold, uranium complex Olympic Dam in Australia on a large scale? How is the progress in the development of this process?

Andrew Mackenzie: Olympic Dam has made progress to develop heap leach technology through an integrated pilot facility in Adelaide. The overall goal of our heap leach development is to replace the conventional hydromet process that currently exists which uses heat and strong acid, and replace it with a process that uses weak acid and time. This in turn delivers potential significant savings in both capital and operating costs, and increased scalability. While heap leach processing is proven in copper mines around the world, further developments are required to be able to apply it to the poly-metallic orebody of Olympic Dam, to extract copper, uranium, gold and silver more cost effectively.

The pilot program began in 2012 at laboratory scale and is expected to be completed by 2020 with a series of larger scale experiments to demonstrate the unit processes. The most recent milestone, has seen smelter pilot plant test work commence at Outotec in Finland in September 2016. This test-work aims to determine the effectiveness of smelting concentrate from the heap leach process with existing Olympic Dam concentrate in a pilot flash matte smelter.

Frank Leschhorn: The results of the COP21 climate conference in Paris was hailed by environmental groups as the end of “king coal”. Coal which accounts for 40% of the world’s power production and needed for steel production had become the most hated commodity in public opinion, mainly in the US and Western Europe but especially in Germany. Do you have any explanations why the Germans do not have the relaxed view on critical social-political issues as the Anglo-Americans use to have?

Andrew Mackenzie: BHP is a company with an intergenerational perspective on our industry, the communities we operate in and the planet that we inhabit. Intergenerational thinking means doing the right thing today to maximise prosperity for many decades – if not centuries.

Intergenerational thinking demands that we must look at a number of approaches to greenhouse gas reduction particularly those with the potential for meaningful reductions. Debate that centres on making one fossil fuel appear more climate friendly than another misses the point! Fossil fuels (coal, gas, oil) will remain a part of the energy mix for the foreseeable future.

Importantly, emissions activity from steel production will also be substantial, and in many cases there are no immediate alternatives to replace key ingredients such as metallurgical coal.

So we must think to solutions that address the carbon emissions we are forecast to produce in power production and industrial activity. Many of these solutions will be technological. One technology that promises an enormous payoff, if we can get it right, is carbon capture and storage. Or ‘CCS’ as we like to call it. CCS is a key technology that has the potential to deliver large-scale reductions from industrial activities. This year I announced a US$7.37 million agreement with Peking University to unlock the potential of carbon capture, use and storage for steel production in China.

There are many ways to cut emissions and we recognise different governments will choose to implement different policies to achieve this but we are encouraged by the momentum for change following COP21.

Frank Leschhorn: The members of the German Society for Metallurgists and Miners know that you spent some time of your earlier career in the Holy Grail of German applied nuclear science at the Kernforschungsanlage in Jülich. What was your special subject there? Are you still in contact with KFA?

Andrew Mackenzie: I had the good fortune to be granted a Humboldt Fellowship which allowed me to pursue research at the Julich Nuclear Research Centre in Germany.

For me the choice was simple, to go where I could further my study under the guidance of a researcher at the cutting-edge of modern geoscience and a leader in the development of basin and petroleum-system modelling.

During that period, I published 50 papers and devised new methods for pursuing subterranean oil deposits through analysis of the steroid molecules in sedimentary rocks. This ended up influencing oil exploration and even the way athletes are tested for drug abuse.

Olympic Dam Australia

Photo: © BHP

GeoResources Journal 2 | 2017

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Frank Leschhorn: Not only after the Brexit, Europe is in political turmoil but tries to be the world’s good conscience. Now we are squeezed between the large economic regions North America, China, Southeast Asia and Russia without significant natural resources but bearing high-cost social systems. Do you think Europe can survive economically? What do they need to do?

Andrew Mackenzie: Geopolitically there is uncertainty. Economically I do think Europe can survive and thrive. Regulatory policy and options for investment and trade will evolve across Europe and between other trading nations.

The EU is a source of strength and power. It has retained influence on global rulemaking, which promote both free trade and social good—particularly environmental protection. The way the EU has built a degree of a social market and tried to embrace a lot of the rising social responsibility issues and meshed it with the ideals of the free market is an effective achievement in the last 30 or 40 years. That is why many Asian countries, who I do a lot more business with, are more likely to take EU rules as part of their legislation to get that balance.

My hope is that Europe and countries within it, look outward to global opportunities to trade.

Frank Leschhorn: Last but not least, a message for our student readers. What advice can you give to the young people who are now studying geo-sciences and mining engineering in Europe?

Andrew Mackenzie: While today I am the CEO of BHP, there was a time when I was a geologist, and a chemist, then an engineer, and finally what I call an industrialist. My ability to move between disciplines at university and in the workplace was greatly helped by my decision to study maths. So I am a strong advocate of the opportunities that Science Technology Engineering Mathematics (STEM) study offers.

Industry knows that STEM professionals are vital to our future prosperity, national productivity and global competitiveness. For the resources industry, this is especially true. BHP employs 65,000 people worldwide, many of them STEM professionals, so we share the responsibility to make sure there is a pipeline of young people who choose to study STEM subjects.

Through the Company’s charities, we have committed more than $55 million to promote STEM studies, in Australia alone.

A curiosity that led me to study science still gets me out of bed each day. My advice to young students is be authentic, stick to your values and find your niche— or your many niches throughout your career, and always be curious.

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The interview was first published in World of Mining - Surface & Underground - Volume 69 (2017), Issue 1, January/February 2017, GDMB.
No nuclear Power – no Disposal Facility?

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1 Introduction

Countries with a nuclear power programme are making strong efforts to guarantee the safe disposal of radioactive waste. The solutions in those countries are large disposal facilities near surface or in deep geological layers depending on the activity and half-life of the nuclides in the waste. But what will happen with the radioactive waste in countries that do not have Nuclear Power Plants (NPPs) but have only low amounts of radioactive waste from medical, industrial and research facilities as well as from research reactors? Countries producing only low amounts of radioactive waste need convincing solutions for the safe and affordable disposal of their radioactive waste. As there is often no funding available, those countries need an appropriate and commensurate solution for the disposal of their radioactive waste.

After an initial explanation of the challenge and the commonly produced types of radioactive waste different possible concepts for waste disposal solutions are discussed (Fig. 1):

- The development of multinational disposal facilities by using the existing international know-how
- Common disposal with hazardous waste
- Permanent storage
- Small scale disposal facilities
  - By utilizing an existing mine
  - By extending the borehole concept
- Others

Even if countries have no nuclear power programme they often produce radioactive waste, e.g. from medical, industrial and research facilities, and have to responsibly deal with low amounts of the waste. This article discusses the challenge and different concepts for safe and affordable disposal solutions.

2 The Challenge

NPPs are operated worldwide in 30 countries, while 71 countries are operating research reactors [1]. Even if the spent fuel is returned to the manufacturer and the production rate of radioactive waste is much lower than at a NPP, the radioactive waste from operation and future decommissioning cannot be neglected. Because there is no commercial power generation, there is also not a levy on power consumption that goes to a waste fund and no money is set aside for the disposal of radioactive wastes generated in these countries. Therefore these countries look for more cost effective disposal routes for the wastes that they produce. The European Commission stipulates each state needs to develop a national programme for the safe disposal of radioactive waste [2]. Similar requirements do exist outside the European Union, with every nation responsible for the safe disposal of their radioactive waste.
management of radioactive waste, including the need to have a disposal plan. The challenge for the future is: which variants for the safe disposal of radioactive waste are possible for countries generating small amounts of radioactive waste?

3 Radioactive Waste in Countries without nuclear Power Programme

Countries without nuclear power plants or any nuclear fuel cycle facilities do not have high level waste (HLW), particularly when the fuel from research reactors is returned to the country of origin. In these countries, only small amounts of radioactive waste are produced. The main sources of this waste are the use of radioactive material in medicine, industry and research as well as the operation and decommissioning of nuclear research facilities like research reactors. Usually a large part of the waste can be cleared as non-radioactive waste after storage or decontamination. The amount of remaining radioactive waste that is suitable for near-surface disposal (LLW) is less than a few hundred tons. Furthermore, in all countries there are disposed sealed radioactive sources, including long-lived sources such as lightning conductors containing mainly $^{241}$Am ($432.2 \ a$) or $^{226}$Ra ($1.6 \times 10^3 \ a$), and ionization chamber smoke detector (ICSD) containing mainly $^{241}$Am, $^{226}$Ra and sometimes $^{239}$Pu ($2.41 \times 10^4 \ a$) which are not suitable for near surface disposal in large quantities due to their long half-life.

In countries without a nuclear programme, significant amounts of radioactive waste arise from the operation and decommissioning of research reactors [3]. The radioactive waste streams depend on the reactor type, the implemented applications and the schedule of operation. They can be activated and include contaminated materials. The most activated part of the reactor structure is the core, while the biological shield, usually made of concrete and steel reinforcements, is exposed to relatively low neutron fluxes. Contamination arises from the activation of the corrosion/erosion products as well as from the dispersion of the irradiated fuel and fission products through cladding breaches and conveyed by the coolant. Fission products in contaminated materials generally become significant in the case of failure of fuel elements. A large variety of radionuclides can be produced by neutron activation at nuclear reactors. The radionuclides which are important from the viewpoint of disposal are the long-lived radionuclides (half-lives higher than 30 $a$). The major long-lived nuclides are:

- $^{14}$C ($5,730 \ a$) which is significant in concretes and graphite
- $^{36}$Cl ($3.01 \times 10^4 \ a$) is present in some stainless steels and aluminum reactors components
- $^{44}$Ca ($1.03 \times 10^6 \ a$) is one of the main constituents of bioshield concrete
- $^{59}$Ni and $^{63}$Ni ($7.6 \times 10^7 \ a$ and 100.1 $a$ respectively) is found in nickel alloys and stainless steel
- $^{99}$Mo ($3,500 \ a$) is present in some stainless steels
- $^{97}$Zr ($1.5 \times 10^9 \ a$) is important in irradiated cladding and in moderator tubes
- $^{109}$Ag ($130 \ a$) is significant in control rods with large amounts of silver

Common examples of solid very low level waste (VLLW) and low level waste (LLW) are items contaminated during handling of radioactive materials such as personnel protection items, cleaning materials and tools as well as components exposed to neutron beams such as container covers for production of radioisotopes or for irradiation of samples. Low and intermediate level waste (ILW) and LLW can be materials used for cleaning of water, as ion exchange resin or materials in the ventilation systems as well as irradiated components of the reactor such as the materials at the reactor core, monitoring equipment (ionization and fission chambers, thermocouples etc.), control rods and startup neutron sources.

Liquid radioactive wastes during operation are usually coolant from the reactor pool or vessel, liquids used for decontamination and liquids produced from hot chemistry laboratories. In case the aqueous wastes cannot be discharged, they are concentrated to minimize the volume and the residues usually solidified in cement. Other liquid wastes like organic solvents are solidified in cement directly or incinerated together with other radioactive waste.

Tritium in liquid wastes is of higher importance in reactors cooled and/or moderated with heavy water. In gaseous radioactive wastes, the main radionuclides are $^{41}$Ar and $^{14}$C which are produced by activation of the air present in the reactor coolant/moderator and irradiation facilities.

A significant application in research reactors is the production of radioisotopes for medicine, agriculture, industry and research. Radioisotopes are produced at research reactors by neutron capture in targets or by nuclear fission of $^{235}$U [4]. In the case of radioisotope production by neutron capture, target encapsulation is an important stream of solid radioactive waste. The use of zircaloy for encapsulation yields waste with $^{94}$Zr while the use of stainless steel results mainly in waste with $^{55}$Fe, $^{60}$Ni, $^{60}$Co. The nuclear fission of $^{235}$U produces the full set of fission products and some actinides.

The main decommissioning wastes are activated and contaminated metals (e.g., stainless steel, carbon steel, lead, aluminum) and concrete from the biological shield. More than 50 % of materials from dismantling of research reactors are exempt waste and a small amount, less than 10 %, are ILW. In research reactors some specific materials like graphite or beryllium are also used. Graphite is used as a moderator and reflector. Some research reactors have a stacking of graphite in one of their irradiation facilities, the thermal column. The long lived $^{14}$C isotope can be produced by neutron activation in the graphite. The activity of this isotope determines the management/disposal options of graphite. Beryllium is used in research reactors as a source of neutrons, moderator and reflector. The material itself is...
4 Existing Concepts for Disposal of radioactive Waste

Europe is running a very intensive research in the area of disposal facilities [5]. For coordination of all the research projects for an effective exchange of information technical platforms were established [6]. The IGD-TP (Implementing Geological Disposal – Technical Platform) was launched for the research for deep geological disposal facilities, where the concept of near surface disposal facilities is described as sufficient for low level and intermediate level waste with short half-life. Geological disposal is recommended for intermediate level and high level waste especially containing isotopes with long half-lives. All these projects for disposal facilities have one thing in common: They are very money and time consuming, because they are designed for large amounts of radioactive waste. Such solutions seem to be not adequate for the disposal of some thousand drums with radioactive waste. Nevertheless, countries with a high progress in such disposal projects shall take over a lighthouse function for those countries, which have just started planning for a disposal facility. Existing concepts are:

- Near Surface burial – low level waste is buried within 10 m of the surface in a conventional style landfill
- Shallow burial – low level waste is packaged and buried within 100 m of the surface
- Engineered structures and concrete vaults – typically for 100,000 m$^3$ of waste or more
- Engineered boreholes for disused sealed radioactive sources
- Geological caverns for the disposal of intermediate level waste or high level waste

5 Alternatives

Fully aware of this challenge the following alternative solutions are also discussed.

5.1 Multinational Disposal Facility

A multinational disposal facility is a disposal facility, which is used by several countries (sometimes also called “regional disposal facility”). This approach investigated by WNA [7] and IAEA [8] makes sense from the technical as well as from the economical view. In EU, the European Repository Development Organization (ERDO) works for the implementation of one or more shared regional repositories for radioactive waste. The idea is compelling, but the political challenges are very difficult. The definition of the area of competence for a supervising and licensing authority might be easy, although it has to be active beyond state borders to control waste packages in other countries and to decide whether waste packages are acceptable or not. There are many challenges:

- How will the costs be shared for the participating countries if the project has a significant delay (which is very normal in those projects) or has to be abandoned?
- What will happen if acceptance of foreign waste is suddenly unenforceable due to a lack of public acceptance?
- How stable will the country, its government and borders be for the life of the control period?
- Would the site become a security risk for all the countries around it?

These challenges are only some of the reasons why politicians see only little chances for a multinational disposal facility.

Groups have nominated Australia as the site of a multi-national repository, and discussed the concept of uranium leasing; the country which mines the uranium has to take the uranium back at the end of its useful life, along with whatever other wastes were produced with it. There is no political will or public support for either idea within Australia, and there is a minority viewpoint that if radiopharmaceuticals are exported then Australia should be exporting that portion of the radioactive waste to the country using the radiopharmaceuticals. There is an idea for a south-east Asian repository, however the issues are still over who will have control, where it will be situated and how this will impact on the regional tensions between countries. This would be a long term goal (100 years) for the region.

5.2 Common Disposal with hazardous Waste

This alternative idea seems to be smart, as requirements for technical barriers at landfills for hazardous (toxic, harmful, dangerous goods) waste are comparable to near surface disposal facilities for very low level waste. Already existing capacities at landfills for toxic waste might be usable for low level waste [9]. But it has to be considered, that in case of a failure of the technical barriers of the landfill the impact on the environment will significantly increase. The health effects by incorporation of radioactive substances might be of minor importance compared to the toxic substances, but the effort for remediation will be much higher. In any case an additional safety assessment is required. This would not be suitable for intermediate level wastes. One advantage is that radiation will eventually disappear, unlike the other hazardous and toxic wastes.

For some governments, the very low level radioactive waste can be stored in hazardous waste facilities.

5.3 Permanent Storage

A different solution can be found in the Netherlands. Radioactive waste has to be stored in a central interim storage (COVRA), designed for an operation of 100 years. Actually, already conditioned waste (supercompressed and cemented) will be checked for their specific activity. Those drums below the Dutch clearance values, are opened, sorted and cleared as conventional waste. By this way COVRA could increase their capac-
The number of clearable drums in Dutch permanent storage COVRA [10].

5.4 Small Scale Disposal Facility

If the above mentioned alternatives are not applicable or do not fulfill the radiological requirements, the following alternatives should also be investigated:

- New construction of a small scale near surface disposal facility for radioactive waste
- Use of an already existing mine or tunnel
- Development of a borehole disposal concept appropriate for more categories of wastes besides the sealed sources

For discussion of the use of an already existing mine as a disposal facility the following aspects have to be considered:

- **Geological situation, the system of natural barriers:** Is a proof for long term safety possible and for which time duration is it necessary? Which additional measures are necessary to keep the safety requirements? For this case additional concrete structures for sealing the drums with radioactive waste from the host rock can be helpful. The safety parameters have to be calculated on the basis of the radioactive inventory, which might be brought into the disposal facility in future. The aim is to prevent radioactive material from coming into contact with groundwater in which it could dissolve, as this is the principal route by which radionuclides could be transported from a disposal facility through the host rock to the near surface, where it can affect humans.

- **History of the mine, rock stability:** The stability of caverns and pillars especially in old mines has to be checked under consideration of the planned operational life time. Additionally, two shafts, a good ventilation and ways for rescue and emergency are state of the art requirements. In general, the use of the mine for the time of operation and closure as disposal facility has to be added into the safety assessment. This can cause a significant effort for repair, reconstruction, and maintenance. Additionally, measures for backfilling of empty caverns have to be taken into account.

- **Robustness against incidents and events:** In old mines shafts are often not appropriate for transport of radioactive waste. A design including the drop of waste packages into the shaft as well as earthquakes is necessary. The calculated potential dose in case of such incidents and events must demonstrate that the legal requirements are not exceeded.

- **Site selection:** In case of selection between different sites logistical aspects for the transport to the site and the infrastructure at the site have to be considered as well as the public acceptance in the surrounding communities.

In consideration of all these points it becomes clear that a disused mine could meet all the safety requirements with a small need for reconstruction and would be a very good choice.

5.4.2 Extension of the Borehole Disposal Concept

Borehole disposal is to dispose of items in a vertical cylindrical hole underground. There are two types – shallow and geological boreholes. If the waste is below a depth of 150 m it is considered as geological disposal. The current use of a borehole is designed for the dis-
posal of disused sealed radioactive sources generally. The extension of this concept is to make the hole diameter slightly bigger and have waste canisters placed into the hole. The borehole could be up to 5 km deep and it would be lined to prevent water from filling the borehole. The waste would be placed in the hole, filled around the waste, a spacer to the next waste canister and it would be filled up to an appropriate level depending on groundwater levels. The advantage of this method is that it does not rely on creating tunnels, inspection systems or ventilation systems. With the mining knowledge and capabilities, a borehole down 1 or 2 km is possible now which could be used. This is a much cheaper form of geological disposal. The packages will have to be stronger as there will be tonnes of force on each package.

5.5 Other Disposal Concepts

Other disposal concepts are also discussed:

- Subsea burial: boreholes under the ocean as another level of protection. The boreholes could be shallower and the capping will increase over time through sedimentation. This method has very little public support, and is more complicated and costly than land-based borehole disposal. This method is banned by international treaties.

- Subduction zone burial: emplacement of waste in land, which is slowly moving under another tectonic plate. The idea is that eventually, the waste will be in magma and dissolved in the fluid rock. This method has never been implemented as the uncertainties around earthquakes and eruptions are too high.

- Use of already contaminated areas (nuclear weapons testing sites): Use of an area within a nuclear test site (above or below ground) for disposal of radioactive wastes, or use of contaminated tunnels for waste placed by robots. This could only be used by a small number of countries, and would have to demonstrate adequate radiation protection to all workers to be enacted. This option is used by Kazakhstan.

6 Conclusion

Countries without a nuclear power programme may produce radioactive waste, and have to responsibly deal with that waste. As there is not a commercial power generation, there is also not a levy on power consumption that goes to a waste fund. There is not the money set aside for the disposal of radioactive wastes generated in these countries. Therefore these countries look for more cost effective disposal routes for the wastes that they produce.

With the wide variety of radioactive wastes which are produced, the simpler forms of conditioning and disposal are more suitable for countries with a small radioactive waste inventory. The first step is to understand the existing and future waste of the country concerned. This should all be reported in the national reports to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management as coordinated by the IAEA. The next step is to understand the options that are available to the country.

An economical solution is a multi-national disposal facility, where the countries pool resources to build a larger facility than any one country could do on its own. However, there are many political problems which are not yet solved. The states may look to co-disposal with other hazardous wastes, or for permanent storage until a disposal option becomes viable, whether that be exemption or a radioactive waste disposal site.

If these possibilities are not feasible, the next option is to create a small scale disposal facility based on existing technologies. This could be a smaller engineered concrete vault structure, the use of an existing disused mine for geological disposal or extending the borehole concept to take in other wastes. These smaller scale structures will still cost money, but not as much as for waste facilities for nuclear power plants.

There is a chance to combine existing possibilities and to fit them individually for each country. But the following aspects have to be considered:

- Governments in some of these countries have not realized the necessity of a final solution for the radioactive waste.
- Some countries might have proceeded in treatment of waste without knowing the final disposal solution; the problems may increase as the waste may need to be re-conditioned.
- At the moment there is no way for funding of a disposal facility.

Especially, the last item hampers small scale and affordable solutions. A support by the European Community in this direction can be useful for many countries.

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No nuclear Power – no Disposal Facility?

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