Scottish Universities Environmental Research Centre

Portable Gamma Spectrometry Surveys of Sites in Portugal in Support of the VADOSE Project.

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Introduction.

The VADOSE project involves the use of multiple techniques to evaluate dose rate variability on different spatial scales. Several sites in central northern Portugal, mostly in the vicinity of Aveiro, have been investigated.

As part of this investigation, portable gamma spectrometry techniques were used to map areas of approximately 100x100m around each sampling location. The SUERC portable gamma spectrometry system used consists of a 3x3" NaI(Tl) spectrometer with integral GPS receiver. Measurements were conducted with 10s integration time. Maps of the dose rate variability in each area were generated in the field, and used to confirm data quality and coverage and identify any remaining locations that would benefit from further measurements prior to leaving the site. Maps of natural radionuclide distribution (^{40}K, ^{214}Bi from the ^{238}U decay series, and ^{208}Tl from the ^{232}Th decay series) were produced after the conclusion of measurements each day. Natural radionuclide specific activities (Bq kg^{-1}) were estimated using a spectral windows method with stripping[1], using a working calibration assuming planar geometry and uniform activity distribution. As agreed prior to the start of work, a working calibration derived from field measurements and photon fluence calculations conducted for similar detectors in the 1990s[2] has been used here, with calibration parameters given in the appendix.

This report presents the dose rate maps produced during the field work, with a very brief description of the data. Summary statistics for each data set are presented in Table 1. All data have been mapped using a UTM (zone 29T) grid, with the approximate location of ground features added by hand as a guide. Further work could be conducted to produce more accurate overlays of ground features. At each site in-situ gamma spectrometry measurements were also conducted by ITN, and the data collected by the two detector systems and the soil samples will be compared at a later date.

[1] Cresswell A.J., Sanderson D.C.W., White D.C. (2006). 137Cs measurement uncertainties and detection limits for airborne gamma spectrometry (AGS) data analysed using a spectral windows method. *Applied Radiation and Isotopes* **64** 247–253.
Sanderson D.C.W., Allyson J.D., Tyler A.N. (1994). Rapid quantification of radiometric data for anthropogenic and technologically enhanced natural nuclides. *IAEA Technical Committee Meeting on the Use of Uranium Exploration Data and Techniques in Environmental Studies*, IAEA-TECDOC-827, 197–216 (Vienna: International Atomic Energy Agency).

[2] Allyson, J.D. (1994). *Environmental Gamma Ray Spectrometry: Simulation of Absolute Calibration of in-situ and Airborne Spectrometry for Natural and Anthropogenic Sources*. PhD Thesis, The University of Glasgow.
Tyler, A.N. (1994). *Environmental Influences on Gamma Ray Spectrometry*. PhD Thesis, The University of Glasgow.

Site	Number of measurements and area		^{40}K (Bq kg^{-1})	^{214}Bi (Bq kg^{-1})	^{208}Tl (Bq kg^{-1})	Dose Rate (mGy a^{-1})
Serra de Boa Viagem	552 7 000 m^2	Mean	306	19.4	6.7	0.241
		Std dev	99	15.4	3.6	0.048
		Median	305	17.8	6.1	0.244
		10th percentile	181	0.8	2.4	0.175
		90th percentile	428	40.1	11.1	0.302
Avelâs de Cima	834 30 000 m^2	Mean	328	29.7	11.1	0.316
		Std dev	108	18.5	4.2	0.045
		Median	320	29.4	11.0	0.309
		10th percentile	196	6.0	6.0	0.266
		90th percentile	446	52.9	17.0	0.382
Arcas – Lameiro Longo	577 12 400 m^2	Mean	982	54.9	22.7	0.749
		Std dev	208	25.0	10.6	0.154
		Median	965	53.9	21.9	0.738
		10th percentile	734	22.7	10.8	0.569
		90th percentile	1258	87.4	35.5	0.947
Macida Eólica	556 12 000 m^2	Mean	580	32.0	10.4	0.399
		Std dev	130	17.5	3.8	0.048
		Median	576	30.6	10.9	0.400
		10th percentile	417	9.9	6.0	0.340
		90th percentile	744	55.6	15.7	0.457
Gafanha do Aquém	418 24 500 m^2	Mean	262	11.3	1.5	0.138
		Std dev	68	9.3	1.9	0.011
		Median	261	11.5	1.2	0.137
		10th percentile	174	-0.8	-1.3	0.123
		90th percentile	351	23.2	3.7	0.152
Minas de Massueime	695 15 000 m^2	Mean	1032	49.7	12.3	0.612
		Std dev	314	22.9	5.1	0.155
		Median	1034	48.7	12.1	0.616
		10th percentile	635	22.8	6.0	0.410
		90th percentile	1462	81.6	19.5	0.814
Entre Castelos	1067 25 000 m^2	Mean	1184	381.5	22.6	1.848
		Std dev	419	399.0	7.5	1.405
		Median	1097	265.0	21.9	1.436
		10th percentile	828	106.6	13.9	0.904
		90th percentile	1562	799.4	31.7	3.172

Table 1: Summary statistics for surveys at each site.

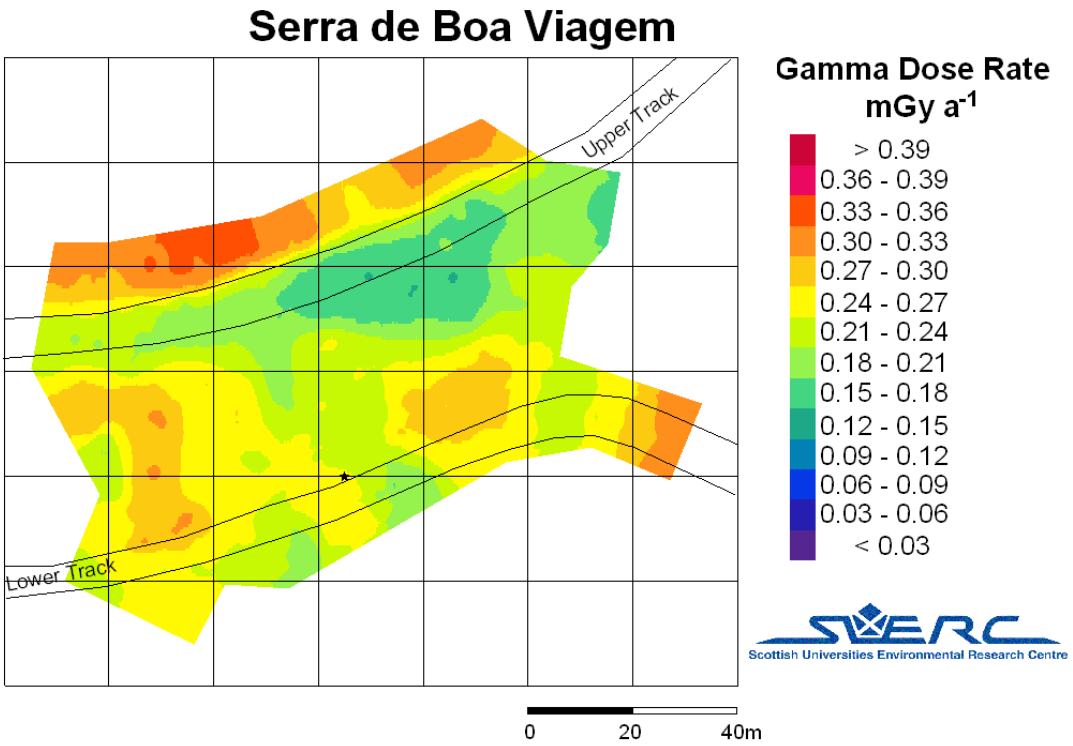

Figure 1: Dose rate distribution at Serra de Boa Viagem.

17th September 2012: Serra de Boa Viagem

The site was in an area of limestone hills approximately 55km south of Aveiro. The samples, of karst/terra rossa, were collected from an exposed face by the side of a track along a steep slope. The area consisted of low scrub and small trees, with considerable dead wood from forest fires a few years ago. This was extremely challenging conditions for portable gamma spectrometry. Data was collected from a 100m long area extending between the track next to the sampling location and another track on the ridge approximately 50-60m above the sampling location. Below the track the slope was slightly steeper and the scrub denser, and an attempt to survey here showed it to be impossible to survey. Examination of the data in the field indicated that there was a reduced dose rate on the ridge, and further lines on the other side of the ridge were planned, this was curtailed after a single line of data was collected due to dense coverage by gorse. A total of 550 measurements were collected.

Figures 1 shows the dose rate distribution on this site. The lower dose rate on the ridge is evident, probably a result of reduced soil thickness compared to lower down the slopes exposing the relatively lower dose rate limestone. The dose rate to the north of the ridge is significantly higher than that to the south, although as noted the terrain did not permit a significant extension of the data down the northern slope. The sampling location is in an area with a dose rate near the average for the area surveyed.

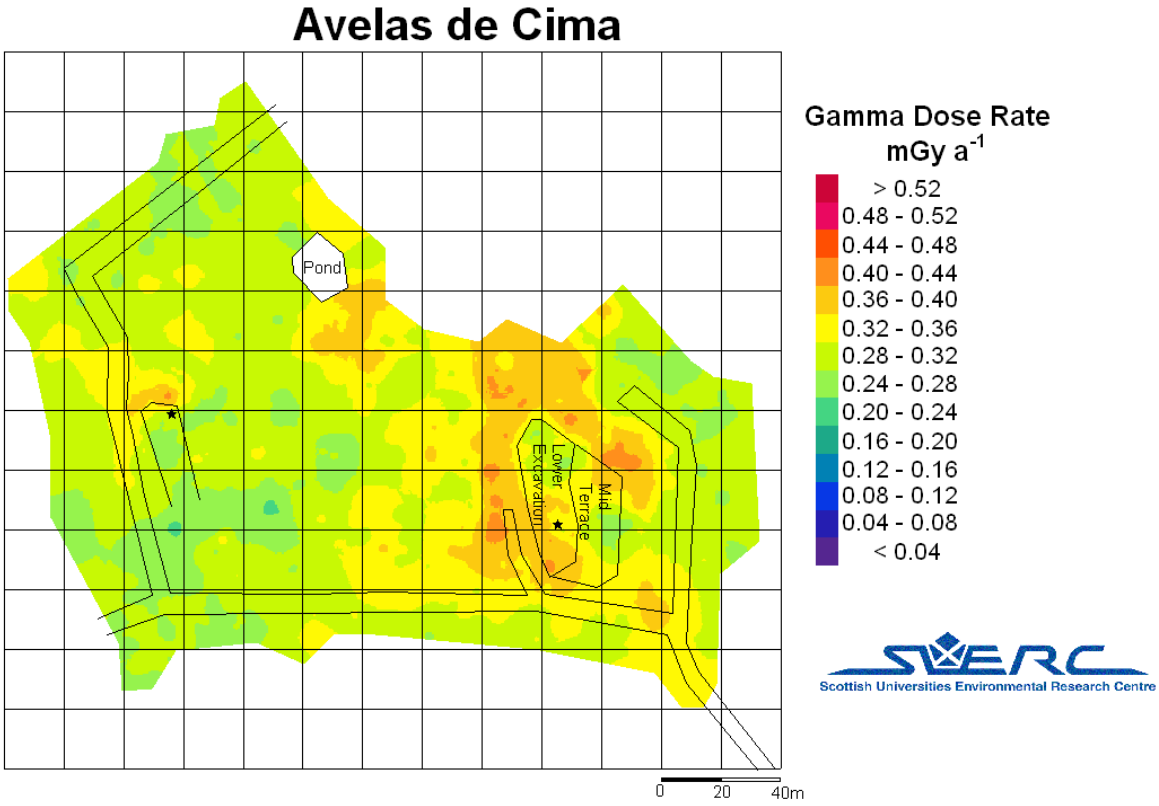

Figure 2: Dose rate distribution at Avelãs de Cima.

18th September 2012: Avelãs de Cima

This site is a quarry, near Anadia approximately 35km south east of Aveiro. Two sedimentary sequences are represented; arenite and clay. Samples were collected from two locations, representing one of each of these sediments, and a gamma spectrometry survey conducted that surrounded both sites. The first sampling location was for arenite, and was within an excavated pit against the side of a shallower terrace. The second sampling location was from the face of a clay ridge approximately 130m to the west of the first location. The area around the first location included quarry workings, the excavated pit the sample was collected from and spoil heaps, surrounded by forestry. The area around the second location was more open, with low density forestry in parallel lines. A total of 830 measurements were recorded.

Figure 2 shows the dose rate distribution on this site. The higher dose rates are mostly associated with the spoil heaps, of an orange coloured sand and gravel material. The dose rate at the second site is elevated in close proximity to the face of the raised ground, and most likely reflects the different geometry.

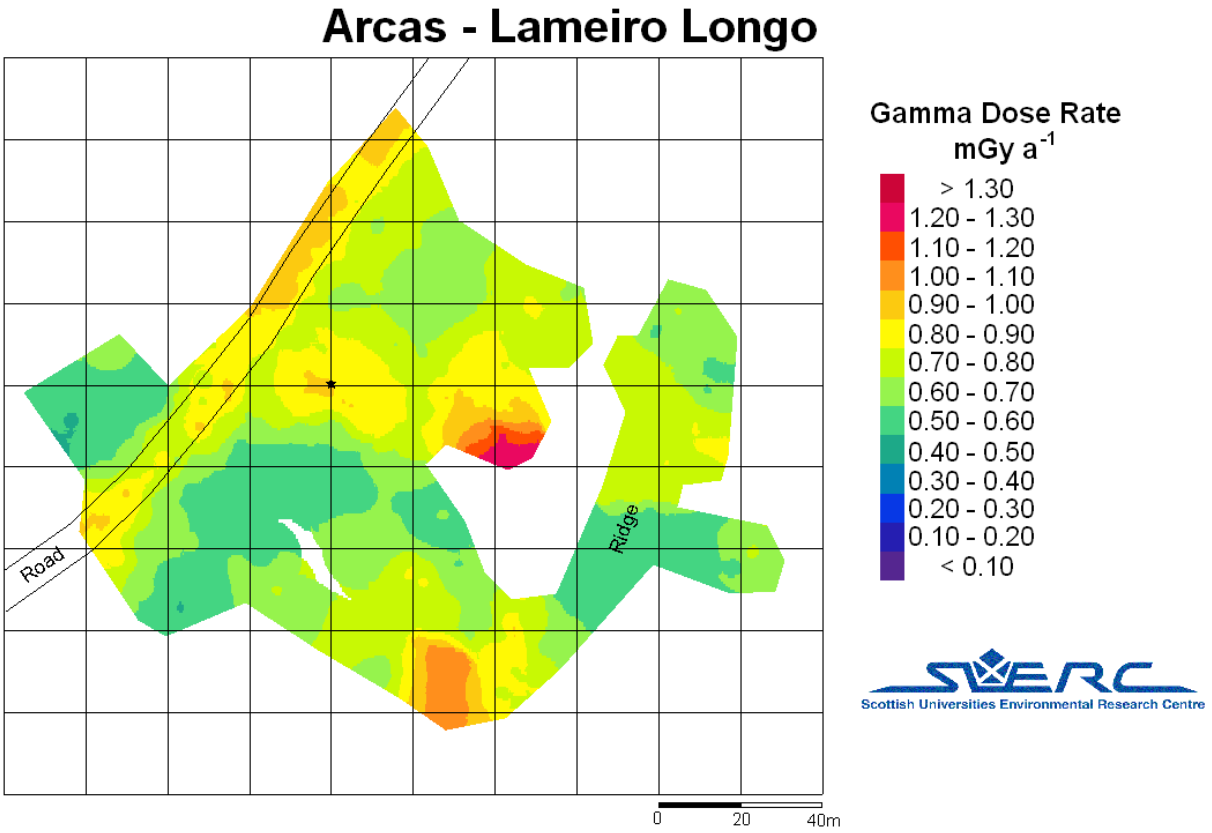

Figure 3: Dose rate distribution at Arcas – Lameiro Longo.

19th September 2012: Arcas-Lameiro Longo

The site is a mountain comprised largely of granite, located near Telhadas approximately 20km east of Aveiro. A recent excavation, to construct a new well, was located and samples collected from an exposed face of this excavation. The terrain surrounding the sampling location was heavily vegetated in places, with some very large and dense patches of brambles and other scrub plants. To the east of the site there were some substantial crags and out crops of rock, with a ridgeline above this. It was not possible to safely access a large area of the location, including the crags and most of the area west of the road. A route onto the ridge was found, that allowed a couple of lines of data to be collected from that location. 570 measurements were recorded.

Figure 3 shows the dose rate distribution in this location. The exposed rock and spoil at the well excavation, with a geometric contribution for measurements within the excavation, produce an enhanced dose rate. The road surface also shows a higher dose rate. About 40m east of the excavation a significantly higher dose rate was observed within the exposed rocks at the bottom of the crags, further access around this location to better define the extent of this feature was impossible. This feature shows enhancements in both K and Th series activity, with no enhanced U series activity. It was noted that the area includes significant quantities of muscovite, indicating the presence of mineralised fractures in the area, and this feature was tentatively ascribed to a vein of minerals reaching the surface.

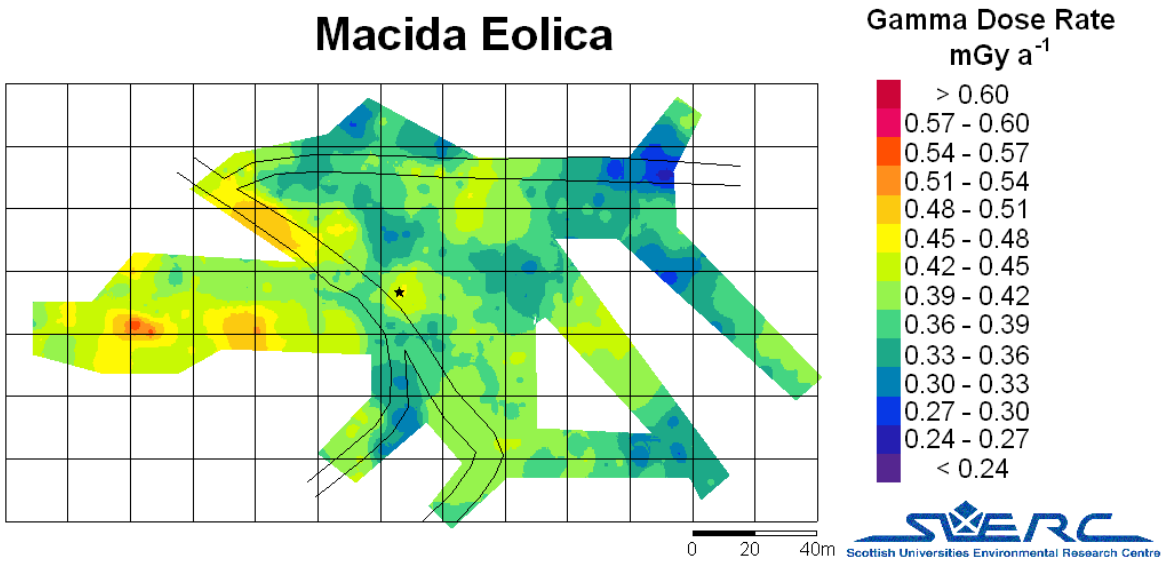

Figure 4: Dose rate distribution at Macida Eólica.

19th September 2012: Macida Eólica

The site, also located near Telhadas, is a heavily forested hill side mostly composed of shist. The sampling location was an exposed section along the side of a track. The area has several tracks, some partially overgrown, that were easy to survey along. The forested areas between the tracks were, with a few exceptions, very heavily vegetated with scrub bushes between the trees. Radiometric data was collected along the trackways and other accessible areas, with low density lines through the much denser scrub within the forested areas. 550 measurements were recorded.

Figure 4 shows the dose rate distribution in this area. The dose rate to the west, downhill, of the sampling location is generally higher than the dose rate to the east. It was noted that along one pathway down the slope a small exposed rock face generated an enhanced dose rate signal.

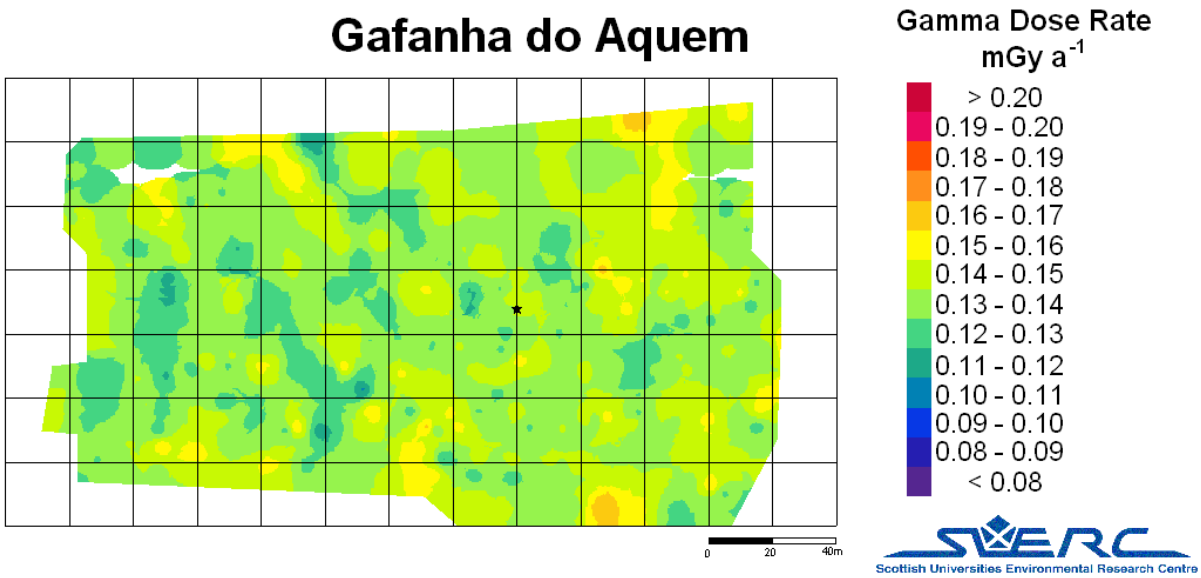

Figure 5: Dose rate distribution at Gafanha do Aquém.

19th September 2012: Gafanha do Aquém

This is a dune sand site approximately 5km south of Aveiro. Samples were collected from the south side of a ridge running east-west. The area is covered with low density forestry, with very little other plant growth. The area had been reworked when the trees were planted 30-40 years ago, and the current dune-like ridges oriented east-west were created at that time. Complete area coverage with survey lines requiring minimal deviation around ground obstacles was achieved, with 420 measurements recorded.

Figure 5 shows the dose rate distribution at this location. The dose rates are very low, as would be expected, with only small variations. These is a pattern of stripes running approximately NW to SE, especially evident in the western half of the survey area. It is probable that this reflects the original dune system prior to reworking at the time the trees were planted.

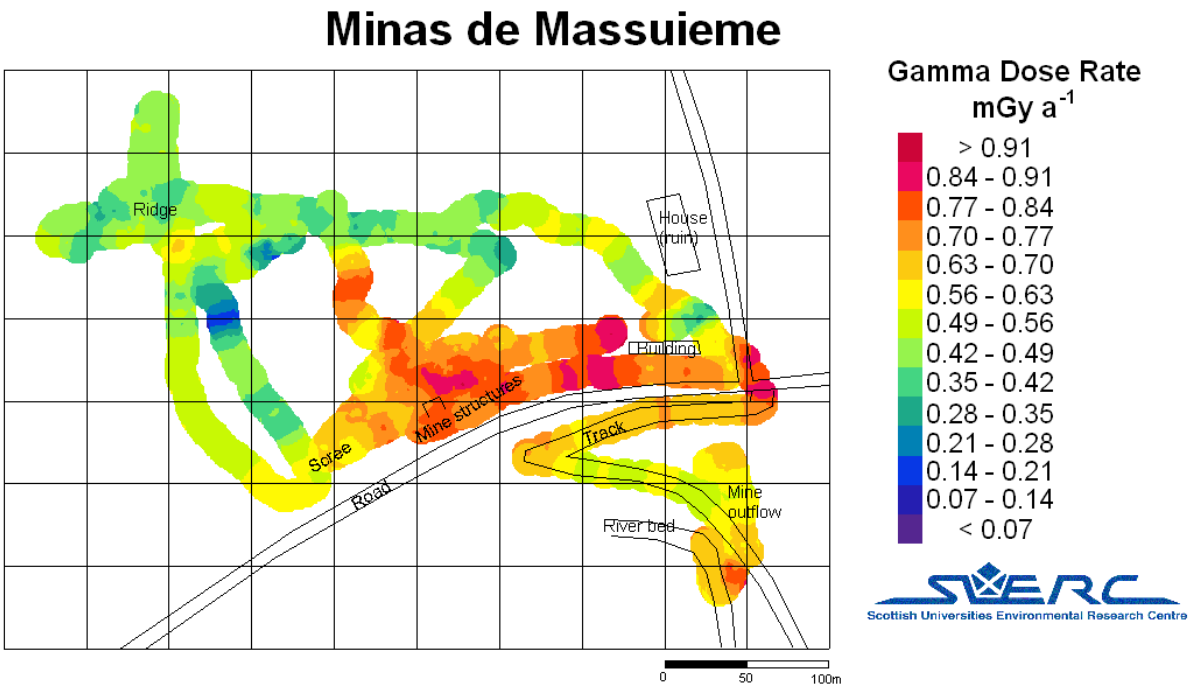

Figure 6: Dose rate distribution around Minas de Massueime.

20th September 2012: Minas de Massueime

Minas de Massueime is an abandoned uranium mine, situated near Cótimos, approximately 150km east of Aveiro. The site was visited to attempt to locate soils containing uranium rich grains. A survey was conducted to find a suitable location, this included the top of the hill where some exploratory pits had been dug prior to opening the mine, areas around mine buildings and scree that appeared to be spoil, the area around the drainage outflow from the mine, and a transect perpendicular to the ridge line. 690 measurements were collected.

Figure 6 shows the dose rate distribution for this survey area. The dose rate on the quartz dominated ridge is mostly relatively low, with one slightly enhanced spot, with no enhanced dose rate observed to the north of the ridge. The dose rate around the mine structures further down the southern slopes is significantly higher, with a small enhancement associated with the outflow from the mine. The material on the ground where the dose rates were highest appeared to be reworked, possibly spoil from the mine, and mostly composed of rock. The observed dose rates were not as high as was hoped for the purpose of soil sampling, and there was little exposed soil. Therefore, further work on the site for this project was not conducted.

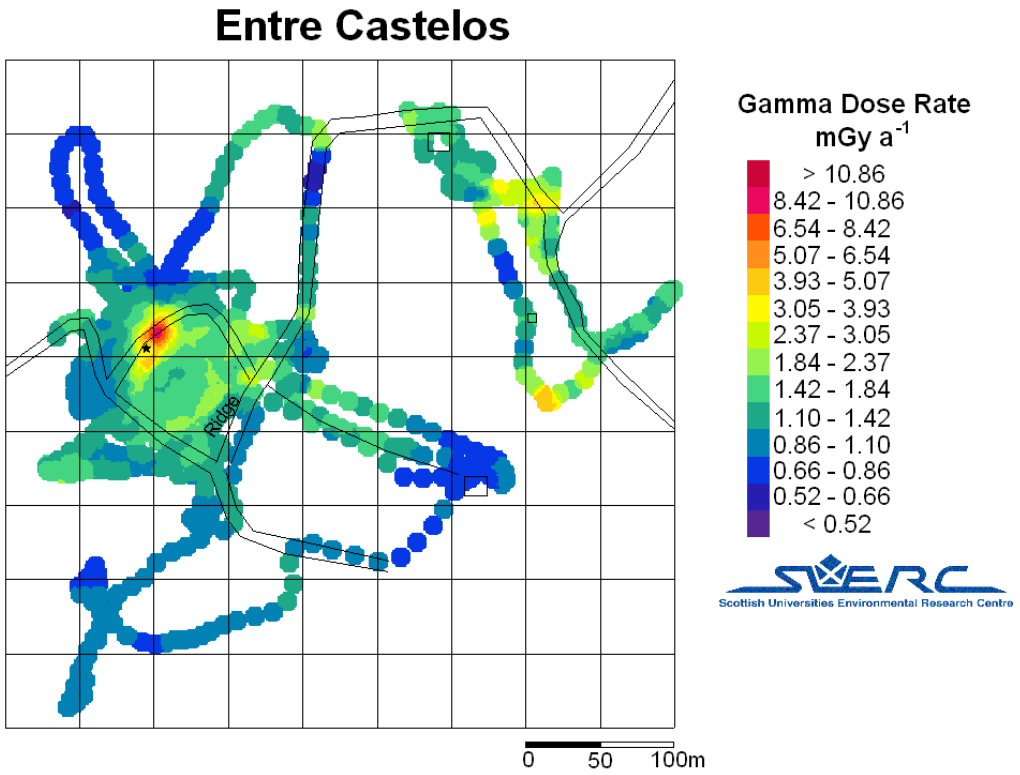

Figure 7: Dose rate distribution at Entre Castelos.

21st September 2012: Entre Castelos

In the late afternoon of the 20th September, following the abandonment of further work at Minas de Massuerime, another former uranium mining site ~1.5 km to the north west was visited. A preliminary survey showed very much higher concentrations of uranium series activity, and a couple of highly localised points with dose rates of ~5 mGy a^{-1}. Based on this data, and further information obtained about the former mining activity in the area, it was decided to return to this site to locate the final sample point for this project. The SUERC portable gamma spectrometry system was used to locate a suitable sampling location. Initially a transect was conducted across the field to the north of the ridge, then back across the ridge and down the southern slope. This very quickly identified a small location with dose rates in excess of 10 mGy a^{-1}, further survey around this point identified an area of approximately 5x15m with dose rates in excess of 3 mGy a^{-1} and high uranium series activity. Based on this data, a section was cut into soils within this area and samples collected. Radiometric surveys were continued to produce a detailed map of the area around the sampling site, with extension lines around this to generate data showing the dose rates and natural radionuclide concentrations for a more general area. A total of 1070 measurements were collected, including the preliminary survey on the 20th September.

Figure 7 shows the dose rate distribution at Entre Castelos. The north east section was collected on the 20th September, showing a patch of enhanced at a point by the track where two drainage channels converge which was explored in some detail during the exploratory visit. Local enquiries indicated that the mine entrance was located in the field just above this feature. Much of the site has dose rates in excess of 1 mGy a^{-1}. The transects across the ridge show relatively low dose rates at both the eastern end, near a small hut at the corner of a large

open space that appears to be related to mine activity, and the western end. The enhanced dose rate feature where the samples were collected is clearly evident, ~50m north west of the ridge line. Figure 8 shows the distribution of ^{214}Bi (in the ^{238}U decay series) specific activity in the area. This distribution shows significantly enhanced specific activities compared to the other areas studied in this project through much of the area, assumed to be a combination of naturally eroded uranium rich minerals in the soil and waste material associated with the mining activity.

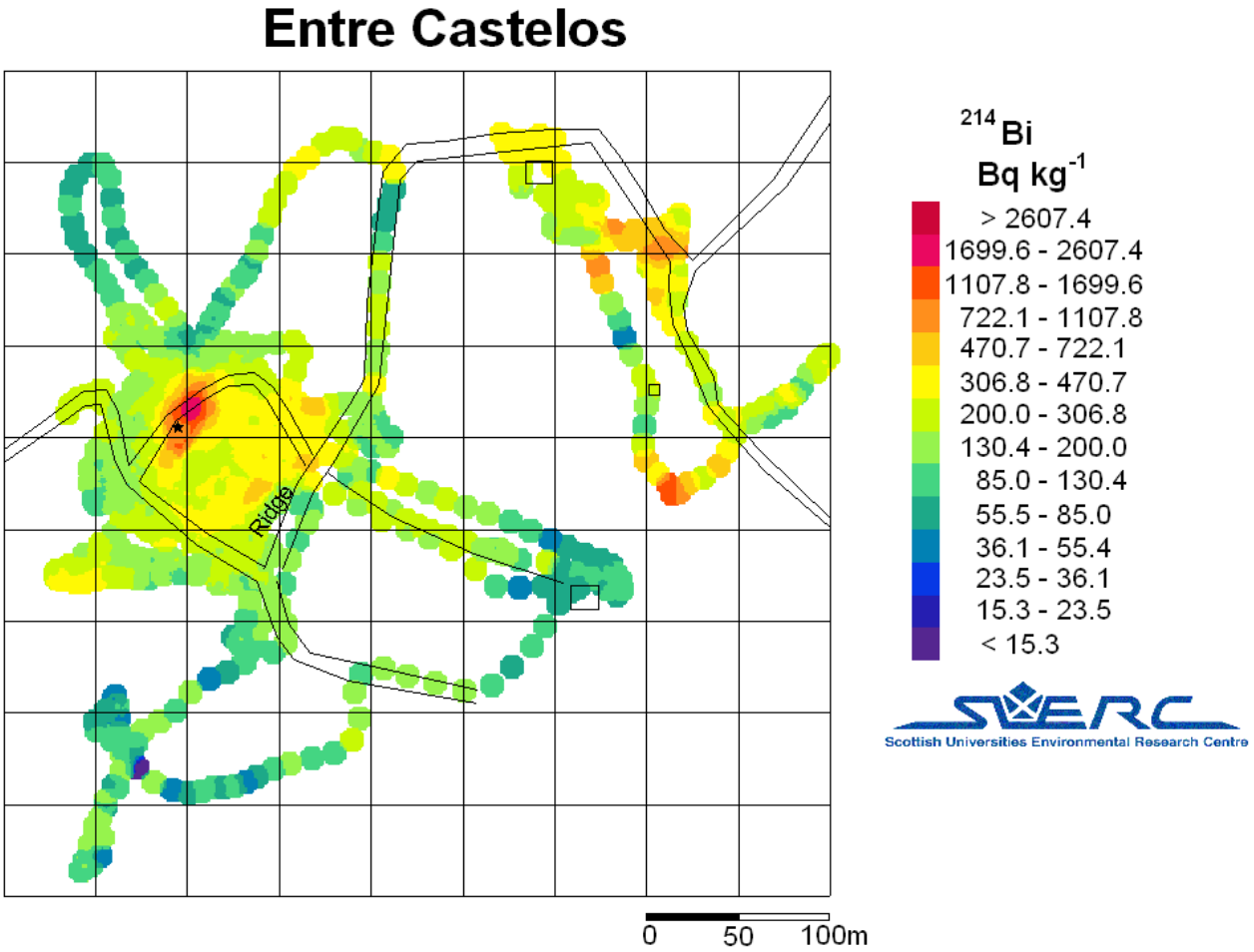

Figure 8: ^{214}Bi specific activity distribution at Entre Castelos.

Acknowledgements

This work forms part of the project VADOSE, PI Dr C.I. Burbidge of IST/ITN. Prof. M.I. Prudêncio, D. Franco, G. Cardoso, G Carvalhal, J. Franco also of IST/ITN assisted in identifying the sampling locations, setting out survey grids were appropriate, and collecting soil samples and other measurements. Prof F. Rocha, Eng. J. Ribeiro and Sr. Graça of the University of Aveiro, Dept. of Geosciences, provided considerable assistance in identifying sampling and survey locations, and driving the team to each location in departmental vehicles.

Appendix – Working Calibration Parameters

Window	Radionuclide	Channel Range	Background cps
1	^{137}Cs (661 keV)	110-132	1.03 ± 0.02
2	^{134}Cs (795 keV)	133-155	0.32 ± 0.02
3	^{40}K (1461 keV)	228-252	0.39 ± 0.03
4	^{214}Bi (1764 keV)	268-296	0.14 ± 0.03
5	^{208}Tl (2615 keV)	387-421	0.10 ± 0.01
6	Gamma dose rate	90-500	5.00 ± 0.05

Table A.1: Spectral windows used and backgrounds.

	^{137}Cs window	^{134}Cs window	^{40}K window	^{214}Bi window	^{208}Tl window
^{137}Cs sheet	1	0	0	0	0
^{134}Cs source	1.55	1	0	0	0
K pad	0.73	0.65	1	0	0
U pad	5.01	2.07	0.70	1	0.01
Th pad	4.32	2.80	0.54	0.68	1

Table A.2: Stripping matrix used.

Window	Radionuclide	Calibration	Calibrated units
1	^{137}Cs (661 keV)	0.48	kBq m^{-2}
2	^{134}Cs (795 keV)	0.50	kBq m^{-2}
3	^{40}K (1461 keV)	106	Bq kg^{-1}
4	^{214}Bi (1764 keV)	39	Bq kg^{-1}
5	^{208}Tl (2615 keV)	12.3	Bq kg^{-1}
6	Gamma dose rate	0.0061	mGy a^{-1}

Table A.3: Calibration coefficients.