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1991–2011

The pattern of radiation exposure at former uranium production sites and measures for exposure minimization

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Structure of presentation

- Problem definition
- Typical exposure patterns
- Measures for exposure minimization
- Case study WISMUT
- Case study Sillamäe tailings

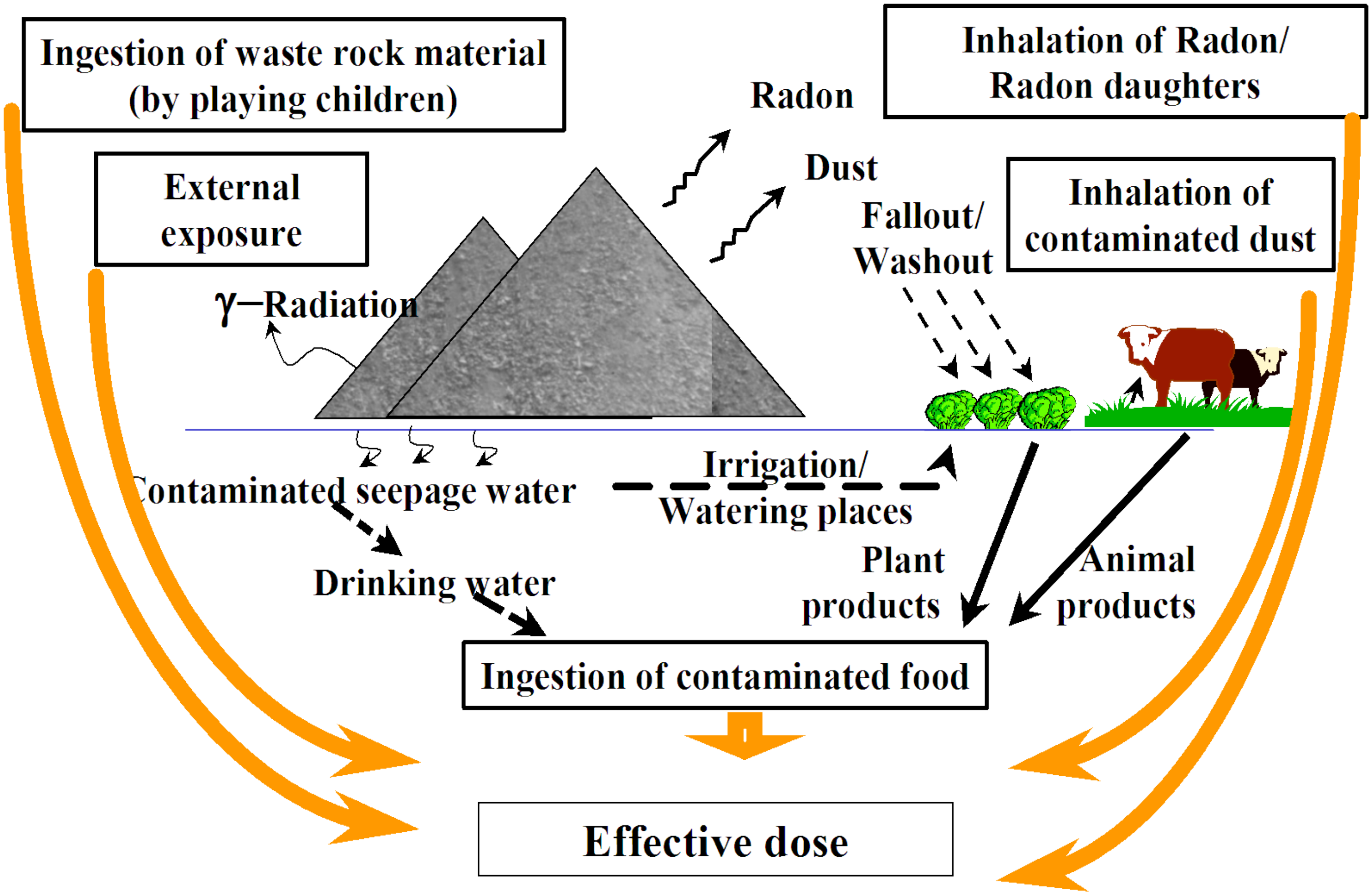
Problem definition (1)

- Pattern of exposure at former uranium mining and milling sites is very site-specific
- Decision on justification and optimization requires a detailed exposure analysis with consideration of the site-specific conditions, i. e.
  - Metrology, Hydrology, hydrogeology, geo-chemistry, morphology (factors triggering the propagation of radioactivity in the environment)
  - location of the most unfavorable point or site of exposure, relevant exposure pathways, relevant exposure scenarios (factors triggering the individual exposure)
- Arrival at recognized values for the effective doses is only possible on the base of harmonized approaches for the exposure analysis

Problem definition (2) – The German Calculation Bass Mining (CBM)

- Reference persons at the most favorable point of exposure
- Dose coefficients for the dose-relevant nuclides (U-238/4, Th-234, Ra-226, Po/Pb-210, U-235, Pa-231, Ac-227)
- Use of defined transfer rates, consumption rates, standard scenario parameters etc.
- Cut off distances for dust and ambient doses
- Water pathway:
  - Surface water: flux depending scenarios
  - Groundwater: assumption of full use of water taken from a “fictive” well
- Consideration of site-specific factors (use of measured concentrations instead of modeled values, site-specific background values, consideration of loca habits, etc.)

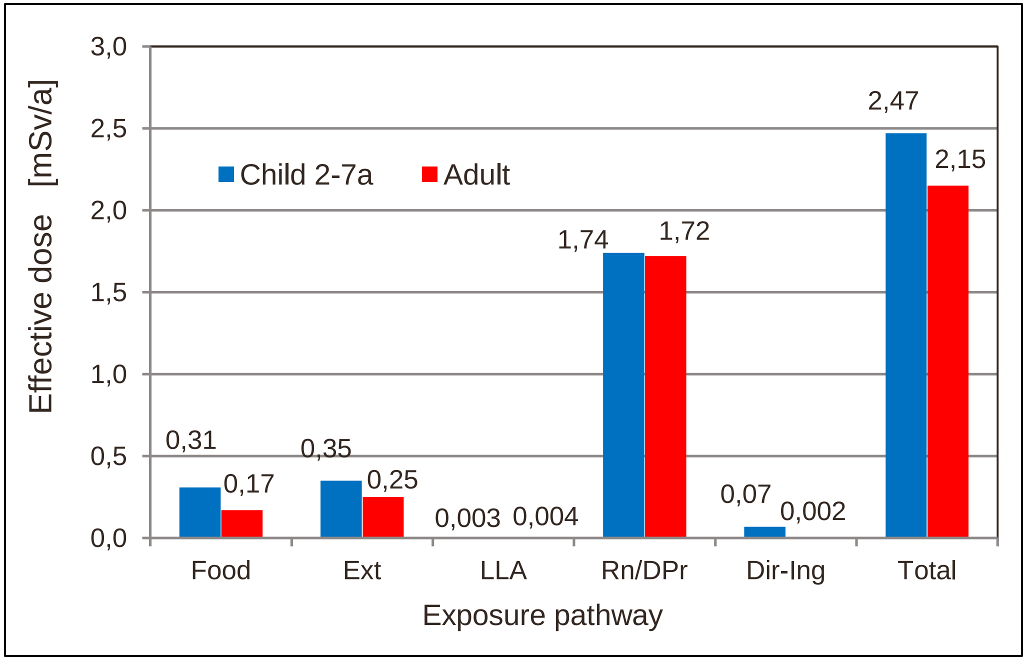
Problem definition (3) – The German Calculation Bass Mining (CBM)



Typical radiation exposure pattern

Case study:
living in a house close to a waste rock pile

- waste rock: 1 Bq/g U-238, radioactive equilibrium
- Rn: 150 B/q m³; ADR: 530 nSv/h; C_{llA} :1 mBq/m³
- seepage water: 0,5 Bq/l Ra-226; 1 mg/l U-nat



Food - consumption of locally grown garden products (25 %)
Ext - external radiation
LLA - inhalation of long-lived alphas
Rn/DPr - inhalation of Rado/Rn daughters
Dir-Ing. - direct ingestion

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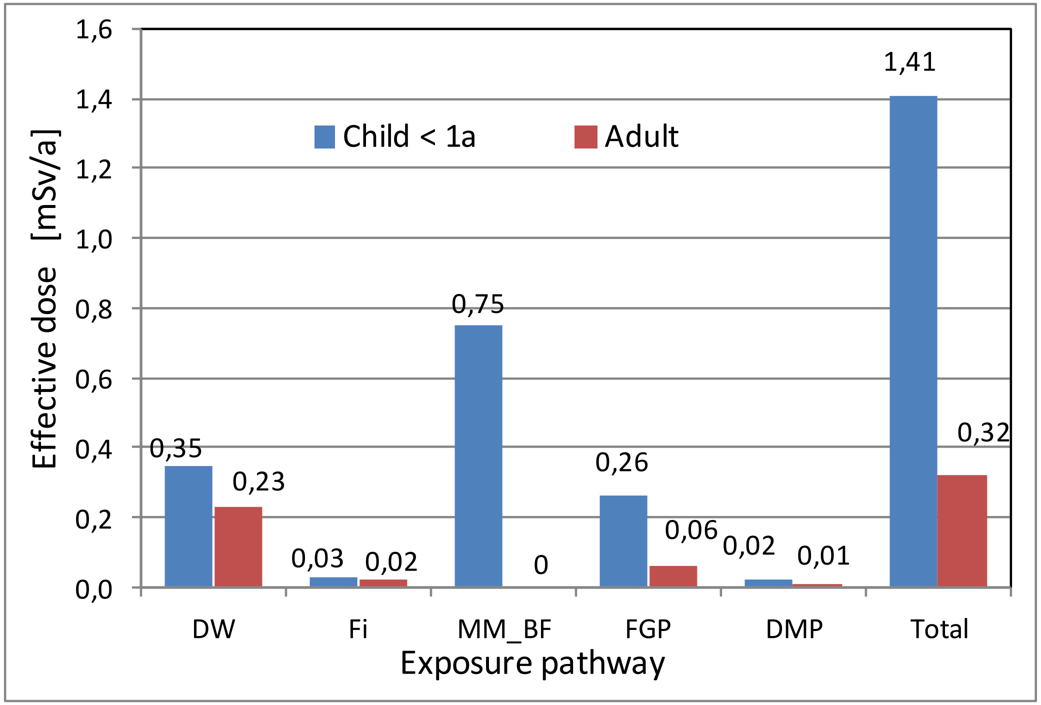
Typical radiation exposure pattern

Case study 2:
Using water contaminated by seepage from a tailings pond (irrigation, livestock watering, fish consumption, drinking water)

Nuclide	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Pa-231	Ac-227
C_i [Bq/l]	5,2	6,1	0,17	0,02	0,025	0,025	0,24	0,015	0,015



DW - drinking water (100 %)
Fi - fish consumption (25 %)
MM_BF - mother milk/baby food consumption (100 %)
FGP - consumption of locally grown field and garden crops (25 %)
DMP - consumption of dairy and meat products (25 %)

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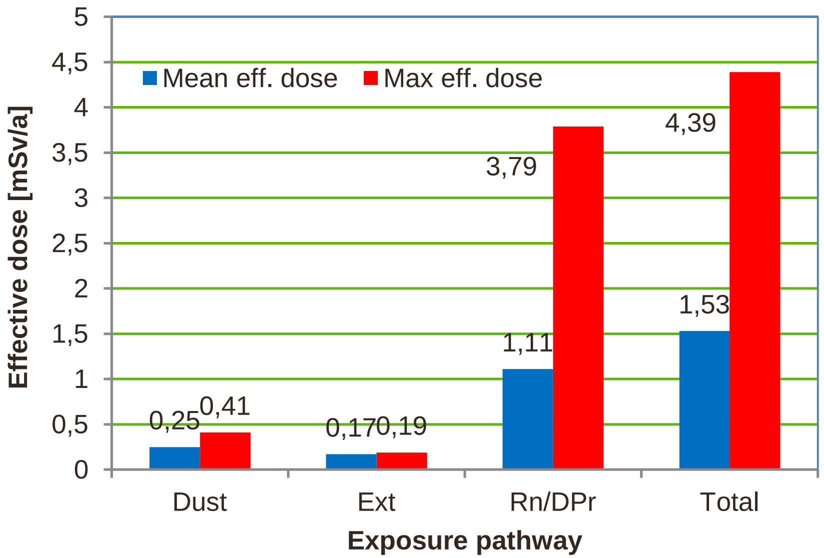
Typical radiation exposure pattern

Case study 3: Exposure of workers engaged with remediation ((WISMUT data, Schlema 2011)

Underground work, Category A workers



Mean:
1400 h,
0,2 µSv/h Gamma
14 mBq/m³ IIA
3,5 MeV/cm³ C_{pot}

Max
1540 h,
0,2 µSv/h Gamma
21 mBq/m³ IIA
11 MeV/cm³ C_{pot}

Work on surface, Category B workers

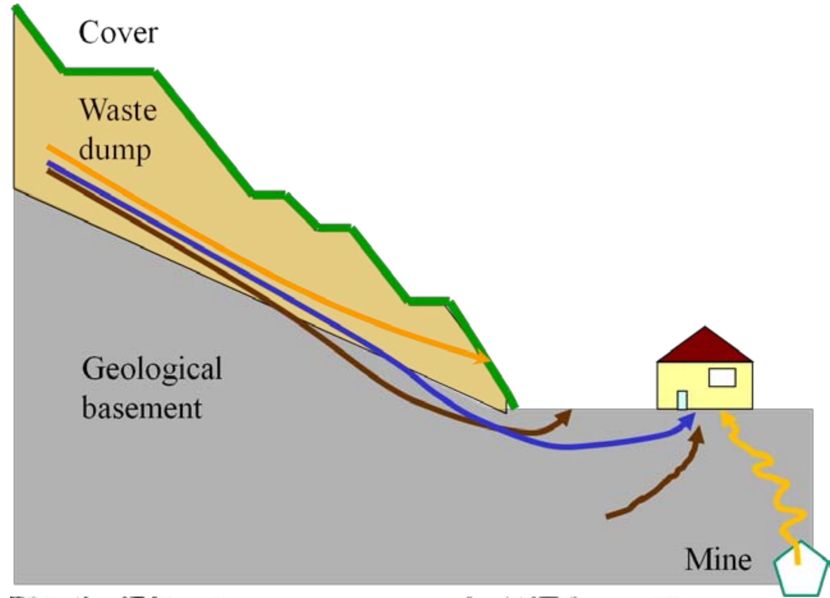
Mean:
1500 h,
0,23 µSv/h Gamma
1,5 mBq/m³ IIA
Rn: 100 Bq/m³,F=0,4

Max
1600 h,
0,29 µSv/h Gamma
6,5 mBq/m³ IIA
Rn: 150 Bq/m³,F=0,4

Mean effective dose: 0,70 mSv/a

Max effective dose: 1,16 mSv/a

Extreme cases



Extreme indoor Rn concentrations caused by:

- waste dumps
- geological basement
- use of contaminated building material
- near surface mine galleries

C_{Rn} > 5'000 Bq/m³; E > 100 mSv/a

Extreme exposure due to loss of institutional control

- Mailuu Suu (Kyrgyzstan) ; house build on a a waste rock dump; extreme indoor Rn concentration (E = ? mSv)
- Kitwe site (Zambia); people living next to a tailing pond, harvesting maize, okra and other products from the tailings surface

E = 45 mSv/a

Case study 1 – The WISMUT Rehabilitation Project (GER)

1946 - 1990, SDAG Wismut in East Germany major uranium supplier to the Soviet Union

- 232,000 tonnes of uranium
- 20+ deposits, 9 mills

Rigorous production philosophy

- Excessive land use
- No substantial technical/ financial provisions for closure
- No (little) rehabilitation during production

1991, Wismut GmbH

- Federal Republic of Germany is the sole owner
- Corporate purpose: decommissioning and rehabilitation of the legacy of the former East German uranium industry
- Employees: 1,350
- Turnover: 143 million € (2011)
- Headquarter in Chemnitz, 3 remediation branches (Ronneburg, Aue, Königstein)
- Total project costs 1990 – 2040: 6,8 billion €

Case study WISMUT – The legacy

More than 1000 objects, main classes:

- 5 Underground mines, 110 km^2 w/ 56 active shafts,
- 1 open pit mine
- 3700 ha operational areas w/ contaminated buildings and facilities
- 60^+ Waste rock piles w/ 325 Mio. m^3 WR
- 10 Tailings Management Facilities w/ 160^+ Mio. m^3
- Radioactive discharges: 25 t uranium (1990)

Case study WISMUT – Main remediation activities

Contaminated structures and areas	Demolition, decontamination, clean-up of areas, Release of lowly contaminated material for restricted reuse, safe disposal of higher contaminated material
Waste rock dumps	In-situ remediation (re-shaping, slope stabilisation, covering); alternatively relocation to a safe site
Tailings management facilities (TMF)	Dry In-situ remediation (dewatering, geo-technical stabilisation, cover placement)
Lichtenberg open pit	Backfilling of waste rock material
Mines	Closure of mine openings, stabilisation of underground mine galleries, controlled flooding
Contaminated water (mine water, seepage, TMF pore and supernatant water)	Active water treatment in special plants, alternatively passive water treatment procedures (biological treatment technologies, phytoremediation, etc.)

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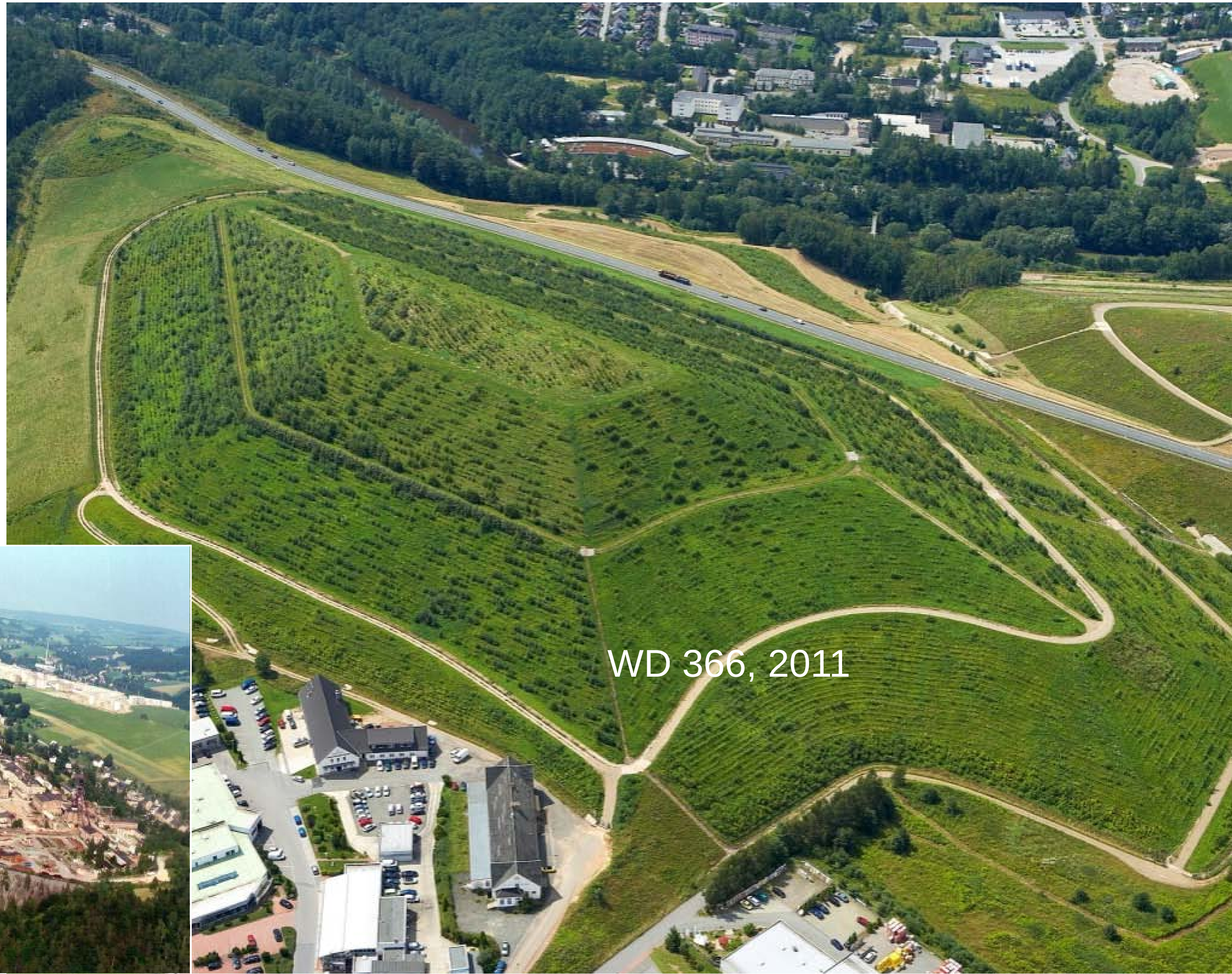
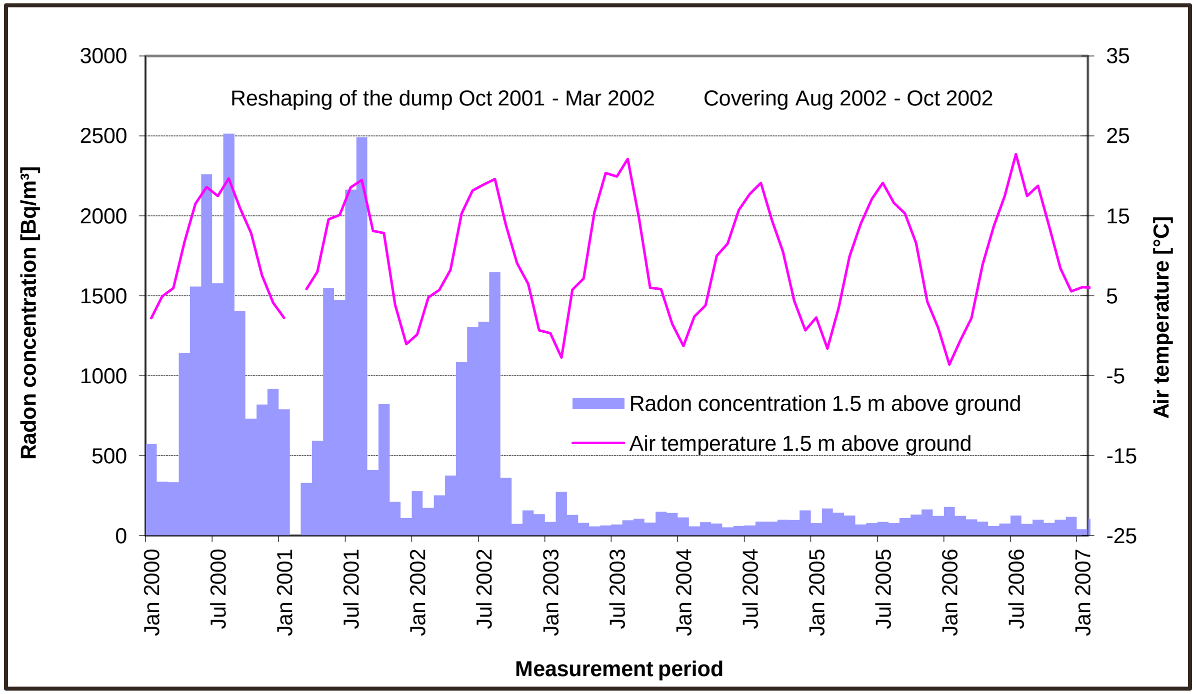
Case study WISMUT – Advanced remediation of waste rock piles at the Schlema site



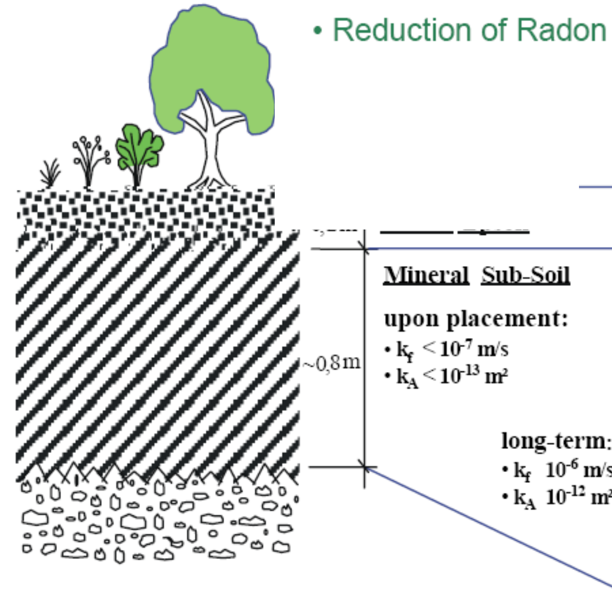
WD 366, 1991

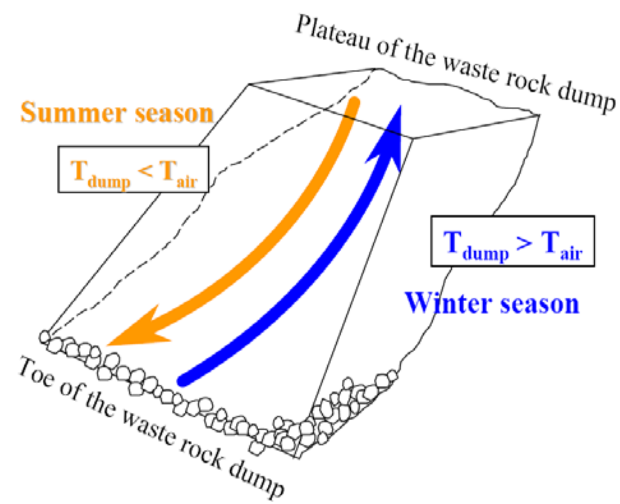
Case study WSMUT – Remediation effects, minimizing radiation exposure (Rn-222)



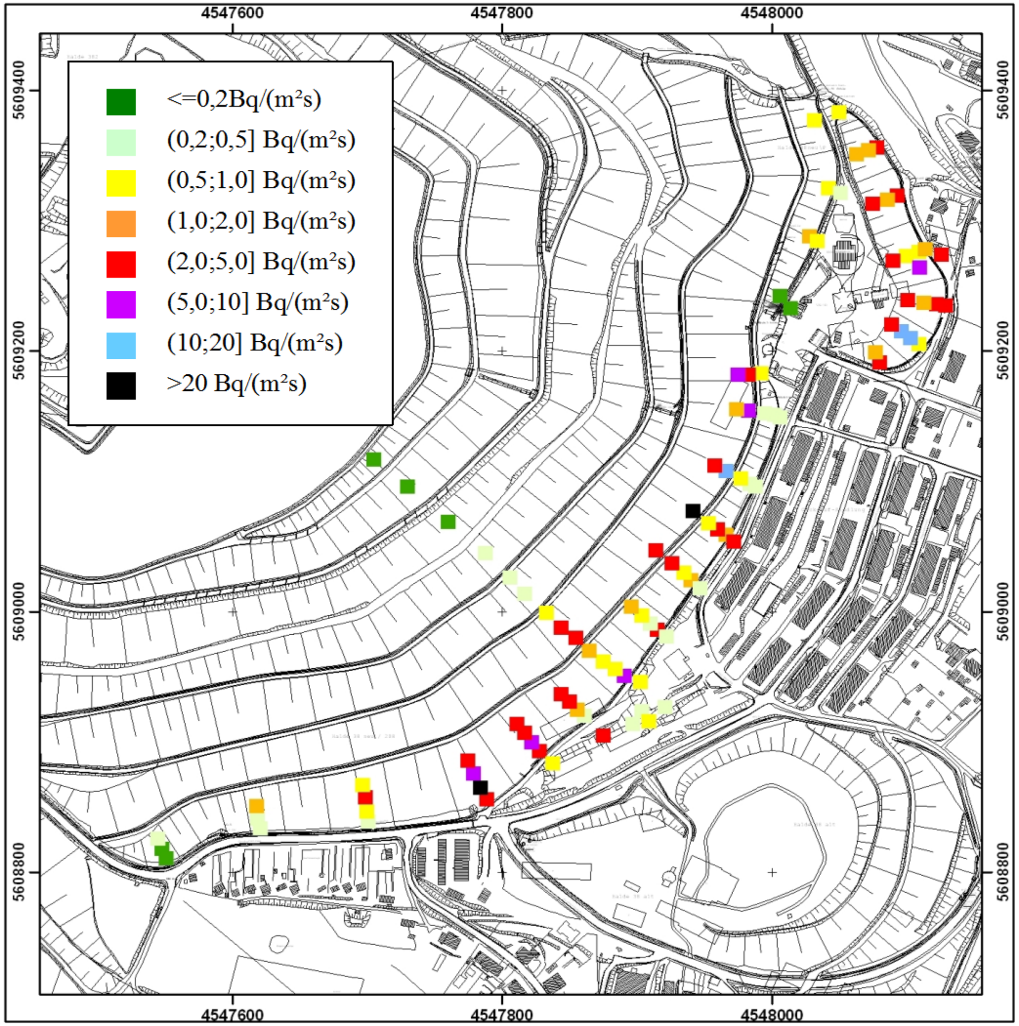
Main objectives:

- Reduction of Radon





Case study WISMUT – Not all model predictions materialize



Radon exhalation rate at a big already covered waste rock pile in Schlema:

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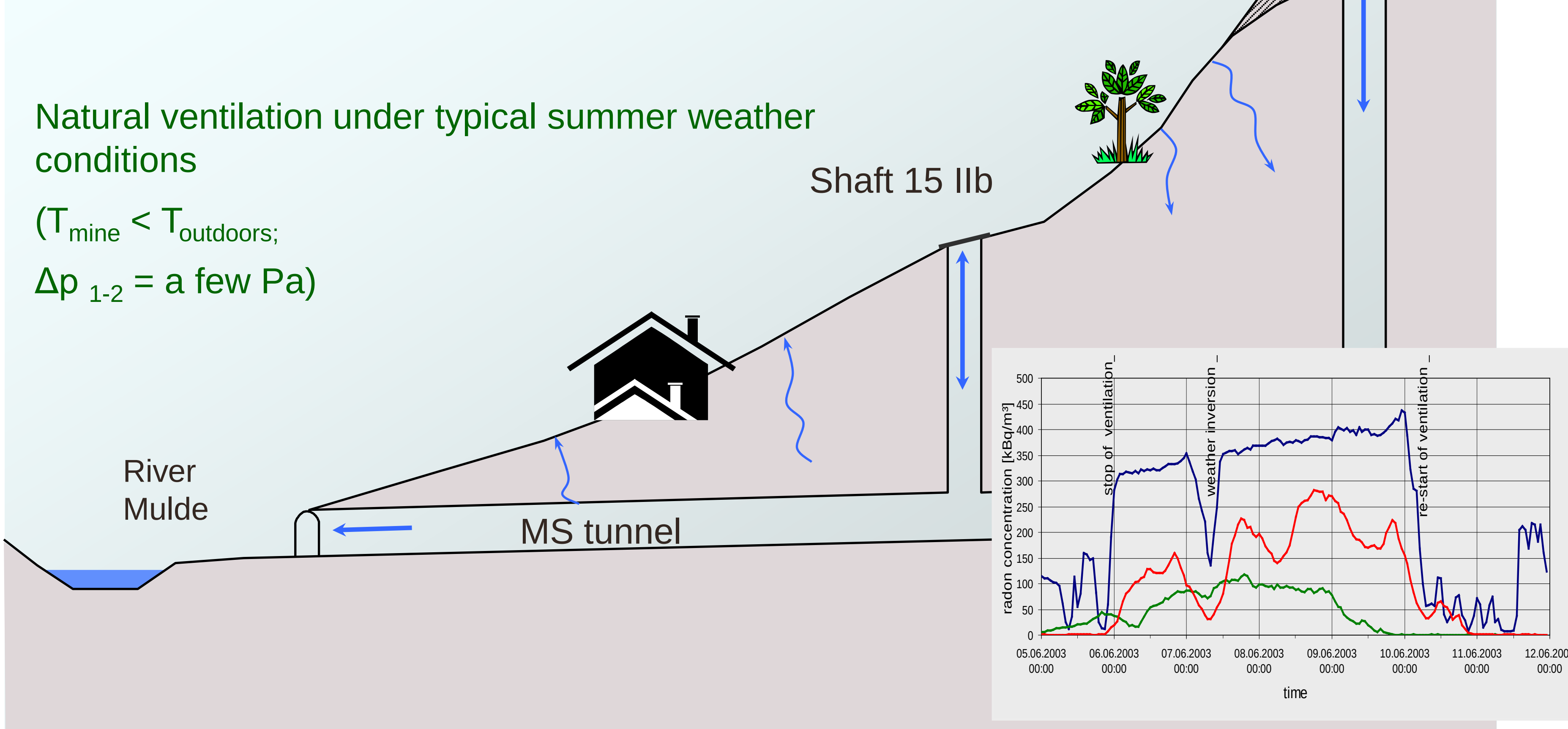
Case study WISMUT – New challenges during rehabilitation

Impact of near surface mine gallaries on indoor radon was not realized as a problem when WISMUT started rehabilitation works !

Natural ventilation under typical summer weather conditions

($T_{mine} < T_{outdoors;}$

$\Delta p_{1\text{-}2}$ = a few Pa)



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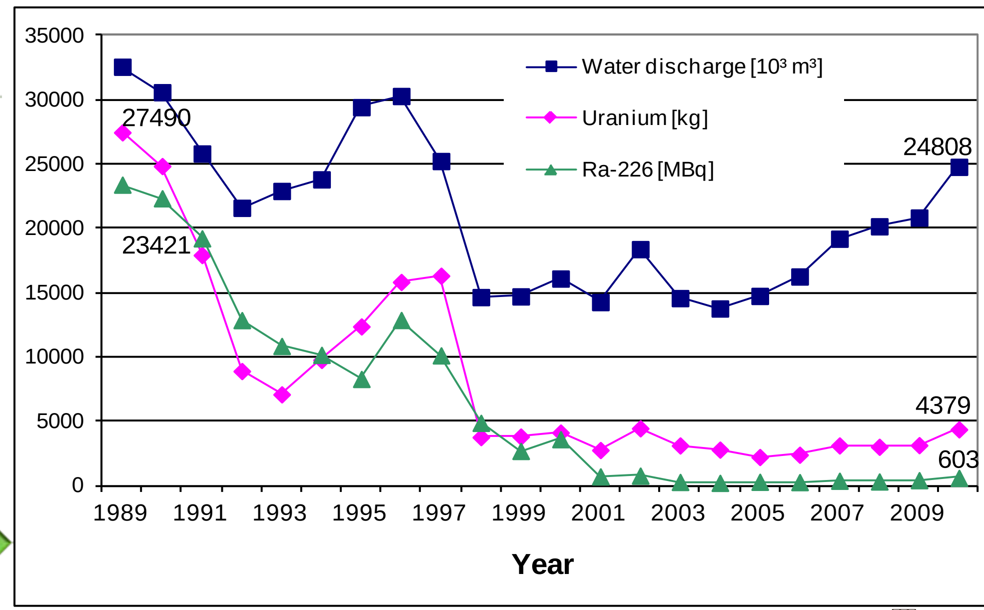
Case study WISMUT – Reduction of discharges

Advanced coverage of tailings and waste rock piles

Pre- and post rehabilitation nuclide vector for a watercourse in the surroundings of a tailings management facility (C_i - activity concentration of nuclide i in water)

Nuclide	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210
C_i [Bq/l] - pre	5,2	6,1	0,17	0,02	0,025	0,025
C_i [Bq/l] - post	0,83	0,85	0,001	0,02	0,002	0,006

Water treatment



Case WISMUT - Conclusions

- Pattern of exposure is very site specific
- Need of a harmonized approach to assess doses at former u mining and milling sites
- realistic scenarios: exposure of the public is dominated by inhalation of Rn/Rn procenies
- dust fall-out may be important, rather than use of water
- ventilation of underground working places manages occupational exposure
- coverage of piles and tailings ponds plus water treatment are keys to reduce water-born releases of radioactivity
- special radon situations require long-term solution

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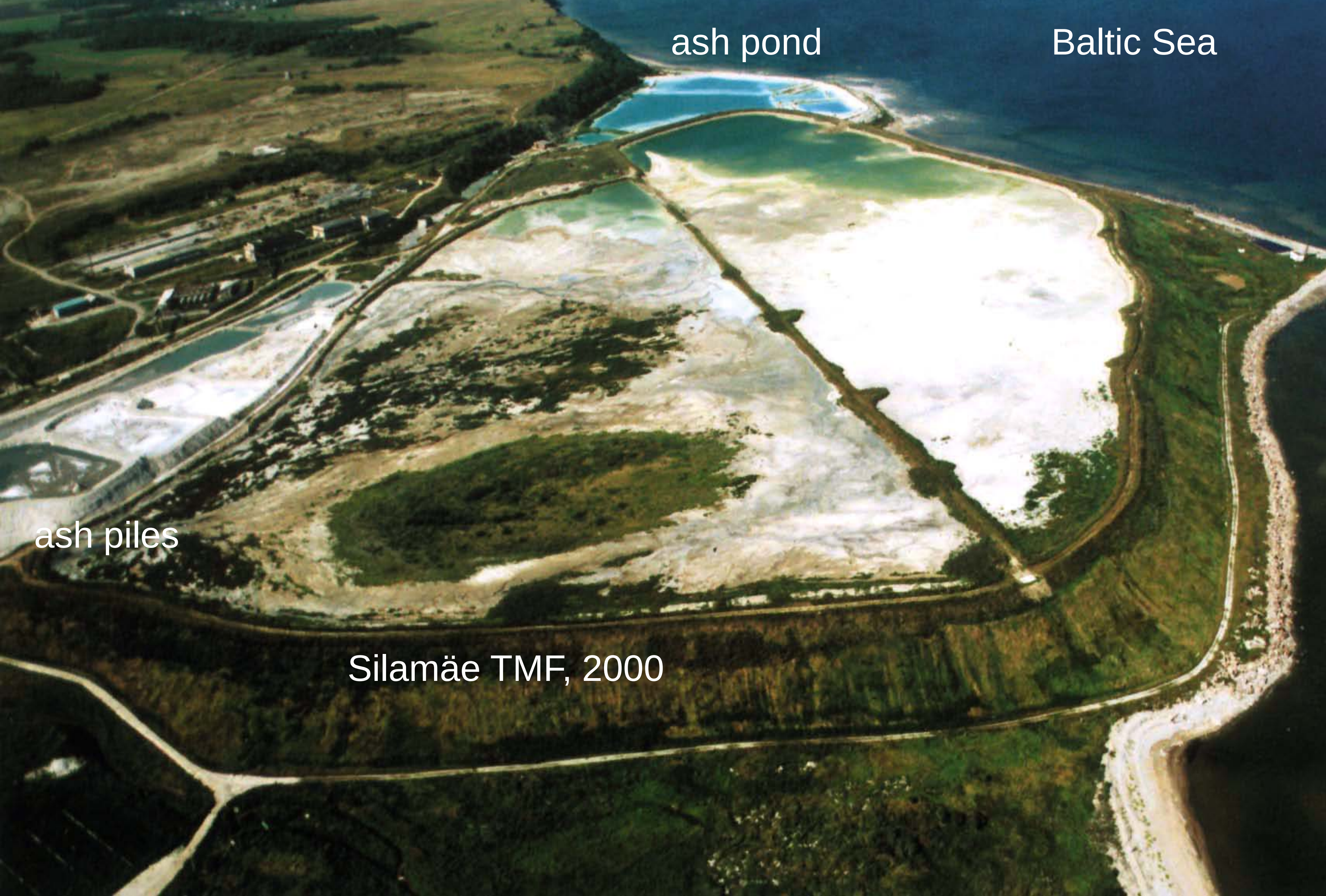
Case studies (2) – Sillamäe Tailings Management Facility (TMF) in Estonia



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Case study Sillamäe TMF - history, legacy

1946 – 1948	**SILMET uranium mill established**
1946 – 1949	**Underground uranium mining on Ordovician alum shales nearby the mill site**
1948 – 1977	**Milling/processing of uranium ores from GDR, HU, CSSR**
since 1978	**Milling/processing of ores for gaining rare earth elements**
1948 – 1959	**Tailings disposal onshore and in small ponds**
1959 – 2003	**Tailings disposal into the Sillamäe Tailings Pond; 50 ha; total 9 Mio t, incl. 4 Mio t radioactive U mill tailings**
1998 – 2000	**Environmental impact assessment, detailed conceptual design (WISMUT, C&E, ÖKOSIL, funded by EC/Phare)**
2001 – 2008	**Remediation (20 Mio €, funded by EU, NEFCO, EST, Nordic countries)**

Case study Sillamäe TMF - Environmental Impact Assessment

Exposure analysis: Effective dose [mSv/a]

Reference Person	Effective Dose [mSv/a]		Critical exposure pathways
	Children (2-7 a)	Adults	
P1 - Person with residence in dwellings near the pond	0,6 mSv/a	0,6 mSv/a	Dust-born llA propagation, Inhalation of radon
P2 - Person walking/playing over/on the pond area	1,6 mSv/a *	0,7 mSv/a	External gamma radiation * plus direct ingestion
P3 - Worker engaged with remediation	-	12 mSv/a **	External gamma radiation (** Occupational exposure)

In case of dam failure: No significant doses resulting from contamination of the Baltic Sea

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Main findings of the EIA:

1) Radioactive impact via external radiation and dusting is way above accepted levels
2) Stability of the seaside dam could not be guaranteed
3) Contaminant seepage into Baltic Sea contains a huge amount of nitrogen components and further contaminants from metal processing

Main objectives for remediation:

1) Reduce actual risk of dam failure
2) Terminate ongoing pollution of the Baltic Sea
3) Ensure compliance of the remediated TMF with the EC Directives on wastewater and radiation protection
4) Ensure compliance of the remediated TMF with: EU Directive on the landfill of waste

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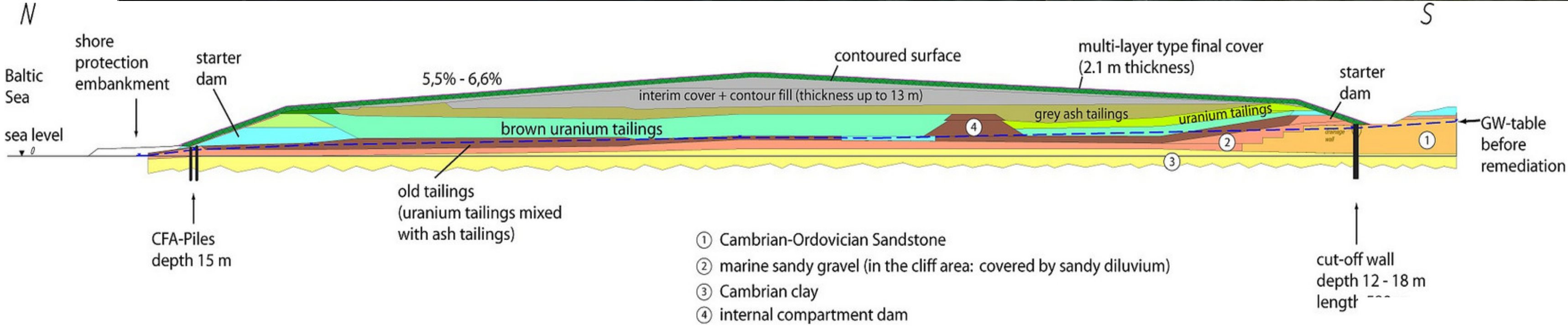
Case study Sillamäe – Remediation concept



Case study Sillamäe TMF – cover construction

Objectives

- percolation rate: < 5% of precip. rate (I < 20,000 m3/year)
- control of radon exhalation rate
- erosion control by vegetation (grass)

Final cover materials

Recultivation layer: humus topsoil

Storage layer: sandy loam or mixtures of fines from crushing of weathered limestone and loamy sands

Suffusion protection layer: crushed and sieved limestone

Drainage layer: crushed and sieved limestone

Sealing layer: Cambrian clay (decomposed on the site by frost, weathering and by adding water)

minimum thickness		layer type	k_f [m/s]
0,30 m		recultivation / storage.layer	$< 10^{-5}$
1,0 m		storage layer	$< 10^{-5}$
0,3 m		suffosion barrier	ca. 10^{-5}
0,3 m		drainage layer	$> 1 \times 10^{-3}$
> 0.30 m (constr. > 0.33 m)		sealing layer	$< 1 \times 10^{-9}$
≥ 1,0 m		interim cover and contour fill placed under WP 3C	$\geq 10^{-8}$
		tailings	$10^{-6} \ldots 10^{-9}$

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Case study Sillamäe TMF – remediated pond in 2011

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Case study Sillamäe TMF –results and conclusions

- Post-remedial monitoring demonstrates:
  - gamma dose rate at background level
  - no longer direct access to material
  - no dust-born radioactivity
  - mean radon exhalation rates: < 0,2 Bq/(m²s)
  - percolation rate < 3 %; seepage reduced from 200’000 m³/a before remediation down to actually 12’000 m³/a (< 0,7 mg/l U_{nat})

  ➡ Radiation exposure of the local public at background level

- Sillamäe TMF is an exemplar where remediation for the main part is not driven by radiological requirements
- Productive re-use of the site as harbor is an effective way to manage long-term surveillance

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General Conclusions

- Pattern of exposure at U mining and milling legacy sites is very site- and object-specific
- As a follow, site- and object-spesific remedial actions allow for management of radiological problems
- Radiation protection must be seen in the context of all aspects driving the remediation (chemo-toxic contami-nations, water protection, socio-economic aspects, etc.)
- Productive re-use of the sites is the most-effective way to manage long-term surveillance

Thank you for attention