INVESTIGATIONS AND RADIOLOGICAL ASSESSMENT OF MINING RESIDUES AND SITES IN GERMANY

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ABSTRACT
Mining and processing uranium bearing ores, in particular uranium mining and milling have left numerous residues and sites contaminated radioactively. Remediation measures have to be considered in many cases. The principles of radiological protection - justification and optimization - are applied to the remediation measure. In Germany the annual effective dose of 1 mSv in addition to the natural background is applied as an action level to justify a remediation in case of radioactive contamination due to any mining activities.

Therefore for the sites where the uranium production ceased in 1990 and a remediation is generally required by law, in decisions on justification the effective dose has to be calculated for each site of interest taking into account the specific conditions and exposure pathways. The approach to dose calculation is described. On the other hand in the mining regions numerous sites are possibly radioactively contaminated due to the uranium mining and milling abandoned in the 40s and 50s. Others date from mining and processing activities of non-ferrous ores, beginning already in the Middle Ages. In the past this problem was poorly characterized and the residues and sites for which a remediation should be considered at all were mostly unknown. Therefore first the radiological situation in the mining region was comprehensively investigated. By applying gamma-dose rate measurements and other simply practicable investigations a general survey was to be given on types and numbers of residues (e.g. waste rock dumps, loading sites, tailings basins, plant areas), the number of contaminated areas, levels of contamination. Those residues and sites were to be identified for which a remediation has to be considered and costly site specific analyses are indispensable. The criteria for the evaluation of the measurements (e.g. specific activity of soil, local gamma dose rate level, radionuclide concentrations) were derived from the effective dose taking into account generic exposure scenarios and from the natural variation of background radioactivity.

INTRODUCTION
Mining and ore processing have a long history in the regions of Saxony, Thuringia and Saxony-Anhalt. The ores were often mineralized with uranium and therefore these residues of mining (e.g. dumps of mining debris, slags and others) and ore processing waste may present a radiological hazard, in particular if the residues from mining have been used as building material or former mining sites have been built up. Immediately after World War II, the Soviet Union began to develop her nuclear capability and the uranium deposits in Eastern Germany (e.g. near Aue and other places) were exploited by the Soviet-owned stock company SAG Wismut. At the beginning the exploitation was concentrated on existing mines which had produced silver and other non-ferrous ores in former times. At that time there was no consideration of the harm to the
employees and of the impact on the environment and the population arising from mining activities.

In the 50s and 60s the uranium production was extended to other parts of East Germany. Numerous mines, mills and other facilities were in operation, waste rock piles and tailings ponds of considerable dimension resulted. In 1954 the SAG Wismut was converted into a joint Soviet-German stock company (SDAG Wismut). On the basis of an agreement between the governments of the Soviet Union and the GDR in 1962 the SDAG Wismut was obliged to observe the German regulations. Nevertheless in handling and dumping waste from mining and milling the radiological protection with regard to the environment was observed only slightly and large areas were radioactively contaminated. After the unification the uranium production was ceased for economic and other reasons and, based on the Wismut Act [1] 1991 the Wismut company was transferred into a corporation (Wismut GmbH). The task of this corporation is the decommissioning of the mines, mills and other facilities used by the SDAG Wismut and the restoration of sites. The Wismut GmbH is responsible for 31 shafts, one open pit mine, 64 big waste rock piles and 10 tailings basins.

In the period up to the 60s many facilities, tailings basins and waste rock piles were abandoned or decommissioned by Wismut and were passed over to other enterprises or to communities. Since at that time radiation exposure due to the waste of mining and milling was not yet an issue of any concern these residues have to be considered a source of serious radiation exposure in particular if waste and sites are used again. As silver and other non ferrous ores and certain types of hard coal can be mineralized with uranium, a serious radioactive contamination has to be considered for the sites where such ores and coal were mined and processed.

The radiation exposures result from operations conducted either under regulatory radiological protection control which is considered to be inadequate from the present point of view or prior to any or to appropriate regulations. That is why the exposure situation needs intervention for reasons of radiological protection.

**PRINCIPLES OF RADIOLOGICAL PROTECTION BY INTERVENTION**

Principles of radiological protection, i.e. justification and optimization in case of an intervention refer to the intervention measure. Any action to reduce a lasting exposure is usually termed remediation. A remediation is justified if the disadvantages associated with the measure are exceeded by the achievable benefit. Optimization of the remediation then is finding out those measures by means of which a maximum benefit is obtained - understood in a broad sense - taking into account all other relevant aspects (e.g. social, economic and political circumstances, acceptance by the public etc.).

In principle, the decision on the necessity of a remediation can be made by applying a cost-benefit-analysis for each case or site of interest. This approach is very costly because of the numerous aspects to be accounted for and in many cases it is more appropriate to establish action levels. From the regulatory point of view the last mentioned approach is the only practicable way if decisions have to be made for a great number of sites of similar radiological characteristics.
Following the International Basic Safety Standards [2] optimized action levels shall be specified in plans of intervention situations. Local and national conditions such as the individual and collective exposures to be averted by the measures, the radiological and non-radiological health risks and the financial and social costs and benefits associated with the measures shall be taken into account in the process. Usually action levels are specified in terms of appropriate quantities such as the annual average of the ambient dose rate or activity concentrations of radionuclides in environmental media that exist at that time when the remedial action is being considered. Sometimes it can be more appropriate to specify an action level as a source-related annual dose for a person (member of the critical group). In particular if contaminated areas are used in different ways the specification of the action levels in terms of annual doses is the approach to be preferred since the authorities can decide more flexibly on remediation in the cases of interest.

In order to derive an action level for a remediation programme the pros and cons of the remediation intended may be generically evaluated in a more or less quantitative way taking into account all relevant circumstances and aspects (e.g. averted doses, remaining risk level, costs to be expected, political, social and economic questions, acceptance by the public). A comprehensive survey on the situation (e.g. number of radioactively contaminated sites to be considered, exposure levels, people affected) is the precondition for this approach. Remembering that the acceptance of a remediation by the public is an important point an action level can also be specified on the basis of an exposure commonly evaluated as being acceptable. This level of acceptance should not be derived from more or less hypothetical risk assumptions, it should rather be fixed at the upper end of the normal range of the natural radiation exposure in regions where the geological conditions are comparable to the affected areas. It has to be pointed out that for acceptance reasons the dose limit 1 mSv · a⁻¹ in force for members of the public in radiological protection for „planned practices“ has been derived also from the comparison with the natural radiation exposure. Such action levels do not contradict theoretical risk considerations. Obviously only individual doses are to be taken into account. For the evaluation of a radioactive contamination due to mining activities with regard to the justification of any remediation this approach is advantageous since the radionuclides causing the contamination occur also naturally and the dividing line between a man-made contamination and naturally-occurring situations is often imperceptible.

If the action level established by the competent authority is exceeded the remediation is obligatory and, according to the principles of radiological protection the definition of the remediation goal and the selection of the measure to be preferred should be made by applying an optimization procedure. Obviously a level (dose rate, activity concentration, annual dose) below the specified action level is acceptable as the goal of remediation and the range of optimization is restricted. Apart from that the fundamental question that has to be decided is: how good is „good enough“ below the action level and what expenditures and costs are justified in each case of interest.

The International Basic Safety Standards [2] state that form, scale and duration of any remedial action shall be optimized so as to produce the maximum net benefit under the prevailing social and economic circumstances without recommending a method practically applicable. The optimization process may range from intuitive qualitative analyses to quantitative analyses such
as a cost - benefit analysis taking into account the collective dose. In this context the term „cost“ includes not only the expenses of a remediation measure but all negative aspects involved as well. In the same way the term „benefit“ includes the risk reduction of the measure and all its positive effects. To apply the quantitative cost-benefit analysis all aspects to be involved have to be quantified. Since many of the relevant quantities are not of objective nature numerous agreements are required, e.g. a commonly accepted conversion factor between risk and a monetary value has to be defined. However we have to recognize that several aspects such as the acceptance of the selected remediation measure by the people affected and political questions cannot be quantified and that those can be decisive. Therefore a quantitative analysis can only be a decision aiding technique.

If an action level has been specified as a result of a generic optimization process or as an exposure commonly accepted a further approach can be discussed. Considering the twofold meaning of the action level - above this level a remediation is obligatory, below this level a remediation is not justified - the further optimization can be restricted to the selection of the cheapest measure that leads permanently and reliably to contaminations or doses below this and that is accepted by the public.

**PRINCIPLES AND CRITERIA OF JUSTIFICATION FOR THE REMEDIATION OF MINING RESIDUES AND SITES IN GERMANY**

Considering the situation in the mining regions the German Commission on Radiological Protection (SSK) recommends an annual effective dose level of 1 mSv for the use of areas, buildings and dumps radioactively contaminated by mining in addition to the natural background level [3]. This level can be interpreted as follows: if the exposure due to the residue (e.g. contaminated ground, dump) does not exceed this level a remediation is not justified, otherwise a remediation has to be considered. In addition the SSK recommends in [3] measurable quantities as criteria. They fulfil the dose criterion and can be applied in deciding on the use of land only on the basis of measurements.

Table I: Criteria for unrestricted and restricted use of land

<table>
<thead>
<tr>
<th>Specific activity of soil [Bq Ra-226 per g]</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.2</td>
<td>unrestricted</td>
</tr>
<tr>
<td>&lt; 1.0</td>
<td>restricted taking into account conditions, e.g. local gamma dose rate &lt; 300 nSv h⁻¹</td>
</tr>
<tr>
<td></td>
<td>for use as industrial site</td>
</tr>
<tr>
<td>&gt; 1.0</td>
<td>dose assessments for decisions on use</td>
</tr>
</tbody>
</table>

These criteria are also intended to enable a distinction to be made between areas which do not, and areas which might potentially require a remediation.
For the exposure to radon the SSK recommends [4] a separate criterion for the justification of remediation: if the source-related radon concentration (the outdoor radon concentration due to the exhalation of a waste heap or another residue of mining) assessed for the nearest residential areas does not exceed the level of 50 Bq \cdot m^{-3} a remediation because of the exposure to radon is not justified. The reason for establishing this concentration value as an action level is the intention that the indoor level of 250 Bq \cdot m^{-3} accepted by the SSK as the upper end of the normal concentration range occurring naturally should not be significantly increased by „man-made“ radon from outdoors. Since the source-related radon concentration can only be calculated site-specifically and such assessments have to be made for numerous residues and sites the Commission recommends to measure the outdoor radon concentration in the residential areas of interest. Only in cases in which the annual average of the outdoor concentration exceeds the level of 80 Bq \cdot m^{-3} - it is the upper end of normal geogenic radon concentrations outdoors in the mining areas - site specific assessments should be made to estimate the contribution to the outdoor level due to the emission of the residue.

When applying the measurable quantities a two-step procedure can be made for the justification of the remediation: If the measurements exceed these criteria site specific assessments have to be made and if these assessments result in an annual effective dose of > 1 mSv or a radon concentration of > 50 Bq \cdot m^{-3} a remediation is justified.

In [3] the SSK recommends for the demonstration that if the effective dose level is not exceeded in case of a given contamination, conditions must be assumed as realistic as possible but sufficiently conservative. The demand for realistic calculations of an effective dose must be observed strictly, otherwise purely hypothetical exposures will be eliminated and that would be a waste of money.

In [5] the SSK provides an approach to the dose calculation that can be applied practically. To demonstrate how this requirement is translated into instructions for dose calculation the following examples can be discussed:

**Relevant exposure pathways**

For calculating „realistic“ doses in intervention situations it is obvious that only actually existing scenarios and pathways must be taken into account. Therefore in [5] exposure pathways are listed which are generally to be considered „relevant“. The SSK stresses that the actually relevant pathways for the case of interest should be selected from these. On the other hand the SSK recommends to include additional pathways in the calculation procedure if appropriate in exceptional cases. However, extreme habits should be unconsidered and costly inquiries about the habits of the population group affected should not be made in identifying the relevant pathways.

**Parameter for dose calculations**

The dose calculation has to be implemented for infants (1 year), children (5 years) and for adults to identify the critical group. The age-groups are defined by the age-depending dose coefficients and by parameters describing the breathing rate, the occupancy times indoors and outdoors for certain scenarios and the annual consumption of food. Costly inquiries should be avoided in
estimating the parameters, too, and „best estimated“ figures should be applied for calculating the effective dose. Examples for such figures are listed in Table II.

Table II: Examples of parameters recommended for dose calculation

<table>
<thead>
<tr>
<th>Age group</th>
<th>Occasional stay</th>
<th>Using the area (gardening, playing)</th>
<th>Annual ingestion (in kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td>-</td>
<td>1000</td>
<td>250</td>
</tr>
<tr>
<td>Child</td>
<td>250</td>
<td>1000</td>
<td>440</td>
</tr>
<tr>
<td>Adult</td>
<td>100</td>
<td>1000</td>
<td>440</td>
</tr>
</tbody>
</table>

**Consideration of natural background**

For a realistic assessment the dose calculation should be based on measurements of the contamination. Since the reference level of an effective dose refers to exposures caused by radioactive contamination due to mining activities and the radionuclides to be considered are the same which occur naturally the natural background level has to be subtracted from the measurement to avoid an overestimation. To minimize the expenditures in estimating the natural background levels the SSK recommends a three step procedure: First the calculation should be made based on the measurements without the subtraction of any background level. If the effective dose calculated exceeds the reference level, a generic level of environmental radioactivity recommended by the SSK should be subtracted and, only if the exposure calculated in this way still exceeds the reference level, site specific levels should be estimated and applied in order to calculate the effective dose realistically.

**RADIOLOGICAL ASSESSMENT OF MINING RESIDUES AND SITES**

**Residues and sites in the possession of Wismut**

The Wismut Act [1] prescribes that Wismut has to decommission the tailings basins, dumps and other facilities and to carry out remediations, if required. Therefore Wismut carries out the radiological assessments for each site or facility to justify the remediation. The assessment is made in the form of a dose calculation applying the approach recommended by the SSK. The criterion for the justification is the annual effective dose level of 1 mSv established in the Ordinance for Nuclear Safety and Radiological Protection of the GDR - VOAS [6] which is in force for the decommissioning and remediation of residues and sites in the possession of Wismut. Although the VOAS regulates only the radiological protection in "planned practices" regulations generally applicable for radiological protection in mining and milling are included and can be applied to control decommissioning and remediation. Within the framework of the Wismut remediation programme the exposure to radon is included in the annual effective dose of 1 mSv for the justification of a remediation measure. The entire process is under the supervision of the
authorities in the Federal States which are responsible for carrying out radiological protection. In order to use the funds provided by the Federal Government for the Wismut remediation programme in an optimized way the parties involved in the decision process (Wismut GmbH, authorities, experts) have agreed on applying a quantitative cost-benefit analysis as far as possible for the definition of the remediation goal and selecting the best solution for each case. Non-radiological risks are included in the analysis. The approach is described in [7].

**Residues and sites from past mining activities**

Unlike the information on the Wismut sites the information on the residues and sites due to the uranium production in the 40s and 50s and due to other ore mining in the past was incomplete since this problem was poorly investigated in the past. A decision to generally consider remediations for all these sites had resulted in site specific assessments for some thousands of waste heaps and other sites possibly contaminated and required a lot of investigations, time and money. Therefore the Federal Ministry decided to carry out an investigation programme to provide a comprehensive survey on the total radiological situation in the mining regions and to identify these residues and sites for which a remediation should be considered.

In 1991 the BfS developed the project „Registration, Investigation and Radiological Assessment of Mining Residues“ with the intention of providing surveys on type and number of residues, their inventory of radioactivity, the magnitude of radioactive contamination and carrying out a classification of residues and sites. The residues and sites were to be divided into those for which any remediation could be excluded (non-relevant residues and sites) and those which had to be regarded as sources of increased radiation exposure of the public and for which remediations were to be considered (relevant residues and sites).

The criteria applied for the classification were taken from the SSK recommendations described above. The recommended criteria of 0.2 Bq·g⁻¹ and 1 Bq·g⁻¹ are key figures for the classification: if the specific activity of materials investigated exceeds the level of 1 Bq·g⁻¹ the residue or site is classified as relevant, if the specific activity of material does not exceed the level of 0.2 Bq·g⁻¹ the residue or site is classified as non-relevant. In the range between 0.2 Bq·g⁻¹ and 1.0 Bq·g⁻¹ the classification was carried out taking into account additional criteria, e.g. the volume of material dumped, the area occupied by dumped materials and aspects of use. Values for the local gamma dose rate were derived from the levels of specific activity (e.g. the level of 300 nSv·h⁻¹ from the specific activity of 1 Bq·g⁻¹ assuming that a cover on the residue is less than 10 cm thick) allowing an evaluation of the residues on the basis of local gamma dose rate measurements which can simply be carried out. These criteria were also applied in combination with the criteria for the volume of materials and the occupied area and, if any covers were existing, taking into account the thickness of the cover.

In view of the large number and scattering residues and sites under consideration, a step-wise procedure of investigations described in [8] and [9] has been developed for the project with the intention of excluding as quickly as possible the residues for which a remediation is definitely not required. As a first step of investigations 34 areas of former mining activities have been defined as "suspected areas" using information on regions where uranium ores and other ores with above-
average concentrations of uranium were mined as well as regions where the terrestrial gamma radiation is increased in comparison with the average level. The total area of "suspicion" is about 1 500 km². For these areas, all available documentations such as reports on geological explorations of uranium and other ore deposits, work reports of mines, mills and other ore processing plants, registers of mining authorities have been evaluated and data and information that can be helpful for the radiological evaluation of mining residues and sites have been compiled. In this way about 8 000 mining residues of different kinds have been identified and registered in a data bank, most of them being waste rock piles. The total of areas covered by the residues amounts to about 73 km², the total of areas with above-average gamma radiation to about 170 km². Further investigations concentrated on these areas ("investigation areas"). As expected the data and information available after the first step of investigation did not yet permit the classification intended. Additional efforts to verify and complete the registered data and information were required. By field inspection the information on the state of objects, sites etc. was updated and the data and information needed for the assessment were checked, revised and completed, if required to provide a standardized database. Screening measurements of the local gamma dose rate were included in this verification procedure. Following the verification procedure, a first classification was made evaluating in particular the local gamma dose rate measurements. Even at that stage of investigation about 57 % of the residues and sites could be classified as "non-relevant". Within the scope of the Federal Project only the rest ("possibly relevant relics and sites") were investigated in greater detail and were subjected to specifically evolved measurement programmes. These final programmes provide comprehensive information about dimensions of contaminated areas, thickness of contaminated layers, concentrations and inventory of radioactivity, radioactivity released and spread (e.g. radioactivity in seepage waters), relevant pathways and radiation exposure to the public. Grounds adjacent to the relics were included in the investigations.

The field investigations of the project were finished in 1997. The evaluation of measurements and other data ascertained is still going on. Based on preliminary estimations the number of relevant residues or sites requiring site specific assessments will be 500, most of them are dumps of mining debris. It is evident that the scope of site specific assessments can be substantially decreased, in particular as the measurements now available for the relevant sites are mostly sufficient for proper dose calculations and the site specific assessments can be concentrated on the identification of the really relevant pathways.

Currently an ordinance is in preparation for regulating the radiological protection in connection with mining and other industrial residues. It will specify the criterion to be applied for the justification of the remediation of these sites and will regulate the responsibility for the site specific assessments and for the implementation of remediations. The criterion for the justification will be an effective dose level, the figure of which still being under discussion. Likewise the question is under discussion in which way the optimization has to be implemented in this area of radiological protection.
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