Quality Assurance/Quality Management in Remediation Work in Abandoned Mines

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1 Preliminary remarks

Working Group 4.6 Abandoned Mines of DGGT and DMV prepares recommendations on various key aspects of abandoned mines. Abandoned mines comprise all cavities created by mining (mine workings), including boreholes, as well as open pits, spoil heaps, dumps and residual voids that are no longer used for mining purposes (DGGT WG 4.6 2004).

The recommendations are guidelines for a uniform and efficient engineering and mining-technical approach to damage-relevant legacies of abandoned mines. The differentiated mining-technical measures are applied to ensure safety, in particular depending on the use of the ground surface.

The present recommendation “Quality assurance/quality management in remediation work in abandoned mines” deals with measures to safeguard minimum standards in the investigation, assessment and remediation as well as the monitoring of abandoned mine legacies.

Without well-thought-out quality management and quality assurance tailored to it, there is no guarantee that all requirements are taken into account. If quality standards and rules for dealing with abandoned mines are disregarded, necessary remediation measures could be made more difficult or, in the worst case, even fail. Risks exist with regard to technical as well as economic requirements and the time required. A quality assurance and quality management system (QA/QM) is therefore the basis of the considerations and work to be carried out. An integrated approach to the issues of abandoned mines thus enables sustainable (economic, ecological and social) processing and thus the opportunity to meet the challenges of long-term and perpetual tasks.

The recommendation is based on the state of knowledge in the relevant national and international technical literature and recommendations of DGGT, DMV and DGGV. In particular, the recommendations of Working Group 4.6 Abandoned Mines of DGGT (DGGT WG 4.6 2020) and the recommendations of Working Group 2.10 Geotechnical Measurements of DGGT (DGGT WG 2.10 2022) are to be mentioned as a basis. Further sources are not listed; reference is made to the aforementioned documents.

2 Definitions

Quality assurance and quality management serve to ensure that products, services and processes comply with the specified quality standards and meet the requirements.

Quality assurance

Quality assurance is a systematic approach to ensuring that the specified quality requirements are met. It comprises all measures taken to ensure that a product or service meets the desired quality standards. Quality assurance often involves monitoring and testing products, processes and systems to ensure that they meet the defined specifications. It also includes the implementation of methods and procedures to identify, correct and prevent errors in the future.

Quality management

Quality management refers to the totality of activities carried out to control and improve quality in an organisation. It is a comprehensive approach that covers all aspects of the company and aims to create a process of continuous improvement. Quality management includes the development and implementation of quality policies, processes and procedures to ensure that the quality objectives are (or can be) achieved. It also includes staff training, the promotion of quality awareness and the establishment of a quality management system that is regularly reviewed and improved.

Quality management is of crucial importance here, as it lays the foundation for ensuring that the work and the documentation comply with the required standards and rules. This influences, among other things, the following points:

- risk minimisation
- efficiency and thus cost reduction
- satisfaction of the clients, the competent authorities and all project participants

To reduce remediation risks in abandoned mines, quality management must cover various subject areas. In addition to technical topics, legal and economic boundary conditions must also be taken into account.

3 General approach/course of action

Various steps are necessary for the successful remediation of abandoned mine legacies. Depending on the project, it is necessary to set different priorities and to adapt the handling of the individual steps to the situation on site.

The general procedure can be outlined as follows:

- identify, report, register and document a damage event or risk/hazard related to abandoned mines. This is done in accordance with the specific requirements in the individual federal states;
- initial assessment by the competent public order authority or mining company; if necessary, implementation of immediate measures;
- assessment of the extent of the damage according to the generally recognised state of the art;
- examination of responsibility (cost bearer) by the mining authority or competent authority;
- involvement of experts;
- preparation of a concept/planning for investigation and remediation;
- invitation to tender for the investigation and remediation work with specification of works, bill of quantities and contract conditions;
- checking of the tenders, award proposal with price comparison and award of contract;
- execution and construction supervision of the investigation and remediation work;

- final documentation and, where applicable, recommendations on measures for medium- to long-term monitoring;
- implementation of monitoring, documentation and assessment of the monitoring results.

4 Aspects of quality assurance in individual steps

4.1 Criteria for selecting a suitable engineering consultancy

In the remediation of abandoned mine legacies, in addition to the actual operational investigation, securing and/or closure measures carried out by suitably qualified mine-securing, drilling or civil engineering companies, administrative work for planning and supervision as well as expert assessment of the measures must also be carried out.

Depending on whether a crown hole, a preventive measure within risk management or ground improvement as part of planned construction measures is concerned, all or only some of the tasks and activities described in this quality recommendation may be required.

In such projects, both the complexity and the diversity of the disciplines involved must be taken into account. In addition to other topics from the fields of mining, mine surveying, engineering geology, hydrogeology, gas emission, occupational safety, organisation and environmental engineering, the disciplines also include general economic and legal topics. It is therefore recommended that these activities be awarded, at least in part, to one – or, where appropriate, several – engineering consultancies. If the work is awarded separately, coordination and alignment of the individual tasks are imperative.

The knowledge and experience of an engineering consultancy will influence the success of the measures in terms of technical, safety and economic factors. It is therefore important that, before awarding the contract, the client gains an understanding of the personnel, technical and also economic capacity of the applicants or of the engineering consultancies under consideration.

General requirements

In carrying out the work, the engineering consultancy to be commissioned must take into account the legal provisions, administrative instructions and standards relevant to the work, which relate to many fields such as subsoil, occupational safety and structural analysis. In particular, the provisions relating to abandoned mines must be observed and complied with when performing the services. Depending on state-specific regulations, work in abandoned mines is often carried out under mining supervision or at the instigation of the public order authorities – consequently, the laws, ordinances, etc. of the respective competent authority are to be applied. Knowledge of these legal provisions and standards is therefore indispensable for engineering work on measures in abandoned mines. The further recommendations of Working Group 4.6 “Abandoned Mines” provide guidance on the regulations to be applied.

Depending on the task, it is a qualitative advantage if employees of the engineering consultancies to be commissioned can provide evidence of appointment as publicly appointed and sworn or recognised experts, for example for the various fields of post-mining. If there is no such

recognition, the suitability to provide expert and planning services in abandoned mines should be demonstrated by relevant experience and expertise as well as appropriate reference projects.

For example, the extraction of many raw materials is associated with specific gas emissions that continue, perhaps to a lesser extent, even after extraction has ended, e.g. emission of methane from coal or leaking gas production wells. In order to take into account and plan for the risks/hazards resulting from gas emissions during the remediation measure, but also for the later safe and economic discharge of gases via the remediation structure, an engineering consultancy must have the relevant knowledge.

Furthermore, the engineering consultancy must incorporate occupational health and safety and environmental protection knowledge (HSE) into the project, in particular when planning the work processes and the equipment to be used and when later supervising the remediation measure. With regard to these topics, in addition to planning and daily operations on the construction site, the handling of possibly contaminated soil and/or excavated material in the course of remediation measures should also be mentioned.

Knowledge of public procurement law is required for the preparation of any necessary tender documents (specification of works, bill of quantities …) and/or for participation in the award of contracts (review and evaluation of tenders).

If the remediation measure involves interventions in nature, which is usually the case, the authorities responsible for water, nature and species protection must be involved in the application procedure and in the execution of the measure. Depending on the size of the intervention, this may result in the need for compensatory measures and, accordingly, the preparation of landscape conservation reports or accompanying plans.

In addition to the public order, mining authority or other regulations explained in more detail above, it is therefore necessary that the engineering consultancy to be commissioned has knowledge of the regulations in the aforementioned disciplines.

Evidence of economic and financial capacity

It is important that the client obtains a picture of the economic capacity of the contractor before awarding the contract, in order to prevent, in the worst case, the contractor dropping out during the term of the project. The documents listed in “ADDITIONAL INFORMATION on evidence” (see Annex II) contribute to such a picture.

Evidence of technical and professional capacity

The documents listed in the information section “ADDITIONAL INFORMATION on evidence” (see Annex II) are intended to indicate to what extent the applicant, on the basis of its expertise, is able to meet the technical and organisational requirements of the abandoned mine project.

The variety of requirements listed, which in each project is extended by further specific requirements, may mean that an engineering consultancy cannot meet all of them on its own. In this case, parts of the tasks, e.g. the tasks under nature and species protection law, can be subcontracted to a further engineering consultancy. For the transfer of subtasks to a

subcontractor, the client must reserve the right to give its consent and must ensure that the subcontractor also meets the necessary requirements.

4.2 Requirements for research (including archive research)

Sometimes only little is known about abandoned mines. Old surface openings, mine workings and underground cavities often have to be investigated first. For the competent authorities, the prevention of hazards/risks arising from these abandoned mine legacies to ensure public safety and order is part of their official duty. For owners and legally responsible parties, it is part of their duty of care.

For the regular recording and assessment of abandoned mine legacies, as well as after damage events, available sources are used first. These include, above all, the graphic representation of the mine workings in mine plans and mine maps. However, documentation in historical maps, such as adit maps, separation maps, vein and seam maps, cadastral maps and topographic maps (1:25,000) as well as geological maps, etc., can also contain valuable information on the location and extent of the mine workings.

The corresponding mine files, operating plans, deeds and chronicles often contain and describe further details. These documents can be supplemented by historical photo collections and aerial photographs.

In addition to the archives of the competent mining authorities, the state archives of the federal states, the archives of museums, libraries of universities and collections, company archives as well as archives of municipalities and mining associations are, above all, important sources. In some federal states (including Saxony and Lower Saxony), the respective mining archives, as branches of the state archives, are a rich source for the tradition and compilation of files from the various mining administrations and eras as well as from mining companies.

The competent mining authorities usually hold documents on abandoned mines, such as mining damage analyses (BSA), mining/abandoned mine cadastres or abandoned mine or geotechnical/mine-surveying assessments or closure/final documentation, which allow a quick overview of the situation and, if necessary, the derivation of initial hazard prevention measures.

The mining authorities have always ensured that files and mine plans are preserved and archived. To this day, they form the cornerstone of the holdings in the state and mining archives. However, it must be pointed out that a large number of mine workings were created before the obligation to keep mine plans was introduced. In these cases, only the files themselves can be used. However, the positional or spatial reference remains very difficult and in some cases can no longer be reconstructed. The same applies to mining in times of war and hardship, where any information on abandoned mines is often missing. In such cases, it is occasionally still possible to draw on accounts from contemporary witnesses and local historians.

A further problem arises from missing files and plans that have been lost as a result of fires/town fires, floods and the turmoil of war, etc. As a result, information on entire mining districts and mining eras may be missing.

Furthermore, research should also be carried out with the relevant competent authorities regarding contaminated sites, suspected unexploded ordnance and protected assets that may be affected, and the basic information should be recorded and documented.

The basis for establishing the basic data is traceable and comprehensive archive research. The selection of archives and holdings is particularly important, since only in this way can the completeness of the available information be ensured. The time required for archive research is considerable and must not be underestimated. Adequate quality (including document quality and resolution, but also the informative value of the content and the possibility of horizontal and vertical positioning) must be ensured for the research, including its evaluation, as this forms the basis for further conclusions and assessments as well as planning services. Risks/hazards caused by abandoned mines, investigation and remediation measures as well as cost estimates are derived from this.

Expertise in archival work and experience in handling archival records are prerequisites for research in the context of establishing the basic data. Archival work is a spatio-temporal analysis of historical data sets! Geographic information systems (GIS) should therefore already be used when establishing the basic data. The foundations laid here can then be used in the further course of the project.

Archive research must be based on a structured and scientific working method and organisation. Depending on the temporal context and the administrative allocation, the abandoned mine documents for a mining district may be allocated to different archives and even be distributed across different federal states. The spatial and subject-matter competence as well as the constitutional/administrative affiliation of the mining object/mining district to be assessed form the basis for identifying the relevant archives.

Within the archives, the records are divided into holdings. These are structured according to the provenance of the documents and are usually provided with a description of the content and the time span covered, which allows an initial overview.

Within the holdings, the relevant files are to be researched using finding aids or databases and selected for inspection. It should be pointed out that not all holdings and finding aids have yet been digitised, nor are all of them available online. Digital online research is helpful but no substitute for research in the archives on site.

After the records have been selected and retrieved, they are to be inspected and read according to relevance, and their contents made available for further use and documented. The essential contents important for the project are to be adopted. Since the effort cannot be estimated in advance, it is advisable to have it calculated on the basis of verified expenditure. This allows effort-related and reliable quality assurance.

Knowledge of historical scripts is indispensable for inspecting the records. Reference must be made here to the very variable quality of the handwriting. The texts of the files may need to be transcribed in order to make them available for evaluation.

Furthermore, expertise in mining/mining technology and mine surveying is required in order to be able to assess and classify the contents of the records.

The procedure and results of the archive research are to be documented in a traceable manner. All archives, holdings and sources researched are to be listed and described, including negative results. The content and quality of the sources are to be presented.

As a result of the archive research, the data collected are to be evaluated and prepared as a basis for the further engineering services. The plans and maps serve to visualise the mine workings. These are to be georeferenced using sufficient and suitable control points. The research results from the files serve the general description of the mining district and the detailed description of the abandoned mine objects. The object description must contain all available mining-technical information, such as cross-section, depth, support and securing, etc.

In addition, comprehensive research into modern geodata – including as web services – is to be carried out which describes the current geoscientific and technical situation at the site (including hydrogeological maps, geological maps, web portals of national and/or international ground motion services).

In summary, integrated research forms the basis for recording and assessing abandoned mine objects. It is indispensable for the investigation, assessment and ultimately remediation of mining objects and for monitoring. Well-founded research and the spatio-temporal evaluation of the results obtained make it possible to plan and carry out investigation, remediation and monitoring services professionally, which enables effective hazard/risk investigation and prevention and ultimately cost optimisation.

4.3 Requirements for the condition survey (stability assessment) and the remediation concept

Condition survey

Professional handling and construction support must be ensured for the condition survey. In addition to written documentation, GIS-based documentation of the available geodata is recommended.

The relevant building standards, regulations and legal provisions must be observed for the investigation of the subsoil and the determination of geotechnical parameters in general, and for the investigation and assessment of abandoned mine legacies in particular.

The key components of a technically sound investigation for the condition survey are:

- comprehensive research, such as inspection of mine plans, historical maps, descriptions of mining districts, etc., to create a sound planning basis for further investigation (see Section 4.2 Requirements for research (including archive research));
- surveying/mine-surveying recording and geotechnical/abandoned mine documentation of the mine workings (e.g. drainage galleries);
- site-adapted investigation and mapping of the ground surface, of changes in vegetation (as an indirect indicator of structures in the subsurface), of the drainage situation (hydrology, hydrogeology) and of the subsurface structure (soil, geology, tectonics);

- condition survey of the mining legacies (including location, dimensions) and determination of the geotechnical parameters of the surrounding subsurface.

In the context of subsurface investigation, a step-by-step procedure adapted to the locality is often appropriate and is to be carried out in combination with photographic preservation of evidence (date, location reference):

- mapping of the sites with regard to use, damage to structures, deformations and changes in vegetation of the ground surface, water discharges and the like;
- simplified investigation methods with trial pits, small-diameter percussion drilling, dynamic probing, geophysics, etc.;
- if necessary, in-depth investigation with machine drilling or creation of accessible entry to the legacy, as well as investigation/surveying by means of laser scanning or borehole camera;
- adaptation of the investigation grid to the type, location and dimensions of the objects to be investigated;
- continuous adaptation of the investigation programme to previously obtained results.

The aim of the condition survey is to determine all parameters necessary for assessing stability and, where applicable, for developing a suitable securing and monitoring concept. This includes, among other things, the following information:

- maps/mine plans showing the type and spatial arrangement of the mine workings (support, overburden, location, dimensions) as well as their connection to surrounding mine workings and the rock mass;
- stability-relevant features (e.g. collapses, deformations, water flow, backfill);
- deposit model (if necessary, digital 3D model), geological/tectonic conditions and geotechnical parameters.

As part of the condition survey, the zone of influence relevant to the ground surface is also to be determined or defined (if necessary, via web services on ground movement).

Stability assessment

In principle, the relevant building standards apply, such as DIN EN 1997-1 and -2, DIN 4020 and DIN 1054. In addition, the relevant regulations (in particular those of the mining authorities) as well as publications (general state of the art and development) on abandoned mines are to be taken into account for the assessment of the stability of the ground surface. This expressly includes the recommendations of Working Group 4.6 “Abandoned Mines” already published.

Particularly in the case of abandoned mine problems, the actual stability level (or a residual risk) often cannot be stated with certainty owing to insufficient availability of the required assessment parameters. In such cases, the monitoring principle can be applied in particular, or an adapted inspection and monitoring programme and the application of threshold and limit values are to be used.

Remediation concept

The remediation concept must be designed in such a way that a safety level adapted to the use of the ground surface is achieved for the area at risk. Wherever possible, the safety level to be aimed for at the ground surface and the type of remediation concept should already be defined during the condition survey.

In principle, remediation can be carried out by securing or closure, depending on the safety level aimed for at the ground surface:

- establishing permanent stability of the ground surface (e.g. where it is built on);
- partial securing of the ground surface, e.g. by geogrids, to minimise the potential impact (e.g. for traffic areas);
- fencing off the area at risk to ensure public safety without measures to secure the ground surface.

Furthermore, the following types of remediation concepts are to be distinguished:

- closure of the mine workings (requiring no aftercare);
- full or partial securing;
- structural securing according to the resistance or yielding concept;
- securing measures at the structure or in the subsoil;
- preserving or restoring securing measures.

The specific measures of a remediation concept are to be adapted to the local conditions and agreed with the competent authority.

When drawing up remediation concepts, the possible influence on the water flow in the mine workings must always be taken into account. A functioning drainage system existing in the mine workings should not be changed if possible. If changes are necessary, their effects are to be investigated, assessed and monitored.

On the basis of the results of the condition survey, the safety level can be adjusted, where appropriate also, for example, for reasons of proportionality. It is therefore important that the commissioned expert presents possible technical variants of a remediation and assesses them economically.

When planning interventions in mine workings in the course of the condition survey or remediation, it must be clarified at an early stage whether ownership rights to the mine concerned are still granted. This is done most reliably via the mining authorities, which hold the mining land registers with the necessary information.

4.4 Requirements for construction companies and for the execution of remediation work

In post-mining investigation, exploration and remediation work, the tender phase and the boundary conditions for the execution of such work are defined through basic research, planning and specifications of works.

The tender specifies the order of precedence of the underlying contractual conditions for the execution of the services. In addition to the bill of quantities, the contractual conditions generally include further documents, laws and regulations, such as the German Civil Code (BGB), the German Construction Contract Procedures (VOB) or individual purchasing conditions or self-declarations. The contractual content is agreed between the parties (client/contractor) before the contract is awarded. The contractual conditions generally already set out general requirements for the construction companies with regard to compliance, information obligations, responsibilities, etc.

The specific technical requirements relating to the construction measure are addressed in the individual items of the specification of works.

General construction description and notes

- task description;
- description of the geology and tectonics/subsurface conditions/groundwater conditions/contaminated sites/gas issues;
- description of the mining conditions (information already available on existing abandoned mines)/presentation of possible cavities that may be encountered/mine plan documents;
- requirements for site set-up/identification of owners/access permits/statement on unexploded ordnance/site infrastructure (water, wastewater, etc.);
- requirements arising from duties of care;
- requirements for the preservation of evidence;
- requirements for surveying during construction/final survey;
- description of the supply and disposal lines;
- obtaining excavation permits/utility clearance certificates;
- notification of the work to the competent authorities;
- requirements for the use of equipment;
- requirements for the building materials to be used (proof of suitability);
- disposal instructions.

Notes on technical execution

Irrespective of the type of reopening, such as vertical (shaft) or horizontal (drift/adit) excavations, various boundary conditions and tasks must be observed:

- determination of the possibilities for on-site interim storage and disposal routes;
- sampling and laboratory testing of the excavated material and of the inflowing water;
- rock-mechanical conditions/stability:
    - drift cross-section/cross-section enlargements required (re-ripping),
    - ventilation,
    - gas emissions, e.g. natural gas/mine gas, hydrogen sulphide, carbon dioxide, and their monitoring by measurement,

    - radon (regular measurements/personal dosimetry);
- definition of the investigation method (exploratory drilling/trial pits, etc.);
- definition of the investigation technology/technical parameters (borehole diameter/inclination of the borehole/trial pit depth, etc.);
- documentation of the investigation results.

Reopening technology

- in the design of the technical installations, the TAS (technical requirements for shaft and inclined hoisting installations) may have to be observed; up to a depth of 50 m, the guideline for pre-sinking applies;
- if required, definition of the type of support (as a rule, back-anchored, reinforced shotcrete);
- securing of underground cavities (e.g. anchors, structural supports):
    - temporary securing for the duration of construction,
    - securing to ensure long-term stability;
- auxiliary ventilation;
- backfill placement technology (hydraulic, pneumatic);
- securing/closure of the accesses.

Securing and closure works

- backfilling and grouting services, including definition of the backfilling/grouting technique (pressureless/low pressure/grouting);
- monitoring by measurement, in particular the monitoring of infrastructure, buildings, etc.;
- closure of the cavities:
    - definition of the closure technology,
    - definition of the closure horizon,
    - definition of the design of the abutments/closure plugs;
- sealing without complete closure:
    - construction of a dam structure,
    - water paths/observance of discharge permits.

Occupational safety and environmental protection

- compliance with statutory requirements, e.g. occupational safety in accordance with the Workplaces Ordinance (ArbStättV)/DGUV regulations and rules, immission control in accordance with BImSchV, nature conservation (NatSchG), etc.;
- work in areas with gas emissions in accordance with TRGS 900 (e.g. radon, carbon dioxide), explosion protection (e.g. methane, hydrogen) to be considered by an expert;
- work in contaminated areas (e.g. TRGS 524, TRGS 402);
- notification of the work to the competent supervisory authority.

General conditions

The bill of quantities and the quantity framework requested form the costing and planning basis for preparing the tender. In addition, further evidence/documents may be required for assessing the suitability of the company. Information on possible evidence is provided in the “ADDITIONAL INFORMATION on evidence” compiled in Annex II.

4.5 Requirements for backfill and filling materials

In addition to the choice of suitable backfill material, the placement technology is decisive for achieving the remediation objective and for the economic efficiency of the measure.

4.5.1 Requirement criteria/approvability

Before backfill and filling materials are placed, the requirement criteria are defined depending on the intended remediation objective and taking into account the local conditions. Approvability is to be assessed against the background of protected assets (water, nature conservation, monument protection, etc.).

The requirement criteria include the definition of the mechanical properties (for hydraulically setting backfill: properties in the unset and set state) such as degree of compaction, compressive strength and flow behaviour, as well as the chemical properties such as heat development and resistance of the backfill to aggressive water. Furthermore, the requirements to be met with regard to environmental compatibility are formulated.

4.5.2 Proof of suitability/quality assurance plan

Proof of suitability

The proof of suitability is the evidence that the requirement criteria for the intended backfill material are met.

The proof of suitability is submitted by the contractor before the start of construction and is checked and confirmed by the planner. If necessary, further suitability tests are carried out on the backfill material.

Quality assurance plan

The quality assurance plan comprises the definition of all measures necessary for monitoring compliance with the specified requirements for the backfill and its placement.

Definition of quality monitoring during the placement phase:

- requirements for internal quality control, specifying the test methods and the scope of testing;
- requirements for external quality control, specifying the test methods and the scope of testing;
- description of the monitoring of material flows;
- definition of the scope of retained samples, including storage period and location;

- description of the monitoring required by the construction process (e.g. backfilling rate, monitoring of the degree of filling, suspension density measurements, magnetic-inductive flow measurements).

4.5.3 Supervision – monitoring

To ensure that the investigation and remediation are carried out appropriately (e.g. backfill, reopening, targeted discharge of mine water), a construction schedule is to be drawn up, taking into account boundary conditions for performance and deadline control. The construction schedule is adapted and updated according to the state of completion and the construction process as well as gains in knowledge. It is the subject of the construction meetings:

- control of the remediation work, quality assurance programme;
- compliance with occupational safety guidelines;
- control of the safety and health protection plan of the executing company;
- compliance with the remediation technologies (e.g. drilling and backfilling methods);
- compliance with the specified locations (e.g. backfilling and drilling points);
- levelling, measuring marks on buildings, crack monitors for subsidence monitoring, among others, during drilling and grouting work;
- control of backfill escapes (including documentation and recording of quantities);
- determination of the degree of backfilling (theoretical (calculated) degree of backfilling in %);
- sampling, field tests and documentation:
    - material samples from backfill production,
    - weighing slips/delivery notes/measurements,
    - mass flows per unit of time (magnetic-inductive flow measurements),
    - pressure curves (for hydraulic backfill), soundings,
    - geotechnical tests of the backfill (if accessible, e.g. plate load tests),
    - control boreholes for organoleptic assessment and, if necessary, for sampling and laboratory tests,
    - levelling, crack monitoring;
- laboratory tests:
    - chemical analyses (e.g. declaration analysis of backfill material, mine water analysis),
    - geotechnical tests (e.g. soil-mechanical parameters).

4.6 Documentation and monitoring

Mine-surveying and geotechnical monitoring may be required in all phases of a remediation project, from project preparation through the execution phase to aftercare.

4.6.1 Need for monitoring

Possible reasons include:

- changes at the ground surface and in the subsurface, hazards and environmental impacts;
- opportunity and risk management;
- quality assurance of construction measures and control of the construction process;
- preservation of evidence (if necessary in conjunction with a baseline measurement/status quo measurement);
- communication with, and participation of, affected parties and authorities;
- documentation of the operating condition of areas and structures;
- observation of the closure and post-operation condition.

A monitoring concept is to be designed specifically for the task and comprises the following components (Rudolph, Yin & Goerke-Mallet 2023):

- definition of the objective of the monitoring in accordance with higher-level objectives (e.g. regulatory requirements and statutory provisions);
- definition of the necessary monitoring routines and periods (regularity and duration), the size of the area and the minimum spatial resolution, taking into account the spatio-temporal variation of the monitoring objective;
- selection of suitable monitoring methods, i.e. the combination of measurements and statistical evaluation methods, taking into account regulatory requirements, corporate standards, guidelines and (action) recommendations;
- definition of warning and alarm values for assessing the results;
- definition of action and response processes for feedback in the provision of georesources (e.g. temporal delay in the groundwater lowering of open-pit mines to prevent further ground movements).

4.6.2 Necessary design information

Requirements are to be specified for drawing up monitoring concepts. These include above all:

- spatial extent of the object, its geometry and its zone of influence (spatial resolution and coverage);
- time horizon of the project (temporal resolution and coverage);
- target variables and target parameters (measurement resolution and range);
- quality requirements for recording the target parameters with regard to accuracy (precision), reliability and probability of error.

The zone of influence refers to the area whose properties or functionality may be adversely affected by the object to be remediated. A spatio-temporal delimitation is not always possible at the start of the project. Several phases of monitoring must therefore be considered, and the monitoring methods and parameters adapted accordingly:

- exploration phase, with the application of the initially defined monitoring over short- to medium-term periods (baseline measurement);
- development phase, with the evaluation of the results of the initial monitoring methods and adaptation and/or extension of the monitoring/monitoring parameters over medium-term periods;
- production phase, with the optimal application and integration of monitoring over medium- to long-term periods;
- closure phase, if necessary with reduction of monitoring to a necessary minimum in terms of (permitting) law and technology over long-term periods, and the final termination of monitoring.

For mine-surveying and geotechnical issues, the possible target variables include above all geometry, kinematics, mechanics/hydraulics, geology/hydrogeology, metrology, geophysics, environmental parameters and other anthropogenic influencing variables (e.g. other extraction operations, groundwater management).

As a rule, statistical indicators are suitable as target parameters, e.g. the mean value, the variance or the probability of exceeding or falling below critical limit values.

In the case of change monitoring, the quality requirements comprise accuracies, confidence intervals or error probabilities (type I and type II errors).

4.6.3 Measurement methods in monitoring

Different methods are available for monitoring different target variables and parameters:

Target variable (parameter)	Selection of possible measurement methods in monitoring
Geometry (e.g. spacing, length, distance, coordinates and their changes, height differences, inclination)	Tachymetry, GNSS, laser scanning, radar interferometry, photogrammetry, geometric levelling, gauges, hydrostatic settlement measurements, extensometers, fissurometers, convergence meters, plumb lines, inclinometers, strain gauges, fibre-optic systems
Mechanics (e.g. strain, force, stress and pressure, volume flow)	Load cells, measuring anchors, strain measurement systems, hydraulic pressure cells, earth pressure cells, fibre-optic systems
Metrology (e.g. precipitation, temperature, air pressure, volume flows)	Various measuring systems for recording water, soil and structure temperatures, soil moisture, magnetic-inductive flow measurement, ultrasonic flowmeters, sampling, climate stations
Geophysics (e.g. electrical resistivity, gravity anomalies)	(Micro)seismics, geoelectrics, electromagnetics, ground-penetrating radar, gravimetry, magnetics
Groundwater/mine water	Water level measurements, flow measurements, analyses of water chemistry

4.6.4 Evaluation methods in monitoring

The quality of monitoring methods is generally assessed with regard to the criteria of spatio-temporal resolution, accuracy, trueness and precision.

Resolution describes the smallest counting increment of the measurement method. Precision is a measure of the scatter of the measured values (random measurement noise) around a mean value, and trueness is a measure of the systematic deviation of the measured values from a true value. Accuracy considers the interaction between random and systematic measurement uncertainty.

The basis of the measurement and evaluation approach of the monitoring concept is formed by the precision and trueness indices of the monitoring methods used. Using these and the statistical methods for measurement uncertainty analysis according to GUM (JCGM 2008):

- different monitoring concepts can be compared and optimised in the sense of an a priori estimate, and
- after the measurement, the measurement results can be analysed statistically.

This process essentially involves probability-theoretical and statistical considerations. Details are not presented here; reference is made to the sources cited (JCGM 2008, DGGT WG 2.10 2022).

4.6.5 Documentation

The data, calculation records and result records collected in monitoring projects should be archived in accordance with the principles of traceability, transparency, correctness and unambiguity, prepared for the necessary experts and, where appropriate, made accessible to the public. It is recommended that the data be compiled in a (web-based) GIS which serves as an information and exchange platform (where appropriate also for a public participation process). Working Group 4.6 “Abandoned Mines” proposes the following model structure for a monitoring report:

- reason;
- objective;
- initial situation (including baseline measurement, status quo measurement) and historical situation as well as available, relevant open geodata;
- requirements for the monitoring;
- presentation of the monitoring concept and its duration;
- description of the monitoring method and the measurement methodology/measurement method;
- description of the data acquisition, storage and further processing procedures and evaluation methods, presentation of the method of the summary assessment;
- presentation of the individual monitoring results over time and, where appropriate, comparison with predicted values, as well as presentation and interpretation of changes;
- explanations of optimisations of the monitoring concept;
- summary assessment of the changes to the object and the area;

- conclusions.

4.7 Requirements for the final report on investigation and remediation work

The final documentation provides evidence of the investigation and remediation work carried out and forms the basis for future estimates of effects on the ground surface as well as for risk and hazard assessments. The final documentation also documents and archives the knowledge gained about the abandoned mine facilities and preserves it and keeps it available in the long term. In addition to the description and graphic representation, the main component of the final documentation is the expert assessment of the measure carried out.

As a matter of principle, final documentation is to be prepared for all measures on abandoned mine workings or underground cavities as well as spoil heaps and residual voids and handed over to the competent authority.

For simple works that have no significant influence on the abandoned mine situation, the final documentation can be reduced to a simplified form of presentation of results in agreement with the mining authority.

The requirements for preparing the final report are set out in the model structure (see Annex I). The bullet points are reminders that are to be verified on the basis of the specific implementation of the measure and then substantiated in the text. Necessary additions to the mine plans are to be checked and confirmed by a mine surveyor. The model structure presented in Annex I is not exhaustive and can be supplemented or adapted with regard to the respective case.

5 Selected references

DGGT AK 4.6 (2004): Empfehlung „Geotechnisch-markscheiderische Untersuchung und Bewertung von Altbergbau“ – Veröffentlichung 4. Altbergbaukolloquium 04. bis 06.11.2004 in Leoben, Anhang, S. 1–23, Verlag Glückauf Essen. [Recommendation “Geotechnical and mine-surveying investigation and assessment of abandoned mines”]

DGGT AK 4.6 (2020): Geotechnisch-markscheiderische Untersuchung, Bewertung und Sanierung von altbergbaulichen Anlagen – Empfehlungen des Arbeitskreises 4.6 „Altbergbau“. [Geotechnical and mine-surveying investigation, assessment and remediation of abandoned mine facilities – Recommendations of Working Group 4.6 “Abandoned Mines”]

DGGT AK 2.10 (2022): Empfehlungen des Arbeitskreises 2.10 – Geomesstechnik der DGGT. [Recommendations of Working Group 2.10 – Geotechnical Measurements of DGGT]

TAS: Technische Anforderungen an Schacht- und Schrägförderanlagen – Stand: Dez. 2005. [Technical requirements for shaft and inclined hoisting installations – status: Dec. 2005]

BVOS – Bergverordnungen für Schacht- und Schrägförderanlagen der Länder, z. B. Stand: 04.12.2033 (NRW), 15.10.2003 (Niedersachsen). [Mining ordinances of the federal states for shaft and inclined hoisting installations]

DIN 1054 – Baugrund – Sicherheitsnachweise im Erd- und Grundbau – Stand: Dez. 2010. [Subsoil – Verification of the safety of earthworks and foundations]

DIN 4020 – Geotechnische Untersuchungen für bautechnische Zwecke – Stand: Dez. 2010. [Geotechnical investigations for civil engineering purposes]

DIN 4118: Fördergerüste und Fördertürme für den Bergbau – Einwirkungen, Berechnungs- und Konstruktionsgrundlagen – Stand: Dez. 2018. [Headframes and winding towers for mining – actions, principles of calculation and design]

DIN EN ISO 9001 (2015) – Quality management systems – Requirements

DIN EN 1997 – Eurocode 7: Geotechnical design; Part 1: General rules and Part 2: Ground investigation and testing – status: 2010

Annex I – MODEL table of contents for the final report

I. Table of contents
   1. Reason for and objective of the measure
      – reason for taking action
      – brief description of the case
      – party responsible for the measure and parties involved
   2. Initial situation/basic data chapter
      – description of the location and morphology of the project area as well as location details
      – description of the regional geology, description of the geographical conditions
      – description of the geological conditions
      – overburden and country rock conditions, the deposit, the hydrogeology and the tectonics (faults)
      – description of the geotechnical and hydraulic conditions
      – description of the properties of the overburden and of the geotechnical and hydraulic conditions
      – description of the mining and mining damage conditions, presenting:
        ○ outline of the mining history,
        ○ mining title situation,
        ○ driving, support and, if applicable, backfill conditions,
        ○ condition of the object and, where applicable, the associated mine opening to the surface before the measure was carried out, and the preliminary risk/hazard assessment
      – description of the documents used:
        ○ archival records,
        ○ mine maps,
        ○ mining title files,

    - historical documents etc.
3. Investigation and remediation concept
   - description of the planned programme of risk/hazard investigation or of the planned measure for risk/hazard prevention
   - objective and procedure for achieving the objective
4. Documentation of the investigation and/or remediation work carried out
   - overview and sequence of measures during construction
   - preservation of evidence
   - type and scope of the investigation work
   - type and scope of the reopening work
   - type and scope of the remediation work
   - presentation and evaluation of mass balances
   - deviations from the planned implementation of the measure
   - restoration of the ground surface
   - special features (e.g. backfill escapes, crown holes, etc.)
5. Quality control and assurance
   - control or verification boreholes
   - building materials used
   - building material tests
6. Survey and monitoring programme
   - horizontal or vertical measurements or crack monitoring
   - expert review
7. Geotechnical and mine-surveying assessment of the subsequent use of the remediated area
   - result of the measure
   - mine-surveying documentation (control points used, reference systems (horizontal, vertical), interpretation of the results including an assessment of the accuracy of the mine plan (rate of missed boreholes, causes))
   - calculation of the backfill factor
   - assessment of the permanent stability of the ground surface
   - delimitation of the scope of remediation
   - where applicable, information on the sealing of mine openings to the surface
   - notes on subsequent use (if necessary, restrictions of use) and
   - reassessment of risk, including assessment of the residual risk
   - inspection and maintenance regime
8. Summary

II. List of figures

III. List of annexes

Annex 1: Topographic overview map

Annex 2: Site plans according to sheet layout (with graphic representation of the affected zone of influence and, where applicable, risk areas)

Annex 3: Detailed site plans/representation in the mine plan: backfill, risk area including risk class after the measure; cadastral situation and special features

Annex 4: Sections showing the technical measures

Annex 5: Photo documentation of the measure (object-related) for the preservation of evidence (actual situation of areas, special features (e.g. geotechnical events, backfill escapes, if applicable cracks in buildings as a result of the remediation measure, final condition of areas))

Annex 6: Proof of stability or structural calculations or drilling and probing logs (including proof of proper removal of support and backfilling of boreholes)

Annex 7: Test reports, quality certificates, product data sheets as well as sampling and laboratory reports

Annex 8: Acceptance record

Annex 9: Survey records including sketches

IV. Bibliography/documents used

V. Abbreviations

Annex II – ADDITIONAL INFORMATION on evidence

> Note: The proposals are to be adapted to the specific project.

Evidence of economic and financial capacity

- extract from the professional or commercial register, not older than 6 months;
- current presentation of the company structure as well as of interdependencies and shareholdings under company law;
- certificate of registration with the competent employers' liability insurance association;
- declarations on the (non-)existence of insolvency or similar proceedings;
- declarations on the (non-)existence of entries in the central trade register;
- payment plan;
- certificates, e.g. quality management (ISO 9001), occupational safety (ISO 45001, SCC certification), environmental protection (ISO 14001).

Further declarations that the engineering consultancy meets its entrepreneurial obligations, e.g. payment of social security contributions, payment of taxes, total turnover of the company, bank reference, operational liability insurance, may be requested.

Evidence of technical and professional capacity

- references from the recent past, e.g. the last 3 years, of comparable size and task, with a brief description of the services provided and completed by the applicant; success reports/press releases of the client (e.g. website, public media);
- assurance by the applicant that it can provide the required services; details of the applicant's persons who will work on the project if the contract is awarded, with their position in the project: name, CV and references:
    - evidence of staff capacity,
    - training certificates of staff (e.g. further training certificates, drilling rig training);
- evidence of the equipment and machinery intended to be used;
- proofs of suitability of building materials (environmental compatibility, mechanical properties, availability), where applicable a licence for handling radioactive substances;
- a self-declaration that the applicant has a quality management system in accordance with DIN EN ISO 9001 or equivalent may also be required;
- construction schedule/timetable.