Appl. Radiat. Isot. Vol. 40, No. 7, pp. 607–613, 1989
Int. J. Radiat. Appl. Instrum. Part A
Printed in Great Britain

0883-2889/89 $3.00 + 0.00
Pergamon Press plc

Soil Sampling and ^{137}Cs Analysis of the Chernobyl Fallout in Greece

S. E. SIMOPOULOS

Nuclear Engineering Section, National Technical University of Athens, Athens 10682, Greece

(*Received* 21 *November* 1988)

A total of 1242 samples of soil, collected over Greece, during the period May–November 1986, were counted and analysed for ^{137}Cs from Chernobyl fallout. The counting was performed using a NaI detector on-line to a microcomputer; moreover, 252 of the samples were also analysed using Ge detectors, for inter-comparison and also for the assessment of other long-lived isotopes in the fallout. The results show that ^{137}Cs fallout from Chernobyl presents a remarkable geographical variability. The evaluated ground activity due to ^{137}Cs deposition ranges between 0.01 and 137 kBq/m^2.

1. Introduction

Fission product radioactivity from the Chernobyl reactor accident, has been observed and reported by several Laboratories in Greece (DEMO 86/3 G, 1986; Alexandropoulos *et al.*, 1986; Simopoulos *et al.*, 1987). It has also been reported that the plume of the radioactive material, passing over Greece, reached a maximum on 3 May 1986 (DEMO 86/3 G, 1986).

It is widely accepted that soil analysis is a principal method for surveying radioactively contaminated areas of soil. *In-situ* γ counting, with solid-state detectors, has been used in the past for determinations of radioactivity in the soil, particularly for fresh fallout; this technique offers the considerable advantage of speed. However, the soil sampling method provides more precise estimates of deposition, and it has been adopted in the present work to detect and quantitatively analyse the long-lived isotopes in the Chernobyl fallout in Greece. Furthermore, *in-situ* measurements were also conducted, but their results are not presented, since they have only been used as an indication of the radioactivity of the soil before being sampled.

During the period May–November 1986, 1242 soil samples of surface soil were collected over Greece. The samples were counted for ^{137}Cs using an NaI detector. Furthermore, 252 of the samples—those with the higher ^{137}Cs contamination, were analysed using Ge detectors. Both counting methods are described below. Results of the ^{137}Cs counting of the 1242 samples collected, using the first of the above-mentioned methods, are presented. Moreover, results of the activity of the rather long-lived isotopes in the fallout as well as the natural radioactivity of the 252 samples, already analysed, are also included.

2. Soil Sampling

Soil samples of about 1000 cm^3 each, were taken from apparently undisturbed sites in open areas at the ground surface using a specially fabricated spade which collected the 1 cm surface layer of the soil. Particular care was taken in order to avoid sampling at sites where undulations in soil might have made a controlled 1 cm sampling depth difficult. The soil at the sampling sites was not covered with grass or other kinds of vegetation; besides, it was unlikely to find grass on Greek soils during the sampling period (summer and early autumn).

The sampling covered all geographic subdivisions of the mainland, the so-called "Departments", and was conducted in five discrete time periods shown in Table 1. The sampling during the first period, extending over central and northern Greece, was organized in such a way as to include those parts of the country where heavy fallout deposition was expected, according to preliminary analysis of foodstuffs existing at

Table 1. Sampling scheme

Sampling period	Number of samples	Department codes
1–12 August 1986	297	2, 4, 8, 3, 6, 7, 25, 24, 27, 22, 33, 39, 36, 34, 38, 29, 42, 43, 41, 32, 31, 40, 30, 37, 35, 26
27–30 September 1986	296	2, 4, 7, 24, 27, 28, 35, 39, 36, 31, 30, 36, 37, 25
7–8 October 1986	153	2, 4, 7, 25, 24, 26
25–29 October 1986	250	1, 13, 11, 10, 12, 15, 14, 9
15–17 November 1986	151	4, 8, 3, 23, 21, 17, 22, 20
May–August 1986	95*	Miscellaneous

*Eighty of these samples were not collected by the author.

Fig. 1. Subdivision of Greece into Departments (names of Departments and Capitals—shown with a dot—appear in Table 2)

that time. It must be emphasized that before proceeding to another sampling stage, the samples already collected were counted and analysed for ^{137}Cs. The results obtained from this analysis also provided a clear indication about the regions already visited, which then needed a more detailed sampling. It is in this way that the plan of each one of the successive sampling periods was set-up.

The map of Fig. 1 illustrates the various officially nominated geographic regions of the country, their code numbers and also their capitals. Table 1 presents details of the sampling conducted, giving for each sampling period the Departments in the sampling sequence followed. The names of the Departments and their respective capitals are given in Table 2.

It is worth mentioning that the weather was mostly dry during the whole sampling period. It is obvious that rainfalls could have disturbed the surface of the soil and, accordingly, could have caused horizontal and vertical migrations of the radionuclides deposited.

A final remark concerns the 1 cm sampling depth adopted in the present sampling. Such a sampling depth has been suggested for similar studies by several investigators (Sumerling, 1983; Stoutjesdijk, 1983, etc.), since during the first year following deposition of the fallout on the soil, the migration of the radionuclides to deeper soil layers is considered negligible. We have tested this assumption by collecting a second 1 cm thick soil layer sample at 20 sites, at a depth of 10 cm. The results showed that the ^{137}Cs activity of this 10 cm deep soil layer was less than 10% of that of the surface layer. The lack of time—we wanted to assess as soon as possible the surface soil contamination—did not allow us to proceed further with this additional sampling. However, we systematically organized this sampling one year later (June 1977) and although we are still analysing the results, it may be reported that the ^{137}Cs distribution in the soil, one year after the deposition, is found to exponentially decrease with a decay coefficient of $0.09 \pm 0.02\,cm^{-1}$. This result amplifies the view that the migration to deeper soil layers, the first few summer months following deposition, should have been negligible.

3. Sample Preparation

The soil samples collected were brought to the laboratory and, if necessary, air-dried under ambient temperature. After that, traces of dried grass, pebbles, rubbish or other foreign particles likely to exist were removed. In any case, particular attention was given to avoid removing any soil particles adhering to the above material. Thus, an ample quantity of more or less clean soil was used to fill a 0.282 L plastic cylindrical box, about 72 mm dia and 70 mm high. The boxes were weighed and then sealed hermetically and covered with a film of epoxy resin, to ensure that no gases escaped from them.

Table 2. ^{137}Cs Fallout radioactivity of greek soils

Dept Code	Department	Dept Capital	Sample size	Ground activity (kBq/m^2) Mean	SD	Min.*	Max.*
1–2	Attica	Athens	37	1.2	1.1	0.0	4.4
3	Aetolia & Akarnania	Mesologi	47	1.6	1.4	0.2	6.0
4	Boeotia	Leivadia	44	3.1	1.7	0.5	6.8
5	Euboea	Chalkis	2	0.3	0.2	0.1	0.4
6	Evritania	Karpenissi	8	2.7	1.8	0.8	5.4
7	Phthiotis	Lamia	74	8.2	11.8	0.4	96.1
8	Phocis	Amphissa	27	3.6	3.8	0.3	15.1
9	Argolis	Argos	24	3.3	3.5	0.2	16.2
10	Arkadia	Tripolis	73	3.4	3.7	0.3	23.2
11	Akhaia	Patra	44	1.7	2.0	0.1	9.5
12	Ilia	Pyrgos	28	1.3	1.4	0.0	5.1
13	Korinthia	Korinthos	19	1.0	1.0	0.2	4.2
14	Lakonia	Sparti	29	2.1	3.0	0.1	11.4
15	Messenia	Kalamata	52	1.8	3.7	0.2	21.6
17	Corfu	Corfu	28	1.9	1.7	0.2	7.2
20	Arta	Arta	14	0.7	0.3	0.3	1.2
21	Thesprotia	Igoumenitsa	30	2.8	4.4	0.1	22.7
22	Yanina	Yanina	33	1.6	1.7	0.2	8.7
23	Preveza	Preveza	10	1.1	0.8	0.3	2.9
24	Karditsa	Karditsa	148	29.7	33.0	0.5	137.2
25	Larisa	Larisa	91	14.4	13.6	0.3	67.5
26	Magnisia	Volos	22	4.9	9.4	0.5	46.4
27	Trikala	Trikala	64	36.0	28.3	3.6	110.4
28	Grevena	Grevena	19	10.9	7.5	2.4	34.9
29	Drama	Drama	9	3.8	2.3	1.2	9.2
30	Imathia	Veria	31	36.2	34.1	5.4	135.7
31	Salonika	Salonika	28	14.7	13.3	0.5	61.7
32	Kavala	Kavala	7	2.0	1.5	0.6	4.3
33	Kastoria	Kastoria	6	10.9	4.3	6.9	18.9
34	Kilkis	Kilkis	4	6.2	5.4	2.0	14.0
35	Kozani	Kozani	46	17.8	17.5	2.6	83.2
36	Pella	Edesa	25	15.5	11.1	3.5	39.2
37	Pieria	Katerini	25	22.8	23.7	0.6	79.3
38	Serres	Serres	15	3.3	2.2	0.2	7.7
39	Florina	Florina	28	18.6	16.2	2.8	80.8
40	Khalkidiki	Polygyros	16	5.7	4.8	0.4	20.9
41	Evros	Alexandroupolis	17	4.5	4.3	0.5	14.6
42	Xanthi	Xanthi	5	2.8	0.7	2.2	3.9
43	Rodopi	Komotini	7	2.8	2.5	0.4	7.3
44	Dodecanesos	Rhodos	2	0.2	0.1	0.1	0.2
46	Lesvos	Mytilini	2	0.8	0.4	0.5	1.0
48	Chios	Chios	2	0.3	0.2	0.1	0.5

*Range of SE 1–10%.

4. Methods of ^{137}Cs Measurements

As already mentioned, two counting methods have been applied in order to estimate the ^{137}Cs radioactivity content of the samples:

—counting with a NaI detector, and
—counting with high resolution Ge detectors, that allowed the assessment of other long-lived isotopes in the fallout, as well as that of the natural radioactivity of the samples.

A certified mixed radionuclide solution (Amersham, 1985) was used as a standard for energy and efficiency calibration in both counting systems. This standard

Table 3. ^{137}Cs ground activities and statistically significant differences of samples collected at adjacent sample points

Sampling location–Dept. Code	Sample code	Ground activity Mean (kBq/m^2)	SE (kBq/m^2)	Observed difference (kBq/m^2)	Significant difference (α = 1%) (kBq/m^2)
Katara	131	12.7	0.57		
27	132	12.2	0.53	0.5	2.2
Mascholourio	431	4.8	0.23		
24	432	4.6	0.23	0.2	0.9
Neraida	446	4.2	0.19		
24	447	4.3	0.20	0.1	0.8
Agrapidia	700	4.9	0.26		
7	701	5.9	0.26	1.0	1.1
Neraida	825	29.4	1.23		
25	826	31.6	0.35	2.2	3.7
Dafni	922	6.2	0.27		
10	923	6.9	0.34	0.7	1.3

provided eleven principal γ rays, including ^{137}Cs, covering the energy range of 90–1800 keV, in reasonably well spaced intervals. The certificate of calibration of this standard conforms to the recommendations of the International Commission on Radiation Units and Measurements (ICRU Report 12). The standard solution filled a cylindrical box, like those used for the samples. Finally, no self-absorption correlation was applied, since several tests conducted showed that the standard solution used for calibration (4 M HCl) and the soil samples examined produce, under similar geometries, similar photopeak attenuation.

The details of the measurements with each one of the above two counting systems are presented in the sections which follow. In both cases the activity per unit mass of each sample was first evaluated. Afterwards, the activity per unit area (ground activity, Bq/m^2) was calculated by assuming the sample area to be equal to the volume of the counting containers (0.282 L) divided by the sampling depth (1 cm). Actually, this calculation was based upon the assumption that the soil did not expand or compress when put in the counting containers. Measurement of the actual sample area might have been an extremely time-consuming task, which would not allow the sampling of such a great number of samples in a relatively short time. In a few cases the actual sample area was measured and its was found that the deviations observed were not significant. The mean value and the standard deviation of the density of the 1242 samples in the counting containers were 1.23 ± 0.26 kg/L.

4.1. *Measurements with a NaI detector*

A 3 × 3 in. NaI detector, inside a 50 mm thick lead shield, was used for these measurements. The detector's signal, after being amplified, was fed to a single channel analyser tuned to the 661.62 keV photopeak of ^{137m}Ba (^{137}Cs). This spectroscopy system was controlled by a spectrum stabilizer, which served as a negative feedback element, compensating for gain changes by increasing or reducing system gain appropriately. Using this technique, the system gain was held constantly to better than 0.1%, ensuring the analysis of events exclusively due to photons emitted with energies of about 661.62 keV. Moreover, the spectroscopy system was interfaced to an LSI-11 computer which was used both as a data-acquisition system and as a supervisor controlling the measurements according to the following scheme:

—Each sample was repeatedly counted for 20 s, at least 3 but no more than 10 times.
—If the accumulated standard error of the repeated measurements of a sample was less than 5%, the measurements were concluded.

All relevant counting data were recorded by the computer, which calculated the background subtracted ^{137}Cs activity of the sample and updated a specially built data base containing detailed information such as sample position, time, and mass. The sampling position was recorded with an accuracy of about 100 m.

Using this scheme the counting time of a sample was very short, ranging between 60 and 200 s. This allowed the counting of the 1242 samples to be performed quickly but with an accuracy that proved to be quite satisfactory.

In order to test the statistical variations associated with the collective process of sampling, preparation and counting, in several cases two samples from the same site were collected. A few, but representative such cases are shown in Table 3, together with the results of a two-tailed statistical test to investigate whether the differences observed are significant. It becomes obvious that at the 1% level of significance none of the differences presented in Table 3 is significant; this is also true for all the cases examined.

4.2. *Measurements with Ge detectors*

Two high-resolution/high-efficiency set-ups were used, each one consisting of a shielded detector, connected to a 4096 channel analyser on-line to a PDP-11/04 computer which collected and analysed the spectra. The detectors were a Ge(Li) coaxial (efficiency 23.8%, resolution 1.97 keV FWHM at 1.33 MeV, peak/Compton 47:1 at 1.33 MeV) and a coaxial pure Ge (efficiency 33.8%, resolution 1.78 keV FWHM at 1.33 MeV, peak/Compton 66.5:1 at 1.33 MeV). Detailed information concerning both the hardware and software configuration of the above two γ-spectroscopy set-ups can be found elsewhere (Simopoulos and Angelopoulos. 1987a; 1987b).

Counting times when using the present technique range between 2×10^5 and 3×10^5 s, because with these measurements the radioactivity content of other isotopes in the fallout, as well as the natural radioactivity of the samples, is also evaluated. Thus, only 252 of the collected samples (those with the higher ^{137}Cs concentrations) have until now, been analysed with this method.

The rather long-lived isotopes in the fallout detected are presented in Table 4, together with the photon energies used for the evaluation of their activity. The concentration of isotopes detected at more than one energy was derived as the weighted mean of the activities of its photopeaks. In any case the activities were decayed down to 1 May 1986. All data required for this evaluation were taken from Erdtman and Soyka (1979). Apart from the isotopes in Table 4, which were systematically detected in the samples analysed (at least as long as their decay time allowed it) in several cases traces (10–100 Bq/kg) of ^{154}Eu and the transuranium isotopes ^{241}Am and ^{257}Fm were also detected. It is worth mentioning that ^{241}Am was also detected in air filters sampled in our Laboratory in May 1986.

Table 4. Isotopes in the fallout detected with Ge detectors

Isotope	Origin	Half-life	Photon energies used for evaluation of the activity (keV)		
^{54}Mn	Fast neutron reaction with ^{54}Fe	312.2 d	834.81		
^{95}Zr	Fission product	64.4 d	724.18	756.72	
^{103}Ru	Fission product	39.35 d	497.08		
^{106}Ru	Fission product	368.2 d	No photons—detected by its daughter ^{106}Rh		
(^{106}Rh)		29.9 s	621.80	1050.10	1128.00
^{110m}Ag	Several views, expressed by: Jones *et al.* (1986) Flowers R. H. (1986) Dam H. (1986)	249.9 d	884.67 1505.00	937.48	1384.27
^{125}Sb	Fission product	2.77 yr	427.95	463.51	636.15
^{134}Cs	Fission product	2.062 yr	475.35	563.26	569.29
			604.66	795.76	801.84
			1038.50		
^{137}Cs	Fission product	30.1 y	661.62		
^{141}Ce	Fission product	32.38 d	145.45		
^{144}Ce	Fission product	284.2 d	133.53		

Detailed information about the detection and analysis of natural radionuclides in the samples can be found elsewhere (Simopoulos and Angelopoulos, 1987b).

Replicate measurements of the same sample were performed in several cases, using alternate detector set-ups. Some characteristic results are presented in Table 5.

The above-mentioned data base is also updated with the ^{137}Cs radioactivity of each sample, as evaluated by this method. This enabled the calculation of the r.m.s. deviation of the ^{137}Cs radioactivities evaluated with both methods used which, for the 252 samples, was found equal to 7.2%.

5. Results and Discussion

Table 2 presents, for each one of the Departments investigated, the minimum and maximum values of the ^{137}Cs soil deposition observed, as well as the arithmetic mean value and standard deviation.

It should be emphasized that the division of the area of the country on an administrative basis into Departments might not be considered as ideal for the statistical analysis and study of phenomena such as the distribution of radioactive fallout. However, the more or less geographical similarity and homogeneity of the area of each Department and also the difficulty of finding a more suitable solution led us to using the Departments as a basis for synoptically presenting our results. The fact that the distribution of the mean values does not significantly differ from the distribution of the maximum values observed in each Department, is an indication that our choice was not entirely unreasonable.

Looking at the results presented, one concludes that ^{137}Cs fallout from Chernobyl shows a remarkable geographical variability, even over short distances. This probably resulted from rainfall patterns prevailing when the cloud passed. For example, the radioactivity of Department 24 ranges between 0.5 and 137 kBq/m^2. In order to expand upon this observation, the details of two cases which show such a pronounced variability, are shown in Table 6. There is no doubt that this variability of the results may be partly attributed to the fact that some parameters of this experiment could not be strictly controlled, despite the care taken. Such parameters are: the undu-

Table 5. Characteristic results of replicate measurements with Ge set-ups

Sample code–Dept. code Location	Analysed on	Ground activity ± SE (kBq/m^2)				
		^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
596–30	10–11–86	51.8 ± 0.4	2.8 ± 0.2	74.0 ± 0.1	144.5 ± 0.2	13.9 ± 0.4
Naoussa	12–11–86	52.1 ± 0.6	2.8 ± 0.2	74.2 ± 0.1	147.8 ± 0.2	14.0 ± 0.6
	15–7–87	53.8 ± 0.5	2.7 ± 0.2	75.7 ± 0.1	148.2 ± 0.2	13.9 ± 0.5
744–24	11–12–86	48.0 ± 0.4	4.0 ± 0.2	55.2 ± 0.1	109.4 ± 0.1	24.8 ± 0.3
Karpochorio	14–12–86	47.3 ± 0.6	4.2 ± 0.2	55.2 ± 0.1	110.7 ± 0.2	24.8 ± 0.5
746–24	19–11–86	55.3 ± 0.4	4.5 ± 0.2	71.8 ± 0.1	139.5 ± 0.1	33.3 ± 0.4
Karpochorio	21–11–86	56.4 ± 0.6	4.5 ± 0.2	72.3 ± 0.1	144.5 ± 0.2	32.5 ± 0.5
	15–7–87	56.3 ± 0.7	4.0 ± 0.3	72.1 ± 0.1	143.4 ± 0.1	32.4 ± 0.7
825–25	14–12–87	20.8 ± 0.3	1.5 ± 0.1	15.6 ± 0.1	31.1 ± 0.1	5.7 ± 0.3
Neraida	24–12–87	20.5 ± 0.3	1.5 ± 0.1	15.6 ± 0.1	31.1 ± 0.1	5.8 ± 0.3
1048–15	12–8–88	7.9 ± 0.6	0.5 ± 0.1	9.2 ± 0.1	18.0 ± 0.1	2.3 ± 0.7
Christophileika	2–9–88	7.3 ± 0.3	0.4 ± 0.1	8.9 ± 0.1	17.5 ± 0.1	1.8 ± 0.4
	6–9–88	7.9 ± 0.5	0.4 ± 0.1	9.2 ± 0.1	18.0 ± 0.1	2.1 ± 0.8

Table 6. ^{137}Cs activities of samples collected at neighbouring sample locations

Sampling site	Sample Code	Sp. activity (Bq/kg)	Ground activity (kBq/m^2)
Aghios Theodoros	114	18743	113.2
(Dept. 24)	734	221	3.6
located near the	735	4430	49.4
Department's capital	736	19889	100.4
Karditsa, and	737	15402	91.5
within a radius of 1 km	738	13290	95.8
	739	18370	112.2
	740	15782	100.5
	741	11078	74.9
	742	14431	102.6
	743	22224	133.3
Alexandria (Dept. 30),	266	2207	17.1
located about 23 km	267	8291	77.2
north-east of the	583	1057	11.2
Department's capital	584	3008	35.8
Veria, and within a	589	958	10.6
radius of 2 km			

lations present in soil that make a controlled 1 cm depth difficult: the compression or expansion of the soil in the counting containers which could account for errors in the calculation of the sample area; differences in the attenuation of the 662 keV photons between the standard solution and the soil samples; the horizontal and/or vertical migration of radioactivity during the period between its deposition and the sampling; probable disturbances of the ground during the same period, etc. For these reasons it was decided to collect a large number of samples and also to repeat the sampling, at the same sampling locations at different sampling periods in order to limit as far as possible any systematic effects in the methodology of this experiment.

The lack of similar published data, presenting the ^{137}Cs deposition of the Chernobyl fallout in Greece, did not allow any intercomparison. The results presented in DEMO 86/10G (1986) are not suitable for comparison inasmuch as:

—they are very few (101 samples extending over 23 Departments),
—the soil samples were collected at a depth of 0–20 cm,
—the specific activity (Bq/kg) of the soil is only given.

Table 8. Ninety five percent confidence interval of the activity ratios of some pairs of isotopes (decayed down to 1 May 1986)

$^{137}Cs/^{134}Cs$: 2.04 ± 0.02
$^{103}Ru/^{106}Ru$: 4.4 ± 0.2
$^{144}Ce/^{141}Ce$: 0.72 ± 0.08

Table 9. Specific activity (Bq/kg) of natural radionuclides in the 252 soil samples analysed

Radionuclide	Range (min.–max.)		Mean	SD
^{226}Ra (^{238}U)	5 ± 0.5	153 ± 1.2	23	18
^{228}Ra (^{232}Th)	3 ± 1.0	126 ± 2.6	19	13
^{40}K	55 ± 1.5	1570 ± 15	370	197

Table 7 presents results of the analysis of the 252 samples analysed with Ge detectors. The minimum and the maximum of each isotope thus far detected, as well as the analysis of the sample with the highest ^{137}Cs concentration (745, collected at Karpochorion) are given. Table 8 gives the activity ratios of pairs of isotopes of the same element, which lead to the estimation of the reactor fuel burnup. Moreover, these ratios, the values of which are in very good agreement with those reported by previous investigators, may provide useful traces of Chernobyl fallout in future environmental studies. Finally, Table 9 gives results concerning the natural radioactivity content of the samples, for comparison purposes.

6. Conclusion

The principal idea about the present experimental work was the quick, but reliable determination of the Chernobyl ^{137}Cs deposition on greek soils. The extended soil sampling over the country and the NaI–LSI/11 system set up allowed this determination. Detailed analysis of the long-lived isotopes in the fallout is also performed. The data presented are considered to be important since they can be used:

—in the assessment of dose to the population of the country.

Table 7. Ground activities of isotopes detected with Ge detectors (decayed down to 1 May 1986)

Isotope	Minimum detected: Ground act. ± 1σ (kBq/m^2)	Minimum detected: Sample code–Dept	Maximum detected: Ground act. ± 1σ (kBq/m^2)	Maximum detected: Sample code–Dept	Sample 745 Ground act. ± 1σ (kBq/m^2)
^{54}Mn	0.02 ± 0.01	279–35	0.23 ± 0.02	596–30	0.19 ± 0.02
^{95}Zr	0.7 ± 0.3	473 27	17.4 ± 0.2	739–24	13.2 ± 0.2
^{103}Ru	52 ± 21	597–30	337 ± 2	747–27	230 ± 1
^{106}Ru	7.2 ± 0.2	621–37	79.1 ± 0.4	747–27	53.6 ± 0.3
^{110m}Ag	0.10 ± 0.05	607–37	1.36 ± 0.02	747–27	0.87 ± 0.2
^{125}Sb	0.33 ± 0.07	1190–21	4.6 ± 0.1	747–27	4.4 ± 0.1
^{134}Cs	8.1 ± 0.02	499–27	76.1 ± 0.1	745–24	76.1 ± 0.1
^{137}Cs	15.9 ± 0.02	499–27	149.1 ± 0.1	745–24	149.0 ± 0.1
^{141}Ce	9 ± 6	749–27	46 ± 2	746–24	38 ± 3
^{144}Ce	1.28 ± 0.02	511–28	32.9 ± 0.2	746–24	28.4 ± 0.3

—for the localization of agricultural areas suitable for further study of the soil-to-plant concentration ratios.
—For the localization of fields suitable for the study of the vertical migration of radiocesium.
—For testing computer codes to predict the dispersion of radioactive clouds and radiocesium deposition.

Acknowledgements—The author is grateful to Professor M. Angelopoulos, Head of the Nuclear Engineering Section of the National Technical University of Athens, for his advice in conducting this research and also in presenting this report. Acknowledgements are extended to Dipl. Eng. D. Petropoulos for his significant contribution in setting-up the counting systems.

References

Alexandropoulos N. G., Alexandropoulou T., Anagnostopoulos D., Evangelou E., Kotsis K. T. and Theodoridou I. (1986) Chernobyl fallout on Ioannina, Greece. *Nature* **322,** 779.

Amersham (1985) *Mixed Radionuclide Gamma-ray Reference Standard Code QCY.44*, Data sheet 11534. Amersham International plc, Buckinghamshire, England.

Dam H. (1986) Silver from Chernobyl. *Nature* **324,** 216.

DEMO 86/3 G (1986) *The Chernobyl Nuclear Accident and its Consequences for Greece*, Report No 1. Greek Atomic Energy Commission, Nuclear Research Centre Democritos, Athens, Greece.

DEMO 86/10 G (1986) *The Chernobyl Nuclear Accident and its Consequences for Greece*. Report No 2. Greek Atomic Energy Commission, Nuclear Research Centre Democritos, Athens, Greece.

Erdtman G. and Soyka W. (1979) *The Gamma Rays of the Radionuclides*. Verlag Chemie, Weinheim.

Flowers R. H. (1986) Dragon's exhalation give clue to Chernobyl, *Nature* **323,** 208.

Jones G. D., Forsyth P. D. and Appleby P. G. (1986) Observation of ^{110m}Ag in Chernobyl fallout. *Nature* **322,** 313.

Simopoulos S. E. and Angelopoulos M. G. (1987a) Natürliche Radionuklide in Braunkohle der Ptolemais-Region (Griechenland) und ihren Aschen. *Z. Angew. Geol.* **33,** 99–104.

Simopoulos S. E. and Angelopoulos M. G. (1987b) Natural radioactivity releases from lignite power plants in Greece. *J. Environ. Radioactivity* **5,** 379–389.

Simopoulos S. E., Leonidou D. J. and Angelopoulos M. G. (1987) Research objectives of the Nuclear Engineering Section of the National Technical University of Athens. In *Proc. Symposium on the Significance and Impact on Nuclear Research in Developing Countries*, Athens, 8–12 September 1986. IAEA, Vienna.

Stoutjesdijk J. F., Desmet G. M., Pennders R. M. J., Sibbel R. M., Sinnaeve J. and Ginkel Van J. H. (1983) The determination of soil plant transfer factors of Mn-54, Zn-65, Sr-90 and Cs-137 under natural circumstances. *Seminar on the Transfer of Radioactive Materials in the Terrestrial Environment Subsequent to an Accidental Release to Atmosphere*. Dublin, 11–15 April 1983. Vol. I, p. 329.

Sumerling T. J. and Crick M. J. (1983) A preliminary evaluation of a dynamic model for the transfer of radionuclides in the pasture–cow–milk pathway with data from a field investigation. *Seminar on the Transfer of Radioactive Materials in the Terrestrial Environment Subsequent to an Accidental Release to Atmosphere*. Dublin, 11 15 April 1983. Vol. II, p. 571.