
Radiological criteria and methods for remediation of contaminated former mining sites

H. Biesold*, H. Thielen*, D. Weiß**

Gesellschaft für Anlagen und reaktorsicherheit (GRS) mbH

**GRS, Schwertnergasse 1, 50667 Cologne, Germany*

***GRS, Kurfuerstendamm 200, 10719 Berlin, Germany*

Abstract: Mining and ore processing have a long history in the New States of Germany, Saxony, Thuringia and Saxony-Anhalt. The ores were often mineralized with uranium and therefore the residues are a radiological hazard to man and environment. Immediately after World War II the Soviet Union started to develop its nuclear capability by mining uranium ores in the occupied zone of East Germany. At the beginning the exploitation was concentrated on former underground mines of silver and other non ferrous ores. Afterwards, new uranium deposits were explored in Saxony and eastern Thuringia. Numerous waste rock piles and tailings ponds of considerable size resulted from these mining activities. Uranium production reached some 220,000 t between 1946 and 1990. After the reunification in 1990, production was finished for economic and other reasons. The German Federal Government was faced with one of the largest ecological, social and economic challenges.

In this report an overview is given on kind and amount of the mining residues, the radiation protection criteria, models and data bases used for risk assessment and dose calculation are explained and remediation methods are described.

1. INTRODUCTION

With the reunification of Germany in 1991 a series of human, political, social and economic questions about societal and political accountability came up which were at least partly answered over the last ten years with a due commitment and high level of responsibility. In the environmental protection area questions concerning the impact e.g. of the remnants of lignite mining and the radiological consequences of uranium mining as well had to be answered. Although the conventional influences on the landscape of coal and uranium mining and the rehabilitation of nature could fall back upon the available regulations, a considerable dearth existed at least in western jurisdiction when it came to determining the radiological consequences of natural radioactivity. Since the rules, guidelines and laws of the GDR pertaining to this matter met with international convention, these were adopted and are mainly valid up to now. In the recent newly amended Ordinance on the Protection against Damage and Injuries Caused by Ionizing Radiation (Strahlenschutzverordnung) [1] these rules for the cleanup of the remnant legacies of uranium mining in the newly established German States were carried over as a temporary measure.

2. MINING RESIDUES IN GERMANY

Mining and ore processing have a long history in the regions of Saxony, Thuringia and Saxony-Anhalt. Since the Middle Ages, silver, copper, cobalt and other non-ferrous materials have been mined and processed. Waste rock from mining, as well as slags and other debris from the ore processing have been dumped in the mining regions and the landscape is marked by numerous waste heaps. The ores were often mineralized with uranium and therefore the residues from the mining and processing present a radiological hazard to man and environment.

Immediately after World War II, the Soviet Union began to develop its nuclear capability by mining uranium ores in the occupied zone of East Germany. At first the exploitation was concentrated on existing underground mines which had earlier been producing silver and other non-ferrous metals (Erzgebirge mountains). In 1946, the Soviet-owned company SAG Wismut was established and, due to the post-war conditions, its activities were not under the supervision of any German authorities. At that time there was no consideration of the harm done to the employees nor of the impact on the environment and the population arising from mining activities. In addition to the mining itself the ores were milled and uranium concentrate (yellow cake) was produced. New uranium ore deposits were explored in Saxony (near Koenigstein and Freital) and in eastern Thuringia (near Ronneburg). The uranium production extended to these parts of East Germany occupied much land and changed the landscape as well as the infrastructure. Many underground and open pit mines, mills and other facilities were put into operation. Numerous waste rock piles and tailing ponds of considerable size were created.

In 1954 Wismut was converted into a joint Soviet-German company. In the period up to the 1960s many sites and facilities were decommissioned and given back by Wismut to the former owners, e.g. other enterprises, communities or private persons. Aspects of radiological protection were of minor importance or were not observed.

Uranium production reached some 220,000 t between 1946 and 1990. Uranium production and processing generated a total of 800 million t of waste and seriously affected and devastated areas extending over about 10,000 km². Wismut was operated all the time under the military status of total secrecy and was not controlled by the national regulatory authorities, even in 1962 when the company was obliged to meet radiation protection regulations.

In 1990, after the reunification of Germany, uranium production was halted for economic and other reasons and the German Federal Government was faced in the Wismut area with one of its largest ecological and economic challenges, because Wismut turned at once from the production phase to the decommissioning phase without any preparation or prior planning. There was much concern within the local population regarding possible radiation detriment because no information about radioactive contamination and resulting exposures has been passed on to the public before the political changes occurred in East Germany.

Even today numerous mining legacies, especially waste rock heaps and uranium mill tailing ponds leave their mark upon the landscape. The biggest potential hazard comes from the industrial tailings ponds in which the residues of uranium ore processing were left. In the first line, the older facilities were not laid out while giving any consideration to long-term stability and were either not cleaned up until now or have since been used as garbage dumps.

According to the legal guiding conditions and the ownership structures with respect to Germany, distinction is made between two groups of the mining residues from former uranium ore mining and processing:

- The Wismut rehabilitation sites.

This concerns vast former uranium mining and milling sites which belonged to Wismut in 1990. Therefore, the original owner could be made liable for the restoration. For these sites a

large Federal remediation programme was begun in 1990. It was based on radiological as well as on social and economic concerns.

- Uranium mining and milling sites which no longer belonged to Wismut in 1990, as well as the remnant mining residues carrying enhanced natural radioactivity from the old mines.

For these legacies, sometimes dating back to the Middle Ages and often with unknown ownership relations, an evaluation of their radiological relevance was necessary before decisions on the justification of a remediation process could be made. This was the objective of a federal programme on registration, investigation and evaluation of mining residues (1991 – 2000). Till now only minor remedial activities have been carried out in cases where an urgent need for countermeasures were detected.

3. REMEDIATION CRITERIA

The criteria for remediation of contaminated former mining and milling sites are based on recommended and control values specified in or derived from laws, guidelines, norms or standards relevant to the main components of safety. These include:

geomechanics and technical installations,
radioactivity, and sometimes
conventional contaminants.

3.1. Geomechanics and environment protection

Referring to the German Mining Act [2] it must be guaranteed that all piles and tailing ponds will be stabilized and recultivated after use to prevent unacceptable damage and to allow for reuse. In the case of mining and milling sites the regulations on water and soil protection and natural conservation are in the mining regulations. Only radiation protection is treated separately during the licencing procedure and it must be certain that no contradictions between these two areas of legislation occur.

For all mining legacies which come under mining supervision, proof of the geomechanical safety status is one of the requirements for a mining permit. Nevertheless, there are no uniform standards for discharge concentrations and/or the amounts of pollutants in the ground and surface water associated with the legacies. A basis exists for appraising contaminated soils and former industrial sites, namely in the Soil Protection Ordinance [3]. However, trigger and action values were not established for all of the relevant conventional pollutants here. In the published recommendations [3] the hazard coming from the groundwater pathway is estimated using test values for seepage water which are derived from or correspond to the limit values for drinking water.

3.2. Radiation protection

In accordance with the contract agreement the Radiological Protection Ordinance [4] and the implementation provisions [5] of the former GDR are in force together with certain restrictions on natural radioactive matter. Hereby, radiation protection among other things during the cleanup of remnant mining legacies is to be assured in accordance with the principles of justification and optimisation, as well as by the strict observance of radiation protection limit

values. Pursuant to the unified agreement on the continuing valid order for mining legacies [6] waste rock piles and uranium mill tailings ponds are to be covered and recultivated. For the waste rock piles, use as forest or for agriculture is permitted, but for the tailings ponds only forestry is allowed. Essential to this is the need to guarantee the long-term stability of a pile or tailing pond. In the case of tailings ponds any increase in radionuclide concentrations in the ground and surface waters is to be prevented.

Regardless of the necessity for cleaning up these legacies, as shown in the regulations [6], what must be established next is whether or not the reference values for radiation exposure in the present state of the facility are being exceeded. Therefore, criteria for the evaluation of mining legacies have been developed by the German Commission on Radiological Protection (SSK) to justify remediation. According to the recommendation of the SSK [7] a dose reference value of 1 mSv/a for all exposure pathways except for the inhalation of radon is advised as primary criterion for early mining sites. This dose value agrees with that of the Radiological Protection Ordinance [4] of the former GDR. For tailings ponds, however, the SSK dose criterion is not valid. The necessity of cleanup is also given if in the actual state of the facility the dose reference value is not exceeded [6]. The possible hazard is critical here because of the real or potential capacity for release of the generally very high radioactivity and pollutant inventory of such facilities.

For the Inhalation of radon the SSK [8] has recommended 50 Bq/m³ supplementary radon concentration emanating from an object as the primary criterion for the justification of cleanup. Additionally, the SSK has established reference levels [7] corresponding to the upper end of the range of variation of the natural background. This pertains e.g. to unrestricted land use provided that the specific activity of the soil is less than 0.2 Bq/g of Ra 226 in equilibrium with all nuclides of the uranium-radium decay chain. For restricted use, e.g. as grassland or forest or for industrial purposes, a maximum specific Ra-226 activity of 1 Bq/g was recommended.

Reference values also of radionuclide concentrations in seepage water or groundwater were derived. Nevertheless, different reference values exist because the harmonisation of legislation between the two regions of Germany is still going on (s. Table 1).

Table 1: Recommended values of maximum permissible radionuclide concentrations in liquid effluents, ground-, seepage- and drinking water [Bq/l]

Nuclide	§ 28 (4) DB VOAS [5] (discharge into surface waters)	§ 28 (6) DB VOAS [5] drinking water) ¹	SSK [9] (drinking water) ³	EC [10] (drinking water) ⁴	SMUL[11] (restoration target ⁵ ; groundwater)
U_{nat}	4.0 (0.16 mg/l)	2.5 (0.1 mg/l)	7.0 (0.3 mg/l)	1.1 (0.05 mg/l)	0.125 (0.005 mg/l)
U238	2.0 ²	1.2 ²	3.5 ²	0.5 6	0.06 ²
U 234	2.0 ²	1.2 ²	-	0.5 1	-
Ra 226	0.7	0.44	0.7	0.2 8	0.10
Ra 228	0.9	0.56	0.7	-	-
Pb 210	0.2	0.125	0.4	0.0 20	-
Po 210	1.0	0.625	0.6	0.0 15	-
Th 230	1.0	0.625	-	0.1 6	-
Th 232	0.3	0.19	-	-	-

¹ 800 l/a ² calculated from U_{nat} ³ value corresponds to 0.5 mSv/yr ⁴ value corresponds to 0.1 mSv/yr
(without Rn/RnDP; steady state; age group 7 – 12 yr, consumption rate 440 l/yr ⁵ value corresponds to 10 µSv/yr

When examining the radiation protection criteria for guaranteeing the long-term safety of a remnant legacy, there is no binding legal basis because the conditions for the final disposal of radioactive wastes do not apply. In Germany, for the risk assessment, timeframes equaling 200 years for waste rock piles and 1,000 years for tailing ponds were established. Hence, adherence to an individual equivalent dose of 1 mSv/a should be guaranteed over these periods. To estimate the radiological long-term stability of a mining legacy suitable assessment models based on the amounts of material and activity to be contained and the durability of natural and technological barriers were developed.

In accordance with the Principle of Optimisation the radiation protection measures are to be so planned and conducted that the radiation burden of personnel and population be kept as low as attainable in regard to socially acceptable expense. Once the necessity of restoration measures has been justified the selection of the most appropriate option is the second step in the decision-making process. The optimisation of radiation protection has become a key function in the decision making and in the licensing process for the remediation of the Wismut residues. Within the licencing procedure the responsible authorities have decided to accept the cost-to-benefit analysis (CBA) as a quantitative decision-making tool.

The basic idea behind this method was to weigh the costs of different remediation methods against the corresponding reduction in the collective dose. Consequently, this calls for a monitoring of the reduction in the collective dose. Since this has to do with intervention situations in the sense of the ICRP in conjunction with mining-related residues, and the established cleanup target value of 1 mSv/a per person lies within the area of the natural radiation exposure, and hence cleanup variations are compared which differ by mere fractions of a mSv as to the remaining exposure, this approach is very questionable. The LLE method applied here (loss of life expectancy) [12], also quantifying non-radiological risks, inevitably presupposes that the remaining exposure after cleanup as determined by each individual remedial variant does not change during the period mentioned (200 years for waste heaps and 1,000 years for tailing ponds). Furthermore, it is assumed that the population distribution and usage characteristics do not change. All of these assumptions are

extremely unrealistic. It is not presently known how a particular covering of a waste dump will change over the long term in regard to radon emissions or how in the future the community will develop. If one looks at this situation in retrospect, then e.g. the area around Schlema (one of the most important Wismut sites) was totally unpopulated 1,000 years ago. For these reasons this form of CPA is to be understood at best as an aid to decision making regarding very complex remnant legacies (e.g. very large tailing ponds) and is not legally binding in the licencing process because the application of the collective dose to intervention situations is inadmissible under German law. The long-term adherence to the individual dose of 1 mSv/a is decisive here and legally binding in all of Germany meanwhile in accordance with the new Radiological Protection Ordinance [1].

4. REMEDIATION METHODS

The remnant residues of uranium ore mining and processing mainly entail:

- Dump mounds (mining waste heaps, lowgrade ore heaps and tailing piles)
- Industrial waste settling ponds (for tailings and sludge)
- Work areas for mining and processing operations, ore loading platforms
- Buildings and accessories as well as
- Mine shafts, pits and galleries.

The following methods of cleanup were applied for the most part to the Wismut operations using the expertise of Wismut as well as of other lands with uranium ore-mining experience. These methods also make up the basis for the cleanup of the old Wismut sites taking into consideration the least potential hazard:

4.1. Mining heaps

Principally, the cleanup measures are to be so made up that the radon releases from the heap and the water intrusion into the body of the matter will be reduced longterm to a level where the cleanup target value of 1 mSv/a can be rightly adhered to. Most of the heaps are cleaned up in situ. A relocation of the mass takes place only for small piles (i.e. < 0.2 ha) or for piles within a built-up area. The material is redispositioned onto the neighboring heaps and included in their remediation. Over and above that, the use of heap materials (specific Ra 226 activity 0.2 – 0.5 Bq/g) is permitted for road construction in accordance with current law [6]. This is practised, however, only as an exception (mostly temporary paving along transport lines).

Regardless of the object-specific features, for the heap cleanup in situ, in conjunction with the geochemical source term and/or the distance to the next situated housing area, one decides between:

Two-layer covering for heaps without pyritoxidation near to town: The covering consists of 0.80 m of mineral soil and 0.20 m of arable soil with a concluding first planting viz. reforestation. Because of the geochemical properties a cleansing of seepage water is mostly not necessary. These heap types appear especially in the Saxonian mining districts.

Two-layer covering for heaps with pyritoxidation: The covering here consists of 0.40 m of mineral soil and 1.50 m of arable soil. Any intrusion of rain water will be almost completely stopped by the large layer thickness, to prevent a further pyritoxidation and thus pollutant

transport into groundwater. This is almost exclusively in reference to the Wismut heaps in Thuringia.

Minimal cover for remote heaps without pyritoxidation

Remote mining heaps (> 1,000 m from housing areas) in wooded regions as well as without sensitive use in their surroundings should after contouring and compression of the mound surface be covered with about 0.30 – 0.50 m of arable soil and reforested. A reduction in radon exhalation is reached through the gradual introduction of an autarkic water balance. This covering is planned for the Wismut heaps in Saxony and can be applied to most of the old mounds, also on small piles near town.

4.2. Tailings ponds

In accord with the certified Wismut cleanup concept an in-situ dry dumping will be carried out for all tailings ponds. This manner of cleanup is also planned for all of the old tailings ponds. In this connection new, in part worldwide, unique technologies have to be developed. In general the following work is necessary:

- Covering of dry scavenging beaches (first line of hazard defense)
- Free water removal, treatment and delivery into the drainage ditch
- Final covering, landscape design and reforestation
- Seepage water collection, treatment and delivery into the drainage ditch.

4.3. Work areas, ore loading platforms

Contaminated areas will be bagged off and the materials placed onto mining heaps or into settling ponds. Depending on the type of subsequent use the cleanup target values are 0.2 Bq/g Ra 226 (unrestricted use) and 1.0 Bq/g (industrial, commercial or forestry use) [7].

4.4. Buildings and technical accessories

Buildings with a "non removable" surface contamination < 0.5 Bq/cm² (natural uranium) can be used further commercially or industrially. In [7] construction debris from demolition work with < 0.2 Bq/g Ra 226 can be released without restriction (scrap collection or recycle). At specific activities between 0.2 Bq/g and 1.0 Bq/g dumping onto contaminated areas follows for which unrestricted release is in any case not planned (heaps and tailings ponds). At specific activities > 1.0 Bq/g dumping is to be studied from a radiation protection viewpoint.

Scrap with a surface contamination < 0.5 Bq/cm² (after cleaning) can be released for smelting. Because of the poor quality and the expensive process involved to attain free release, however, cleanup is usually waived and the entire matter is kept on a heap or in a tailings pond.

4.5. Pit mine buildings

Below ground mining pits are first emptied and if necessary stabilised (to guarantee geomechanical stability) and subsequently flooded. Old shafts and galleries are closed at the port insofar as nothing is to follow.

4.6. Water purification

As the flooding of pits and cleanup of heaps and tailings ponds take place residues from the water treatment (pit and seepage waters, tailings pond discharges) have enhanced natural radionuclide content (and chemotoxic matter). These residues principally in the Wismut legacies are included in the cleanup viz. they are dumped onto mining heaps, into tailings ponds or pits. Since, however, contaminated waters that have to be treated (until the permitted level for discharge into a surface water is reached) accrue over several decades after conclusion of the cleanup work, if necessary suitable disposal concepts are to be developed for these, viz. the dumping locations for receiving the residues from the water treatment must be kept open over the entire period of water treatment.

5. DATABASE

To get an overview of all of the remnant residues of mining and milling the federal project "Radiological Registration, Investigation and Evaluation of Mining Residues" of the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz-BfS) was carried out in 1991-2000 under the professional and organisational supervision of the Gesellschaft für Anlagen und Reaktorsicherheit [13]. Altogether, on a total surface area of 1500 km², approximately 9000 objects of the mining and milling remains were identified which exhibited the most important specific parameters and gave rise as well to representative local dose rate (LDR) values. These data together with actual photographs of the objects were placed in the A.LAS.KA databank. With the aid of the measurements of LDR and additional parameters the potential radiologically relevant objects were identified based on the recommendations of the Federal Commission on Radiological Protection (Strahlenschutzkommission-SSK). These "possibly radiological relevant objects" were examined further in site-specific measurement programmes as to actual hazard potential. Furthermore, representative geo-referenced measurements of the LDR, carried out using a grid of small mesh, and nuclid-specific data from upper soils and bore samplings, seepage and surface water, and plant matter as well were taken on the objects themselves and on their surroundings. This object-specific information along with the accessory cartographical basis of information was integrated into the "Field Information System for Mining-related Environmental Radioactivity (FbU)" ("Fachinformationssystem bergbaubedingte Umweltradioaktivität (FbU)"). This geographical information system (GIS) was made available to the state authorities of Saxony and Thuringia as the basis for decision-making and preparation for remedial measures. Table 2 provides an overview of the scope of the databank.

Table 2: Overview of the scope of the databank

Subject	Number
Mining-related objects	9,000
LDR measurements	250,000
Air, soil, water and vegetation samples	32,000
Radioactivity analysis data	240,000

Functionalities and performances can be seen in the poster session under the title: "Presentation and Analysis of Data on Environmental Radioactivity".

The Wismut company likewise has mining-related objects that fall within its sphere of responsibility in the Wismut Environmental Register databank. The data and information are of help both directly and indirectly for decision-making in the carry-through of remediation projects and the record for successful execution of the rehabilitation. Some of the mining-related objects found in the Wismut data base have already been successfully cleaned up.

6. GENERAL PRINCIPLES FOR THE DETERMINATION OF RADIATION EXPOSURE DUE TO MINING-RELATED ENVIRONMENTAL RADIOACTIVITY

For determining the radiation exposure of humans in intervention situations due to the remnant residues of milling and mining, the Federal Minister for the Environment, Nature Conservation and Nuclear Safety has published general procedures and methods covering releases of radioactive substances [14] and radon [15]. These are to be applied in calculations of radiation exposure coming from the use, decommissioning, clean up and subsequent employment of facilities and systems, as well as in the planning and optimization of exposure-mitigating measures.

6.1. Exposure pathways and scenarios due to mining related radioactivity

Referring to [14] for the calculation of the radiation exposure to man the following exposure pathways and scenarios have to be considered, , when these are actually relevant there.

Exposure scenarios:

- Indoor stay (living quarters, work place)
- Outdoor stay
- Consumption of mother's milk and foods produced locally (vegetable and animal products as well as water).

Exposure pathways:

- External exposure to gamma radiation from the soil
- Exposure by inhalation of dust
- Exposure by Ingestion of mother's milk and locally produced foods (drinking water, fish, milk and milk products, meat and meat products, leafy vegetables, other vegetable products)
- Exposure by direct ingestion of soil.

As reference persons individuals of 6 age groups of the general population are examined in accordance with [1, 14] as well as employees, for which the specific calculational parameters (dose coefficients, breath rates, exposure times as well as rates of ingestion and uptake) are determined.

The calculation of the radiation exposure for all exposure pathways should be carried out in accordance with the knowledge of representative values of the gamma-dose rate, the specific activity in the soil and food as well as the activity concentrations in air and water. These values can be determined by measurements or with the aid of computer models. The general principles themselves neither contain models which describe the transport of

radioactive substances with air and water nor the deposition surrounding the source of exposure.

When the calculation of the radiation exposure made is based on measured values to be considered these values also include the portion of the naturally existing (not mining related) environmental radioactivity. For the determination of the mining-related radiation exposure the portion attributed to the naturally available component is to be deleted.

For a simple check concerning adherence to dose limits and reference values the following two-step procedure is suggested:

1st Step: Calculation of radiation exposure without deleting the natural components: Insofar as no violation of the limit value is detected for the reference person, one may proceed without making additional checks for adherence to the relevant dose values. If the relevant dose values have been exceeded, then

2nd Step: A calculation of the radiation exposure based on the location-specific circumstances, whereby the representative value for the natural environmental radioactivity is absented. For the natural radiation exposure site-specific values or values characteristic of the location are to be introduced. The difference in radiation exposure so determined applies for the comparison with the relevant dose values as mining related radiation exposure.

On behalf of the Federal Board for Radiation Protection (BfS) the GRS developed a PC program called "BerBer" which meets the requirements of [14] and enables access to external data, e.g. FbU-PC, and likewise the storage of results in further-processable EXCEL Format [16].

6.2. General Principles for the determination of the radiation exposure from inhalation of radon and its short-lived decay products

In [15], for the calculation of the radiation exposure due to the mining-related radon dose, the following scenarios and exposure pathway in the area of the highest radon concentration are to be considered, should these actually be relevant there:

Exposure scenarios:

- Indoor stay (living quarters, work place)
- Outdoor stay
- Below-ground work place.

Exposure pathway:

- Inhalation of radon and its short-lived decay products.

As points of interest to be looked at are the places at or in the vicinity of the mining-related objects where people can realistically be assumed to stay. Places at which the mining-related radon 222 concentration amounts to less than 5 Bq/m³ are not considered. The value of the mining-related radon 222 concentration can be established by measurements assisted by computer models or conservative estimates which include the exhalation rate, the surface area of the object and correction factor to take account of the meteorological and topographical local site conditions [15].

Beside the mining-related contribution the measurements also include the naturally occurring radon 222 concentration: For the areas in question a value of 20 Bq/m³ is regarded as representative in [15]. Regarding the mining-related radon dose to the reference persons in

the general population only those places of exposition contribute for which the representative measured value of the radon 222 concentration exceeds 25 Bqm³.

Based on investigations of the atmospheric dispersion of radon emissions from plane sources the generic GENDARM assessment procedure was developed first [17]. For the site-specific calculation of the spatial distribution of the average yearly values of the supplementary Rn concentration which can stem from one or more sources, the GRS developed the SMART model system which comes up to the requirements in [15] especially for complex terrain structures. This is based upon:

- Data on ground cover and terrain heights
- Time series of site-specific meteorological data taken from 25 meteorological stations of the German Weather Service (DWD)
- Certain object data, either manually entered or input based on the Oracle data bank of the "Register of Contaminated Sites" (Database A.LAS.KA.), respectively a selection from within the "Field Information System for Mining-related Environmental Radioactivity"(FbU).

For the calculation of the spatial distributions of the average yearly values of the additional Rn concentrations in the environs of one or more emitters a multiplicity of coupled flow and dispersion calculations have to be carried out. This is based upon the meteorological data, the source term and the terrain. By means of the SMART model a surface-covering meteorological database utilizing the time series of the above-mentioned weather stations (meteorological dispersion class statistics in which the 3-parameters ground level wind velocity, wind direction and stability class are summarized in regard to occurrence) was drawn up. With these frequency distributions the long-term dispersion factors are calculated which represent a measure of the yearly averaged expectation value for the time-integrated ground-level additional Rn concentration. The application of a flow model with subsequent dispersion calculation enables the calculation of surface-covering radon climatologies to be made also in topographically structured terrain. So the influence of the flow field and Radon dispersion is taken into account by means of typical characteristics of the terrain in the former uranium ore mining districts of Thuringia and Saxony.

A computer demonstration of the SMART model system can be viewed in the Poster Session.

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