GAMMA DOSE RATES AND RADIONUCLIDE CONCENTRATIONS IN AND AROUND CONTRASTING SOIL AND SEDIMENT CONTEXTS

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SPATIAL VARIATION OF DOSE RATES IN SOILS AND SEDIMENTS - VADOSE

Project Aims:

- Determine radioactivity and absorption characteristics at different spatial scales (μm - hm) for contrasting soils and sediments.

- Develop MC models tailored to each soil/sediment calibrated by the experimental determinations.

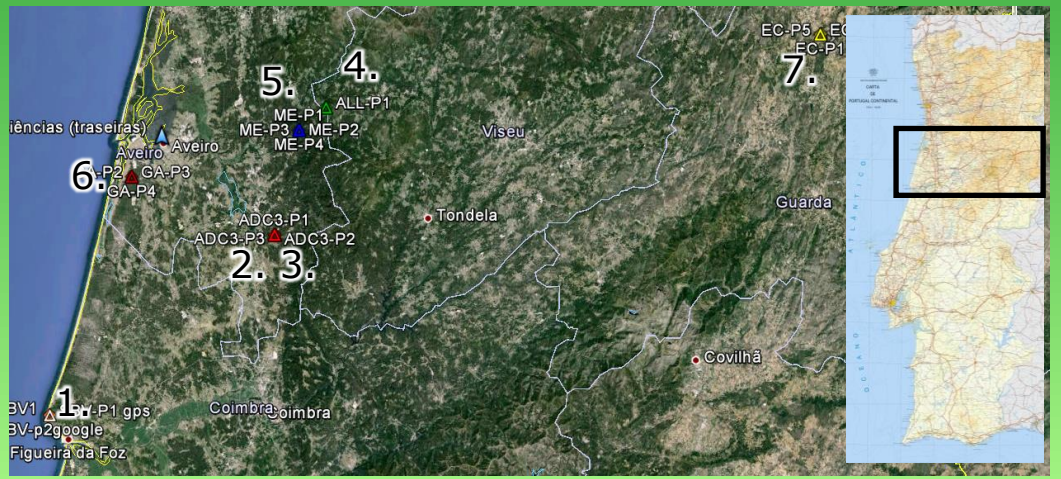
- Assess the accuracy of dose rates predicted from geochemical and radiometric measurements using common methodologies, geometries, and deterministic calculations, to bodies of different sizes within sample media.

- Produce / refine simple recipes for combination with standard experimental measurements / existing baseline values / maps.

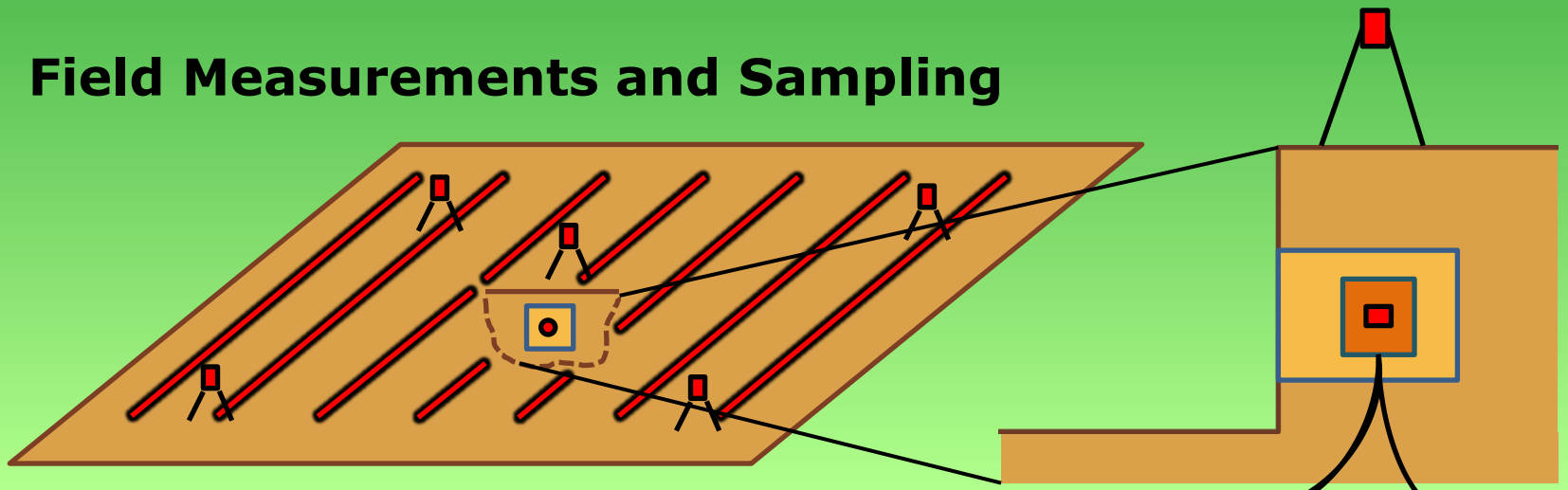
Seven Sites

Centre-North Portugal
Coast to Interior circa Aveiro

1. Terra-rossa. Limestone (SBV)
2. Poorly sorted quartz + clay. Alluvial (ADC1)
3. Clay. Alluvial (ADC3)
4. Organic soil. Granite (ALL)
5. Subsoil. Schist (ME)
6. Dune sand (GA)
7. Subsoil. Uraniferous schist (EC)



Field Measurements and Sampling

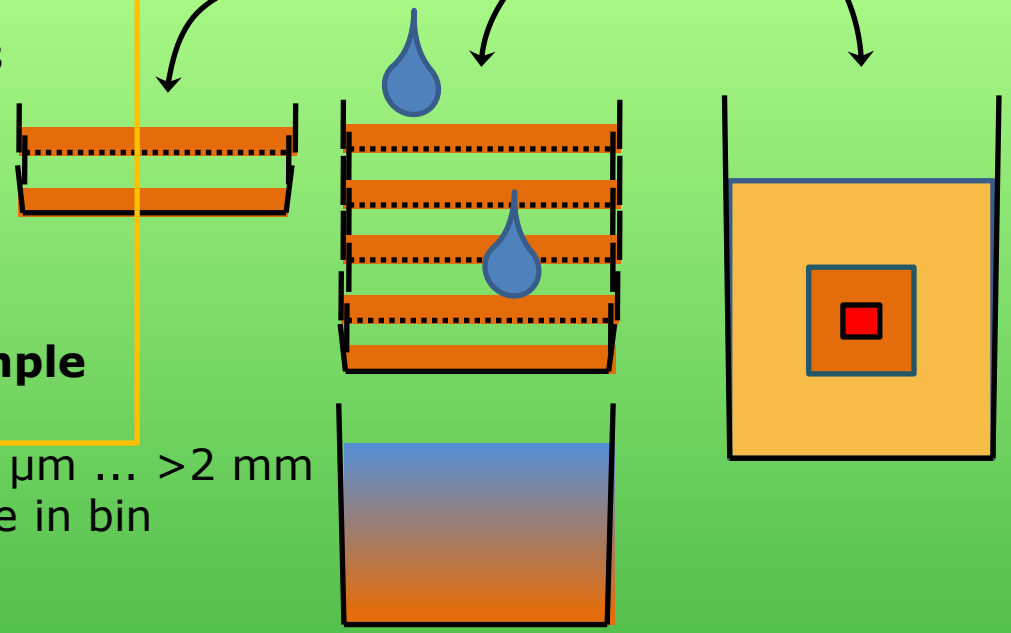


hm – m: 2π NaI field gamma spec.
- Backpack area survey
- Grid of surface measurements

m - cm: sampled section
- 4π NaI field gamma spec.
- 100 kg "total" sample

cm - µm: 20 kg "interior" sample
- 1 kg dry sieved ><2 mm
- 10 kg wet-sieved / settled <2 µm ... >2 mm
- 9 kg buried inside total sample in bin

+ cm - µm: Kubiena tins
- sample with 'intact' peds / structure



Analytical Methods

Field Gamma Spectrometry

Backpack area survey

- 3” x 3” NaI SUERC, 10 s integrals
- Threshold/Windows

Grid of surface measurements*, 1 m elevation*

4π in sampling location*, 50 cm from section face*

- 3” x 3” NaI Nanospec and HPI, 600 s or 1200 s
- Windows

Laboratory Gamma Spectrometry

HPGe 150 cm^3 Canberra

<2 mm fraction, quartered

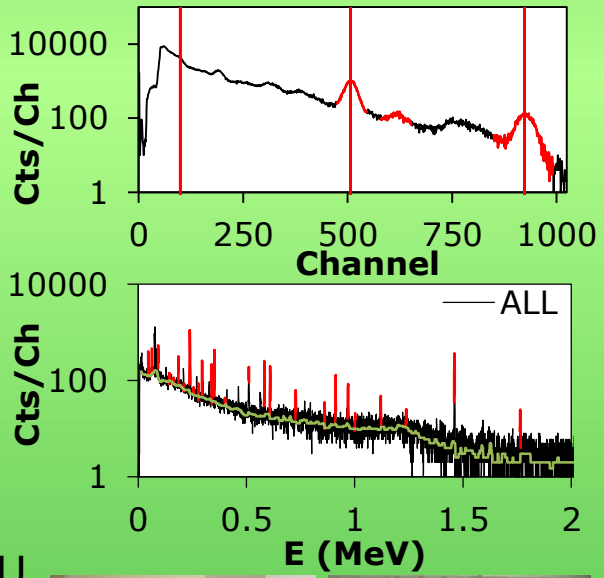
Comparative measurements relative to 4 geochemical reference samples (milled, sealed)

Gamma Spectrometry of Unactivated Samples

- Unmilled, 6 cm diameter petri ~30 g, unsealed
- 25 lines: K; wtMean ^{232}Th,^{238}U pre/postRn,^{210}Pb,^{235}U

Neutron Activation Analysis

- Milled, ~200 mg
- Portuguese Research Reactor
- 30 elements inc. K, Th, U

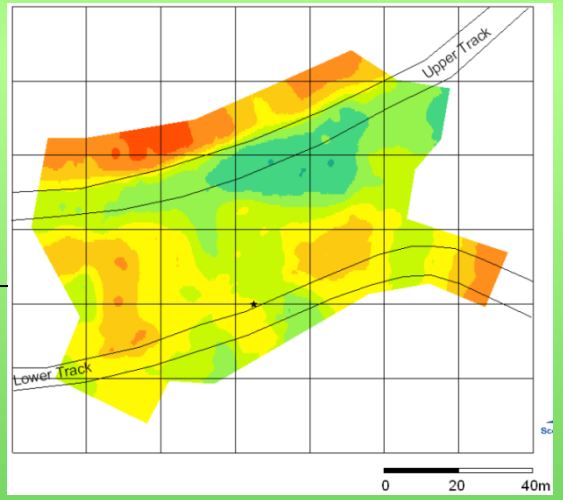


1. Terra-rossa. Limestone (SBV)

Hill slope, dense scrub

High gradient: thin soil cover

Large rock fragments



all dose rates 4π

SBV		$\dot{D}\gamma$	σ_γ	K	Th	U	^{235}U	^{238}U		
		mGy.a^{-1}			Bq.kg^{-1}			<Rn	>Rn	^{210}Pb
NaI	Survey Mean	0.48	0.10	306	6.7	19				
	Grid Mean	0.69	0.33	278	23	23				
	Buried	0.44		154	12	21				
HPGe	<2 mm	2.5		1014	74	90	104	76	98	102

Rn ~ OK

σ_γ survey ≈ 20%

Sample <2 mm ≈ 6 x NaI

2. Poorly sorted quartz + clay. Alluvial (ADC1)

Quarry pit

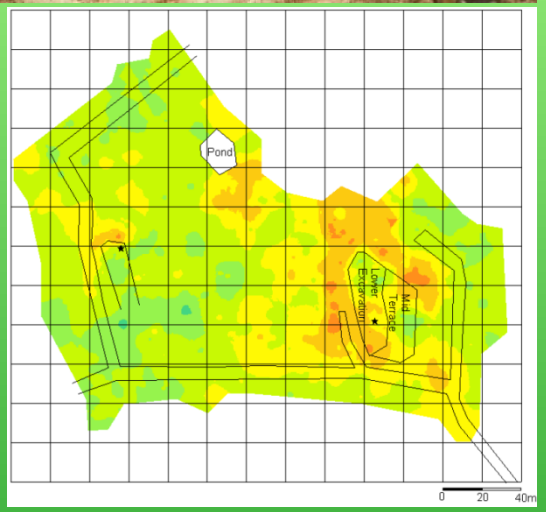
Exposed alluvial sequences

ADC1		$\dot{D}\gamma$	σ_γ	K	Th	U	^{235}U	^{238}U		
		mGy.a^{-1}		Bq.kg^{-1}				<Rn	>Rn	^{210}Pb
NaI	Survey Mean	0.63	0.09	328	11	30				
	Grid Mean	0.81	0.19	258	31	27				
	Buried	0.42		156	15	13				
HPGe	<2 mm	0.41		148	14	15	2	16	15	21
INAA	<2 mm	0.37		119	12	16				

U, Rn ~ OK

σ_γ survey ≈ 15%

Sample ≈ Buried NaI.
Surface higher



3. Clay. Alluvial (ADC3)

Quarry

Wooded surficial ~2 m clay and stripped areas

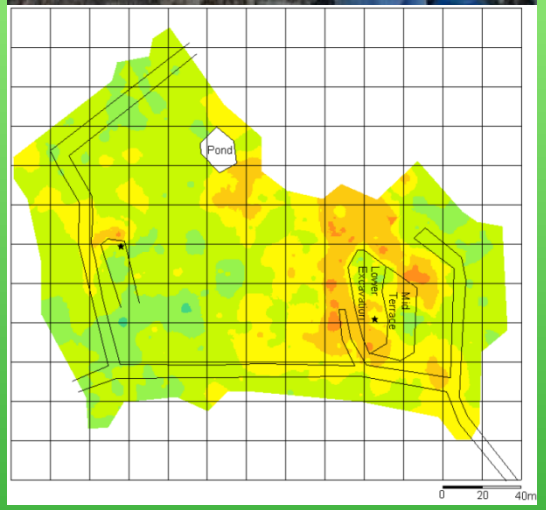
ADC3		$\dot{D}\gamma$	σ_γ	K	Th	U	^{235}U	^{238}U		^{210}Pb
		mGy.a^{-1}		Bq.kg^{-1}				<Rn	>Rn	
NaI	Survey Mean	0.6	0.1	328	11	30				
	Grid Mean	1.0	0.2	319	40	32				
	Buried	1.0		500	37	24				
HPGe	<2 mm	1.8		794	54	58	65	62	56	78

U, Rn ~ OK

σ_γ survey ≈ 15%

Local surface grid ≈ Buried NaI,
Survey lower.

Sample <2 mm ≈ 1.5-2.5 x Buried NaI (K, Th & U)

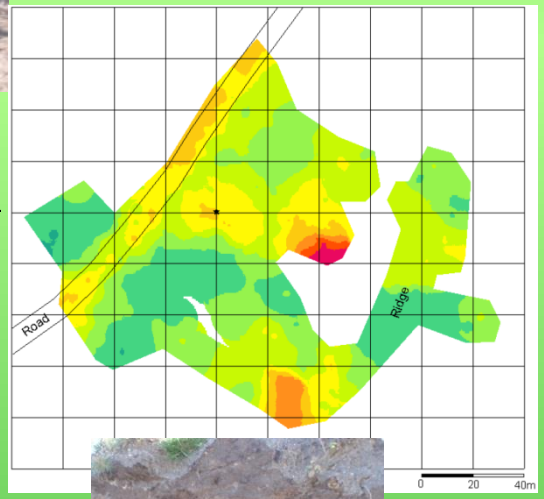


4. Organic soil. Granite (ALL)

Outcrop with deep organic rich soil accumulated at the base

Partly wooded

σ_γ survey ≈ 20%



ALL		$\dot{D}\gamma$	σ_γ	K	Th	U	^{235}U	^{238}U		
		mGy.a^{-1}		Bq.kg^{-1}				<Rn	>Rn	^{210}Pb
NaI	Survey Mean	1.5	0.3	982	23	55				
	Grid Mean	2.4	0.5	931	97	55				
	Buried	1.7		776	67	37				
HPGe	<2 mm	2.7		1114	94	77	93	118	65	147
INAA	<2 mm	2.4		878	84	86				

U: Rn loss. ^{210}Pb: not pre-excavation?
K: Buried NaI vs. HPGe vs INAA, range ~ 30%

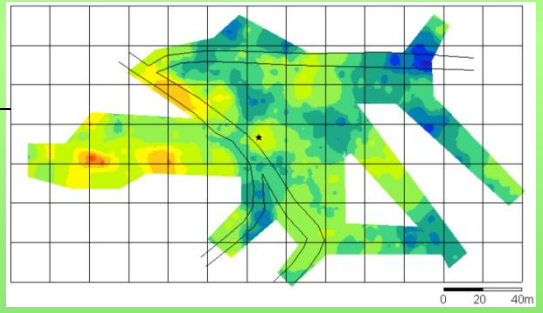
Sample <2 mm ≈ 1.5 x Buried NaI

5. Subsoil. Schist (ME)

Hillslope, forrested

Section by forrest track

ME		$\dot{D}\gamma$	σ_γ	K	Th	U	^{235}U	^{238}U		
		mGy.a^{-1}		Bq.kg^{-1}				<Rn	>Rn	^{210}Pb
NaI	Survey Mean	0.8	0.1	580	10	32				
	Grid Mean	1.3	0.2	595	41	36				
	Buried	1.2		491	39	39				
HPGe	<2 mm	1.9		751	58	74	63	75	72	99



U, Rn = OK

σ_γ survey ≈ 12%

Survey: lower Th

Sample <2 mm ≈ 1.4-1.8 x Buried NaI (K, Th & U)

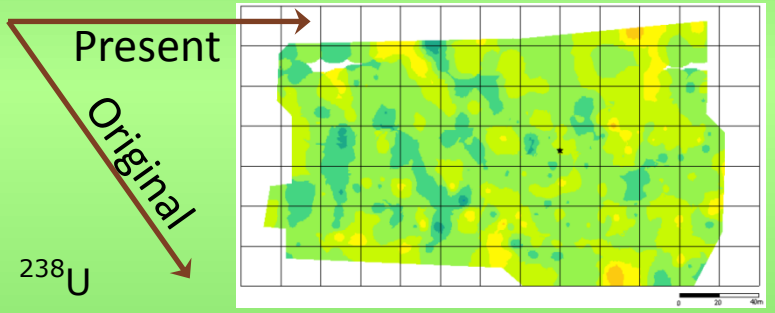
6. Dune sand (GA)

Aforrested sand ridges

"Remodelled dunes"; original allignment identified by area survey

U, Rn ~ OK

σ_γ survey ≈ 8%



GA		$\dot{D}\gamma$	σ_γ	K	Th	U	^{235}U	^{238}U		
		mGy.a^{-1}		Bq.kg^{-1}				<Rn	>Rn	^{210}Pb
NaI	Survey Mean	0.28	0.02	262	1.5	11				
	Grid Mean	0.44	0.03	274	9	14				
	Buried	0.39		285	9	7				
HPGe	<2 mm	0.48		365	9	11	-7	8	12	12

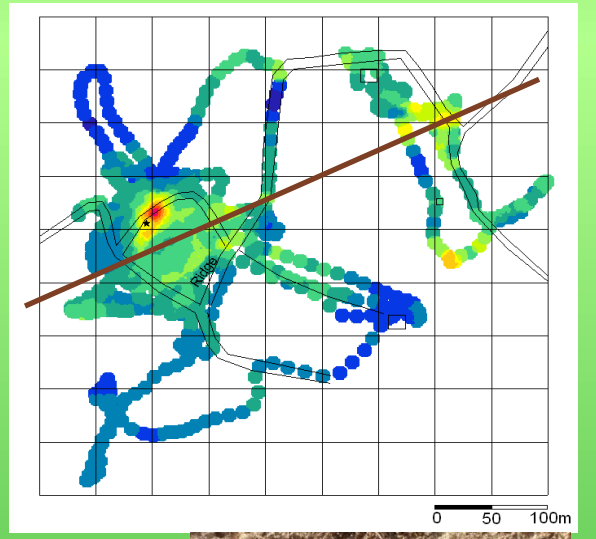
Survey: lower Th

Sample <2 mm ≈ 1.2 x Buried NaI (K & U)

7. Subsoil. Uraniferous schist (EC)

Remediated U mine
- hydrothermal mineralization along fault

Hotspots: outflow and outcrop
- rapidly identified in area survey



EC		$\dot{D}\gamma$	σ_γ	K	Th	U	^{235}U	^{238}U		
		mGy.a^{-1}		Bq.kg^{-1}				<Rn	>Rn	^{210}Pb
NaI	Survey Mean	3.7	2.8	1184	23	382				
	Grid Mean	11	13	989	71	1121				
	Buried	9.5		746	59	936				
HPGe	<2 mm	14		993	92	1376	1649	1024	1691	2328
INAA	<2 mm	6.7		665	51	640				

Rn = OK; U variable: specific activity much higher than reference

σ_γ survey ≈ 76%

Max survey: U ≈ 4500 Bq.kg^{-1}, γ(2π) ≈ 0.8 Gy.a^{-1}
- site is known, but potential public exposure issues...

NaI Surface vs. Buried

Z score: significance of difference given observed variability

$$Z = (\bar{S}-B)/\sigma_S$$

	Site	K	Th	U	γ	Type
1	SBV	0.8	1.3	0.2	0.8	Terra-Rossa, Limestone
2	ADC1	**2.0**	1.5	**4.6**	**2.0**	Poorly sorted quartz + clay. Alluvial
3	ADC3	**-4.1**	0.5	1.2	-0.2	Clay. Alluvial
4	ALL	1.7	1.1	1.9	1.3	Organic soil. Granite
5	ME	1.3	0.4	-0.6	0.5	Subsoil. Schist
6	GA	-0.7	0.7	**5.0**	**1.8**	Dune sand
7	EC	1.0	0.8	0.1	0.2	Subsoil. Uraniferous schist

2. Surface detected/included areas richer in clay
3. Slope wash preferentially removed K
4. Surface detected/included areas of bedrock
6. Surface U enrichment: evapotranspiration / concentration in forest litter / allocthonous ^{220}Rn?

Summary

7 well characterised sites and reference materials in the lab

Surface/buried NaI results most similar for schist (as expected) and limestone (surprisingly, but allowing moderately high variability).

Some calibration harmonisation to be further pursued.

Significant differences in gamma dose rate, between methods and measured geometries, were often observed: explainable context by context, but indicate the importance of making a range of dosimetric measurements.

Inside the samples...

OSLD enclosure dosimetry
Neutron activation & tomography
XRD, SEM, granulometry, water retention...