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RADIOACTIVE CONTAMINATION IN AREAS AFFECTED BY MINING: INVESTIGATIONS OF ABANDONED AND RECLAIMED SETTLING POND

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Description of the problem

Å in underground coal mines in Poland inflowing waters contain natural radioactive isotopes, mainly radium

- several tens of MBq of ^{226}Ra and ^{228}Ra are released daily into the rivers
- mine water can have a severe impact on the natural environment due to its enhanced radioactivity and salinity
- enhanced levels of radium concentration in river waters, bottom sediments and vegetation is observed

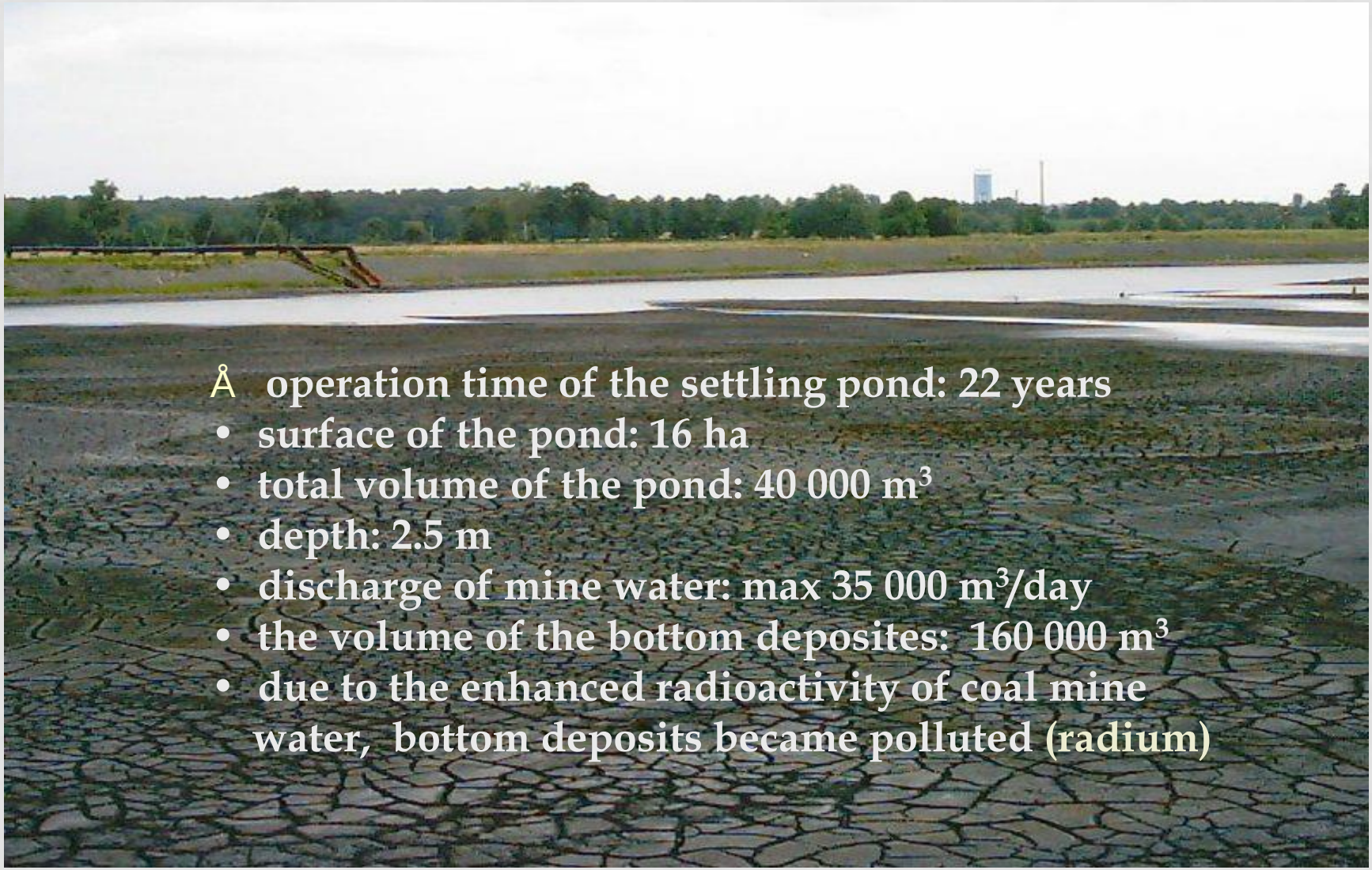
After mine closure, contaminated land is transferred to local communities

In the past 20 years 30 Polish coal mines have been closed

Nowadays more than 20 settling ponds on the surface are still in use

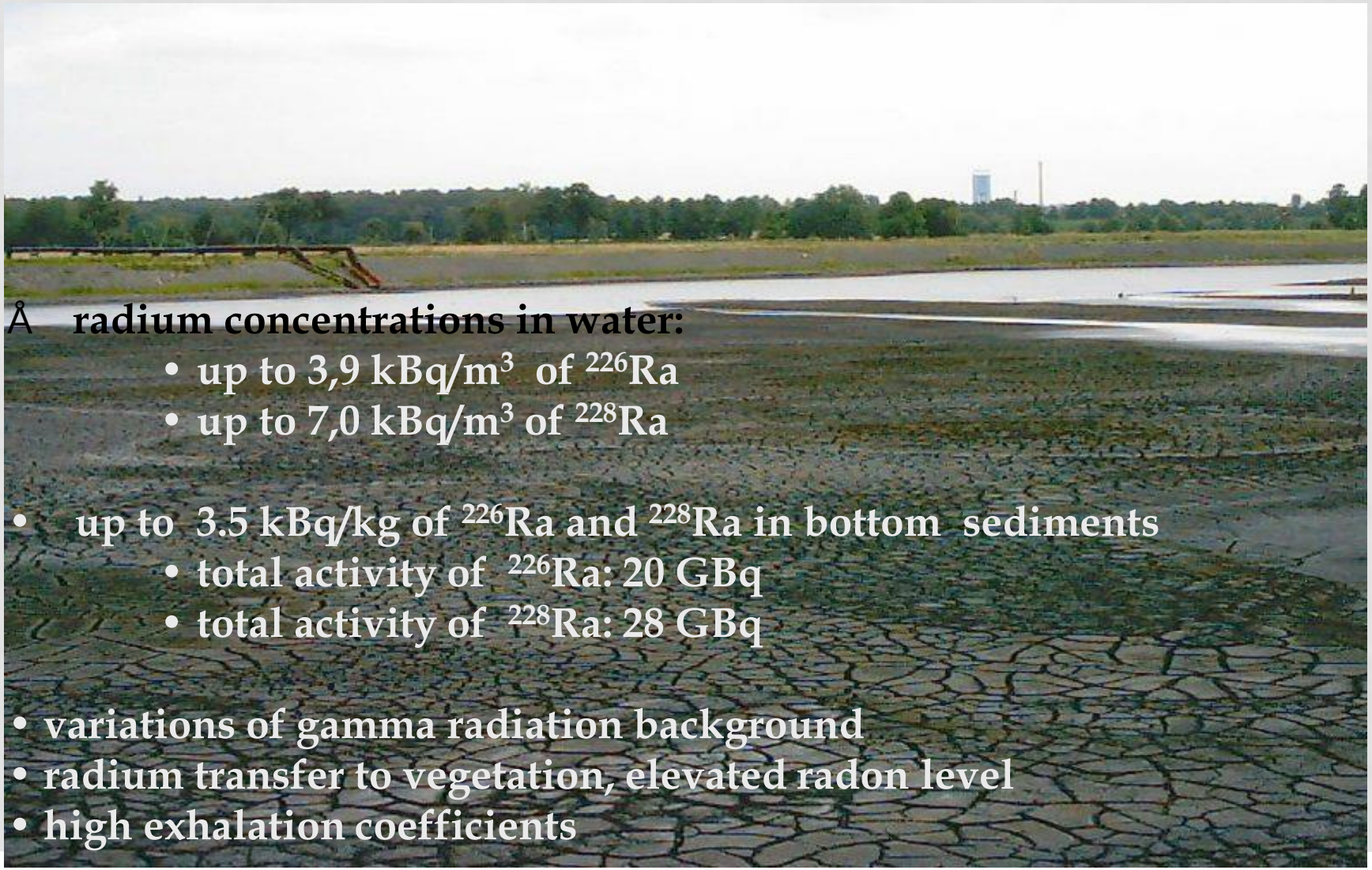
- bottom sediments with enhanced radioactivity due to radium deposition
- the total volume of deposits:
  5 mln m^3

Reclamation of coal mine settling pond, the example



- operation time of the settling pond: 22 years
- surface of the pond: 16 ha
- total volume of the pond: 40 000 m^3
- depth: 2.5 m
- discharge of mine water: max 35 000 m^3/day
- the volume of the bottom deposites: 160 000 m^3
- due to the enhanced radioactivity of coal mine water, bottom deposits became polluted (radium)

The results of investigation and general data



- **radium concentrations in water:**
  - **up to 3,9 kBq/m^3 of ^{226}Ra**
  - **up to 7,0 kBq/m^3 of ^{228}Ra**

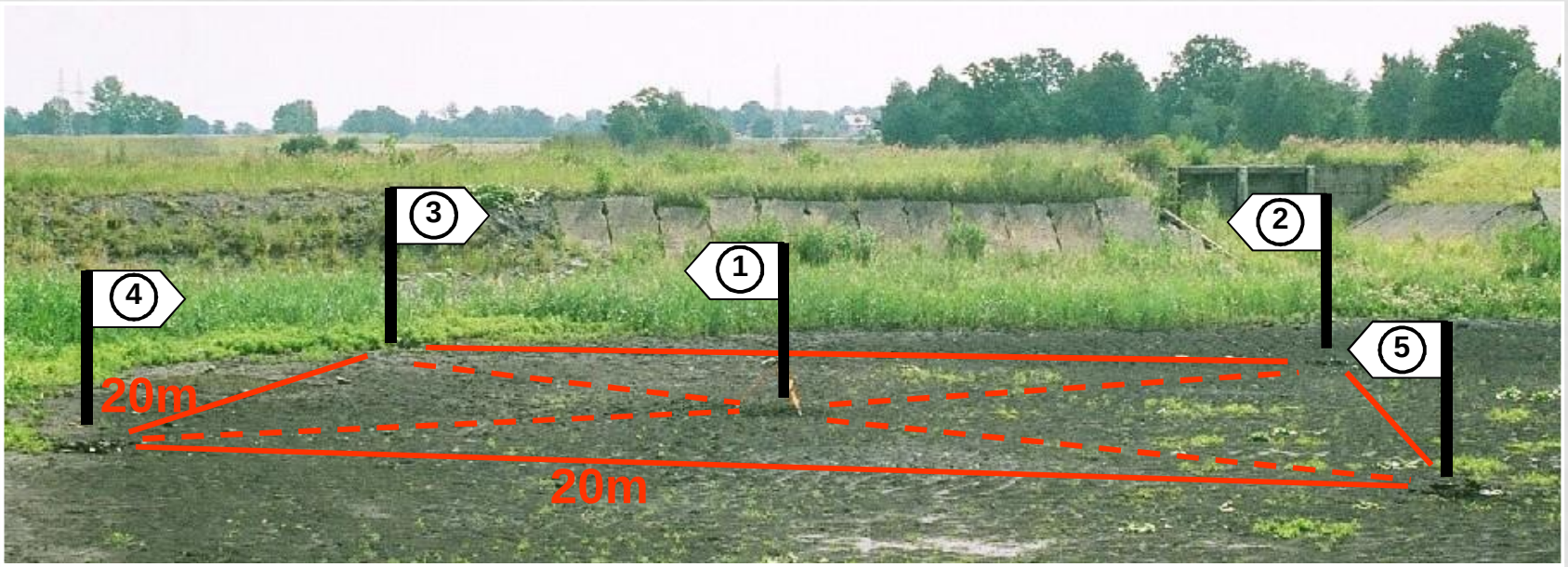
- **up to 3.5 kBq/kg of ^{226}Ra and ^{228}Ra in bottom sediments**
  - **total activity of ^{226}Ra: 20 GBq**
  - **total activity of ^{228}Ra: 28 GBq**

- **variations of gamma radiation background**
- **radium transfer to vegetation, elevated radon level**
- **high exhalation coefficients**

Radiation background measurements before reclamation

Results of measurements

Grid 1

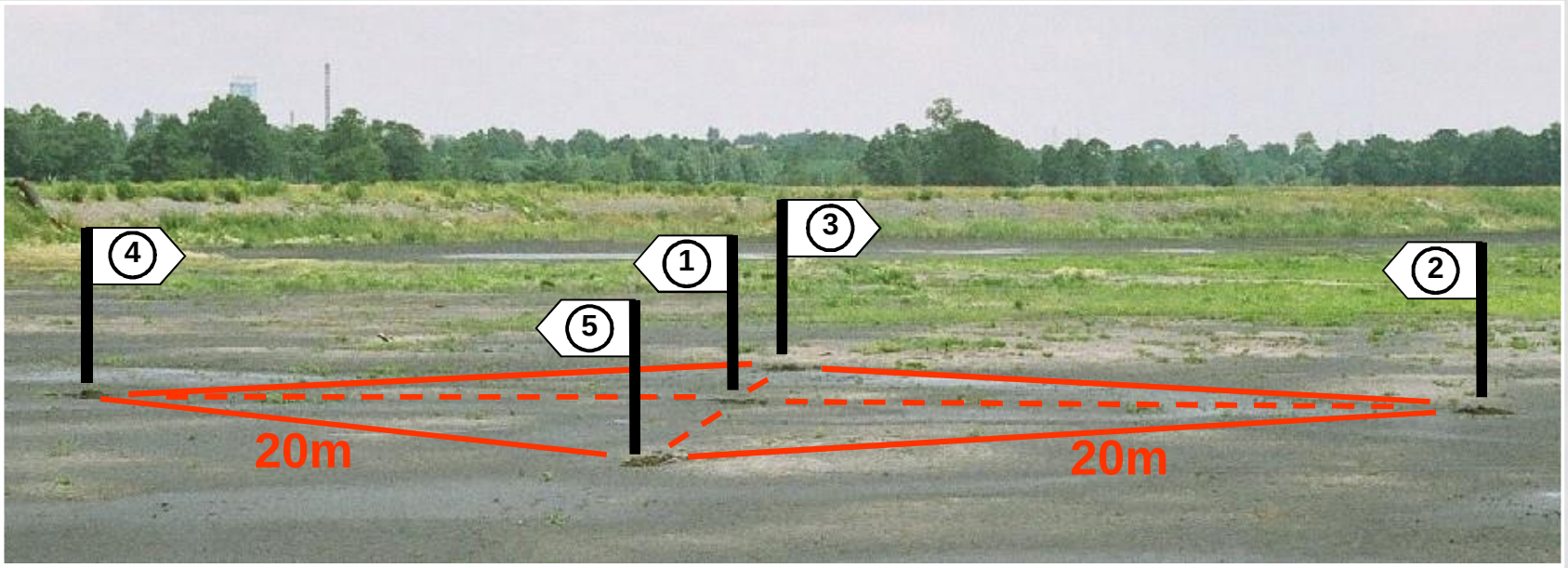


Gamma-dose-rates and Radium-concentrations:

①	1m height: 1,900 nSv/h 3,075 Bq/kg Ra-226; 4,085 Bq/kg Ra-228 600 Bq/kg Ra-226; 650 Bq/kg Ra-228	④	1m height: 1,300 nSv/h 2,740 Bq/kg Ra-226; 4,100 Bq/kg Ra-228 250 Bq/kg Ra-226; 250 Bq/kg Ra-228
②	1m height: 1,100 nSv/h 1,575 Bq/kg Ra-226; 2,265 Bq/kg Ra-228 275 Bq/kg Ra-226; 230 Bq/kg Ra-228	⑤	1m height: 1,300 nSv/h 410 Bq/kg Ra-226; 280 Bq/kg Ra-228 345 Bq/kg Ra-226; 260 Bq/kg Ra-228
③	1m height: 2,000 nSv/h 490 Bq/kg Ra-226; 375 Bq/kg Ra-228 190 Bq/kg Ra-226; 164 Bq/kg Ra-228		

Results of measurements

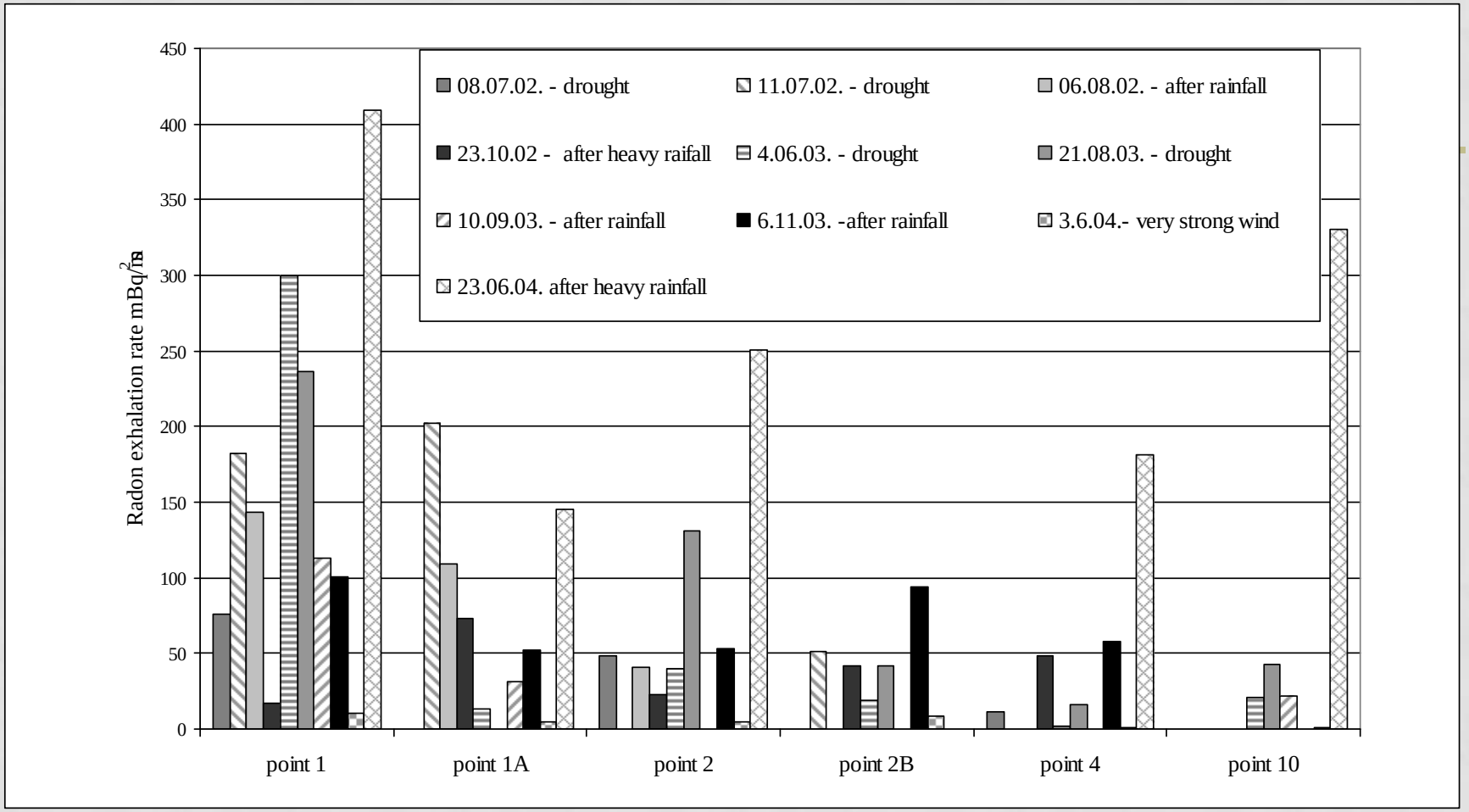
Grid 2



Gamma-dose-rates and Radium-concentrations:

①	1m height:	450 nSv/h
	395 Bq/kg Ra-226;	270 Bq/kg Ra-228
	350 Bq/kg Ra-226;	210 Bq/kg Ra-228
②	1m height:	400 nSv/h
	400 Bq/kg Ra-226;	390 Bq/kg Ra-228
	630 Bq/kg Ra-226;	325 Bq/kg Ra-228
③	1m height:	500 nSv/h
	440 Bq/kg Ra-226;	305 Bq/kg Ra-228
	330 Bq/kg Ra-226;	145 Bq/kg Ra-228
④	1m height:	400 nSv/h
	460 Bq/kg Ra-226;	300 Bq/kg Ra-228
	380 Bq/kg Ra-226;	275 Bq/kg Ra-228
⑤	1m height:	400 nSv/h
	345 Bq/kg Ra-226;	315 Bq/kg Ra-228
	365 Bq/kg Ra-226;	250 Bq/kg Ra-228

Radon exhalation rate from the bottom of an abandoned settling pond – before reclamation



Plant succession before reclamation

Radium concentration in plants – before reclamation

plant	^{226}Ra Bq/kg (dry weight)	^{228}Ra Bq/kg (dry weight)
Calamagrostis Australis	55±17	91±5
Calamagrostis Epigeios	43±20	84±7
Calamagrostis Epigeios	28±18	59±5
Pharagmites Australis	191±22	371±14
Pharagmites Australis	175±30	360±16
Pharagmites Australis reference sample	16±0	17±3
Atriplex Hastata	151±25	286±12
Atriplex Hastata	580±64	1136±42
Atriplex Hastata	170±21	324±13
Atriplex Hastata reference sample	69±13	104±5

Reclamation of the settling pond

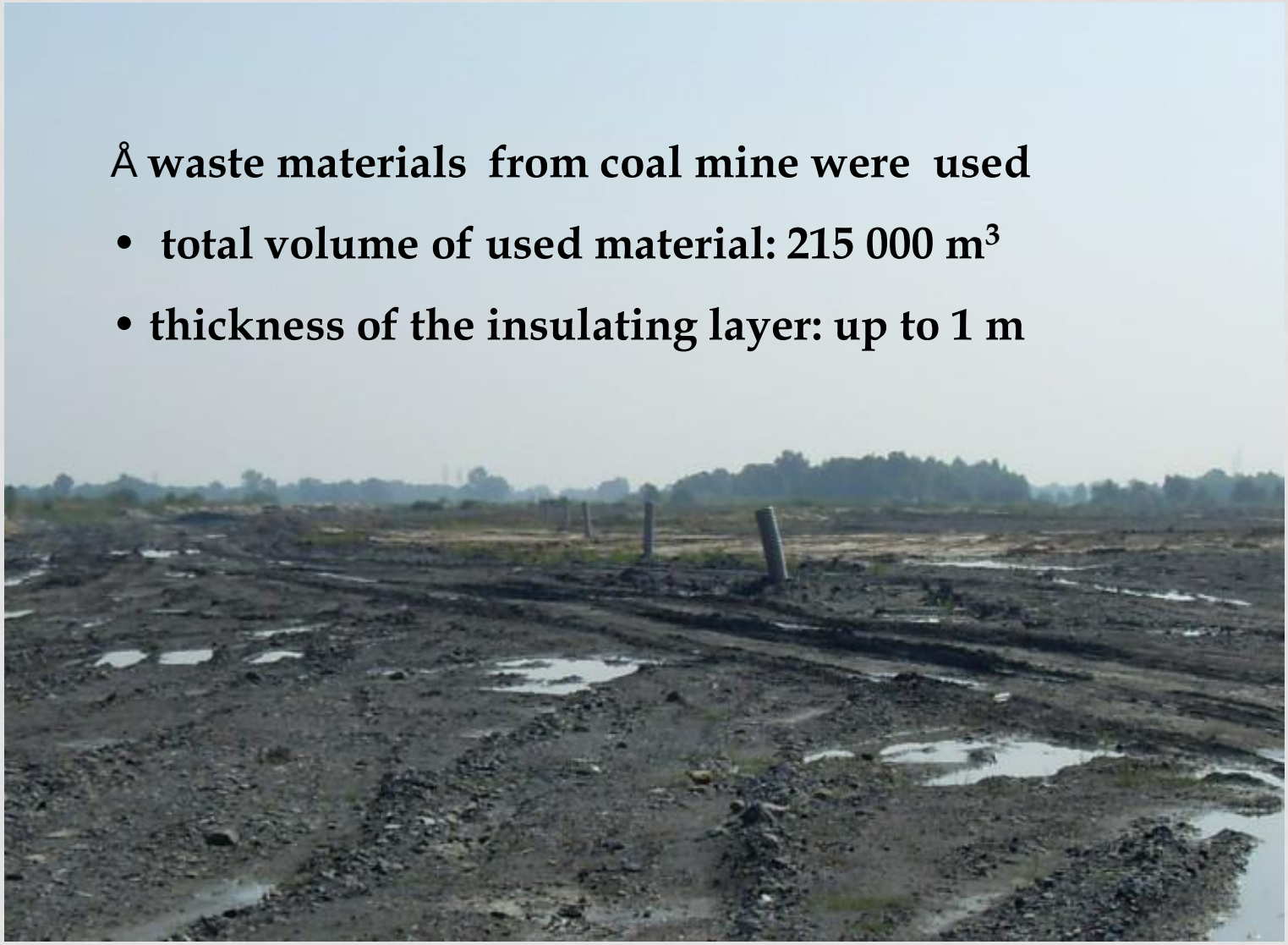
- Reclamation began in 2006 and was finished in 2010.
- Technical method of reclamation was chosen.
- Bottom sediments were left in the settling pond, covered by impermeable layers of waste rocks, sand and finally soil.
- The chosen option was estimated as that the most efficient, enviromental friendly and the cheapest.

Reclamation – compaction of the bottom sediments

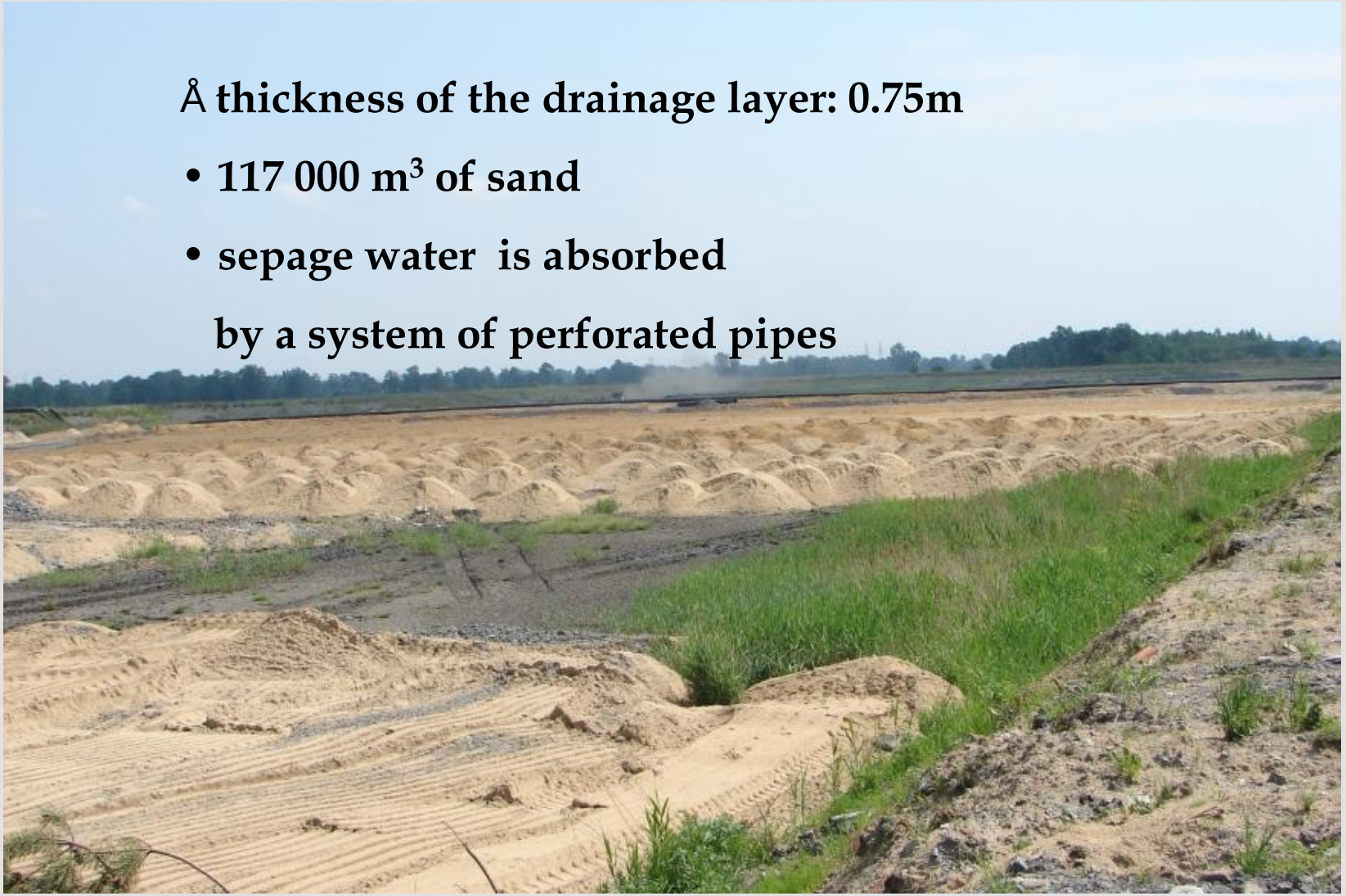
- at the first stage bottom sediments were compacted with use of waste material from the colliery: waste rocks such as mudstone and sandstone

- total volume of the waste material: 40 000 m^3

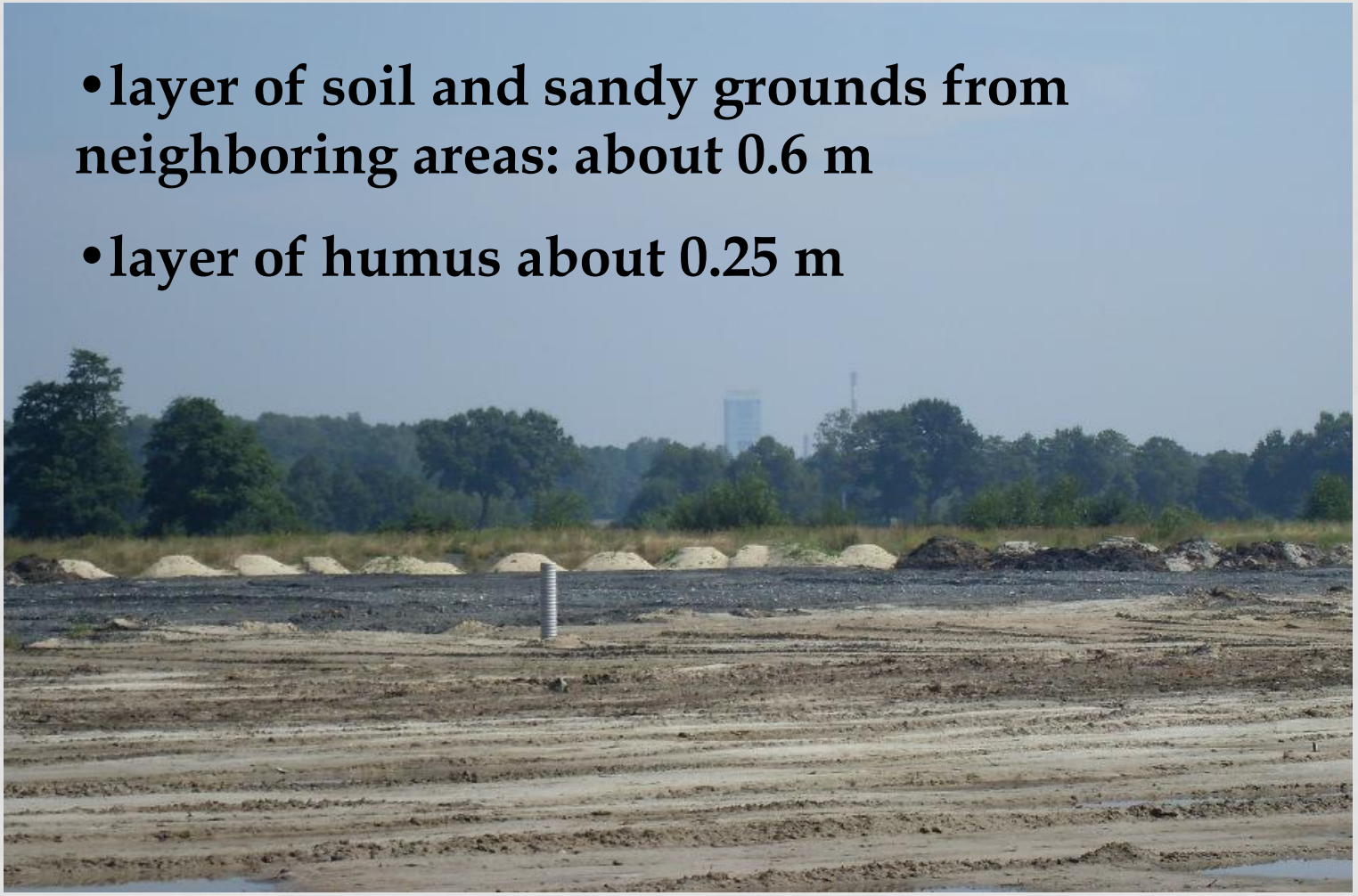
Reclamation – insulatig layer and venting pipes



Reclamation - construction of the drainage layer



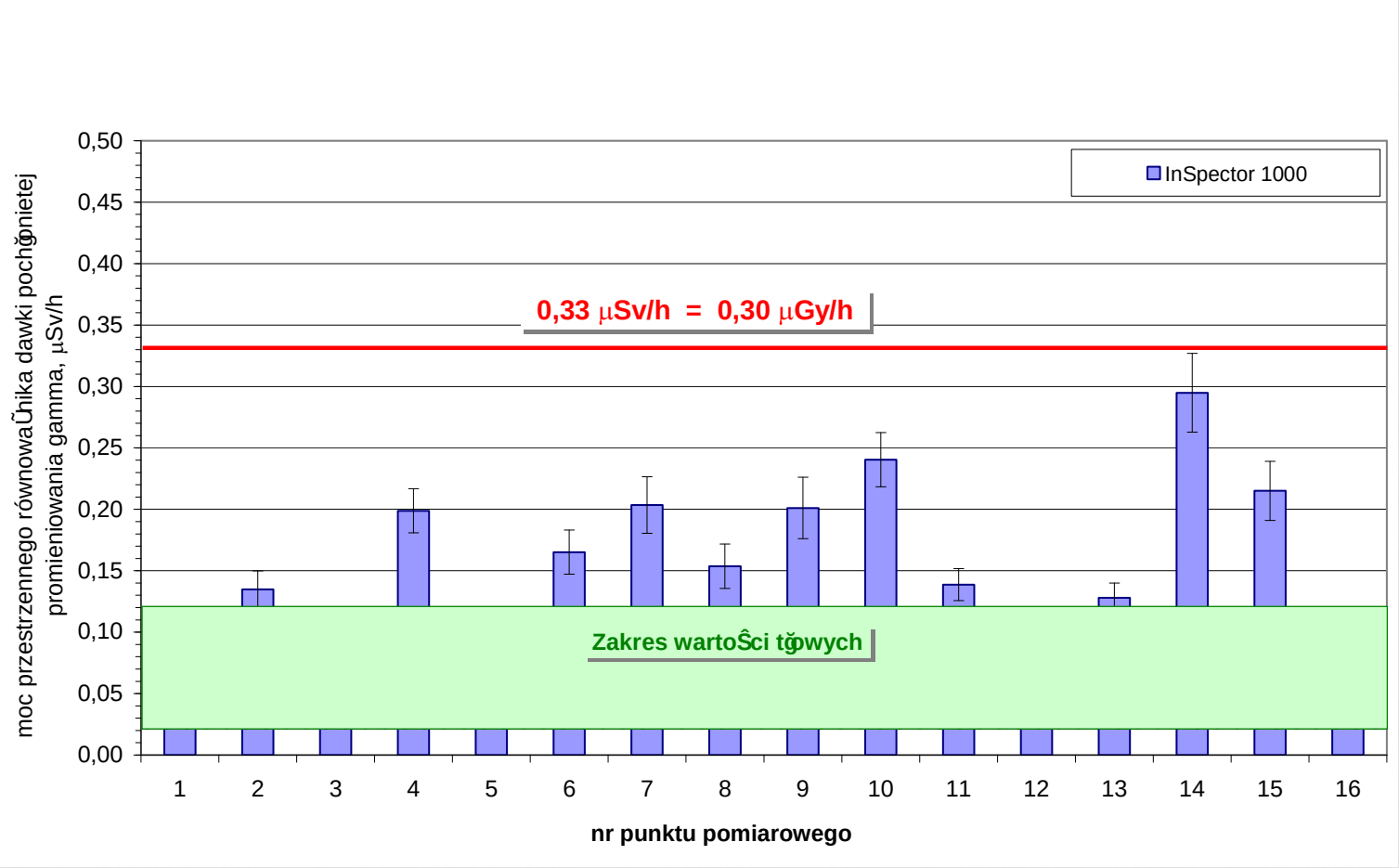
Reclamation - construction of the surface layer



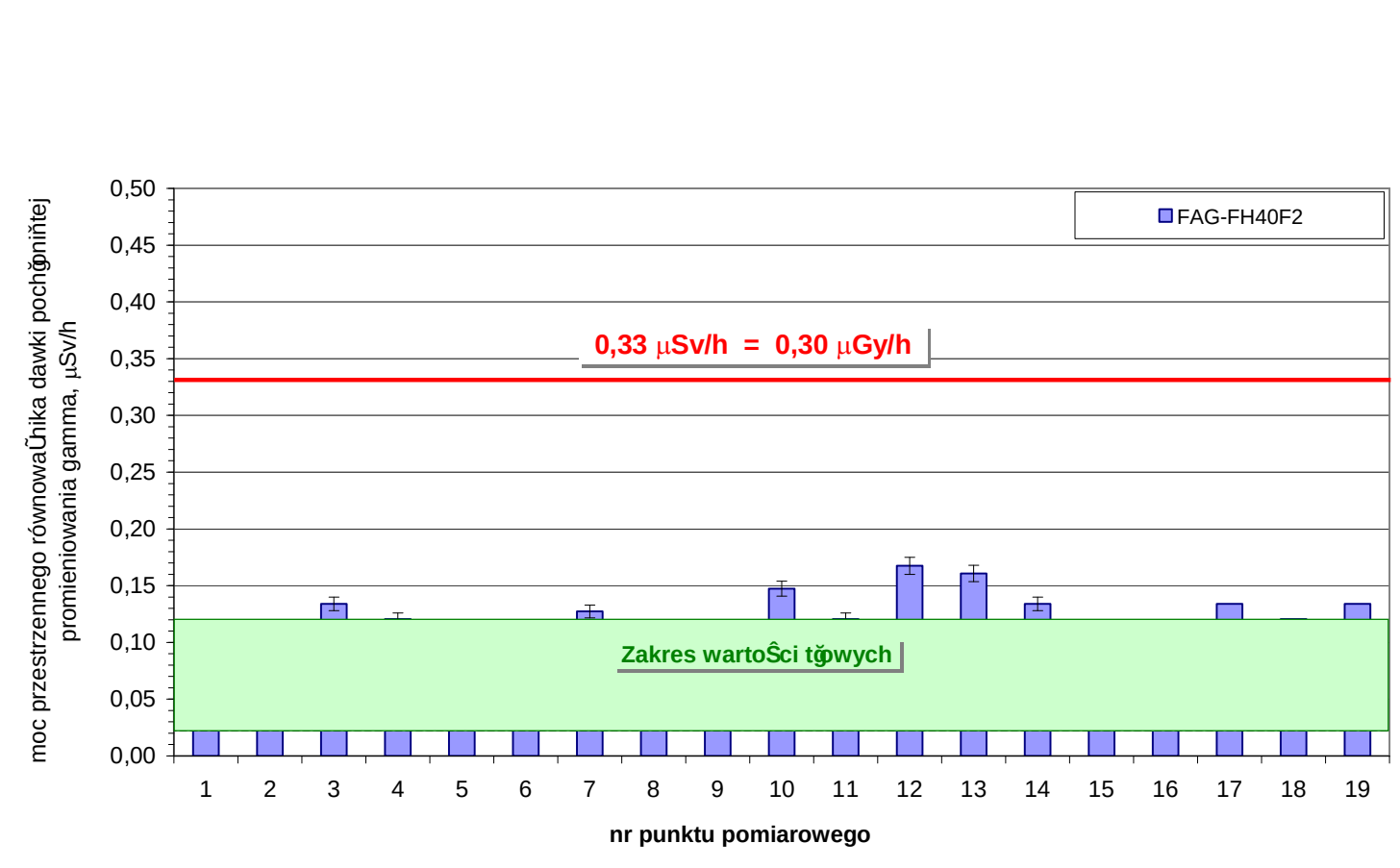
Radiation background measurements after reclamation

Gamma radation background – location of measurement points

Results of measurements of ambiet gamma dose measurements – first campaign

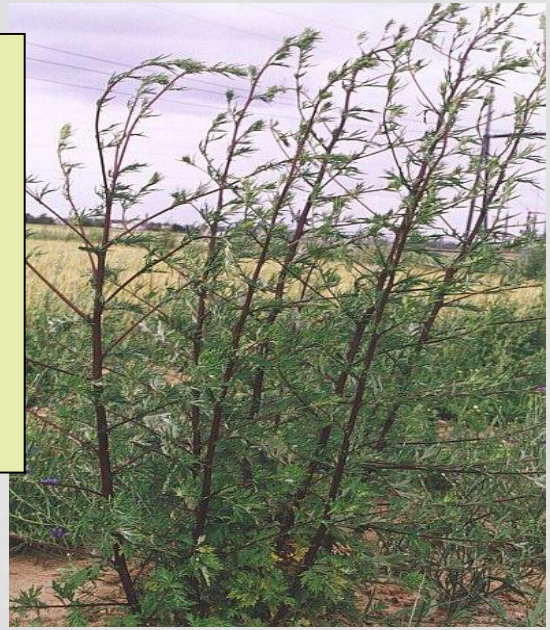


Results of measurements of ambiet gamma dose measurements – second campaign



The results of measurements of plants after reclamation

^{226}Ra Bq/kg (dry weight)	^{228}Ra Bq/kg (dry weight)
3.3 ± 1.3	< 4.1
2.5 ± 1	<3.2



Polygonum aviculare (L.)

Artemisia vulgaris (L.)

Contamination of plants is not observed

The results of measurements after reclamation

Radium concentration in soil profile of 1 m depth located along the most probable ground water flow:

- **radium ^{226}Ra from 9 Bq/kg up to 35 Bq/kg**
- **radium ^{228}Ra from 4 Bq/kg up to 44 Bq/kg**

Pollution of neighbouring land is not observed

Comparison of radon exhalation before and after reclamation

Sampling point	Radon exalation factor mBq/m^2s^1	Radon exalation factor mBq/m^2s^1
Date of measurements	After reclamation : 05/10/2012	Before reclamation: 2004
2	2,1 ± 1,0	330 ± 50
4	3,9 ± 1,1	170 ± 30
8	5,4 ± 1,1	409 ± 68
1	3,6 ± 1,1	90 ± 19
x1	2,8 ± 0.9	250 ± 38
measurements in the vicinity of the settling pond	Range: 1,9 - 4,1	

Radon in soil gas concentration after reclamation

Sampling point	Radon in soil concentration Bq/m^3
Point G1	**426 ± 63**
Point G 2	**162 ± 73**
The range of values measured in not reclaimed sites, archival data, GIG	**120 – 120 000**

Radon in air concentration in venting pipes after reclamation

Sampling point	Exposure time	Radon concentration in air in venting pipes after reclamation Bqm^{-3}
006	26.09.2012. - 14.12.2012.	2380 ± 620
007		2920 ± 730
009		2480 ± 680
010		3730 ± 860
011		3240 ± 770
012		3640 ± 840
- Radon in open air, avg. (Nazaroff and Nero, 1988) - Radon limit in dwellings - The range of radon concentration in dwellings, Upper Sielesia, (archival data GIG)		8 300 10 -1600

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Conclusions

The method of reclamation of the abandoned coal mine settling pond has been selected to reduce the risk of the spread of radioactive plum outside the object

The stabilization of sediments and their insulation from the surrounding prevent secondary leaching of radium from sediments by groundwater and rainwater.

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Conclusions

Concentrations of radon in drainage wells are high and many times exceed not only the values measured in the open air, but also those observed in buildings in the Upper Silesian Coal Basin.

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Conclusions

These results indicate, that:

- **all kinds of damages and cracks in insulation layers can open pathways for radon migration,**
- **potential dwellers of buildings, constructed in this area would be endangered to receive high doses from radon (and its decay products).**

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Conclusions

Post industrial areas contaminated by natural radioactivity should be monitored not only before but also after remediation, mostly due to radon hazard.

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Acknowledgement

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