

COST-BENEFIT ANALYSES AS BASIS FOR DECISION-MAKING IN ENVIRONMENTAL RESTORATION

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An approach is presented for the integrated assessment of clean-up options at contaminated sites. It is applicable to complex environmental situations, such as those frequently encountered at uranium mining sites with a mixture of radiological and non-radiological contaminants present. The methodology presented can also be applied to other problems in the area of environmental restoration where the decision-making about clean-up measures is faced with a variety of risk components affecting humans and the environment.

The approach is based upon a quantification of risks to humans and ecosystems caused by radiological and chemical contaminants. Human health risks are expressed as a loss of life expectancy. This concept is directly applicable to lethal health effects such as cancer. For non-lethal health effects from toxic substances, the deterioration of the quality of life is evaluated and combined with the lethal risks into the common assessment parameter "mean effective loss of life expectancy" (MEL). This parameter is converted into an equivalent monetary value as the basis for a cost/benefit analysis. Damage to ecosystems, in particular surface water systems, and resources (drinking water) is similarly expressed in monetary terms, based on the societal willingness and ability to pay for the prevention or mitigation of ecological damage. On this basis, clean-up options can be assessed in terms of their benefits in relation to the effort, i.e. financial expenditures, required. Uncertainties in the basic data and assumptions are taken into account using probabilistic simulation techniques (Monte Carlo simulations). The approach establishes a basis for rational and transparent decisions about clean-up measures.

The described approach has been developed and tested with regard to concrete situations, particularly in connection with the clean-up at uranium mining sites in Saxony and Thuringia. The paper describes and discusses the methodologies employed and gives a concrete example from the uranium mining reclamation program carried out by WISMUT GmbH.

INTRODUCTION

The clean-up of contaminated sites requires appropriate and efficient methodologies for the decision-making about priorities and extent of remedial measures, aiming at two, usually conflicting, goals:

- to protect people and the environment by reducing detrimental impacts to the extent feasible, and
- to save money and other resources.

Finding the cost-effective balance between these two primary objectives often is complicated by several factors. Examples are incomplete data or a variety of different factors of influence to be considered. Sensible decision-making in this situation requires the use of appropriate methodologies and tools which assist in identifying and implementing the optimal solution. The paper discusses an approach developed in Germany to achieve environmentally sound and cost-effective

solutions. This includes the presentation of approaches for mixed wastes, which are of particular relevance for the reclamation of mining sites, but also have to be dealt with in other areas.

MINING WASTES IN GERMANY

One of the most difficult environmental problems unification has confronted Germany with, has been caused by the uranium mining in East Germany. This has been carried out by the Soviet, later Soviet-German, company WISMUT from the end of WWII until 1990. In addition, traditional mining (silver, nickel, copper and hard coal) of materials with an elevated uranium content has taken place for several centuries in the southern part of the former GDR. Pollutants released from these contaminated sites can affect water, soil and air, usually leading to complex environmental problems.

The situation at the former uranium mining sites in Saxony and Thuringia is particularly complicated, because these large areas affected by mining lie in densely populated areas. The chief residues from the mining and milling activities are:

- Waste rock heaps with approx. 300 million m³ total volume.
- Tailings impoundments, in which the sludge residues from uranium extraction have been dumped, with a total volume of approx. 200 million m³.
- Extensive underground excavations.

In addition, there are operating areas, plants, roads and other areas directly or indirectly affected by the mining. The majority of these mine residues is located on sites which are still in the ownership of WISMUT. An overview of the areas and volumes of the major mining and milling relics for the different WISMUT sites is given in Table I. WISMUT carries out the reclamation activities at these sites on behalf of the Federal Government. The reclamation work has started in 1990 and is expected to last well into the next century. The overall budget estimate for this program is 13 billion DM. More detail about this reclamation program is given, for example, in [1] and [2].

Table I: Area and volume of the major WISMUT mining relics

Site	Area [ha]	Volume [million m ³]
Tailings Crossen	250	45
Tailings Seelingstädt	335	107
Heaps Seelingstädt	520	60
Heaps Ronneburg	620	188
Heaps Aue	311	45
Heaps Königstein	27	3
total	2085	450

A large number of smaller uranium mining and milling sites of the early years of mining already had been transferred to the ownership of GDR authorities in the Fifties and Sixties. These sites are not included in the reclamation program carried out by WISMUT. Knowledge about these sites (size, type of waste, radioactive inventory etc.) has been quite poor in 1990. Therefore, the Federal Government decided to launch an investigation program to identify the relevant old mining sites and to collect data for a first assessment of radiological risks incurred by these sites. This investigation program is also directed at sites from traditional mining operations, dating back into the Middle Ages, which have produced and processed ores with elevated contents of natural radionuclides. Also included are sites from recent copper mining, which has resulted in substantial amounts of slightly radioactive waste, too. After the first registration phase of the project a total of about 5.000 mining related objects was identified, which then were subject to later investigations and assessments.

An overview of the situation and the investigation and reclamation programs launched is given, for example, in [3].

The following section gives an overview of the regulatory background with respect to uranium mining and milling residues. An approach for assessing reclamation activities at complex sites, such as those dealt with in the WISMUT reclamation program, is described in Section 5.

REGULATORY APPROACH

The German Commission on Radiological Protection (SSK) has issued a number of recommendations including criteria for the determination of reclamation necessities at contaminated sites. [4]. As a primary reference level it is recommended, following the recommendations of the International Commission on Radiation Protection (ICRP) [5], to use an individual effective dose of 1 mSv per annum in addition to natural background for the use or release of sites, waste rock heaps and buildings from uranium mining. This is consistent with the criterion stipulated by the former GDR radiation protection ordinance applicable to mining activities in the presence of enhanced levels of natural radionuclides, which of course includes uranium mining.

Using a dose limit corresponds to a risk-based approach, within which decisions about reclamation measures are based on actual risks to the population. This is different from criteria used elsewhere, for example within the US UMTRA project for the reclamation of uranium tailings impoundments from the military uranium production [1]. In that remediation program activity concentrations are prescribed as site-independent reclamation targets. Such a practice does not consider real risks at the sites as is done with the application of a dose criterion for the determination of reclamation goals in the German program. This difference has to be seen with regard to the different situation in the United States. For example, the population density in the vicinity of most of the UMTRA sites is, in contrast to the German situation, very low, so that a dose-related criterion would not necessarily be suitable for decisions on remediation measures. In the German situation, however, the application of site-independent intervention levels or reclamation targets would be almost impossible and at least extremely unfavorable from an economical perspective. These criteria would have to be very strict in order to appropriately address the situation at all sites, i.e. they would have to be determined by the most unfavorable site conditions occurring. Application to other sites with more favorable site conditions, would then result in

doing more than really required at those sites in terms of actual risks and, consequently, in a substantial waste of money.

The primary reference level mentioned above, a limit of 1 mSv per annum for the individual dose, only partially meets the demand for easy applicability, because the effective dose is a quantity which has to be calculated based on measurements using exposure models and parameters. Therefore SSK derived secondary reference levels for measurable quantities based on the primary dose level. They recommend a classification of heaps and site areas from uranium mining. The main criteria are the activity concentration of radionuclides of the uranium-radium series and the current or planned land-use:

- For heaps and site areas with an activity concentration less than 0.2 Bq/g no land-use restrictions are recommended.
- In the activity range between 0.2 and 1 Bq/g restricted use is possible, provided that some additional conditions are fulfilled, concerning for instance the size of the contaminated areas. Details on the restrictions and types of land-use considered acceptable in this activity range are given in [4].
- Above an activity concentration of 1 Bq/g, site-specific assessments are necessary to check compliance with the primary dose criterion of 1 mSv per year.

All reference levels for activity concentration include the natural background, which makes the determination considerably easier.

The parameters and models used for the derivation of these reference levels are quite conservative. Consequently, it can be assumed with a high degree of certainty that the primary reference level, i.e. the dose criterion, will not be exceeded if compliance with the secondary levels is given. However, it cannot be concluded that a violation of a secondary reference level automatically gives rise to an effective dose above 1 mSv per year. Therefore, the secondary levels have the character of 'non-action levels'. If they are exceeded, site-specific assessments are necessary. This is being further discussed in the following section.

ASSESSMENT METHODOLOGY FOR COMPLEX SITES

In contrast to most of the old sites, the situation at the large WISMUT sites is very complex. There is a large variety of different types of wastes present, some of which represent huge volumes in the order of 100 million m³. The clean-up of these contaminated sites must take into consideration a variety of different contaminants and risks to humans and the environment arising on various exposure pathways. A particularly important aspect for assessing the clean-up measures required is the combination of radiological and non-radiological risks involved. In general, the following factors must be included in the investigations:

- Radiological risks through external irradiation and incorporation of radioactive substances.
- Risks from carcinogenic substances such as arsenic and organic contaminants.
- Possible health damage through toxic substances such as heavy metals in the uranium ore or chemicals used in the uranium extraction process.
- Damage to ecosystems, especially lakes and rivers, by contaminants discharged into them.

- Damage to resources, such as the contamination of groundwater aquifers.
- Direct physical risks, e.g. the danger of dam failures.
- Risks entailed by the clean-up activities themselves, e.g. additional release of contaminants, or traffic accidents when transporting materials on public roads.

The relative significance of these different risk components cannot be determined in general, because substantial differences exist between the individual sites with regard to contaminant levels and land-use of the surroundings. Comprehensive planning of the clean-up operations must therefore be capable to take each of these risk components appropriately into consideration.

Traditionally, the assessment of the hazards and risks is made under various jurisdictions with different philosophies, methods and standards. This separate assessment, however, does not give due consideration to the overall risk originating from a site and can therefore lead to inappropriate decisions. Under unfavorable circumstances this can result in clean-up measures which, for example, improve the radiological situation but produce undesirable consequences for other environmental aspects. Furthermore, the positive effect achieved by clean-up activities usually appears in several environmental contexts. For example, covering a heap or tailings impoundment can at the same time lead to a reduction of radon released into the air and a reduction of radioactive and non-radioactive contaminants discharged into rivers. The determination of cost-efficient clean-up measures requires in this situation cost/benefit considerations, which take into account all improvements achievable in the different sectors on a common basis and relate them to the required financial expenditure.

In such situations, quantitative risk assessments can only be performed if a common assessment basis for the different risk components is available. This can then serve to identify appropriate protection and clean-up measures for the respective objects and sites. This makes it necessary to develop an assessment approach with which all relevant risk and damage components can be quantified consistently in an integrated method. Decisions aiming at a cost-effective use of financial resources can then be based on a quantitative analysis, determining to what extent clean-up measures should be implemented for individual objects, exposure pathways and risk components, and as from which level of protection further efforts for reduction of risk would no longer be considered reasonable.

On this basis, an integrated assessment methodology has been developed. Its main goals consists of the following aspects:

- Making the different risk and damage components quantitatively accessible.
- Establishing a basis for comparing the various possible risks to human health and the environment.
- Allowing for quantitative optimization decisions by determining the willingness and ability of society to pay for the prevention of risks and damage.

Substantial work for developing the integrated assessment approaches described below has been carried out within the scope of research projects^{*)} commissioned by the German Federal Ministry

^{*)} The contractors were: BRENK SYSTEMPLANUNG, Aachen

for the Environment, Nature Conservation and Reactor Safety. A provisional conclusion of this work, which has already been running since 1990, was recently reached with the submission of a summarizing report [6]. An overview is given in [7]. Although the development of these methods is an ongoing process, an approach now exists whose practical viability has been demonstrated by application within the scope of a number of important clean-up decisions.

The development of the assessment principles had to be based on a number of assumptions and conventions which have to be checked and if necessary modified by discussion on a wide front. It must thereby be taken into consideration that the complexity and diversity of contaminant effects on humans and ecosystems require simplified model assumptions. In practice we need instruments with which the existing problems can be decided and solved today. On the other hand, it is self-evident that research must continue in order to further acquire and substantiate knowledge. Therefore, an assessment concept was chosen which can be further developed without departing from the general line.

The assessment principles feature the following essential elements (see Fig. 1):

- Risks for human health
 - Radiological risks are estimated for the relevant pathways, using contaminant migration and dispersion models where necessary. The collective dose is used to quantify the radiological damage. This measure can be converted to the mean loss of life expectancy, using the risk factors published by the International Commission for Radiation Protection (ICRP).
 - Risks caused by carcinogenic chemical substances are treated analogously. Risk factors published by the U.S. EPA are used, which estimate the additional cancer risk as a function of the incorporated amount of contaminants. The target parameter of the assessment is again the mean loss of life expectancy.
 - Toxic chemical substances are assessed based upon toxicological parameters (NOAEL, LOAEL). Within the currently applied approaches only the water pathway is considered, which is particularly important in the case of mining residues. The assessment results in a quantification of the damage as a mean effective loss of life expectancy, measuring the impairment of the quality of life, allowing for a comparison of toxic and carcinogenic effects.
 - Direct physical risks, which can, for example, be due to traffic accidents caused by clean-up activities or dam failures, are assessed on the basis of their probability of occurrence. The mean loss of life expectancy is again used as assessment parameter.
- Contamination of water bodies
 - The effect of contaminants discharged into surface waters is included as a further important component. The effects on drinking water supply and aquatic biota are considered. The assessment is based on models for the impairment of the aquatic environment by

contaminants discharged into them, i.e. by immission considerations. The target parameter is here the relative contribution of the considered contaminant source to the overall impairment of the water quality.

- A further important component of the assessment is the impact on groundwater bodies. Within the assessments, consideration is also given to protection of the groundwater as a resource for future generations. This is an aspect of considerable importance, on account of the often long-term damage which can be caused even by a short-term discharge of contaminants.

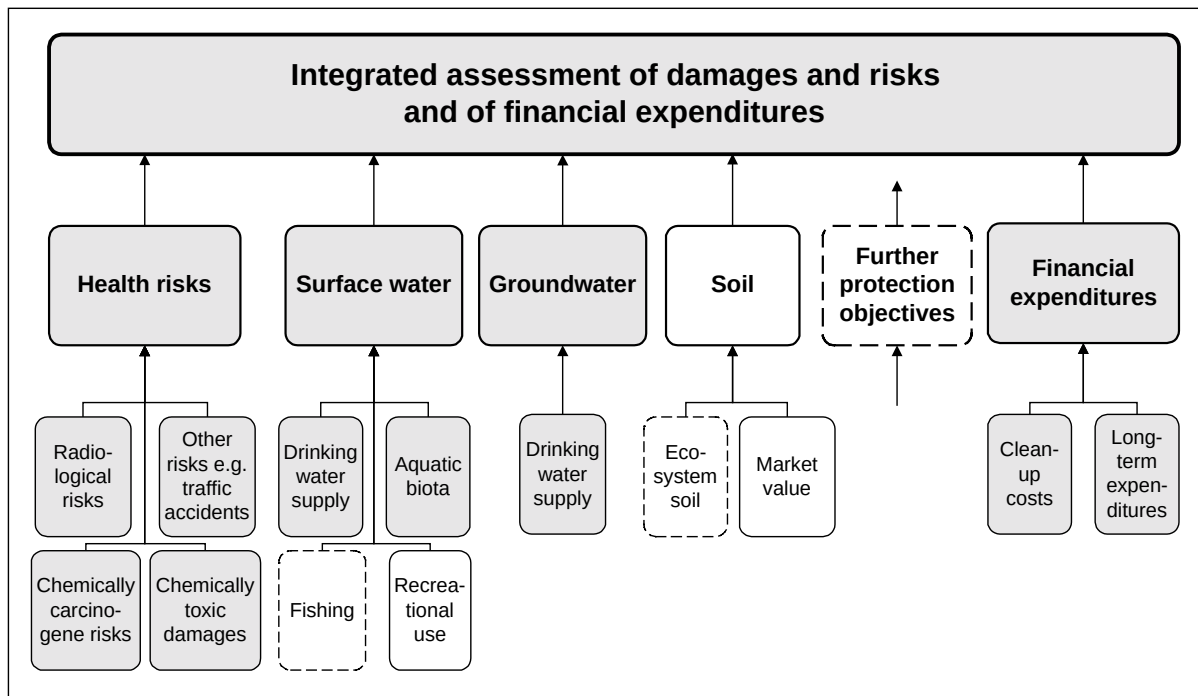


Fig. 1: Overview of the elements of the integrated assessment approach

An important element of the developed approach is the monetarization of risks and damages, making them comparable with each other and with the financial expenditures required for the reclamation work. The assigned monetary equivalent can be considered as a measure for the societal willingness to pay for preventing the respective damage (statistical risks for lethal and non-lethal diseases, damage to resources such as drinking water, damage to ecosystems). The data basis used to define the parameter of the monetarization (so-called “conversion factor α ”) reflects this definition and is based upon payments actually made or investigations of the willingness to make payments in order to prevent or mitigate damage in the specified categories.

Setting out from the monetarization of the damage, it is possible to make a comparison with the short-term and long-term financial expenditures, which can be brought to a common reference basis by appropriate discounting techniques.

The different aspects of risk reduction and the expenditure necessary for implementation of the remedial measures, are assessed within the scope of a costs/benefits analysis for the clean-up options to be considered. The final result consists of recommendations for clean-up measures which combine economic aspects with ecologically sound clean-up measures consistent with the

overall goal of a sustainable development. A concrete example for the application of this approach is given in [8].

The described approaches have been developed and tested with regard to concrete situations, particularly in connection with the clean-up at uranium mining sites in Saxony and Thuringia. So far no legally binding stipulation for the concrete application of these or other methods from the German Federal Ministry for the Environment or from the responsible government authorities of the federal states exist. This will only be possible after a still outstanding comprehensive discussion of the presented and possible alternative approaches, which will probably take a considerable amount of time. In the opinion of the responsible government authorities, however, it is nevertheless possible and appropriate, to apply the presented methods to concrete cases already now. On the one hand, this assists further qualification of these methods, and on the other hand relevant results are obtained for the required clean-up decisions. The extent to which the actual decisions for clean-up operations are based on the results of these methods, is determined individually on the merits of each case.

One of the tasks in the course of further work is the inclusion of additional protection objectives, on the merits of their relevance. An important example is the protection of the soil. Another task is the further development of the already existing approaches with regard to the employed parameters and assumptions, in order to reduce the still existing assessment uncertainties step by step.

The integrated assessment approach establishes links between different fields of jurisdiction. This provides chances for a problem-oriented further development of the approaches presented here. The applicability is thereby not restricted to the examples of mining residues considered here. Other contaminated sites pose similar problems which can be approached in a similar manner with the methodology which has been developed here.

INTEGRATION AND APPLICATION

Optimized clean-up decisions

In the preceding section a method has been introduced which enables a combined assessment of health risks as well as economic and ecological damage originating from contaminated sites. A monetary equivalent of the damage is considered as the appropriate criterion for making comparisons, since the funding required for clean-up measures is also a monetary quantity. On this basis, the total costs for a clean-up option can be determined covering damage costs and financial expenditures:

$$\text{Total costs} = \text{financial expenditures} + \alpha \cdot \text{health risks} + \text{water damage costs}.$$

Different clean-up options can then be compared quantitatively. The option with the lowest total costs is the optimum variant.

These considerations also include estimates reaching far into the future, e.g. for contaminant release, effectiveness of the clean-up operations, and consumption quantities. Uncertainties in the data for these parameters are larger than for estimates of present factors. These uncertainties can be integrated in the assessment procedure by stochastic methods (Monte Carlo simulations), yielding probability distributions instead of fixed values for the risks, damage-equivalent costs,

financial expenditures, and total costs. The width of these distributions reflects the existing uncertainty. This procedure is illustrated in the next section presenting an example.

Part of the financial expenditures for the clean-up is required only in the long-term for surveillance and maintenance. A simple addition of all costs arising would not be economically correct. Instead, a discounting of future expenditures is required. The discount factor to be applied can be a decisive parameter for the assessment. Its definition is based on expected economic growth, but also has to take equity considerations between different generations involved into account.

The quantitative optimization procedure outlined above should be considered as a decision aid constituting a transparent starting point for the actual decision process. This role of the described methodology is consistent with the view of the ICRP [5]. The actual decision-making has to consider additional factors such as public acceptance and social compatibility. Therefore, the eventual decision is not necessarily identical with the quantitative cost/benefit results. But even if this is the case, the quantitative analysis is not useless, because its results provide a basis and guidance for the decision-making process, enabling an evaluation of the disadvantage associated with selecting a quantitatively non-optimal clean-up option for social or political reasons.

Application example

The following example concerns a waste rock heap of the uranium mining operations in Thuringia. With its volume of approximately 27 million m³ this heap is one of the largest dumps of the uranium mining region in Thuringia and Saxony. The heap was used between 1962 and 1972 for dumping mainly overburden material from an open pit mine. Oxidation of the large pyrite content of the heap mobilizes uranium and other heavy metals, which are then washed-out by precipitation. Relevant contaminants are uranium and other radionuclides, as well as nickel, cadmium, manganese and sulfate. One of the decay products of uranium is radon which, being a radioactive gas, is released from the heap and causes radiological risks via the atmospheric pathway.

The three principle clean-up options for this heap are: as basic option, stabilization of the slopes without any further measures for contaminant retention (option "BC"); in-situ reclamation of the heap by applying a mineral cover to reduce contaminant wash-out and radon release (option "IS"); and relocation of the heap material into the neighboring open pit (option "R"). The options BC and IS would require a treatment of contaminated seepage from the heap over long time periods in the order of centuries.

The following figures show the health risks, the ecological and economic damage as well as the costs for each of the three clean-up options in comparison. In each figure the results are depicted as bars, reflecting the uncertainties in the results determined within a Monte Carlo analysis. The resulting probability distributions are characterized by their percentiles in the bars: the 50% percentile (median) lies in the center of the dark shaded region, 30% and 70% percentiles at its edges, ranges between 10% and 30% as well as between 70% and 90% are shaded lightly and the remaining ranges between 5% and 10% as well as between 90% and 95% are not shaded. In addition to the percentiles, the average values are shown as black dots which are joined by a line for better visualization.

The depicted results are based on a consideration period of 200 years. A water treatment period of 100 years is assumed for the clean-up options BC and IS. Sensitivity analyses, for which no

further details are given in the overview shown here, have been carried out for these parameters as well as for other parameters which are of relevance for the assessments.

Figure 2 shows the collective health risks caused by the heap according to the assessment models described above. They are given as mean effective loss of life expectancy (MEL). Figure 3 shows the health risks according to Figure 2 converted into a monetary equivalent, the damage-equivalent costs for damage to surface waters and the financial expenditures. Figure 4 shows the total costs resulting from the sum of the contributions in Figure 3.

Without attempting to analyze in detail the depicted results for the clean-up options of the heap, some fundamental advantages of the integrated assessment method are clearly illustrated by this example:

- The consequences of different kinds of damage can be compared quantitatively, here for example the radiological health risks and the damage caused by toxic substances (Figure 2, top).
- The relevance of individual risk components for the clean-up decision becomes directly evident: For example, the risks due to carcinogenic substances and traffic accidents are less significant in this case.
- When using stochastic simulations for taking data uncertainties into consideration, the accuracy of the results becomes transparent: While financial expenditures can be estimated with relative certainty in this example, the various uncertainties in the estimates of contaminant release and migration lead to relatively large bandwidths of the possible extent of damage to surface waters (cf. Figure 3).
- The parameter "total costs" (Figure 4) provides an integrated assessment criterion, with the help of which a direct analysis of costs and benefits associated with the clean-up options considered is possible: In spite of the fact that the financial expenditures for the relocation of the heap material (option R) are significantly higher than the costs of the other options, the total costs are smaller compared to the other options, so that the costs/benefit ratio for this option is the most favorable.

The relevance of individual contaminants, exposure pathways and resulting risks depends sensitively on the actual circumstances of each particular site. In particular the dominance of the damage-equivalent costs for the aquatic biota in the example presented is characteristic for the site considered here. It is caused by the large heavy metal content of the ore and overburden. In other cases, other damage components can be of dominant significance, for example damage to groundwater or – in the case of sites containing large amounts of organic contamination – health risks through carcinogenic substances.

The presented example demonstrates how the decision procedure for clean-up of complex sites can be facilitated with the help of the integrated assessment methods described above. Furthermore, it clearly shows that the decision process can become more transparent by quantitative inclusion of qualitatively different factors of influence, because the importance of the individual damage components can be identified directly.

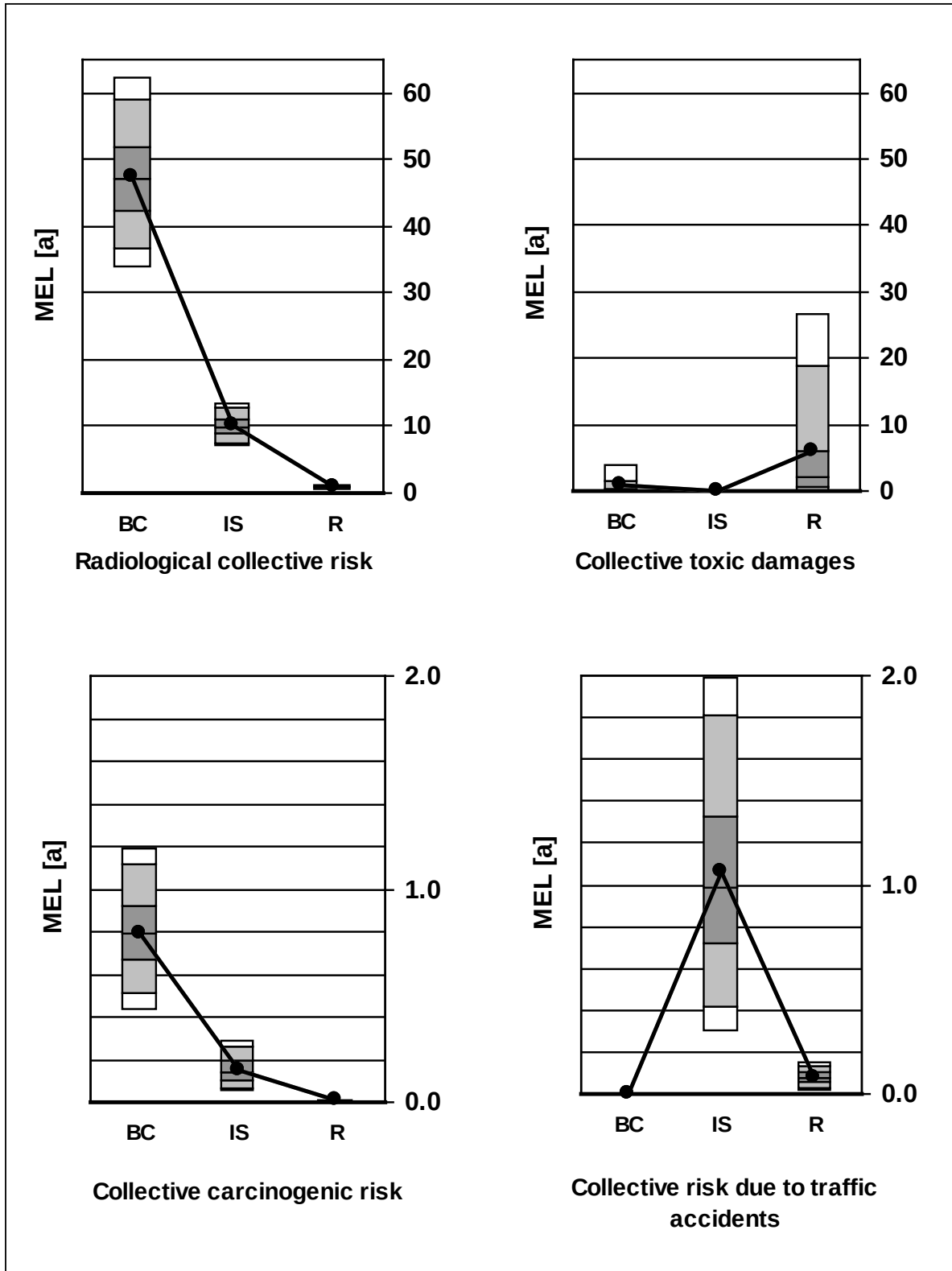


Figure 2: Comparison of the health risks entailed by the clean-up options

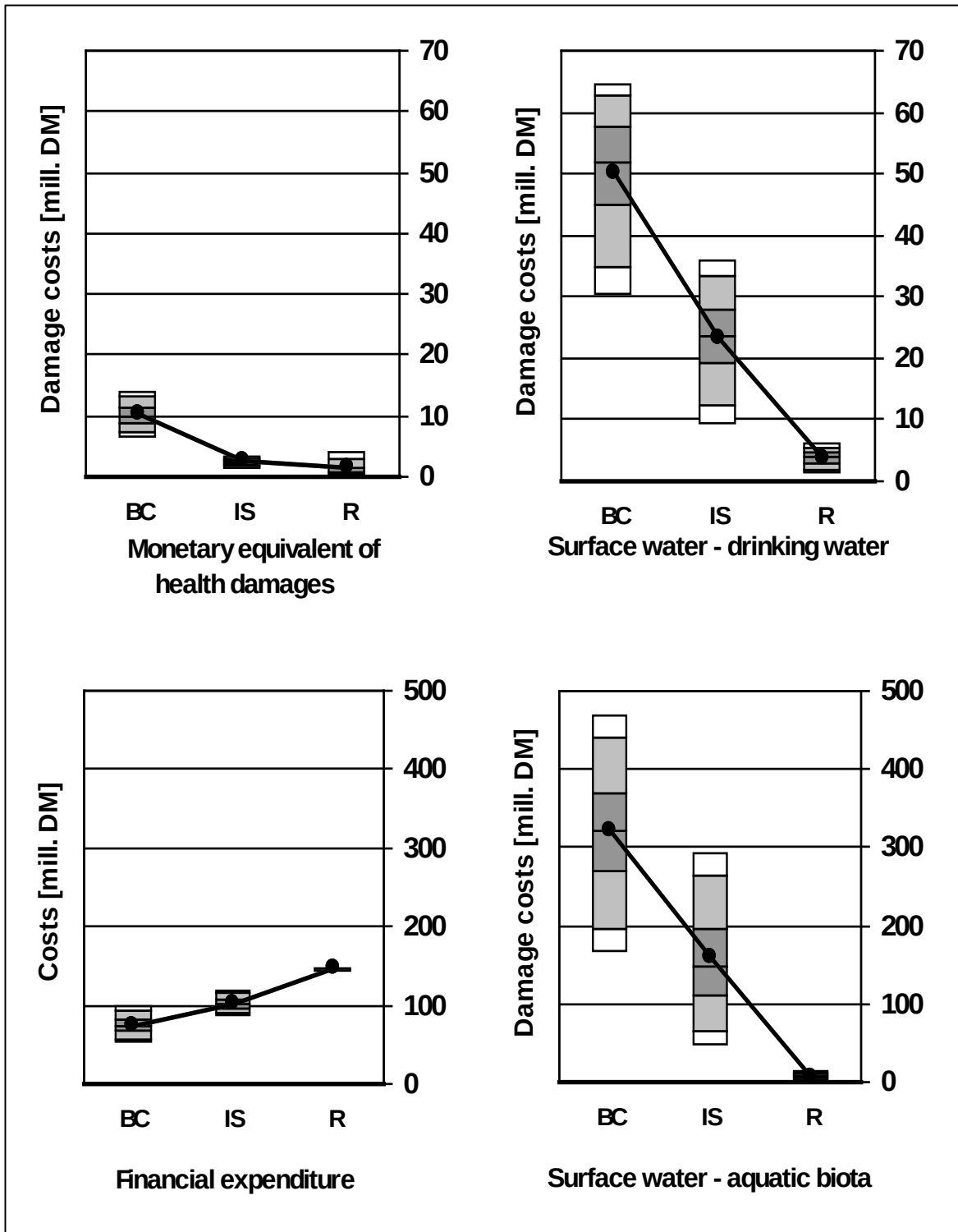


Figure 3: Comparison of the costs and damage-equivalent costs of the clean-up options

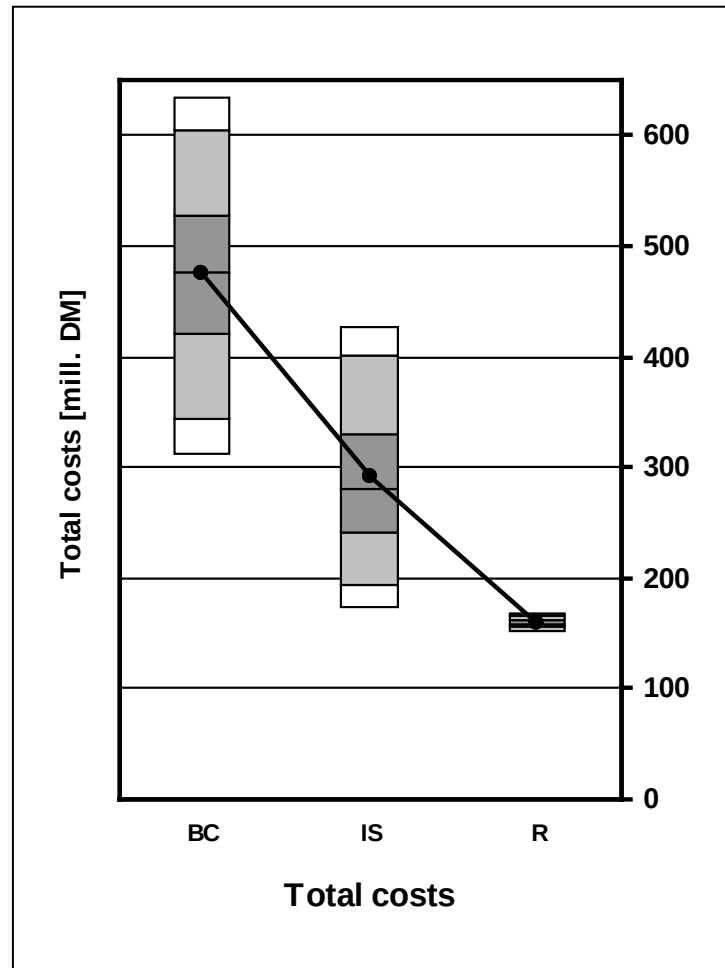


Figure 4: Comparison of the total costs for the clean-up options

CONCLUSION

An overview of approaches to address the environmental problems associated with the reclamation of residues from uranium mining in Germany has been given. These approaches are also applicable to other environmental restoration activities. The key element is the derivation of monetary equivalents to the various kinds of risks and damages incurred by these sites. This serves as a basis for performing a cost-benefit analysis for the determination of the optimal clean-up option.

Activities to remedy the situation in East German caused by the presence of radioactive wastes and contaminated sites are still ongoing. This is also true for the development of the assessment approaches described. Nevertheless, achievements of the last eight years since unification are substantial and show that the approaches taken are viable and suitable for dealing with the environmental challenges encountered.

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