Methodology for evaluation of field measurements (RADOIL project)

Measurement of radon in soil gas as an indicator of contamination by petroleum substances

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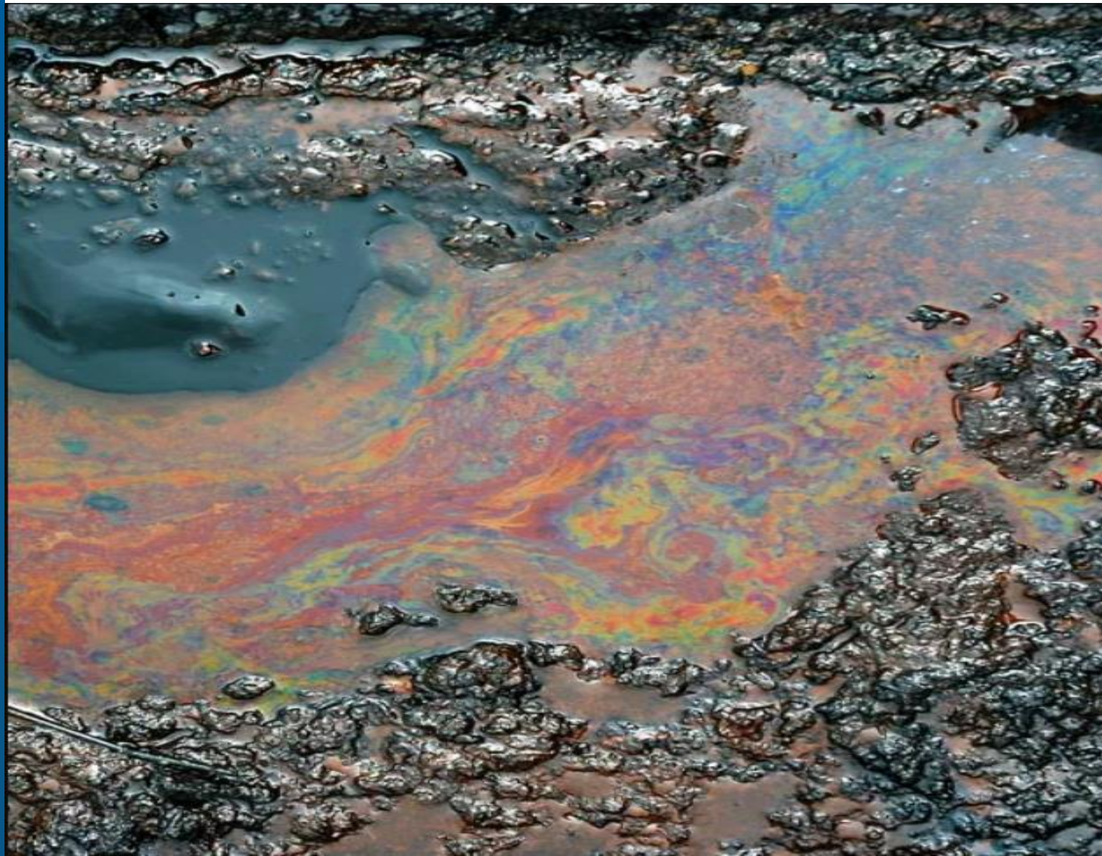


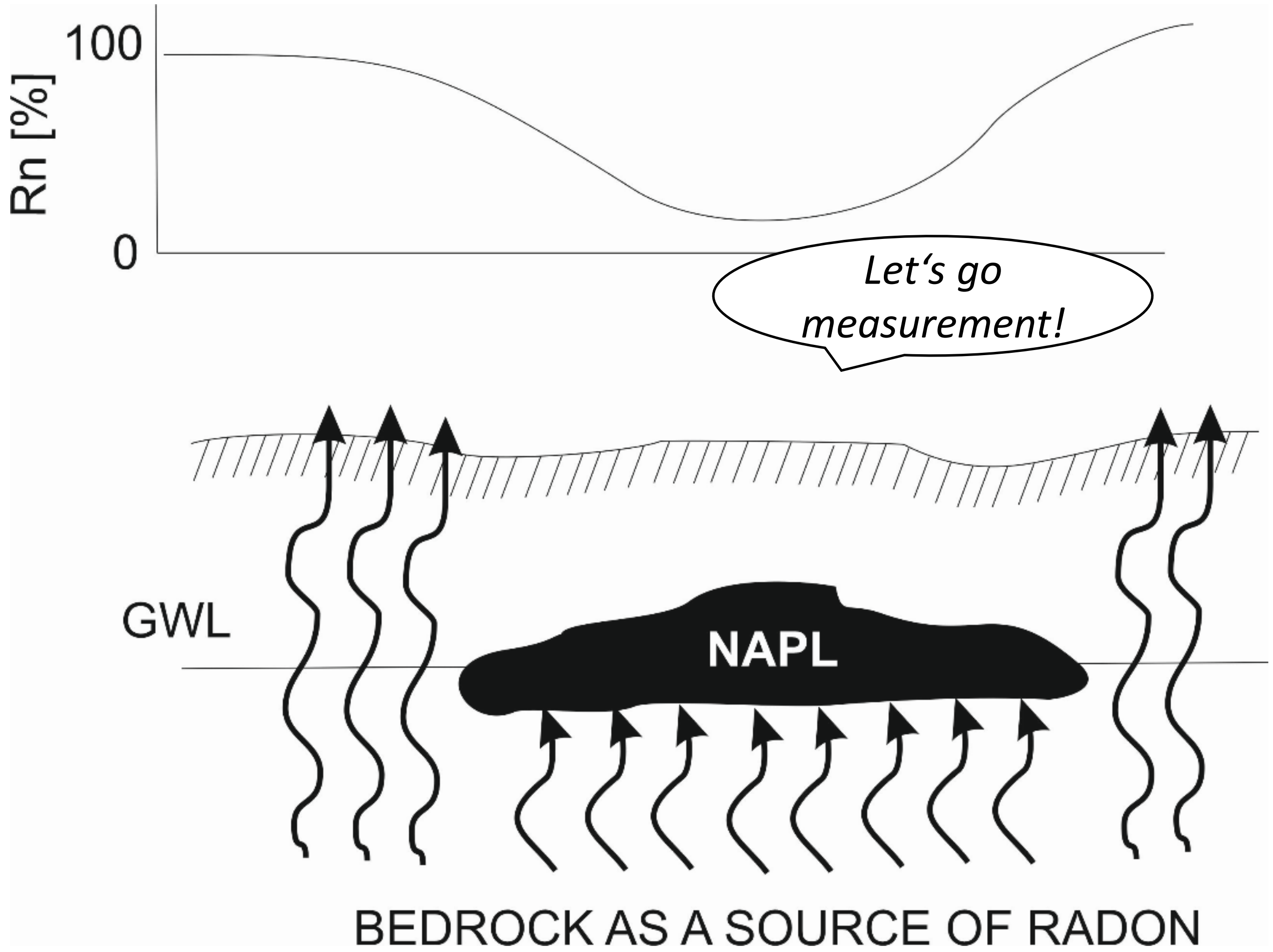
Theoretical background

Rn PARTITION COEFFICIENTS

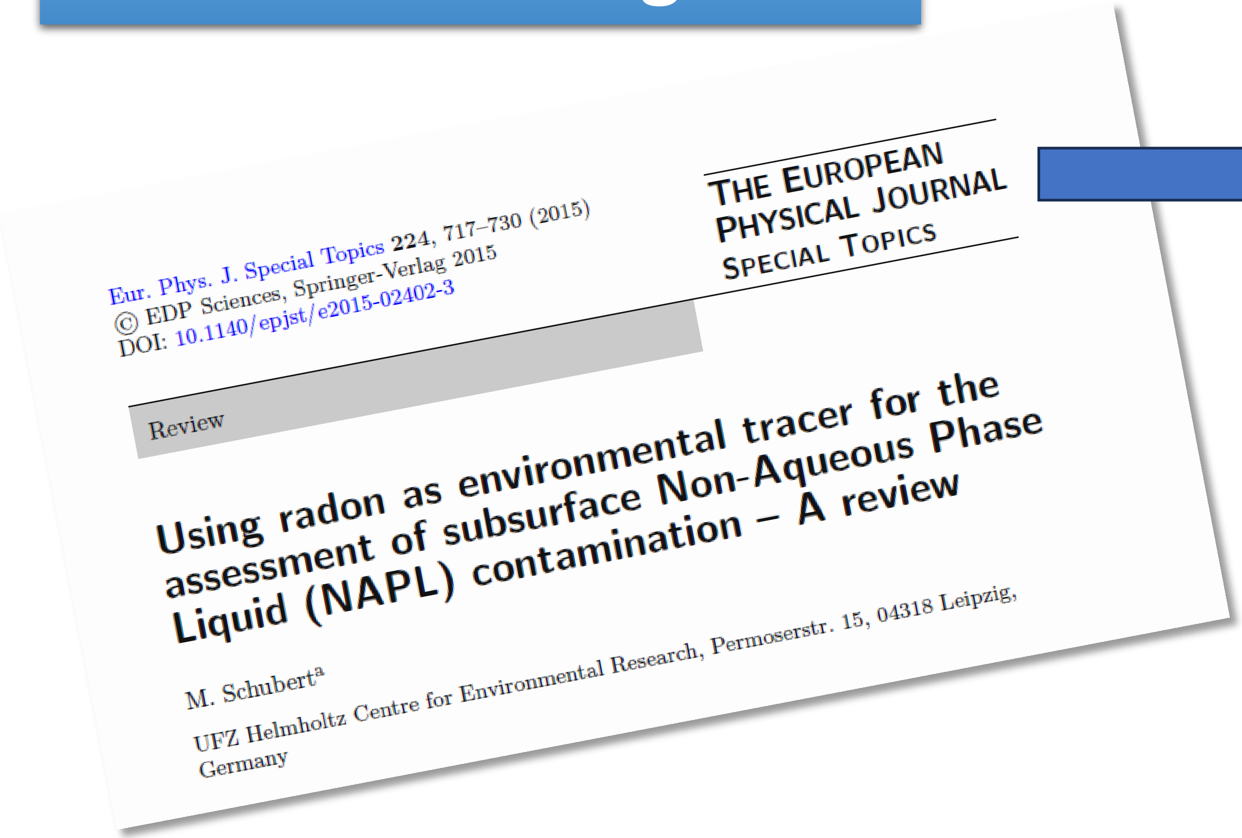
~ $K_{DIESEL\ FUEL}/_{W}$ = 60 [15 °C]

~ $K_{DIESEL\ FUEL}/_{SG}$ = 10 [15 °C]

~ $K_{W}/_{SG}$ = 0.30 [15 °C]



Theoretical background



Theoretical calculation of the equilibrium concentration of radon in the pore space

$$C_\infty = \frac{\varepsilon A_{Ra} \rho_d}{n} \qquad [\mathrm{Bq/m^3}]$$

Theoretical calculation of the equilibrium concentration of radon in the pore space, where the contaminant and pore water are together

$$C_\infty = \frac{\varepsilon A_{Ra} \rho_d}{n(1 - S_F + K_{W/SG} S_F (1 - X_{NAPL}) + K_{NAPL/SG} X_{NAPL} S_F)}.$$

Description	Unit	Label	Value
Emanation coefficient	-	ε	0.25
Specific activity of Ra in soil	Bq/kg	A_{Ra}	30
Porosity	-	n	0.2
Bulk density - density	kg/m3	ρd	1875
NAPL fraction in pore space		S_{NAPL}	
Water fraction in pore space		S_W	
Air fraction in pore space		S_{SG}	
Saturation of pore space with fluid (i.e. NAPL or water)		S_F	

$$S_{NAPL} + S_W = S_F = 1$$

Theoretical background

When normalized to 100%, i.e. C∞ = C [%], the following table describes how much radon concentration we can theoretically measure compared to the background [100%]

Saturation of the pore space with fluids (i.e. NAPL, water)

NAPL fraction in the pore space \ X - S_F	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.0	**100**	**108**	**116**	**127**	**139**	**154**	**173**	**197**	**229**	**273**	**338**
0.1	**100**	97	95	93	90	88	86	84	82	81	79
0.2	**100**	89	80	73	67	62	57	54	50	47	45
0.3	**100**	82	69	60	53	48	43	39	36	33	31
0.4	**100**	76	61	51	44	39	34	31	28	26	24
0.5	**100**	71	55	45	38	33	29	26	23	21	19
0.6	**100**	66	49	39	33	28	25	22	20	18	16
0.7	**100**	62	45	35	29	25	21	19	17	15	14
0.8	**100**	59	41	32	26	22	19	17	15	14	12
0.9	**100**	55	38	29	24	20	17	15	13	12	11
1.0	**100**	53	36	27	22	18	16	14	12	11	10
Y - X_{NAPL}											

Example: The pore space is filled with 30% fluids, of which 20% is contaminant. I.e. 70% soil air, 24% water and 6% NAPL. So we theoretically measure a concentration of Rn at the level of 73% of the background. Difference is only only 27%.

Values colored dark yellow indicate conditions when the change of radon concentration will be probably unmeasurable, les than 30 % (e.g. 10 and 15 KBq/m^3)

→ **NAPL phase**

The factors influences the soil gas radon measurement

- Standard method for soil gas sampling and measurement in CZ (according the recommendation of SÚJB – State Office for Nuclear Safety)
- In principle we measured proportionately (comparing background vs. area of NAPL source) and we somehow neglected the known **meteorological factors**. However we followed these rules: measure the location in a short time (in one day) during the stable weather, not in the winter and after the rain.

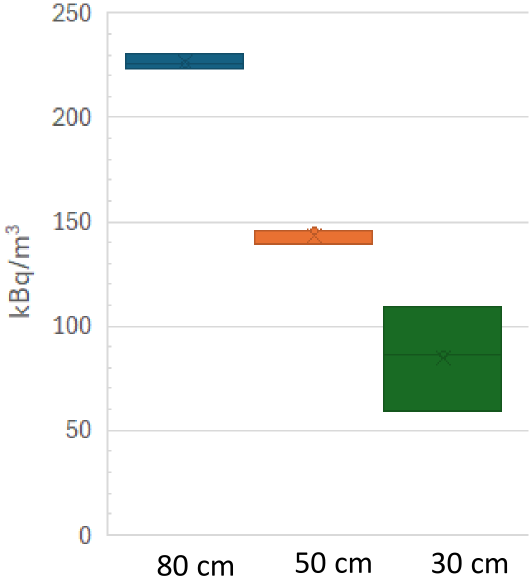
Meteorological Factor	Mode of Action	Typical Effect on Radon Concentration
Atmospheric pressure	Drop in pressure promotes radon flow to the surface; rise in pressure suppresses it.	↓ Pressure → ↑ Concentration ↑ Pressure → ↓ Concentration
Soil temperature	Influences diffusion and gas movement; frozen soil hinders radon escape.	Higher T → ↑ Diffusion and ↑ surface concentration Frozen soil/snow → accumulation below surface
Precipitation and soil moisture	Water fills pores; diffusion in water is very slow.	After rain → ↓ Concentration Drying soil → ↑ Concentration
Wind	Alters pressure at surface and exchange between soil and air.	Usually minor effect; may cause fluctuations
Snow cover	Insulating layer reduces diffusion.	Radon accumulates beneath snow → ↑ Concentration in soil

The factors influences the soil gas radon measurement

The depth of soil gas radon measurement

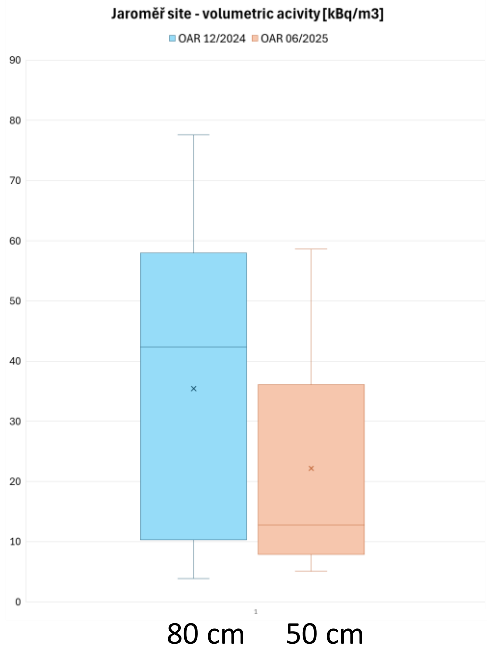
- the variation of radon concentration with depth is significant -> the same depth for all the measurements is recommended (the 50 cm depth is optimal)

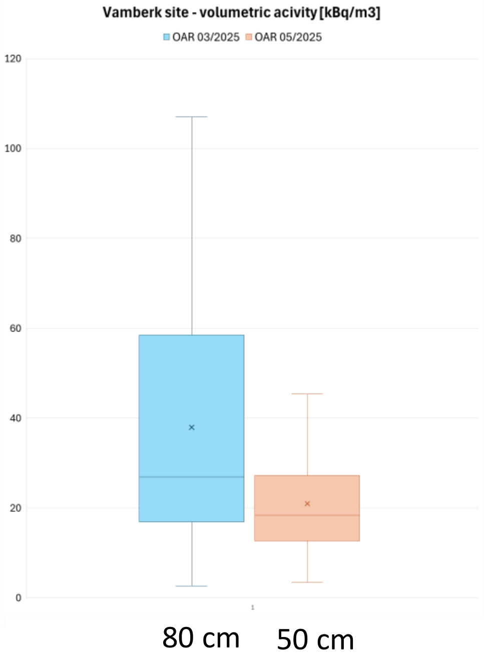
- One point measurement in three depths (triplication)



- Bernartice site
  point 71

- Two datasets, two depths, Jaroměř and Vamberk site





The factors influences the soil gas radon measurement

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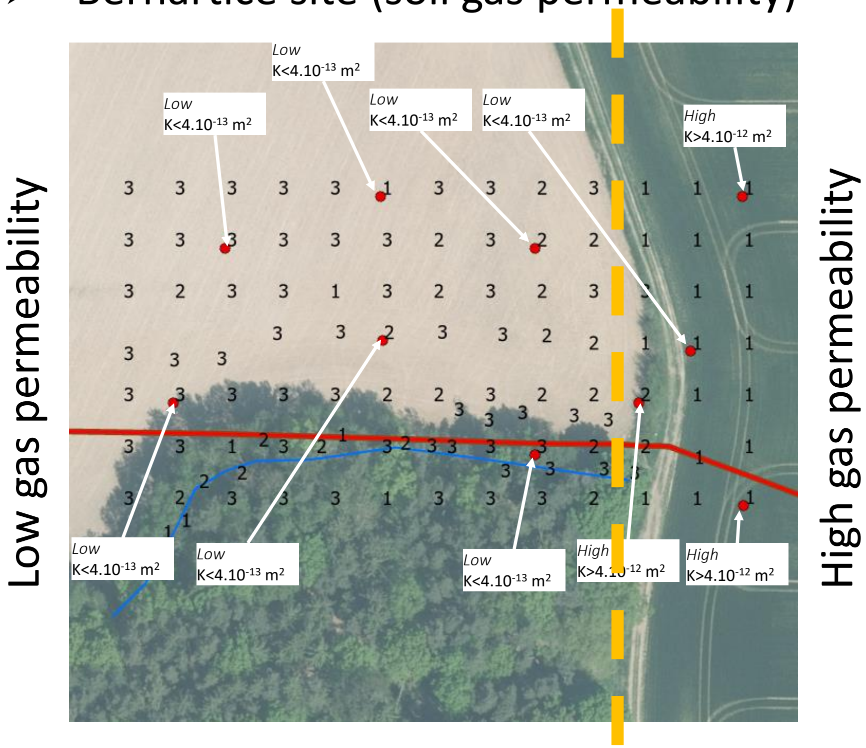
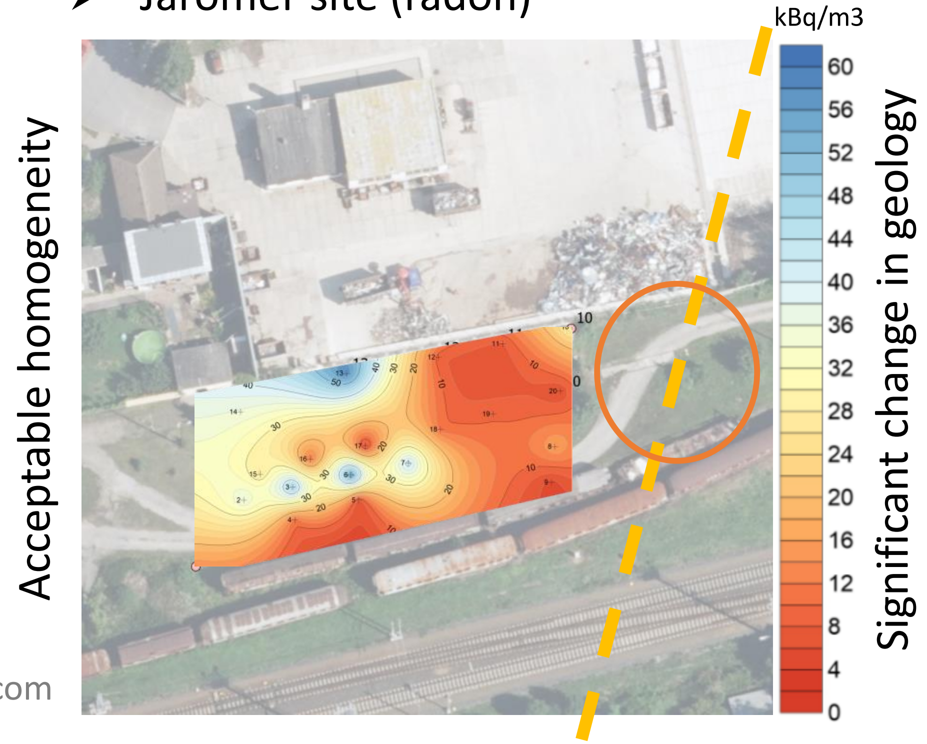
Homogeneity of the geological environment

- the overlying geological formation should have similar gas permeability without large anomalies -> for first insight the subjective resistance of syringes could be the guide followed by standard soil gas permeability measurement (e.g. with RADON JOK)

- Bernartice site (soil gas permeability)



- Jaroměř site (radon)



The factors influences the soil gas radon measurement

Shallow groundwater

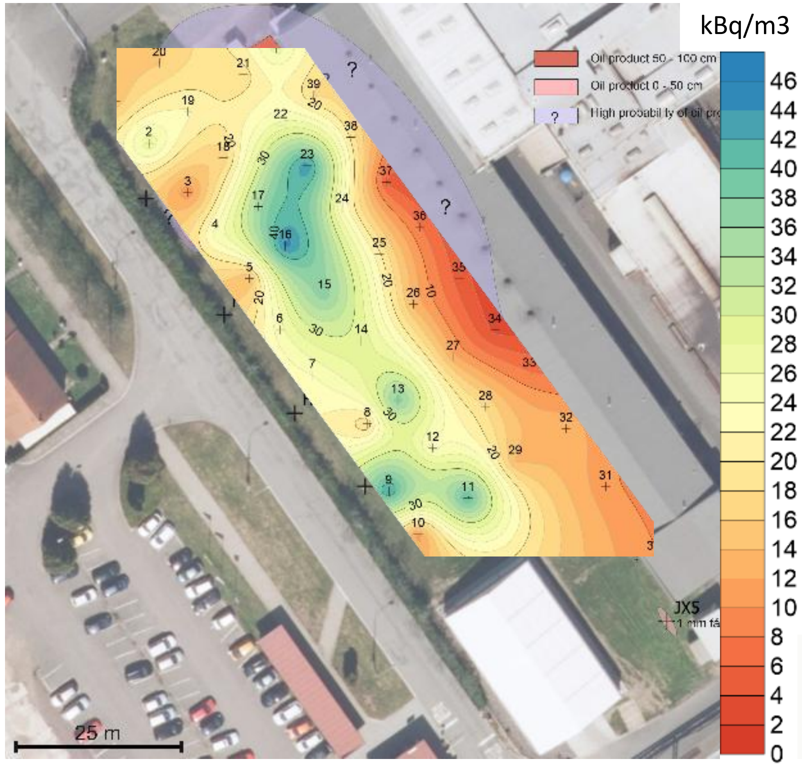
- absence of shallow groundwater (e.g. groundwater on the clay lens within more permeable geological environment), impossibility of correct radon measurement -> Bernartice site (part of site with GW ~ 0,7-1 m b.g.)

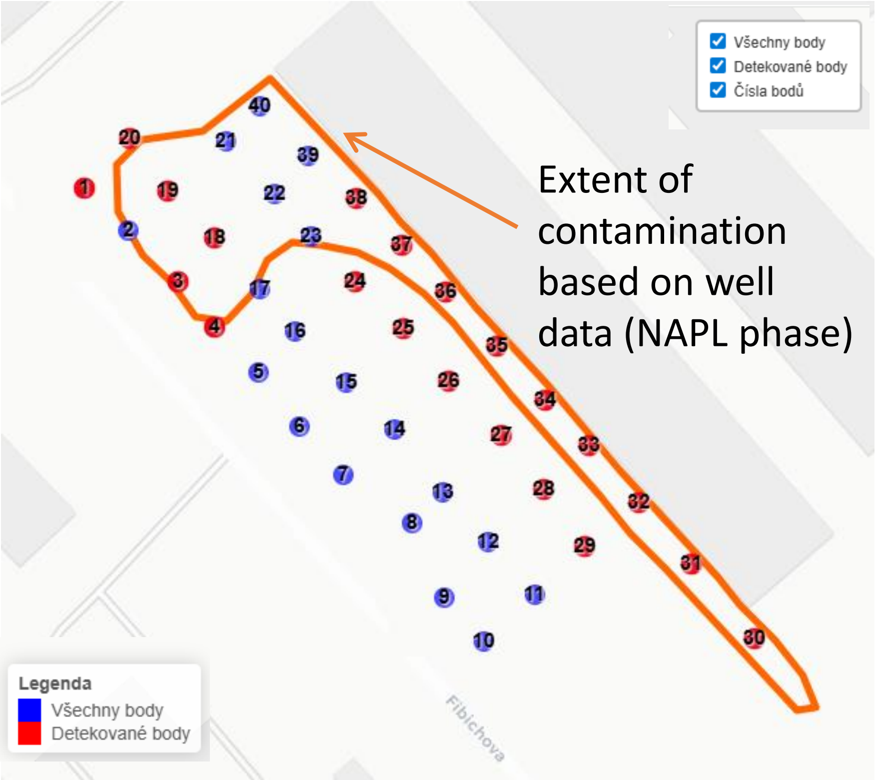
NAPL geometry

- extent of contamination -> large continuous contamination vs. small scattered contamination areas
- the thickness of the NAPL layer -> phase of cm to m vs. very thin layer
- the type of NAPL differs in Rn partition coefficients

Evaluation of field measurements

- The simple software platform for data evaluation and visualization was developed based on R programming language. The fundamental evaluation of the method is based on comparing the actual outline (extent) of contamination with the results from radon measurements in soil air, utilizing simple statistical analysis.

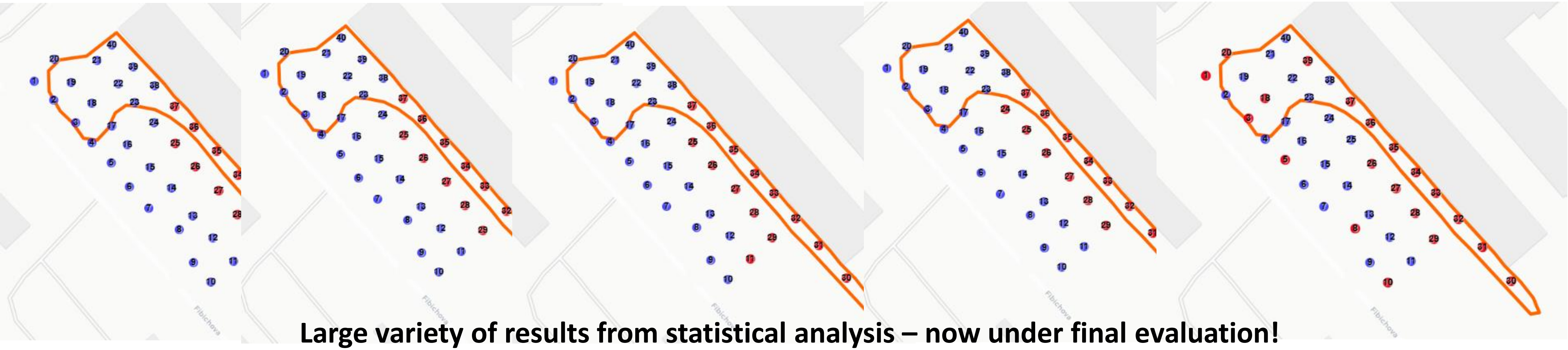




Evaluation of field measurements

➢ Simple statistical analysis based on:

- Percentiles from individual points – classification of points according to the percentiles of the entire dataset (e.g. values below the 40th percentile marked as low)
- Percentiles from average square values (2, 3 and 4 points) – average of the values of the four nearest neighboring points; if the average fell below a specified threshold, the square was marked as suspicious
- Two or Three-Nearest Point Method – calculation of the average of two or three points to capture smaller anomalies
- "3 of 4" Method – a group of four points was marked as anomalous if at least three had a value below the threshold
- Calculation of square centroids – visualization of the area occurrence of low values using the centroids of square groups



Large variety of results from statistical analysis – now under final evaluation!

Conclusion

- The main application of this methodology is at sites where contamination has already been indicated and there is a need to monitor its status over time.
- The key advantages of the method lie in its speed, low cost, and straightforward data interpretation. The method can serve as a useful complementary tool alongside more robust site investigation techniques.

Acknowledgement

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