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Uncertainty assessment method for the Cs-137 fallout inventory and penetration depth

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ABSTRACT

Within the presented study, soil samples were collected in year 2007 at 20 different locations of the Greek terrain, both from the surface and also from depths down to 26 cm. Sampling locations were selected primarily from areas where high levels of ^{137}Cs deposition after the Chernobyl accident had already been identified by the Nuclear Engineering Laboratory of the National Technical University of Athens during and after the year of 1986. At one location of relatively higher deposition, soil core samples were collected following a 60 m by 60 m Cartesian grid with a 20 m node-to-node distance. Single or pair core samples were also collected from the remaining 19 locations. Sample measurements and analysis were used to estimate ^{137}Cs inventory and the corresponding depth migration, twenty years after the deposition on Greek terrain. Based on these data, the uncertainty components of the whole sampling-to-results procedure were investigated. A cause-and-effect assessment process was used to apply the law of error propagation and demonstrate that the dominating significant component of the combined uncertainty is that due to the spatial variability of the contemporary (2007) ^{137}Cs inventory. A secondary, yet also significant component was identified to be the activity measurement process itself. Other less-significant uncertainty parameters were sampling methods, the variation in the soil field density with depth and the preparation of samples for measurement. The sampling grid experiment allowed for the quantitative evaluation of the uncertainty due to spatial variability, also by the assistance of the semi-variance analysis. Denser, optimized grid could return more accurate values for this component but with a significantly elevated laboratory cost, in terms of both, human and material resources. Using the hereby collected data and for the case of a single core soil sampling using a well-defined sampling methodology quality assurance, the uncertainty component due to spatial variability was evaluated to about 19% for the ^{137}Cs inventory and up to 34% for the ^{137}Cs penetration depth. Based on the presented results and also on related literature, it is argued that such high uncertainties should be anticipated for single core samplings conducted using similar methodology and employed as ^{137}Cs inventory and penetration depth estimators.

1. Introduction

The main aim of this study is to propose a method for the uncertainty assessment in measuring ^{137}Cs inventory due to a fallout event using sampling techniques for surface soil and core samples and laboratory -γ spectroscopic analysis. This method could be also applied even at time points rather distant from the initial fallout event, in this case two decades after the Chernobyl fallout. The Nuclear Engineering Laboratory of the National Technical University of Athens (NEL-NTUA) has surveyed the ^{137}Cs that was initially deposited on Greek continental surface soils due to the Chernobyl accident radionuclides fallout. This survey was carried out as early as in the second half of the year 1986 and resulted to the collection of more than 1200 surface ground samples, which were analyzed and recorded in a database (Simopoulos, 1989). Up to the reference year of the present work, i.e. 2007, about 20 years after the accident, radioactive ^{137}Cs migrated mainly vertically into deeper ground layers because of various natural processes and other causes (see for example in Antonopoulos-Domis et al., 1995). This ^{137}Cs is detectable even below 20 cm or more rarely below 30 cm of

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undisturbed soil surface.

Consequently, and due to this vertical migration, single and surface-only soil samplings is not the method to provide enough information for the estimation of the ^{137}Cs inventory in soil. Therefore, at-depth samplings must be used, in order to determine: (a) ^{137}Cs inventory, and (b) the effective penetration depth, as an estimator of the maximum depth in ground in which ^{137}Cs could be detected. Natural processes and human activities on the ground as well as the surface and at depth soil sampling methods, along with the sample preparation and measurement methods are likely to introduce uncertainties to the estimation of the ^{137}Cs inventory and penetration depth. In order to investigate these uncertainties, topsoil and core samples down to a depth of 26 cm, were collected in 2007 mainly from undisturbed ground at 20 different locations of the Greek peninsula. The uncertainty assessment method employed consists of a sampling and samples processing protocol. This protocol could effectively account for the uncertainty budget as a whole, without the need to meticulously calculate the uncertainty contributors of less significance. The proposed method seems consistent with similar investigations made previously for other field tests which provide spatial uncertainties only. Therefore, it could be employed universally for establishing of an inventory sampling uncertainty budget.

2. Materials and methods

2.1. Sampling locations

The qualitative characteristics of the surface and at depth soil sampling locations were selected in such a way in order to represent undisturbed soil types, namely:

(a) Pasture soil, (b) uncultivated terrain, and (c) forest soil or soil under fruiting trees.

The sampling locations were selected based on:

(1) The results of the initial surface soil sampling in 1986 (Simopoulos, 1989; Petropoulos et al., 1996). Following the mapping of these results as per Fig. A1 in the Appendix, specific locations in West Thessaly (Central continental Greece) and West Macedonia (North-Western continental Greece) were selected. In the selected locations areas, relatively higher ^{137}Cs concentrations were deposited due to the Chernobyl accident. These areas even 20 years after the initial deposition, still demonstrate detectable ^{137}Cs concentrations on the surface soil as depicted in the previously unpublished mapping of Fig. A2 (see Appendix), which was a result of samplings between the years 2000 and 2007 (Hinis and Simopoulos, 2007; Papadakos, 2012). The mapping in Fig. A2 was obtained with the same methodology as the mapping in Fig. A1 (Petropoulos et al., 1996)

and

(2) The preliminary findings from a trial soil sampling survey that was conducted in West Thessaly (WT) and West Macedonia (WM), in years between 2004 and 2006. The trial sampling verified that, in most cases, a depth of about 25 cm includes almost all ^{137}Cs migrated from the surface (Karfopoulos et al., 2007).

A small number of other locations in Attica region (A) of low ^{137}Cs deposition were also investigated as reference sites for comparison purposes. Table 1 presents some details of the sampling sites investigated. Information regarding the soil type and the geology of the investigated sites may be found in Yassoglou (2004).

Table 1
Sampling locations details and characteristics.

	Sampling site	Characterization/Region	$N_{samples}$[a]	N_{cores}[b]
1	Mavrommati (grid)	P/WT	32	16
2	Vlachogianni	P/WT	4	2
3	Ag. Kyriaki	P/WT	4	1
4	Ag. Vissarion	P/WT	4	1
5	Stefanovouno	P/WT	4	2
6	Loxada	T/WT	4	1
7	M. Kefalovryso	T/WT	4	1
8	Palaiokastro	P/WM	4	1
9	Mikrokastro	T/WM	4	1
10	Skiti	T/WM	3	1
11	Trikokkia	F/WM	4	1
12	Melissio	F/WM	4	1
13	NTUA 1, NTUA 4	T/A	6	2
14	NTUA 2	T/A	3	1
15	NTUA 3, NTUA 5	T/A	3	1
16	Chamolia	T/A	4	1
17	P. Rafti 1	T/A	4	1
18	P. Rafti 2	T/A	4	1
19	P. Rafti 3	T/A	4	1
20	Ag. Konstantinos	F/A	4	1

P: Pasture, T: Uncultivated Terrain, F: Forest/fruiting trees soil, WT: West Thessaly, WM: West Macedonia, A: Attica.
[a] Number of surface soil samples collected.
[b] Number of core samples collected.

Table A1 and Table A2 in Appendix contain a more detailed presentation.

A significant part of the sampling effort in this study, was the detailed grid sampling of 16 soil cores from one specific pasture field at location #1 in Mavrommati of West Thessaly. The Chernobyl fallout observed in 1986 throughout the greater area of this pasture field location, was approximately 50 $kBqm^{-2}$ in average. This is relatively much higher than that of the rest of the Greek terrain (averaging to about 10 $kBqm^{-2}$, see Petropoulos et al., 1996). At this location, samplings were conducted orthogonally within a 60 × 60 m rectangle at evenly spaced nodes of 20 m distance from each other (see Fig. 1). The grid sampling protocol aimed at assessing the levels of ^{137}Cs inventory uncertainty and its uncertainty due to spatial variability within a location of a relatively confined, undisturbed, open and flat area in which the phenomena

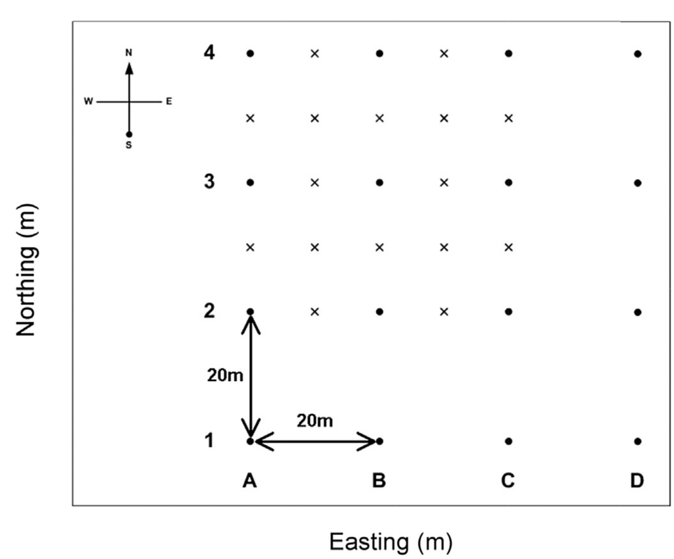

Fig. 1. Orthogonal grid sampling points at the Mavrommati location in West Thessaly. (bullet: surface and core sampling point, "x": additional surface sampling point).