FLORA AND VEGETATION ON DUMPS OF URANIUM MINING IN THE SOUTHERN PART OF THE FORMER GDR

HARTMUT SÄNGER

C & E Consulting und Engineering GmbH,
Jagdschänkenstraße 52, D- 09117 Chemnitz

(Received: April 7, 1995. Accepted: October 25, 1995)

ABSTRACT

From 1946 to 1990 an intensive uranium mining had been carried out with underground mining and also with opencast mining by the Wismut enterprise in the southern part of the former GDR. The mining activity lead also in the surroundings of Ronneburg to a permanent growth of devastated areas, among others in the form of dumps and tailings. These areas form by reason of mining-specific contaminations, extrem biotops which demand high claims on the pioneer organisms during the phase of natural first settlement. From 1990 to 1992 vegetation mappings were carried out on 15 dumps of the Thuringia mining area according to Braun-Blanquet (1964). The utilization of the computer programm Flora_D (Frank and Klotz 1990) enabled the ecological characterisation of the dumps. On the 15 investigated dumps found were 498 higher plants, belonging to 65 families. One hundred species are species with a high dominance. The number of species per dump fluctuates between 11 and 282. Pioneer plants occur on the berms mostly in the second year after stoppage of the dumping, on the slopes after five to ten years. After nearly ten years the first step of settlement seems to be finished. Among the mechanisms of spreading dominate wind- and burdock spread. According to the form of life forms the dump species are predominantly hemicryptophytes, further therophytes, geophytes and phanerophytes.

KEY WORDS: uranium mining, dumps, flora, vegetation, bioindication, ecological characteristics.

INTRODUCTION

From 1946 to 1990 an intensive uranium mining had been carried out with underground mining and also with opencast mining by the Wismut enterprise in the southern part of the former GDR. The main mining areas were located in Thuringia by the town Ronneburg and in Saxonia in the Ore Mountains and in the so-called Saxonian Swiss. During 46 years 220 000 t of uranium were produced. With this quantity the Wismut enterprise was the biggest uranium producer in Europe and the third biggest in the world after the USA with 350 000 t. and Canada with 240 000 t.

After the stoppage of uranium mining in 1990 the modification of SDAG Wismut into an restoration enterprise took place. The only task of this new enterprise was to reconstruct the closed uranium mines and uranium-refine factories in such way that soil-, water- and airpollutions be eliminated.

The work which is carried out during the restoration must be evaluated with reference to its effectivity and continuation. This task should be realized by a complex monitoring system.

The term "monitoring" is here defined as an all area control of processes in the environment.

In the centre of investigations on biomonitoring, in the range of environmental contaminations in uranium mining and uranium refinery, at present the following topics are considered:

- Evaluation of the actual condition of biotopes which were impaired for decades by uranium mining, for instance:
 - Registration of biotope types
 - Registration of fauna and flora
 - Registration of water quality in the receiving streams which are influenced by mining processes
- Bio-assays/Bioindication
 - Ecotoxicological evaluation of sediments in the receiving streams
 - Evaluation of distribution and effect of air contaminants using the method of registration of necrosis in *Pinus sylvestris*
 - Accomplishment of radiation-biological examinations using the honey-bee (*Apis mellifera*) as bioindicator
 - Evaluation of heavy metal contamination of dumps using higher fungi as bioindicators
 - Investigation of contents of natural radionuclids in plants
- Support of accomplishment of restoration arrangements
 - Evaluation of environmental compatibility of the planed restoration arrangements before realization
 - Accompanying investigations during the realization of restoration measures
 - Control of restoration success.

Fig. 1. Location of the investigated area.

MATERIAL AND METHODS

The mining activity described at the beginning lead also in the surroundings of Ronneburg to a permanent growth of devastated areas, among others in the form of dumps and tailings. These areas are, by reason of mining specific contaminations, extrem biotops which demand high claims on the pioneer organisms during the phase of natural, first establishment.

In this process the following phenomena act very selectively: the acidic soil conditions, the coarse-grained dump material, leakage water from dumps with high hardness of water and high contents of sulphate, chloride and uranium, radon vapours and the high surface temperatures of dumps in areas with black dump material especially in the summer months.

During restoration of the dumps it was shown that location investigations had to proceed to a successful green resurfacing of the dumps. This fact is demonstrated among other things in the investigations by Schubert (1953/1954) on dumps of copper slate mining in the eastern Harz foreland, by Wünsche (1963) on dumps of hard coal mining in the district of Zwickau-Lugau-Oelsnitz and also by Richter (1963) and Ranft (1966) on dumps of ore mining in the Ore Mountains.

Annotations to the investigation area

Position and boundary:

The east Thuringian uranium mining area in the surroundings of Ronneburg is a part of the richly articulated East Thuringian – West Saxonian hilly country. The investigation area has an extent of 21 km in north-south direction and 10 km in west-east direction (Fig. 1).

The altitude levels of the investigation area extend from 250 to 350 m above sea-level. The investigated dumps are up to 450 m above sea-level.

Rainfall- and temperature conditions:

The investigation area belongs to the area of the "Middle German mountain and hill-climate". It is situated in the transitory area between the relatively rain-rich Thüringisch-Vogtländischen slate mountains and the relatively warm and dry Altenburg-Zeitzer-Loess area. Late frosts can occur up to the middle of May in the investigation area.

Characteristics of the investigated dumps

The investigations were carried out on 15 dumps of the Thuringian mining area. The selected dumps differed in the following features:

- age
- lithological characteristic
- morphology
- cultivation

They can be subdivided into:

- dumps of the opencast Lichtenberg
- dumps of the opencasts Culmützsch, Trünzig and Sorge-Settendorf

Fig. 2. The opencast Lichtenberg.

- dumps of underground mining
- dumps of chemical uranium production (leaching dumps)

Dumps of the opencast Lichtenberg:

The uranium mining in the opencast Lichtenberg began in 1959. With the end of mining in 1976 the devastated area amounted to 350 ha with a volume of the open pit of 84 million m³. The opencast reached a depth from 230 m and represents today an incision of a length of 1,6 km and a breadth of 900 m (Fig. 2).

The dumps of the opencast Lichtenberg consist of Ordovician, Silurian and Devonian rocks. The contents of uranium in the beds of the Ronneburger type vary between 0,05 and 0,2 up to 0,3 % with an average of 0,08 %. Characteristic is here the occurrence of pyrit and markasit as well as the relative high share of organic carbonaceous substances. The ores date back from the Lower Permian up to the Alpinic about 90 to 240 million years ago.

The refined samples of the Palaeozoic rocks show pH-values between 4,4 and 6,1. Of special interest for the primary natural plant growth of the dumps is the sulphur content. The toxic limit for plant development lies approximately at 0,7 mass % total sulphur as SO₃ according to different data in the literature.

Table 1 contains the sulphur contents of a selection of rock samples from the opencast Lichtenberg according to information from Rau and Pantel (1964).

TABLE 1. Sulphur contents of a selection of rock samples from the opencast Lichtenberg after Rau and Pantel (1964). Values in mass % total sulphur as SO₃

Sample Material	Σ S
Clay-Slate Og ₃	0,08
Silicic-Slate S ₁	1,91
Silicic-Slate S ₁	4,58
Alum-Slate S ₁	25,26
Siltstone S ₂	7,67
Siltstone S ₂	15,10
Alum-Slate S ₃	7,60
Alum-Slate S ₃	10,88
Clay-Slate D ₁	0,24
Clay-Slate D ₁	0,17
Clay-Slate D ₁	0,09

Dumps of the opencasts Culmützsch, Trünzig and Sorge-Settendorf:

The deposit Culmützsch-Sorge was discovered in 1946. It contained on an average 0,04 % uranium. This deposit must be ascribed to the Upper Permian, whereas two large chan-

ging heads, each 1,5 m or 3 m, of sandstone, slate and dolomite appeared on a large surface area of about 4 km² as a horizon of ore.

The opencast Culmützsch was opened 1955 and was mined until spring 1967. Formerly its entire size amounted to about 400 ha of which 270 ha are allotted to the dumps and 130 ha to the opencast itself. The mining activity in the opencast Culmützsch arose the dumps Jashalde, Lokhalde, Südhalde, Waldhalde and Gauernhalde. The dump Trünzig on which is today a tailing, arose by overground mining in the 1946 opened opencasts Trünzig and Sorge-Settendorf.

On the dumps of the opencast Culmützsch predominately rocks from Middle Permian limestone, over Permian limestone and from lower set sandstone were deposited.

Dumps of underground mining:

Parallel to the opencast mining in the Ronneburger ore field 1952 an underground mining begun, first of all in the mine Schmirchau. There followed between 1956 and 1958 the mines in Reust and in 1960/61 the underground mining in the region Paitzdorf. This underground mining created the four widely visible terrasic dumps from Reust and Paitzdorf (Fig. 3).

In 1980 began the underground mining in the mine Drosen. The mine Beerwalde expanded in this time its drainage area in the direction of Korbußen. The dumps Drosen, Beerwalde and Korbußen emerged (Fig. 4).

The leaching dump from Gessen:

The leaching dump from Gessen heaped up between 1970 and 1990 with the so called poor ores which were leached here by above-ground treatment. The former leaching dump consisted of three tiers, each 15 m of height (Fig. 5).

The base covered 36 ha and the volume after stoppage of leaching was 6,9 million m³. The treated poor ores were composed to 60 % of leather slate and to 40 % of lower graptolite slate. Today the leaching dump Gessen does no longer exist. After 20 years of leaching in 1991 for reasons of environment control the clearing away of the dump began. In the years 1990 and 1991 the registration of the pioneer vegetation took place, thus we have also data from the most extreme sites of the investigated area.

Methods:

The botanical investigations were carried out from 1990 to 1992. For characterization of flora and vegetation 225 vegetation mappings were used.

The investigated plant populations were mapped according to the method of the combined estimate of abundance and dominance according to Braun-Blanquet (1964) and were put together into vegetation units. The size of the separate mapping areas conforms to the extension of the plant society. It lies within a range of 10 to 500 m². The utilization of the computer programm Flora_D from Frank and Klotz (1990) enabled the ecological characterization of the dumps.

RESULTS AND DISCUSSION

Summarizing remarks on flora and vegetation

On the 15 investigated dumps 498 higher plants, divided into 65 families, were found. One hundred species are species with a high dominance. The number of species per dump varies between 11 and 282.

Fig. 3. The terrasic dumps of Paitzdorf.

With regard to site conditions the dump species show a good conformity to the flora of the former GDR.

Among the mechanisms of spreading dominate wind- and burdock spread. This fact is reflected in the percentage of families, 14,5 % of the species are *Asteraceae*. Ants and self spreading contribute also in a larger measure to the spread of plants to the dumps, while man-, water-, digestion- and animal spreading gain only in some cases a higher significance.

Primarily the dumps were settled by species which can quickly and in high quantity of diaspores come to the dumps and here, under adequate ecological potential, are able to build up persistent existences.

According to life forms the dump species are predominantly hemicryptophytes, further therophytes, geophytes and phanerophytes. The calculation of the community coefficient

shows that only between 8 dumps there exists a higher correspondence (over 40 %).

The largest portion of the dump flora belongs to the families *Asteraceae* (14,5 %), *Poaceae* (10,7 %), *Brassicaceae* (6,5 %), *Fabaceae* (6,3 %) and *Rosaceae* (5,0 %). All other 60 families are present in the dump flora with less than 5 %. The reasons for this distribution are to seek, in the first place, in the nature and way of spreading of the species.

Table 2 contains some ecological indicator values according to Ellenberg (1979).

Light tolerance:

The light tolerance lies in a range from 6,2 to 7,8 (average of flora from former GDR = 6,9). Thus, the vegetation of dumps is composed of hemi-shadow plants, hemi-light plants

Fig. 4. The dump of the mine Drosen.

Fig. 5. The former leaching dump from Gessen.

TABLE 2. Ecological indicator values after Ellenberg (1979)

Value	Former GDR	Surroundings of dumps	Dumps
Number of species	2208	818	498
Indigenous	1607	631	398
Archaeophytes	154	79	59
Neophytes	422	108	41
Average			
Light tolerance	6,9	6,6	7,1
Temperature tolerance	5,8	5,6	5,5
Continentality	4,1	5,6	4,2
Moisture number	5,1	5,3	4,9
Reaction number	6,3	6,0	5,9
Nutrient number	4,7	5,2	5,6
Spreading [%]			
Wind spreading	38,2	36,6	40,2
Ant spreading	9,1	10,4	13,6
Burdock spreading	23,2	23,6	27,1
Water spreading	6,8	6,9	2,1
Man spreading	3,1	2,7	2,1
Self spreading	12,9	13,2	7,8
Digestion spreading	6,4	6,1	4,6
Animal spreading	0,3	0,5	0,4
Strategy types [%]			
C-Strategists	24,1	29,9	40,3
CS-Strategists	18,4	15,5	6,7
S-Strategists	3,2	2,1	0,7
SR-Strategists	5,5	4,2	5,1
R-Strategists	9,7	8,3	8,3
CR-Strategists	11,7	14,4	19,7
CSR-Strategists	27,4	25,6	19,2
Life forms [%]			
Therophytes	22,1	21,1	22,6
Geophytes	12,1	11,7	10,5
Hernikryptophytes	41,1	44,0	45,6
herbly Chamaephytes	4,1	4,8	4,4
woody Chamaephytes	2,0	1,4	1,1
Nanophanerophytes	5,0	4,6	4,7
Phanerophytes	3,0	4,0	7,2
Hydrophytes	5,8	5,0	1,1
Epiphytes	0,2	0,1	—
Lianas	1,9	2,2	2,6
Full parasites	0,9	0,4	—
Half parasites	1,2	0,7	0,2
Saprophytes	0,3	—	—

and light plants. Deep-shadow plants, shadow plants and full-light plants do not occur.

Temperature tolerance:

The temperature tolerance fluctuates between 5,0 and 6,2 (average of flora from the former GDR = 5,8). On the dumps exist consequently only temperate-warmth, and warmth indicators. The settlement of this species on the dumps is favoured by south-exposed slopes and black slate areas with a good absorption of warmth.

Continentality values:

The continentality values lie within a range from 3,5 to 5,4 (average of flora from the former GDR = 4,1). On the dumps suboceanic species are dominating, which found their main spreading in Middle Europe.

Moisture values:

The moisture values lie within a range from 4,2 to 6,4 (average of flora from the former GDR = 5,1). According to these values, chiefly fresh indicators found on the dumps, exist on moderately moist soil, avoid, however, wet as well as often dried-out soil. Indicators of dryness and absolut moisture grow on the dumps only sporadically.

PH values:

The pH values range from 4,0 to 7,0 (average of the flora from the former GDR = 6,3). Under dominance of temperate acidophilic plants, here and there exist also acidophilic plants and weak basiphilic plants on the dumps.

Nutrient value:

The nutrient values range from 3,9 to 7,5 (average of the flora from the former GDR = 4,7). The vegetation of the dumps indicates in the majority of described communities of plants, higher nutrient values than the average of the former GDR flora. Most of the dump sites are moderately rich in nutrients. The poorest in nutrients is the "Rubble vegetation of poor sites" (value 3,9) the richest the *Chenopodietum glauco-rubri* (value 7,5).

Spreading mechanisms:

In the 28 plant associations wind spreading dominates. Other important spreading mechanisms for the settlement of dumps are the burdock spread and ant spread. Digestion spread plays on the dumps as good as no role.

Ecological strategy types:

Most frequently (in 19 from 28 vegetation units) rivalry strategies are to be found. In 5 plant communities (*Lactuco-Sisymbrietum altissimi*, *Puccinellia distans* community, *Erigeron canadensis*-*Lactucetum serriolae*, pioneer communities on the test areas, *Atriplicetum nitentis*) dominate cr-strategies, while in the "Rubble vegetation of poor sites" the csr-strategies, in the *Plantagini-Polygonetum avicularis* the r-strategies, in the *Chenopodietum glauco-rubri* the sr-strategies and in the reeds the cs-strategies are in first position. In the flora of the former GDR csr-strategists are found most frequently. On the dumps species with high competitive power prevail.

Hemerobic data:

The dump vegetation is strongly characterized by beta-eu-hemerobic species. This is not surprising when one assumes that the species from the dump surroundings immigrate to the dumps. The surroundings of the dumps are man cultivated

with intensive pastures, meadows and forests which are subject to the influence of man, for instance dunging, liming, application of biocides, herbicides, fungicides and so on. In 7 plant communities mesohemerobic species dominate. The respective communities establish mostly in the inner dump areas which were inaccessible to man during the phase of active mining. Therefore they were subject, contrary to the surroundings of the dumps, only to an insignificant anthropogenic influence. Polyhemerobic species which mark the dumps as special sites are available in all vegetation units, exceed however in no case 25 per cent.

Urbanic species:

With regard to urbanization as a measure for settlement nearness of the separate species in 25 from 28 plant communities urbanoneutral species dominate. The dump species show in that way no preference to nearness or distance to settlement. In the flora of the former GDR the urbanophobic species are in first position (53,1 %).

Behaviour in face of oversalting and the content of heavy metals in soil:

In 71,4 % of the plant communities the number of salt-tolerant species lies significantly over the GDR-average. Regular salt-communities on the dumps are the *Chenopodietum glauco-rubri* (76,5 % of the species are salt-tolerant), the *Puccinellia distans* community (64,8 % of the species are salt-tolerant) and the reeds (41,5 % of the species are salt-tolerant).

In these three communities found were also the most optional halophytes. Obligatory halophytes were till now found in none of the described plant communities.

In their tolerance of higher heavy metal contents of the soil the "Rubble vegetation of poor sites", the "broom-communities" and the "once cut meadows" are especially striking. Here the share of heavy-metal-resistant species in the above named sequence of communities is 6,6 %, 9,1 % and 7,5 %. In additional 15 plant communities the number of heavy metal tolerant species lies clearly over the GDR-average (which is 0,2 % of species). The dump species distinguish themselves from the territory flora by a higher salt-, and heavy metal tolerance.

Life forms:

Just as in the GDR-flora, in 85,7 % of the dump plant communities the hemicryptophytes stands also in first position. Only in the *Chenopodietum glauco-rubri*, in the pioneer communities on the test fields, in the *Plantagini-Polygonetum avicularis* and in the *Atriplicetum nitentis* the therophytes dominate. Phanerophytes are first evident in the pre-wood stages or in artificially newly planted forests. Half-, and full parasites were found only in four associations. Epiphytes were not found. Lianas participate in most of the plant communities in their establishment.

The vegetation of the investigated dumps can be subdivided into pioneer-, and persistent plant communities.

Pioneer-plant communities:

Tussilaginietum farfarae Oberd. 1949

Rubble vegetation of poor sites

Chenopodietum glauco-rubri Lohm. 1950

Puccinellia distans community

Lactu-Sisymbrietum altissimi Lohm. in Tx. 1955

Erigeron canadensis-Lactucetum serriolae Lohm. 1950

Melilotus alba-Artemisia vulgaris community

Lolium perenne-Festuca rubra seed

Pioneer communities on the test fields

Persistent-plant communities:

Calamagrostis epigejos community

Tanacetum-Artemisietum vulgaris Br.-Bl. (31)49

Artemisia vulgaris-community

Tanacetum-Arrhenatheretum Fischer 1985

Oat-grass community

Alopecuretum pratensis Regel 1925

Plantagini-Polygonetum avicularis (Knapp 1945) Pass. 1964

Atriplicetum nitentis Knapp 1945

Field eryngo community

Once-cut-meadow community

High shrub borders at trenches

Reeds

Broom communities

Robinia pseudoacacia afforests

Populus tremula afforests

Populus balsamifera afforests

Populus x canadensis afforests

Birch prewoods

Betulo-Quercetum roboris Tx. 1930

In Figure 6 it was attempted to present the first findings on succession on the dumps. These must be completed by further investigations.

It follows some remarks on the pioneer species on the dumps. Prerequisite for the registration of the pioneer flora were uncovered dump areas. Such areas are today, in consequence of combat from the former dump burnings and present restoration activities, no longer present on all dumps. Loose, undecomposed, humus-free material and, as a rule, shadeless sites cause that the starts of settlement of dumps, also with different dump materials, develop in the same way.

On the investigated slate dumps of the East Thuringian West Saxonian uranium mining area from 1990 to 1992 altogether 177 higher plants as possible pioneer species could be demonstrated. Table 3 shows a survey of species which are attributed to the highest species groups on the investigated slate dumps during the first wave of establishment with a duration up to 10 years.

TABLE 3. The highest species groups on the investigated slate dumps during the first wave of settlement with a duration up to 10 years.

Arrhenatherum elatius, *Artemisia vulgaris*, *Atriplex nitens*, *Betula pendula*, *Calamagrostis epigejos*, *Capsella bursa-pastoris*, *Carlina vulgaris*, *Cerastium holosteoides*, *Chaenorhinum minus*, *Chamomilla suaveolens*, *Cirsium vulgare*, *Conyza canadensis*, *Cirsium arvense*, *Dactylis glomerata*, *Daucus carota*, *Epilobium adnatum*, *Epilobium angustifolium*, *Epipactis atrorubens*, *Fragaria vesca*, *Hieracium murorum*, *Hieracium pilosella*, *Hypericum perforatum*, *Inula conyza*, *Lactuca serriola*, *Lepidium ruderales*, *Leucanthemum vulgare*, *Lotus corniculatus*, *Matricaria maritima*, *Melilotus alba*, *Picris hieracioides*, *Pinus sylvestris*, *Plantago major*, *Poa annua*, *Poa trivialis*, *Polygonum aviculare*, *Populus tremula*, *Puccinellia distans*, *Quercus robur*, *Rubus caesius*, *Rumex acetosa*, *Rumex crispus*, *Salix caprea*, *Senecio vernalis*, *Senecio viscosus*, *Sisymbrium altissimum*, *Solidago canadensis*, *Sonchus arvensis*, *Sonchus asper*, *Taraxacum officinale*, *Tanacetum vulgare*, *Tussilago farfara*

Fig. 6. First findings on succession on the uranium-mining dumps.

The pioneer plants on the slate dumps are up to 76,7% indigenous species. Consequently the share of archaeophytes with 13,1% and of neophytes with 10,2% is small. The pioneer plants are distributed in the following way into groups according to the computer program Flora_D.

Asteraceae (23,7%), Poaceae (13,0%), Fabaceae (8,5%), Brassicaceae (5,6%), Caryophyllaceae (5,1%), Polygonaceae (4,5%), Scrophulariaceae (4,5%), Chenopodiaceae (3,4%), Rosaceae (3,4%), Apiaceae (2,3%), Lamiaceae (1,7%), Ranunculaceae (0,6%), Liliaceae and Orchidaceae in each case 0%.

These occur chiefly photophilous plants which can tolerate the strong illumination of the dump areas which are free from vegetation. This fullness of light is accompanied over a long time by an acute water- and nutrient shortage in the coarse-grained dump material. The superficial vaporization on the dumps appears minimum. The summer warming of the block slate cause surface temperatures up to 60°C. Among the pioneer plants there are only few species which can tolerate such extrem conditions.

Pioneer plants occur on the berms mostly in the second year after stoppage of the dumping, and on the slopes after five up to ten years. They can only then gain a foothold when the dump

material is broken up in consequence of surface weathering. North-west exposed slopes are first accepted. The south sides remain over a long time free from vegetation. This changes as soon as the dumping areas become covered with cultivated soil. On such treated sites develops soon a pioneer flora composed of weeds.

After nearly ten years the first step of establishment seems to be finished. Conditioned by tree species which have appeared in the meantime, a small amount of organic substance can be accumulated (for instance from blown leaves). For some species (in part forest species) in dripping range of branches and leaves and through shadow effect, conditions arise which make an existence possible.

The establishment conditions are unfavourable on the slopes of terrasic dumps. After the dumping the slope disposition amounts here to 40 degrees and more. Through glide and roll movements of the dump material the slope angle degrades up to nearly 36° or 38°. The eroding force of water, frost and heat lead to the fact that the upper dump areas show a fine composition of dump material, while the middle and lower areas are chiefly composed of coarse-grained material. The growth of plants will be there over a long time troubled by rolling dump

rubble. The first settlement of terrasic dumps starts always at the foot of the dump where quiet areas with little sunlight are first established by *Betula pendula* and *Calamagrostis epigejos*.

The interpretation of the vegetation mappings for the documentation of the first establishment of dumps shows that pioneer species, for the most part, are annual herbaceous plants which are characterized by a short lifespan and a high production of seeds and, in this way, can establish pioneer sites in short time.

In addition to the above, there come the rivalry strategies (34,1% of species); trees, bushes and herbaceous species with a strong competitive power which is determined by specific morphological and physiological characteristics and typical signs of their life history.

First results of investigation with bioindication

Performance of biological radiation investigations using the honeybee (*Apis mellifera*) as bioindicator:

Within the framework of the preparation of an environmental land register the radioactivity in bee products was determined by means of Gamma-ray spectrometry (Table 4).

The results show that the radioactivity in honey is twice to three times as high as in that from unpolluted control areas. Nonetheless, the level of honey radioactivity observed in the studied area does not endanger human health.

Estimation of needle necrosis in *Pinus sylvestris*:

For the investigation of air quality with age of needles and needle necrosis in *Pinus sylvestris* in 1991 in 13 sites, which lay as well in the mining area as in uninfluenced by mining control areas, 600 specimens of *Pinus sylvestris* were examined (Table 5).

The so-called "Woodland" with the sampling places at Mörsdorf and Reichenbach was the best area with regard to air quality. The dumps Beerwalde, Waldhalde and Gauernhalde differed but little from the other control points in the surroundings of the mining area near Naulitz, Gera and Langenreinsdorf.

A group of worse sites were formed by the Nordhalde, Dammhalde on the tailing Culmitzsch, Zentralhalde and the tract of land in the former ore-refine plant Seelingstädt. There it is conceivable that synergisms between radioactive radiations of the underground and common concentration of air pollutants exist as described by Reichelt (1984) in the area of Wittichen in the Black Forest (Germany). In order to confirm such conjectures further investigations are needed.

Investigations of macromycetes as bioindicators:

On the dumps of uranium mining in the surroundings of Ronneburg until now 62 species of higher fungi were demonstrated, which can be arranged into 23 taxonomic groups. As frequently present are mycorrhiza fungi (52,2 %); 38,7 % of the species are saprophytes and 8,1 % parasites.

Sixteen species, registered both at the dumps and their surroundings, had been analysed with regard to the contents of mercury, cadmium, lead, zinc and copper (Table 6).

The results of this examination show, that mushrooms from the dumps have no higher contents of heavy metals than the same species which were collected far away. Xylophagous species have lower rates of heavy metals than saprophytes and species with mycorrhiza.

In view of these results it is probable that dump mushrooms, considered up till now are generally less contaminated.

TABLE 4. Radioactivity in honey in the Wismut area in comparison to the notcontaminated control area [Bq/kg].

Honey	U-238	U-235	Rn-222	Th-232	K-40
Wismut					
Swarm 10					
1.	13 ± 05	0,6 ± 0,2	1,2 ± 0,2	0,5 ± 0,2	73 ± 01
2.	13 ± 04	0,3 ± 0,1	1,0 ± 0,1	1,0 ± 0,1	72 ± 01
Swarm 11					
1.	12 ± 04	0,5 ± 0,1	1,1 ± 0,1	0,9 ± 0,1	70 ± 01
2.	14 ± 05	0,3 ± 0,1	1,1 ± 0,1	0,4 ± 0,1	77 ± 01
Swarm 12					
1.	14 ± 04	0,4 ± 0,1	1,2 ± 0,1	1,0 ± 0,1	65 ± 01
2.	04 ± 03	0,2 ± 0,1	1,1 ± 0,1	0,3 ± 0,1	21 ± 01
3.	17 ± 04	0,3 ± 0,1	1,3 ± 0,1	0,3 ± 0,1	87 ± 01
4.	06 ± 03	0,2 ± 0,1	1,0 ± 0,1	0,2 ± 0,1	28 ± 01
Swarm 13					
1.	11 ± 03	0,4 ± 0,1	1,2 ± 0,1	0,3 ± 0,1	29 ± 01
Swarm 14					
	10 ± 04	0,6 ± 0,1	1,5 ± 0,1	0,3 ± 0,1	89 ± 02
Swarm 15					
1.	13 ± 04	0,5 ± 0,1	1,2 ± 0,1	0,8 ± 0,1	76 ± 01
2.	13 ± 04	0,3 ± 0,1	0,8 ± 0,1	0,4 ± 0,1	72 ± 01
Control					
Swarm 16					
1.	08 ± 03	0,4 ± 0,1	1,0 ± 0,1	0,2 ± 0,1	100 ± 01
2.	10 ± 03	0,4 ± 0,1	1,0 ± 0,1	0,2 ± 0,1	31 ± 01
Swarm 17					
1.	05 ± 03	0,3 ± 0,1	1,0 ± 0,1	0,7 ± 0,1	55 ± 01
2.	12 ± 04	0,3 ± 0,1	1,0 ± 0,1	0,1 ± 0,1	83 ± 01
Swarm 18					
1.	06 ± 03	0,3 ± 0,1	1,2 ± 0,1	0,8 ± 0,1	27 ± 01
2.	10 ± 04	0,6 ± 0,1	1,2 ± 0,1	0,3 ± 0,1	89 ± 02

The contents of natural radionuclides in plants:

For investigation of the contents of natural radionuclides in plants since 1992 different test programmes have been in progress. In addition to the analysis of mixed samples, as first step search was carried out for possible reference plants, for the evaluation of the radiological situation in the surroundings of contaminated mining areas.

In view of the demands on a bioindicator it's necessary to have plants which are present over the whole area of the investigation site and over the whole vegetation period. Good results were in this way obtained with the species *Petasites hybridus*, *Atriplex nitens*, *Chenopodium album*, *Tussilago farfara*, *Calamagrostis epigejos* and *Betula pendula*.

TABLE 5. Results of investigation according to air quality, by age of needles from *Pinus sylvestris*

<i>Sites and percentages of different needle age groups</i>													
	1	2	3	4	5	6	7	8	9	10	11	12	13
Age [a]													
1	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
2	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
3	86,7	100,0	90,0	96,0	48,0	16,0	40,0	48,0	68,0	32,0	32,0	68,0	43,0
4	4,0	34,0	42,0	32,0	6,0	4,0	—	4,0	4,0	—	8,0	5,3	2,0

Sites:

1 = Dump Beerwalde, 2 = Reichenbach, 3 = Mörsdorf, 4 = Mörsdorf, 5 = Naulitz, 6 = Central Dump, 7 = North Dump, 8 = Dump Gauern, 9 = Wood Dump, 10 = Dump Culmützsch, 11 = Ore refine plant Seelingstädt, 12 = Gera, 13 = Langenreinsdorf.

The samples were taken both in the mining area and in the areas, which were not injured by mining. In the samples the natural radionuclides from the fission of uranium (U-235, U-238, Ra-226, Pb-210, Po-210 and Ra-228) were determined. In order to control the encumbrance not related to mining, in the samples the nuclides Cs-134 and Cs-137 and also K-40 were determined.

On the basis of the presently valid, the effective equivalent dose for adults through different paths of exposure, for example grass – cow – milk – man, was calculated.

The results show that only in very few areas values exceeding threshold limits were recorded (Table 7).

TABLE 6. Contents of mercury, cadmium, lead, zinc and copper in selected mushrooms [mg/kg dry weight]

	Hg	Cd	Pb	Zn	Cu
I. Saprophytes					
<i>(Agaricus, Lycoperdon)</i>					
Dump mushrooms	1,87-2,80	0,68-21,20	2,53-27,60	91,40-176,40	40,70- 85,60
Mushrooms from other sites	2,10-7,82	0,47-49,40	1,82- 7,28	84,70-236,20	51,70-192,70
Average					
Dump mushrooms	2,31	8,25	11,07	123,07	61,43
Mushrooms from other sites	4,44	10,09	4,72	166,05	109,71
II. Mycorrhiza mushrooms					
<i>(Amanita, Lactarius, Krombholziella, Paxillus Russula, Scleroderma,</i>					
Dump mushrooms	0,01-35,80	0,09-11,19	0,01-9,87	15,20-359,90	1,90- 97,20
Mushrooms other sites	0,01- 1,95	0,06-11,92	0,12-7,52	75,70-332,30	5,80-101,20
Average					
Dump mushrooms	2,87	1,95	1,92	125,78	29,19
Mushrooms from other sites	0,48	2,56	1,49	142,28	56,25
III. Xylophagous species					
<i>(Fomitopsis, Pluteus, Trametes)</i>					
Dump mushrooms	0,02-0,03	0,05-0,21	0,70- 4,50	37,00- 64,20	0,70-12,10
Mushrooms from other sites	0,03-0,23	0,18-5,72	0,15-10,05	21,10-317,10	0,30-29,70
Average					
Dump mushrooms	0,25	0,13	2,60	50,66	6,40
Mushrooms from other sites	0,12	1,07	2,43	103,60	10,67

TABLE 7. Specific activity of radionuclides in plant samples (pasture plants and grass)

Locality	Specific activity [Bq/kg fresh weight]							
	U-235	U-238	Ra-226	Pb-210	Po-210	Ra-228	Cs-134	Cs-137
Reference	0,3	6,4	1,4	6,5	5,5	0,7	0,1	2,2
Dump Drosen	<0,4	<8,9	<2,3	4,1		<0,5	<0,1	<0,2
Dump Beerwalde	<0,1	<3,2	1,1	11,4	0,7	0,1	0,05	0,1
Mine 412	0,4	9,9	2,1	5,1		1,2	0,1	0,1
Area Friedmannsdorf	0,2	5,3	2,9	4,7		1,2	0,1	0,7

Effective equivalent dose for adults through milk consumption for each nuclide

Locality	Effective equivalent dose for adults [mSv]							
	U-235	U-238	Ra-226	Pb-210	Po-210	Ra-228	Cs-134	Cs-137
Reference	7,7x10-5	1,6x10-3	1,6x10-2	2,1x10-2	6,0x10-3	5,7x10-3	7,1x10-5	1,1x10-3
Dump Beerwalde	3,9x10-5	7,9x10-4	8,5x10-3	4,5x10-3	8,2x10-4	9,8x10-4	3,6x10-5	3,6x10-5

LITERATURE CITED

- BRAUN-BLANQUET, J. (1964): Pflanzensoziologie-Grundzüge der Vegetationskunde. Berlin (Springer).
- ELLENBERG, H. (1979): Zeigerwerte der Gefäßpflanzen Mitteleuropas. Scripta Geobotanica, Verlag Erich Goltze KG Göttingen, 2. Aufl. Vol. 9.
- FRANK, D. und KLOTZ, S. (1990): Biologisch-ökologische Daten zur Flora der DDR. 2. völlig neu bearb. Aufl., Halle (Saale). Wiss. Beitr. Martin-Luther-Univ. Halle-Witt. 32=P41.
- RANFT, H. (1966): Untersuchungen und Versuche zur Rekultivierung von Erzbergbauhalden des sächsischen Erzgebirges. Diss. A, TU Dresden.
- RAU, D. und PANTEL, H. (1964): Gutachten über den Kulturwert der gesamten Schichtenfolge im Tagebau und der pleistozänen De-

- ckschichten im Bereich der projektierten Halde des Tagebaues "Philip Müller" Lichtenberg (SDAG Wismut). VEB Geol. Erkundg. West Halle, BA Jena, Abt. Kartierung, Fachgebiet Bodengeologie.
- REICHEL, G. (1984): Zusammenhänge zwischen Radioaktivität und Waldsterben? Ökologische Konzepte, 20: S. 25-53.
- RICHTER, W. (1963): Die natürliche Begründung der Erzbergwerkshalden im Erzgebirge. Dipl.-Arbeit, Martin-Luther-Universität Halle-Wittenberg.
- SCHUBERT, R. (1953/54): Die Schwermetallpflanzengesellschaften des östlichen Harzvorlandes. Wiss. Ztschr. d. Univ. Halle, Jg. III., Math-nat. Reihe, 1.
- WÜNSCHE, M. (1963): Die Standortverhältnisse und Rekultivierungsbedingungen der Halden des Zwickau-Lugau-Oelsnitzer Steinkohlenreviers. Freiburger Forschungshefte, C 153: S. 1-88.

FLORA I ROŚLINNOŚĆ NA ZWAŁOWISKACH KOPALŃ URANU W POŁUDNIOWEJ CZĘŚCI BYŁEJ NRD

STRESZCZENIE

Na terenie byłej NRD prowadzona była w latach 1946-1990 intensywna eksploatacja uranu w kopalniach podziemnych i odkrywkowych. Między innymi w okolicach Ronneburga następowało powiększenie zdewastowanych obszarów w formie hałd i zwałowisk kopalnianych. Obszary te tworzą ekstremalne siedliska dla pionierskich roślin w czasie pierwszej fazy ich naturalnego zasiedlania. W latach 1990-1992 przeprowadzono metodą Braun-Blanqueta (1964) mapowanie roślinności na 15 zwałowiskach w Turynii. Charakterystykę ekologiczną tych zwałowisk umożliwiło zastosowanie programu komputerowego Flora_D Franka i Klotza (1990). Na zwałowiskach tych stwierdzono występowanie 498 gatunków roślin wyższych należących do 65 rodzin. Liczba gatunków przypadająca na pojedyncze zwałowisko wynosi od 11 do 282. Rośliny pionierskie pojawiają się na tarasach już po dwóch latach od zaprzestania wysypów, natomiast na zboczach wyrobisk po 5-10 latach. Po prawie 10 latach pierwsza faza zasiedlania roślin wydaje się zakończona. Wśród mechanizmów rozsiewania dominuje wiatr i rozsiewanie typu burdock. Gatunki zwałowiskowe to głównie hemikryptofity, następnie terofity, geofity i fanerofity.

SŁOWA KLUCZOWE: flora, roślinność, bioindykacja, charakterystyka ekologiczna, kopalnictwo uranu.