Returning the WISMUT Legacy to Productive Use

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> …- Cela est bien dit, répondit Candide, mais il faut cultiver notre jardin »
> Voltaire, Candide

Abstract. The prime goal of the Wismut environmental remediation (ER) project follows from the legal requirement to abate health risks, mitigate existing environmental damages and prevent future hazards.

The extent of remedial measures is derived by investigation of the object-specific remediation feasibility rather than by application of uniform standards. The ER workflow, unlike common civil engineering projects that are a linear succession of tasks, is an iterative process. Within the ER workflow, Conceptual Site Models (CSM) guide the optimization of designs and investigations while both operational works and environmental base line are monitored. The acquired data are collected and analyzed on a corporate wide level to provide decision-making support for senior management.

In the present, advanced stage of the Wismut remediation the reutilization of the reclaimed areas and objects is receiving an increased attention. There are no legal restrictions on utilization of areas, which received a complete clean up. Utilization of areas, waste rock piles and tailings ponds reclaimed for restricted use allows only settlement of industry and trades or forestation, however, exemptions are possible if the responsibility for long term monitoring and maintenance are satisfactorily ensured. A mutually beneficial integration of reclamation plans with the communal/regional development has been successfully practiced in two former

mining towns, the first leading to rebirth of the health spa in Schlema and the second helping the preparation of the Federal Garden and Landscape Exhibition in 2007 (BUGA 2007) hosted by the towns of Ronneburg and Gera.

Background

Between 1945 and reunification of Germany (1989) more than 231 000 t of U_3O_8 have been produced in Saxony and Thuringia, East Germany. The mining and milling sites are in Fig. 1.

The mining and milling operations affected an area of approximately 100 km^2 and left behind probably the "worst" uranium-mining legacy in the world. The inventory and range of liabilities left behind at the time of production closure in December 1990 was as follows:

Operations areas (37 km^2), five (5) large underground mines, an open pit mine (84 M m^3), waste rock dumps (311 M m^3) and tailings (160 M m^3). The specific activity of the waste rock is 0.5 to 1 Bq/g and of the tailings up to 10 Bq/g.

To proceed with the Environmental Remediation (ER) of this legacy, a special "Wismut Act" has been passed in the Federal Parliament, December 1991. Based on this Act the Federal Government committed DM 13 billion (€ 6.6 billion) to the ER Program (the sum was later revised to € 6.2 billion) and for purposes of reclamation the national corporation Wismut GmbH was established.

Initially there was no sufficient and proven uranium mine closure experience available in Germany and, in order to commence work without delay, extensive use has been made of the experience available internationally. Cooperation was sought with the US Department of Energy's UMTRA Project and the relevant institutions and companies in Canada. Yearly international topical workshops were

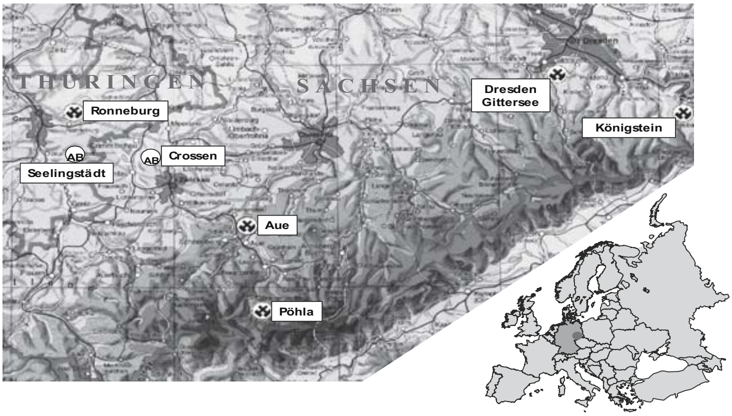


Fig. 1. Mining and milling sites of Wismut.

organized at Wismut to foster know how acquisition and identify suitable technologies to be adopted; Regular meetings of the Uranium Mine Remediation and Exchange Group, UMREG served as a platform for international peer review of the envisaged concepts, methodologies and regulatory approaches.

Objectives and scope of the Wismut Remediation Program follow from the legal requirements of the "Federal Mining Law" (*BbergG*) stipulating the owner's obligation to abate public hazards and mitigate damages caused by mining as well as prevent future hazards after mine closure, "Ordinance for provision of radiation protection for waste rock dumps and industrial settlement ponds and for use of materials deposited therein" (*HaldAO*) regulating the radioactive aspects of remediation and "Water Resources Management Act" protecting surface and ground water from contamination.

The paper views the reclamation of the Wismut legacy as an opportunity to return the affected land, mining and milling waste sites to productive use, thus enhancing the revitalization of the former mining areas in Saxony and Thuringia.

Reclamation Management Framework

The remediation process

Prior to commencement of remedial measures, the pre-existing status of the area deemed to have been affected by mining/milling activities (approximately 100 km^2) was appraised in an initial gamma radiation survey in 1990. The initial characterization survey showed that approximately 85 % of the "affected" area had near background levels of radiation and could be released for unrestricted use.

Following initial survey, the reclamation focused on five mining sites (Ronneburg, Aue/Schlema, Poehla, Koenigstein, Gittersee) and two mill sites (Seelingstadt and Crossen). Conceptual remedial designs and closure plans were developed for each site, often concurrently with preparation of detailed designs and plans. The basic remediation goal (*s. s.*) follows from legal requirements of the Federal Mining Law, Radiation Protection Ordinance and Water Resources Management Act. Compliance with legal requirements can be achieved by straightforward technical measures such as, (a) excavation and relocation of contaminated materials, (b) reshaping of the affected areas, waste rock piles and tailings deposits to stabile landforms having slopes resisting erosion and providing good surface runoff, (c) covering of contaminated areas and objects to contain the health and environmental hazards and support vegetation, and (d) treatment of seepages and discharges.

At the present stage of the Wismut project, the implementation of the remedial measures is done in 14 projects coordinated from 3 Site Management Units (Ronneburg, Aue and Königstein). Strategic direction, feedback, optimization and specialists support is provided from the Head Office in Chemnitz.

Remedial work at Wismut begins with preparation of an object-specific Environmental Impact Assessment (EIA) specifying the type and extent of physical measures to be taken. Although the preparation of EIA sometimes necessitates the acquisition of additional data and performance of investigations, it has the advantage of a transparent and traceable justification of the extent of remediation. The object-/ site-specific EIA approach has been selected over the use of prescriptive environmental limits because the EIA directly relates the extent of remediation to the actual level of risk presented by the contaminated area or object. Thanks to this approach a better remediation economics has been achieved than by use of a prescriptive generic “one solution fits all remedial problems” approach, which in most cases leads to over-engineering and consequently to excessive costs.

The radiological impact is measured by the effective individual dose, calculated for realistic release and uptake scenarios. If the calculated dose in excess of the background level exceeds the 1 mSv per year –a limit recommended by the International Commission for Radiation Protection, ICRP- the required remedial measure is specified such to achieve compliance with the 1 mSv per year criterion. Along with the radiological impact assessment, the regulated limits for conventional contamination are observed as well (e.g., As is a commonly occurring contaminant, which may take precedence over radiological impact). Following impact assessment, the feasibility of remedial design options is evaluated based on cost/benefit analysis.

Unlike in regular civil engineering projects, the implementation of the remedial measures is an iterative process rather than a linear succession of tasks, Fig. 2 (WISMUT 1995).

Although most of the delays in the remedial workflow occur due to the feedback loop created by the regulatory process, sometimes they are caused by inadequate knowledge, need of additional data and investigations. This is particularly the case for contaminants sources collocated at the same site. For optimization of the engineering solution and additional data requirements as well as prioritization of the additional remedial investigations and measures in such cases the use of a Conceptual Site Model (CSM) proved to be very helpful (Jakubick, Kahnt, 2002).

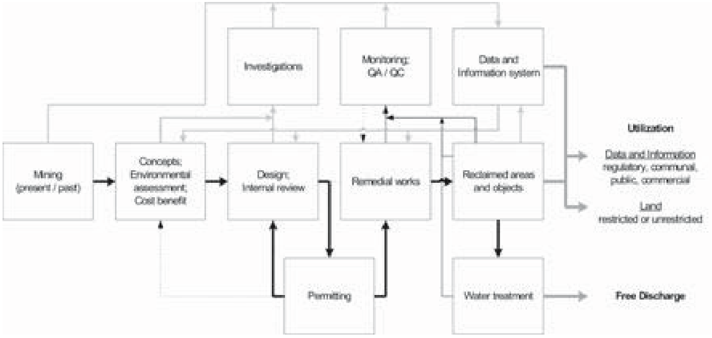


Fig. 2. Remediation process flow, products of remediation and subsequent utilization.

Data Management

The reclamation workflow is managed by an SAP based interactive, process oriented system equipped with applications and tools sufficiently flexible to adjust to the changes occurring in course of the reclamation progress.

For data and information management an interactive, object oriented system has been created that makes the heterogeneous databases accessible on a corporate wide basis, while leaving maintenance and updating responsibilities at the data source level. The typical data/information content of the database comprises documents, photographs, object-related data, monitoring data, measurements and digital maps, geo-referenced aerial survey photographs.

Data transfer is realized through a web-based access to the “source” databanks with subsequent placement of the requested data in an object related (holding) databank on a central ORACLE server (Fig. 3). This allows fast overviews, rapid applications, specific data quires to answer multifaceted questions that require overlaying of different types of data and information. Tasks, using locator and intersection functions for geometry-based data (polygons of objects, locations of measurement points), handled otherwise by GIS can be easily accomplished using the capabilities of the databank. Users access to a continuously updated GIS supported information system is provided at all times and the only requirement on the user side is an internet explorer and fast internet access (DSL). Data safety is secured by applying very stringent conditions to the inter-/intranet access.

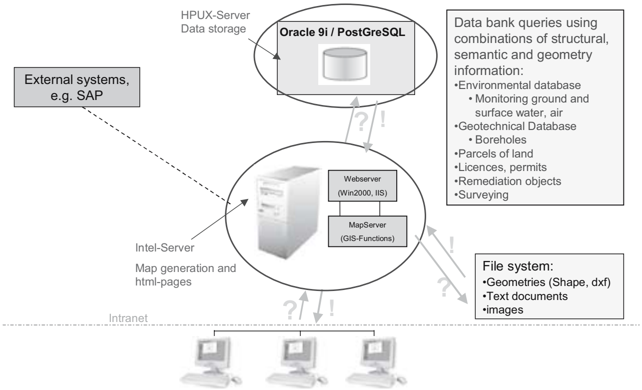


Fig. 3. Technical Data and Information management system used to integrate detached heterogeneous databases.

Implementation of Remedial Measures

Contaminated areas

The reclamation goal for contaminated areas is (whenever feasible) to maximize the number and size of areas reclaimed for unrestricted use, which usually requires a complete area clean up.

Waste rock

Reclamation of waste rock piles is by reshaping/stabilization and covering *in situ* or by relocation to a central pile or into the open pit mine.

At Ronneburg, the waste rock piles located near the surface mine were relocated into the open pit thus resolving both the remediation of the waste rock piles and the stabilization of the open pit. The backfilling procedure follows the strategy of placing the waste rock with the highest acid generating potential (i.e. with high pyrite content) on the bottom of the pit into a zone below the groundwater level anticipated after flooding of the underground and surface mines, thus preventing oxidation of the acid generating minerals and development of acidic seepage (Jakubick, Gatzweiler, Mager, Robertson, 1997). Waste rock containing an overabundance of alkaline minerals is placed in the upper part (zone) of the pit, Fig. 4.

Following the described procedure, approximately 40,000 m^3 of waste rock per day are relocated into the pit.

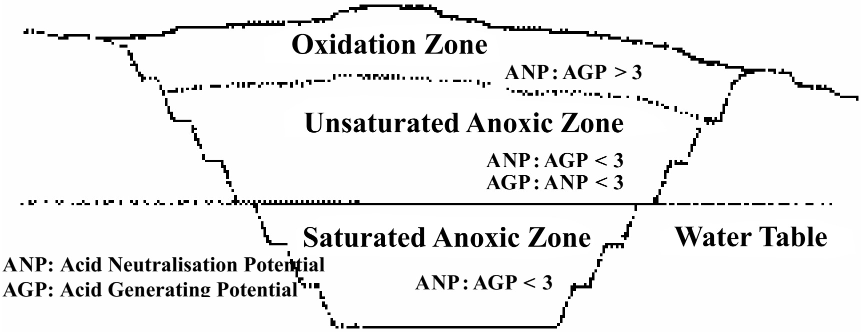


Fig. 4. Backfilling strategy of the open pit mine at Ronneburg. Acid generating waste rock is placed in the saturated anoxic zone, neutral waste rock in the unsaturated anoxic zone and alkaline waste rock into the oxidation zone.

Tailings ponds

The objectives of remediation are stabilization of the tailings mass, provision of erosion stability and prevention of environmental contamination (WISMUT 1999). The tailings ponds at Wismut are reclaimed as “dry landforms”. The “dry” reclamation strategy was justified by using a probabilistic risk assessment under consideration of the remedial costs, health and environmental benefits as well as socio-economic factors with the aim to develop a site-specific remedial solution sustainable in the long term.

The results of the risk analysis for the Helmsdorf tailings pond are presented in Fig. 5 in terms of cumulative probability of equivalent costs (sum of reclamation costs and environmental benefits -including costs of post reclamation maintenance and repairs) over the lifetime of the reclaimed tailings object. The comparison of the “dry” and water capped remedial solutions in Fig. 5 shows a better performances for the dry reclamation above 65 % of cumulative probability, i.e. in the long term, when less probable events of severe consequence (such as dam failure) enter consideration (Roberds, Voss, Jakubick, Kunze, Pelz, 1996). In the short and mid term (up to a cumulative probability level of approximately 65 %), the remedial solution using a water cap (similar to the solution implemented at Elliot Lake) promises a better economic performance. Whether decision-making should consider low probability, high consequence events or not depends on the socio-economic factors relevant for the site. In case of the Helmsdorf site, the seismic zoning of the area and the fact that the main tailings dam is located only 150 m upstream from the community of Oberrothenbach made it necessary to include the possibility of an earthquake in the analysis and consider consequences of a dam failure. The obvious result was the preference of a dry remediation, which precludes any liquefaction of tailings.
On a more general level, Fig. 5 demonstrates that ultimately, beyond cost/benefit

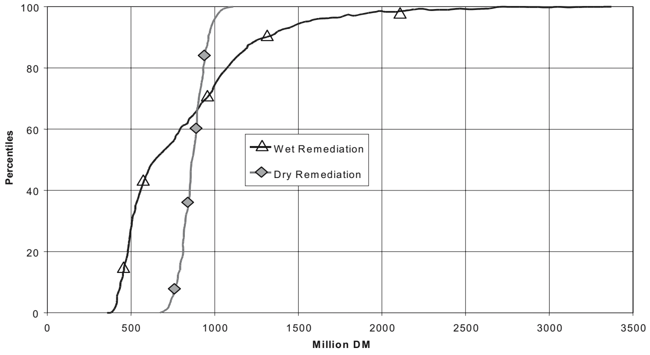


Fig. 5. Equivalent Costs (remedial costs minus environmental gains) for the Wet and Dry Tailings Reclamation Options for the Helmsdorf tailings pond.

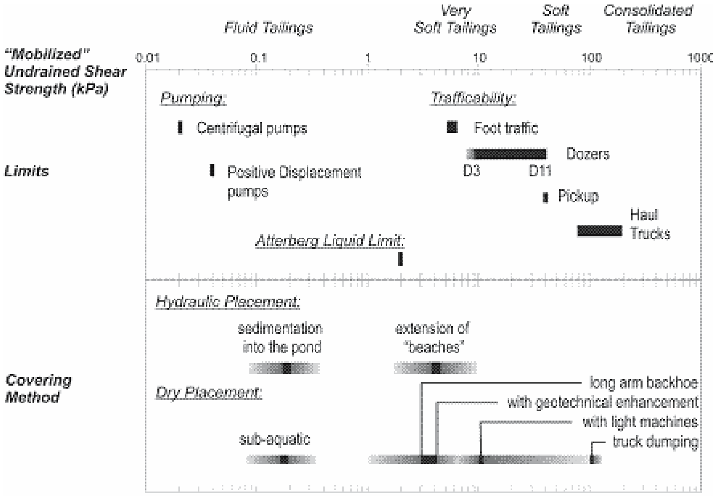
considerations, decision-making in reclamation is controlled by stakeholder's related socio-economic factors.

An overview of the most common technologies, used (worldwide) for stabilization of tailings and limits of their applicability are summarized in Fig. 6 (Jakubick, McKenna, Robertson, 2003). The suitable ranges of application of a particular technology depend primarily on the state of consolidation of the tailings, which is expressed in Fig. 6 in terms of the *in situ* shear strength of the tailings/slimes.

Final Covering

All landforms created out of reclaimed tailings deposits, waste rock piles (remediated *in situ* or relocated into the open pit) receive a final cover designed to reduce radiation, radon exhalation, and limit infiltration and support vegetation of the surface. An exhaustive overview and international comparison of various cover types has been presented at UMREG 2002 (Hagen, Jakubick, Lush, Metzler, 2003).

For steep waste rock pile slopes (1: 2 to 1: 2.5), Wismut experience shows that using cover designs resembling soil profiles indigenous to the area and avoiding any unnecessary interlayering that could act as a sliding plane provides usually the most stabile cover design. The relatively simple, 1 m thick, two-layer cover system (Fig. 7) used for the waste rock piles in the Ore Mountains (Erzgebirge) showed an excellent performance during the period of extreme rainstorms and inundations in August 2002. The weather event brought a multiple of the hundred years precipitation to the region and was rated as the highest rainfall expected in thousand years. Wherever the cover had been completed and the vegetation estab-



Note: "limits" refers to lower bound of operational strength

Fig. 6. Limits and ranges of safe trafficability of the tailings surface and feasibility of various tailings stabilization technologies in dependences to the *in situ* shear strength of the tailings.

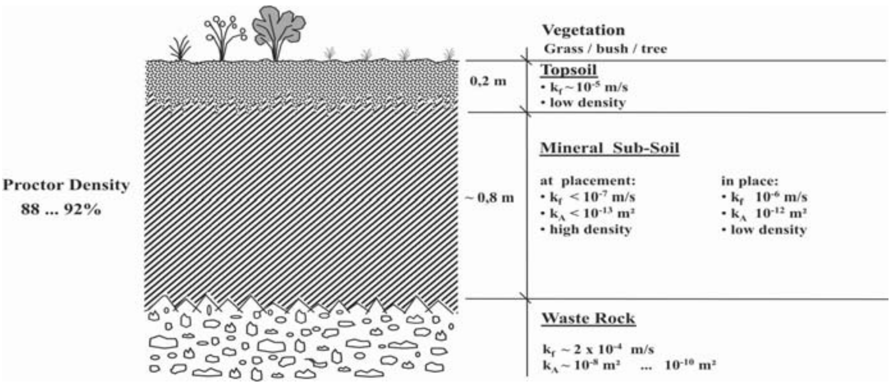


Fig. 7. A two-layer cover system emulating natural soils used at Schlema.

lished, no damage to the cover occurred. Based on the evaluation of the state of the cover after this unexpected natural test it could be concluded that the long term resilience and functionality of the described cover has been effectively proven.

One of the key performance objectives of final covers placed on uranium mining waste rock and mill tailings are, beyond physical protection of the contained contamination, radon attenuation. A novel type of assessment of long-term radon attenuation of covers has been demonstrated at Wismut (IAF Radioökologie GmbH, 2002). The method is based on measuring traces of lead (Pb-210) in the remediated object and in the cover placed on the object.

The lead traces Pb (z) are estimated as the depth-dependent differences of the specific activities of Pb-210 and Ra-226 in a cover layer:

$$\text{Pb}(z) = A_{\text{Pb-210}}(z) - A_{\text{Ra-226}}(z)$$

The method is primarily suitable for testing of covers older than 30 years and is based on growth of Pb-210
($t_{1/2}$ = 22 a) from Rn-222 ($t_{1/2}$ = 3,8 d), a daughter product of Ra-226 ($t_{1/2}$ = 1590 a), which is usually the main contaminant in uranium tailings.

In covers providing adequate sealing, most of the radon decays into Pb-210 after a penetration depth of 1 to 5 cm. The lead traces show discernibly positive values and the sum of the specific activities of the lead traces below and above the cover-object interface is positive.

In inadequate covers, the positive lead traces above the cover-object interface are weak (little accumulation of Pb-210) and the lead traces in the tailings or waste rock are strongly negative due to weak attenuation of radon transported toward the cover. The sum of the specific activities below and above the interface is negative.

Fig. 8 shows the performance of an inadequate tailings cover constructed more than 30 years ago. The thickness of the cover is 50 cm and consists of a single layer of mineral soil (mostly sand). The lead traces measured are clearly negative, evidencing that a 50 cm cover layer of the sandy material used is insufficient to provide adequate radon attenuation.

Flooding of mines

The mine flooding is done in a controlled way to prevent contamination of surface water bodies and of aquifers serving as water supply (Jakubick, Jenk, Kahnt, 2003). Mine water discharges are in order of 50 to >1000 m^3/h, depending on the characteristics of the mine. Other discharges in need of treatment arise from dewatering of tailings ponds (several hundreds m^3/h) and from waste rock dump seepages (1 to 30 m^3/h). The water treatment residues (containing approximately 500Bq/g) are disposed of into waste rock piles and tailings.

Observations of mine discharges, which present the largest long-term source of contaminated water, indicate that the initial peak load of contaminants decreases within several years more or less exponentially (WISMUT 1997). After the peak load is over, it is to be expected that treatment requirements decrease as well, allowing the introduction of alternative, more cost-efficient methods.

Scrap metal

During remediation, considerable amounts of contaminated debris and scrap metals arise from demolition of structures. The contaminated metal components have a total alpha surface activity (TAA) in the range of mBq/cm^2 to Bq/cm^2 (of U-238 and daughters). After demolition, contaminated and non-contaminated scrap metal usually ends up intermixed in unsorted heaps, showing typically a contamination distribution as presented in Fig. 9.

The separation of non-contaminated metal for recycling requires a reliable discrimination from contaminated material. To improve selectivity without giving up using standard portable, large surface (beta) contamination monitors in the field, a sophisticated method of calibration and measurement has been introduced. Based

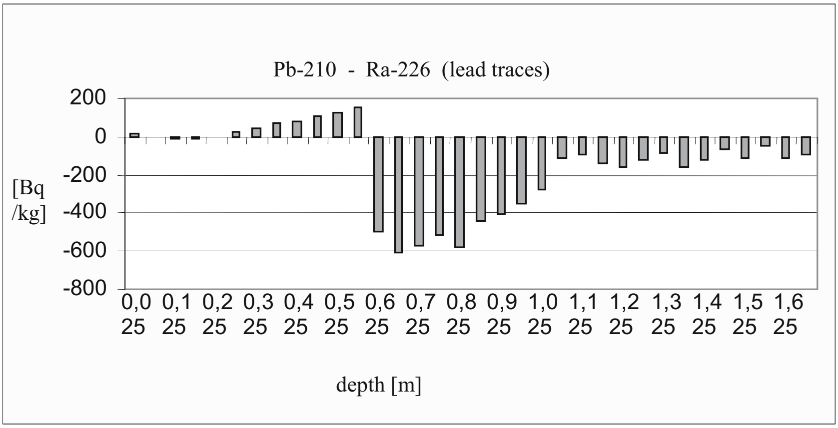


Fig. 8. Distribution of lead traces in a cover- tailings system at Lengenfeld. The cover was built in 1970s .

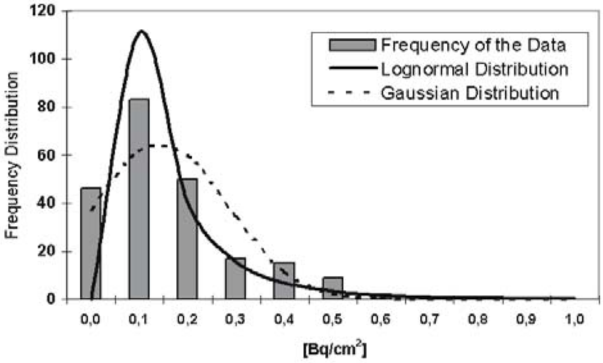


Fig. 9. Typical contamination frequency distribution of TAA values in a scrap metal heap at WISMUT.

on the operational history of the particular facility and/or equipment dismantled, the level of contamination is pre-categorized and the anticipated nuclide vector and index nuclide established in the laboratory. Prior to the field campaign, the field instruments are calibrated against laboratory measurements of the specific waste type. Following this procedure, the estimation of TAA from the measured beta-count rates proved to be feasible with the required accuracy.

The decision whether to release or disposal of the scrap metal is based on the comparison of the TAA reference value (0.5 Bq/cm^2) with the upper limit of the confidence interval (95 % confidence value) applicable to the particular contaminated scrap metal heap.

The contaminated metal, which cannot be released, is disposed of into tailings, open pit backfill or waste rock piles. Investigations demonstrated that the risk potential of these objects increases only marginally due to the added scrap metal.

Monitoring

Operational monitoring

Operational monitoring of the ongoing remedial works is part of the radiation safety plan for protection of workers, general public and environment exposed to the contaminants handled in course of remedial works.

The monitoring is done at the working site where the emissions arise and at places where impacts may be expected. The purpose of operational monitoring is to observe whether in course of handling of environmental, radiological or chemical contamination the regulated standards are kept and the contaminants release does not lead to unacceptable radiological or chemical exposure. In addition to measurements of direct gamma radiation, critical radionuclides and chemical contaminants, great emphasis is placed on measurement of dust emission (that may contain long lived alpha emitters and toxic elements). Sprinkling (water trucks) is applied routinely to prevent dusting at working places and construction roads during dry periods. Commonly, water arising on the site is used for sprinkling, which is then recycled within the site.

Monitoring of the environmental baseline

The monitoring program was designed with consideration of the fact that the remediation is carried out as an intervention measure mitigating a pre-existing situation. Because pre-mining baseline measurements were unavailable for the remediation sites, the monitoring program was developed on the basis of the initial characterization survey (see "The remediation process" section) and predictive analysis of the exposure pathways.

The baseline monitoring network is used to measure the level of contaminants typical for Wismut sources and related parameters in surface and ground water, seepage, air (particulates and radon), gamma radiation levels, soil and, in some instances in the human food chain. Good overviews of the Wismut approach to monitoring and of other international monitoring programs are provided in (UMREG'03).

The monitoring of liquid discharges demonstrates very well the effectiveness of the first remedial measures: Beginning of 1990 the Wismut discharges carried a uranium load of approximately 28 tons, which already 1998 decreased to less than 4 tons of uranium per year. The decrease since 1998 was less spectacular but continual and the Uranium load presently amounts to approximately 3t per year. A similar decrease pattern has been recorded for Ra-226: Early 1990 the discharges contained more than 23 000 MBq Ra-226, which decreased to less than 300 MBq by early 2004.

Completion of reclamation, release from regulatory supervision and long-term stewardship

Upon completion of remediation of an area or object, a final certificate is issued, which presents the basis for application for release from regulatory supervision. Presently, with more complex objects nearing completion the need arises to submit the reclaimed areas and objects to final assessments and, based on the results, adjust the extent of monitoring the future needs.

Concerning data management it follows that for purposes of long-term stewardship it is necessary to retain (WISMUT'05):

- Key data on the inventory and on the "as-remediated" status of the reclaimed areas and objects
- Environmental monitoring data
- Predictions re long term performance along with supporting documentation, such as CSM

The Wismut data system is to serve as an evidence of proficiency of the remedial measures and provide support for:

- Management of the “Wismut real estate”,
- Handling of claims and liability issues,
- Handling of information requests of investors, regional and communal developers,
- Handling of public inquiries,
- Continual adjustment/optimization of water treatment to the development of mine and seepage water characteristics.

In addition, the Wismut data bank system is to serve as a remediation knowledge base and help answering questions in case of potential repairs.

In agreement with the regulator a post-remediation period of five years has been foreseen by Wismut as a “remediation warranty“ period during which the performance of the reclaimed objects regarding erosion, geomechanical failure, direct gamma radiation, radon emission and seepage control will be monitored.

After conclusion of physical remedial works and establishment of stable conditions, the number of monitoring points and frequency of measurements will be adjusted and reduced to the slower rate of changes typical for natural processes.

The duration of the post-warranty phase monitoring is currently a matter of dispute with the regulator.

Utilisation of reclaimed areas and objects

The most tangible results of remediation are the reclaimed land, rehabilitated waste rock piles and tailings. Observing the experience made by external projects led us to conclude that both sustainability of the remediation results and post remedial stewardship is best guaranteed if the reclaimed land and objects are put to productive use (irrespective whether unrestricted or restricted). To achieve this goal,

a) in addition to containment of the health and environmental risks, the socio-economic effect of environmental reclamation, particularly its contribution to the regional revitalization and development must be given due (sometimes even decisive) consideration, and
b) the future use of the reclaimed areas/objects should be specified prior to reclamation.

We believe that value added results can be achieved at no additional (or at reimbursable) costs, if reclamation is done with a well-defined utilization in mind (WISMUT 2004). *Vice versa*, successful utilization goals can only be developed in cooperation with the future user (i.e. municipality or developer), community and regulatory authorities. If consensus is achieved with the stakeholders prior to remedial works, a “reclamation by objectives” becomes practicable, i.e. the objectives for the individual remedial steps can be set consistent with the ultimate utilisation goal.

Concerning utilization, there are no legal restrictions placed on areas completely cleaned up of contamination. Considering the population density of Thuringia (154 inhabitants per km^2) and Saxony (247 inhabitants per km^2), there are usually no problems finding interested parties for the land, which had been completely cleaned-up.

However, given the high costs of a complete clean up and the relatively small risk presented by slightly contaminated areas, a remediation aiming for unrestricted utilisation cannot be justified in many cases. In line with the recommendations of the German Commission on Radiological Protection (SSK-92, volume 23) a partial reclamation can be performed in such cases; the restricted utilisation usually implies that only settlement of industry and trade is recommended.

The utilization of waste rock piles and tailings ponds is regulated by the “Ordinance for provision of radiation protection for waste rock dumps and industrial settlement ponds and for use of materials deposited therein, (HaldAO)”, which specifies forestation as the eligible utilization. Although the type of utilisation in the above cases is restricted, exemptions to the recommended utilisation are possible, if the obligations for long-term stewardship can be satisfactorily settled. The economic objective under the exemption rule is to find a potential utilization, which could at least partly cover the costs of the long-term monitoring and maintenance.

Reclamation with the objective of implementation of a specific utilization often requires an extensive soil conditioning in addition to the “regular” remediation (following strictly legalistic sense). We are of opinion that soil conditioning in such cases is not “additional costs” but present the price for avoiding maintenance costs at a later point; Indeed, a value added upgrading of a remediated area/object should be viewed as an investment into making future utilization possible.

The most common utilizations of reclaimed areas/objects are forestation or establishment of green fields. Forestation has the advantage of being a low maintenance utilization option, sustainable in the long run.

The rationale for implementation of more “creative” types of utilization such as establishment of a golf course, ground for model plane practice, erection of solar panels, etc. is that these uses act as seeds for further regional/communal development.

A good example of successful integration of reclamation and town (re-) development is provided by the city of Schlema, where recreational facilities, such as the health spa, parks, promenade, golf course, etc. were established on a backfilled and rehabilitated mine subsidence area and on rehabilitated waste rock piles.

Major impulses for the development of the former mining towns of Ronneburg and Gera are expected to come from the Federal Garden and Landscape Exhibition in 2007 (BUGA 2007), the planning of which is closely related to the progress of reclamation works in the open pit mine located near the town of Ronneburg.

Furthermore, even if not always fully realized by the stakeholders, the mine and seepage waters discharged after treatment often present an important contribution to maintaining a steady flow in the streams managed by the regional authorities usually affecting a substantial improvement of the environmental quality of the water as well.

Lastly, it must be clearly stated that the know how acquired in course of Wismut remediation presents a unique commercial asset, which is to be utilized as broadly as possible both locally and for the benefit of the numerous areas in need of post mining reclamation.

Technology transfer

In course of remediation a considerable degree of work standardization has been achieved and since 1995 the Wismut remediation technology has been applied in a number of external projects, mainly in Central and Eastern European countries, Russia and Central Asia. The external activities mainly focused on (1) assistance with concept development, planning, engineering and procurement of works, (2) specialized training and education and (3) auditing and project monitoring (STETE European Security, 1/2004). Since 2002, the responsibility for external activities lays primarily with WISUTEC GmbH, a commercial daughter of WISMUT GmbH.

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