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Nielsen, Sven Poul

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Intercomparison of Laboratory Analyses of Radionuclides in Environmental Samples

Sven P. Nielsen
Risø National Laboratory, Denmark

October 2006

Abstract

Thirty-eight laboratories participated in an intercomparison exercise carried out in 2004 and 2005 on laboratory analyses of radionuclides in environmental samples and food. The sample types included seawater, lake water, tap water, sediment, seaweed, fish meal, soil, dry milk, cereal and lucerne and the exercise involved artificial and naturally occurring radionuclides including total alpha and beta radioactivity. The evaluation of analytical performance was based on comparison with median values, a 10% target standard deviation and statistical tests at the 99% level. More than half of the laboratories passed the evaluation criteria for 99Tc, 134Cs, 137Cs, 239,240Pu, 226Ra, 232Th, 40K, 210Po, 7Be and tritium while less than half of the participants passed the criteria for 90Sr, 238Pu, 241Am, 210Pb, total alpha and total beta radioactivity. The analytical results compare well across many of the laboratories. However, the results indicate that there is room for improvement of the analytical quality at most laboratories. It is also noteworthy that the results on total alpha and beta radioactivity in lake water show quite poor agreement, which is a matter of implication for national screening programmes of radioactivity in drinking water. It is important, to recognise the subjective components of the evaluation that include the choice of using median values to represent the true values and the choice of a target standard deviation of 10%. However, for one certified reference material included in the exercise, the median and the reference values were in good agreement.

Key words

Radionuclides, intercomparison, environment, food

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NKS Secretariat
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P.O. Box 49
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Phone +45 4677 4045
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NKS-B Project LABINCO 2004-2005

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Contents

Introduction

The LABINCO intercomparison exercise on laboratory analyses of radionuclides in environmental samples and food was initiated in 2004. The intercomparison exercise was organised as a project under the NKS-B Programme (Nordic Nuclear Safety Research) and coordinated by Risø National Laboratory. Intercomparison exercises contribute to assessing the quality of the analytical work carried out in the laboratories by demonstrating the analytical performance and help identify areas that need attention and improvement. The NKS has previously supported intercomparison exercises on analyses of radioactivity in the environment and food (Nielsen, 1996; Fogh, 2000; Fogh et al., 2002).

Participants

Invitations to participate were extended to laboratories in the Nordic countries, Poland, Estonia, Latvia, and Lithuania including a few others. Thirty-eight laboratories from Germany, Denmark, Estonia, Finland, Hungary, Iceland, Lithuania, Latvia, Norway, Poland, Russia and Sweden participated in the intercomparison as listed in Table 1.

Table 1. Participants.

Name	Laboratory	Country
Kanisch, Günter	Federal Research Centre for Fisheries, Institute of Fisheries Ecology	DE
Herrmann, Jürgen	Federal Maritime and Hydrographic Agency	DE
Nielsen, Sven	Risø National Laboratory	DK
Ennow, Klaus	National Institute of Radiation Hygiene	DK
Jakobson, Eia	Estonian Radiation Protection Agency	EE
Realo, Enn	Institute of Physics, University of Tartu	EE
Lehto, Jukka	Chemistry Department, Helsinki University	FI
Ikäheimonen, Tarja	Radiation and Nuclear Safety Authority	FI
Solatie, Dina	Radiation and Nuclear Safety Authority	FI
Varga, Beata	Dep. of Radiochemistry, National Food Investigation Institute	HU
Palsson, Sigurdur	Geislavarnir rikisins	IS
Vilimaite-Silobritiene, Beata	Environmental Protection Agency	LT
Gudelis, Arunas	Institute of Physics, Vilnius	LT
Lujaniene, Galina	Institute of Physics, Vilnius	LT
Morkunas, Gendrutis	Radiation Protection Centre	LT
Morkuniene, Rasa	Vilnius Gediminas Technical University	LT
Graveris, Visvaldis	Latvian Environment Agency	LV
Lapenas, Antons	Radiation Metrology and Testing Centre	LV
Skujina, Anita	Radiation Safety Centre	LV
Rudzitis, Janis	State Veterinary Medicine Diagnostic Centre	LV
Riekstina, Daina	Institute of Solid State Physics, University of Riga	LV
Raaum, Aud	Institute for Energy Technology	NO
Sværen, Ingrid	Institute for Marine Research, Lab 1	NO
Sværen, Ingrid	Institute for Marine Research, Lab 2	NO
Møller, Bredo	Norwegian Radiation Protection Authority, Svanhovd	NO
Dowdall, Mark	Norwegian Radiation Protection Authority, Tromsø	NO
Brungot, Anne Lene	Norwegian Radiation Protection Authority, Østerås	NO
Skipperud, Lindis	Isotope Laboratory, Dept of Plant and Environmental Sciences, Norwegian University of Life Sciences	NO
Muszynski, Wojciech	Central Laboratory for Radiological Protection	PL

Suplinska, Maria	Central Laboratory for Radiological Protection	PL
Zalewska, Tamara	Institute of Meteorology and Water Management	PL
Stepanov, Andrej	V.G. Khlopin Radium Institute	RU
Appelblad, Petra	Swedish Defence Research Agency	SE
Almgren, Sara	Radiation Physics, Göteborg University	SE
Holm, Elis	Radiation Physics, Lund University	SE
Rääf, Christopher	Radiation Physics, Malmö University Hospital, Lund University	SE
Östergren, Inger	Swedish Radiation Protection Authority	SE
Askeljung, Charlotta	Studsvik Nuclear	SE

Sample Materials

The sample types involved seawater, lake water, tap water, sediment, seaweed, fish meal, soil, dry milk, cereal and lucerne. Furthermore, a certified reference material (soil, IAEA-375) was obtained from the International Atomic Energy Agency and included in the intercomparison without revealing the identity of the sample to the participants. The samples and sample amounts distributed are listed in Table 2. The samples of Swedish origin had higher levels of ^{137}Cs than those of Danish origin. The radionuclides suggested for analysis included ^{90}Sr, ^{99}Tc, ^{137}Cs, Pu-isotopes, ^{241}Am, tritium (tap water samples only), ^{226}Ra, ^{232}Th, ^{40}K, ^{210}Po (sediment sample in particular with expected disequilibrium between ^{210}Pb and ^{210}Po), total alpha and beta radioactivity (lake water sample only). The total alpha and beta radioactivity and tritium analyses are of special relevance in connection with screening of drinking water as required by the EU Drinking Water Directive.

All samples were dried and mixed thoroughly. A number of aliquots were selected from the different materials and analysed by gamma spectrometry to test the homogeneity. For all sample types the gamma emitting radionuclides detected were homogeneously distributed within the statistical counting uncertainty, which ranged from 1 to 6%.

Table 2. Samples distributed for the intercomparison exercise.

Sample type and origin	Amount (kg)
Seawater - surface water from Danish waters, salinity about 8 ‰	50
Lake water - from a Swedish lake	25
Tap water - spiked with tritium	2 x 1
Sediment - from Roskilde Fjord (Mineral matrix I)	0.2
Seaweed - from Danish waters	0.15
Fish meal - Danish origin	2
Soil - Swedish origin (Mineral matrix II)	0.2
Dry milk - Danish origin	1
Cereal - Swedish origin	0.5
Lucerne/alfalfa pellets - Danish origin	2
Soil - Certified Reference Material (Mineral matrix III)	0.1

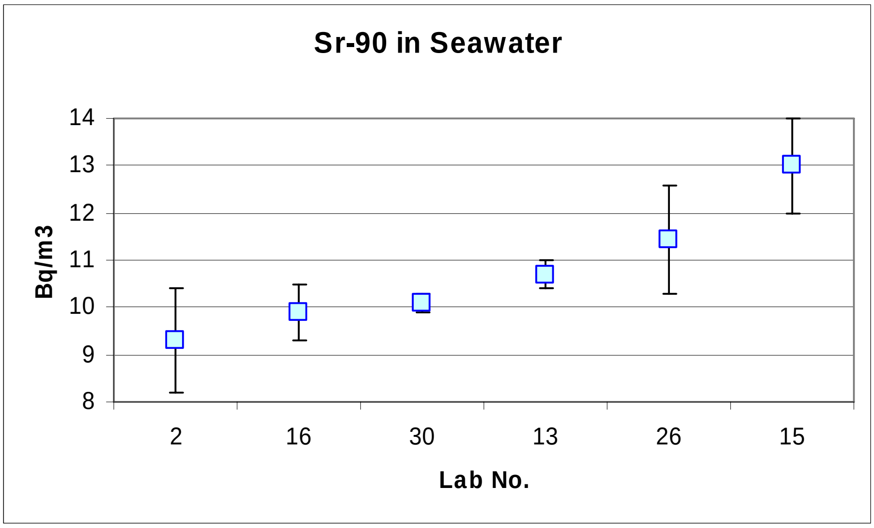
Analytical Results

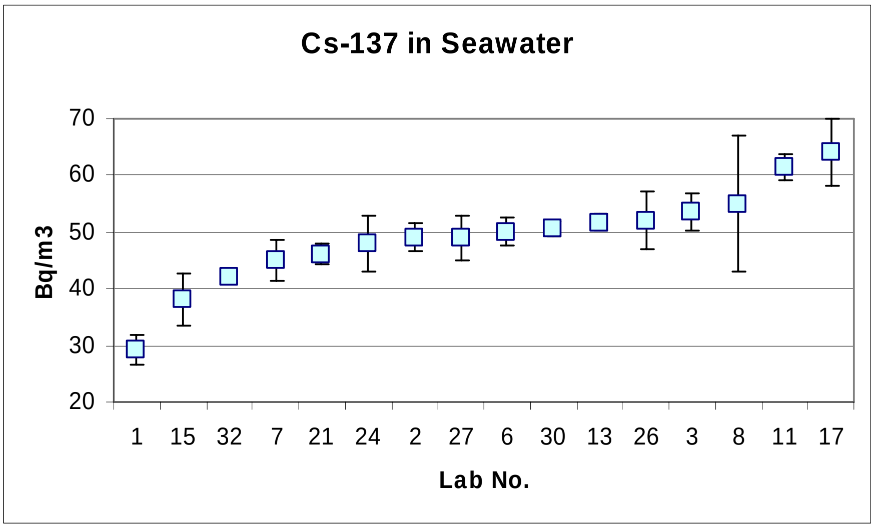
Results were received from three or more laboratories on total alpha and beta radioactivity and 14 radionuclides. Each participant was assigned a code number to ensure anonymity. The reported analytical results and uncertainties are shown in the following tables and graphs. The tables include the median values of the radionuclide concentrations for each sample. The table with results for the certified reference material (mineral matrix III) furthermore gives the decay-corrected reference and information values. The graphs show the results by radionuclide and sample type. Reported detection limits are marked by filled circles.

Seawater

Table 3. Results reported on radionuclides in seawater.

Lab No.	Sr-90 (Bq/m³)	1sd (Bq/m³)	Cs-137 (Bq/m³)	1sd (Bq/m³)	Tc-99 (Bq/m³)	1sd (Bq/m³)
1			29.2	2.7		
2	9.3	1.1	49.0	2.5		
3			53.5	3.2		
6			50.0	2.5		
7			45.0	3.5		
8			55.0	12.0	0.10	0.06
11			61.5	2.4		
13	10.7	0.3	51.6	1.5		
15	13.0	1.0	38.0	4.6		
16	9.9	0.6				
17			64.0	6.0		
21			46.1	1.8		
24			48.0	5.0		
26	11.4	1.1	52.1	5.2		
27			49.0	4.0		
30	10.1	0.2	50.6	1.4		
32			42.0	1.0		
Median	10.4		49.5			

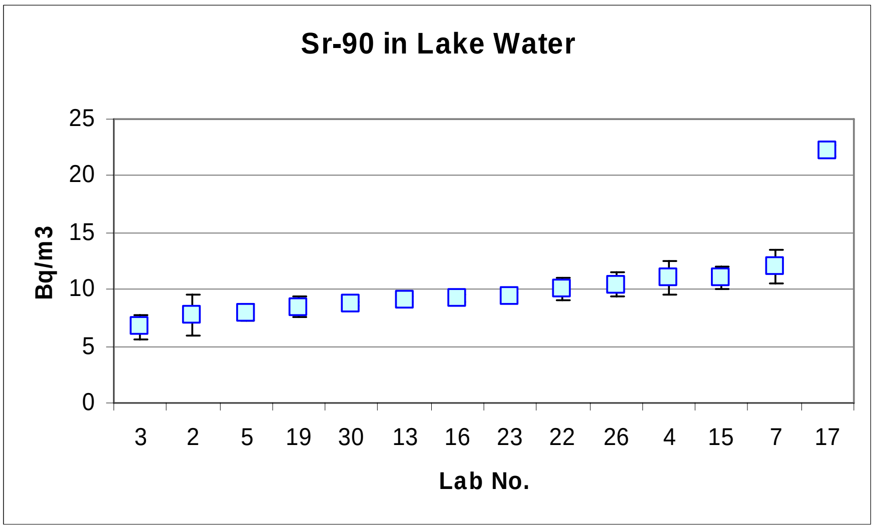


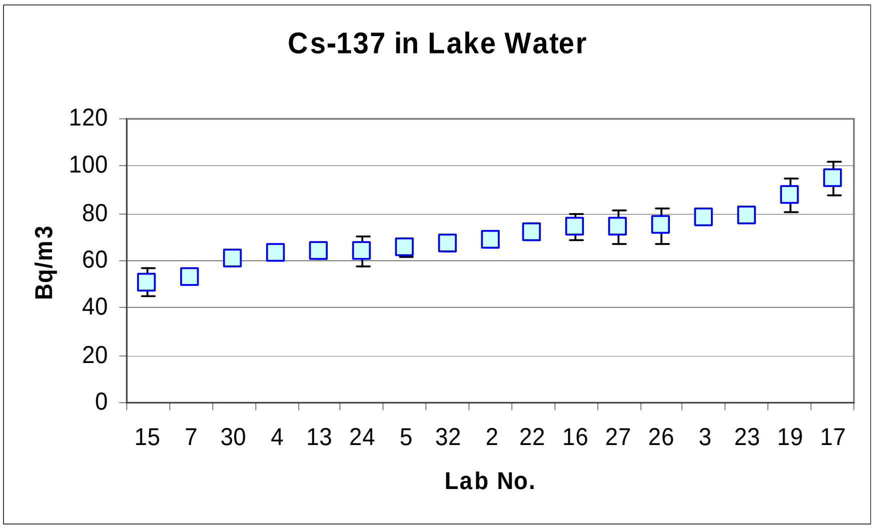


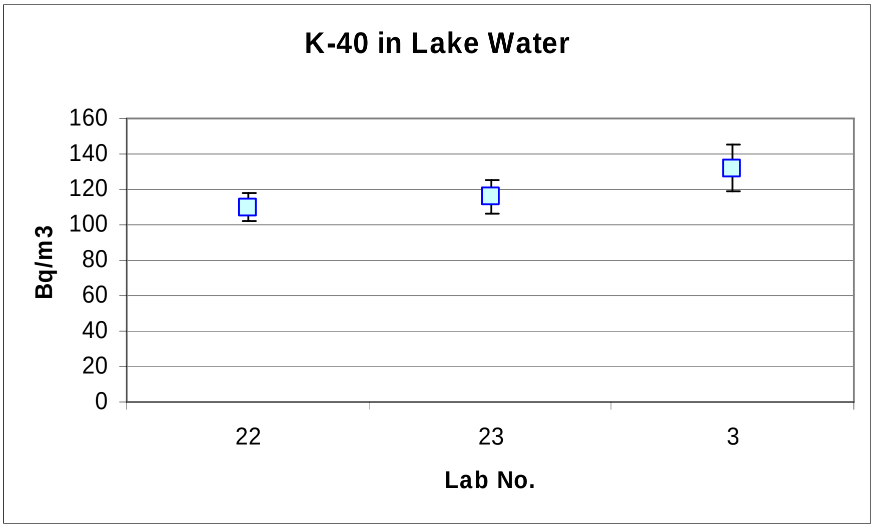
Lake water

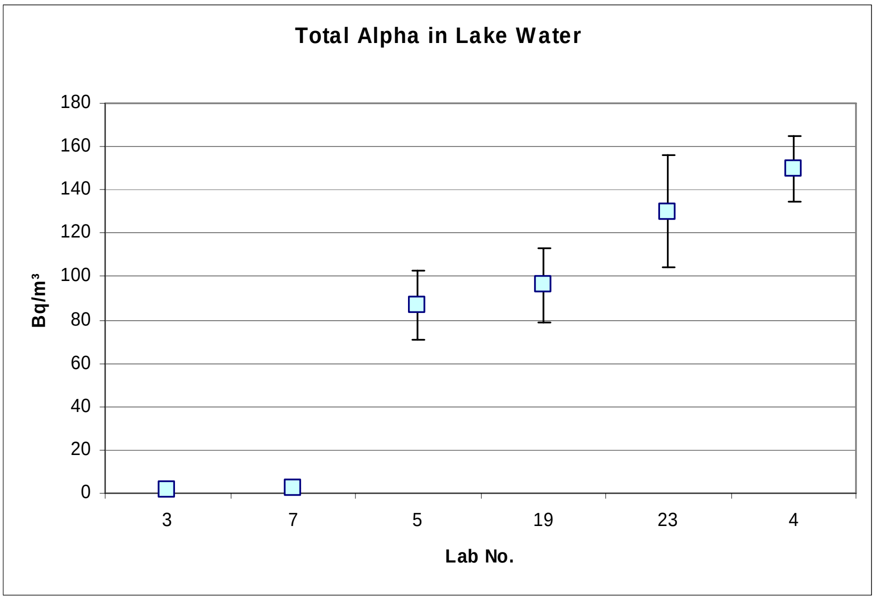
Table 4. Results reported on radionuclides in lake water.

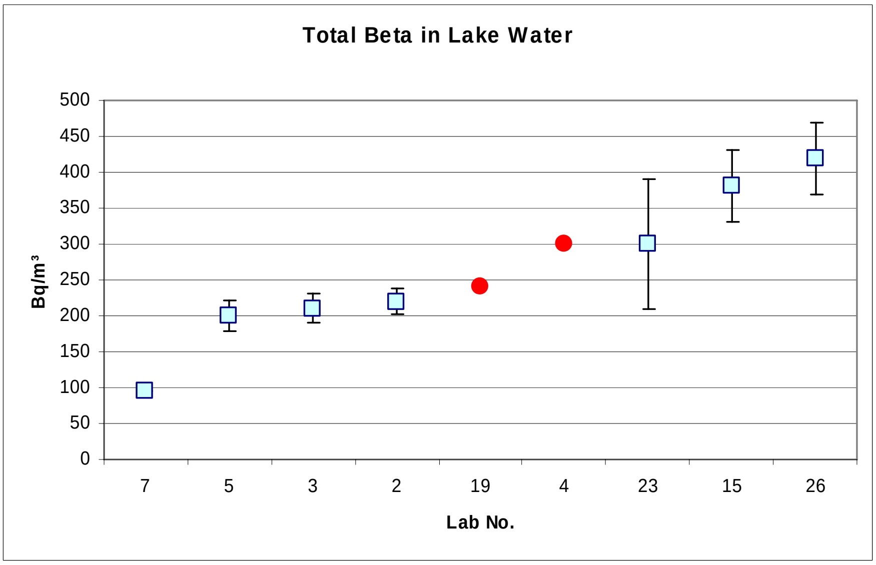
Lab No.	Sr-90	1sd	Cs-137	1sd	K-40	1sd	Total alpha	1sd	Total beta	1sd
	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3
2	7.8	1.8	68.7	3.4					220	17
3	6.7	1.1	78.0	2.3	132	13	1.9	0.2	210	20
4	11.0	1.5	63.0	2.3			150	15	< 300	
5	8.0	0.7	65.6	3.8			87	16	200	21
7	12.0	1.5	53.0	2.0			2.7	0.05	94.7	0.3
13	9.1	0.3	63.7	3.2						
15	11.0	1.0	50.9	6.1					380	50
16	9.2	0.3	74.0	5.5						
17	22.2	0.5	95.0	7.0						
19	8.5	0.9	87.4	7.1			96	17	< 240	
22	10.0	1.0	72.0	3.6	110	8				
23	9.3	0.5	79.0	2.4	116	9	130	26	300	90
24			64.0	6.0						
26	10.4	1.0	75.0	7.5					420	50
27			74.0	7.0						
30	8.7	0.2	60.9	1.1						
32			67.0	3.0						
Median	9.3		68.7		116		92		220	


Sr-90 in Lake Water
Bq/m3
25
20
15
10
5
0
3 2 5 19 30 13 16 23 22 26 4 15 7 17
Lab No.


Cs-137 in Lake Water
Bq/m3
120
100
80
60
40
20
0
15 7 30 4 13 24 5 32 2 22 16 27 26 3 23 19 17
Lab No.


K-40 in Lake Water
Bq/m3
160
140
120
100
80
60
40
20
0
22 23 3
Lab No.



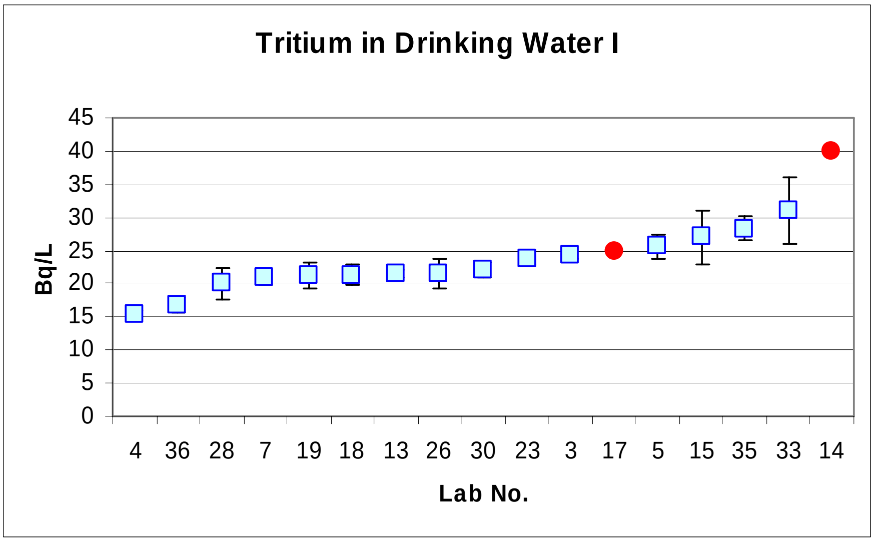


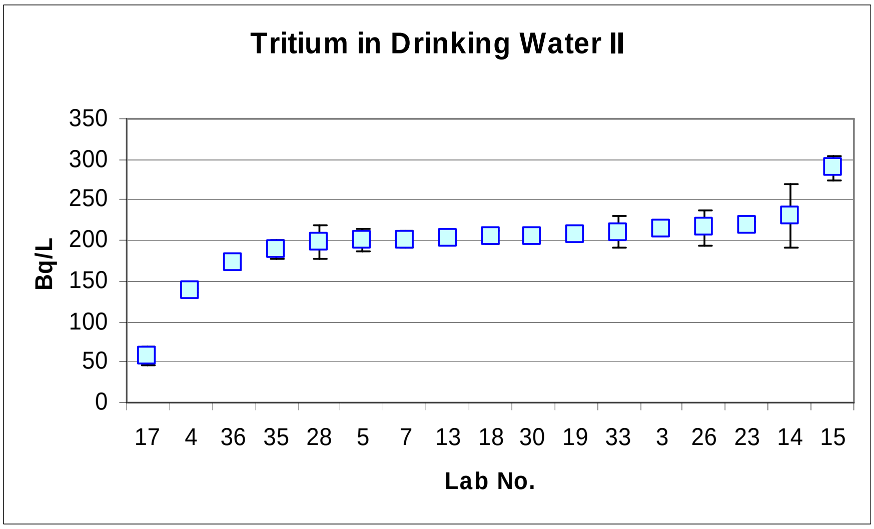
Drinking water

Table 5. Results reported on tritium in tap water.

Lab No.	Tap water I H-3 (Bq/L)	1sd (Bq/L)	Tap water II H-3 (Bq/L)	1sd (Bq/L)
3	24.3	0.6	215	4

4	15.5	0.4	139	3
5	25.6	1.8	200	14
7	20.9	1.2	201	11
13	21.5	0.6	203	4
14	< 40		230	40
15	27.0	4.0	290	15
17	< 25		57	11
18	21.3	1.5	204	8
19	21.2	1.9	208	3
23	23.8	1.0	218	5
26	21.6	2.2	215	22
28	20.0	2.5	198	20
30	22.1	1.2	205	2
33	31.0	5.0	210	20
35	28.3	1.8	189	12
36	16.7	1.1	172	9
Median	21.6		204	

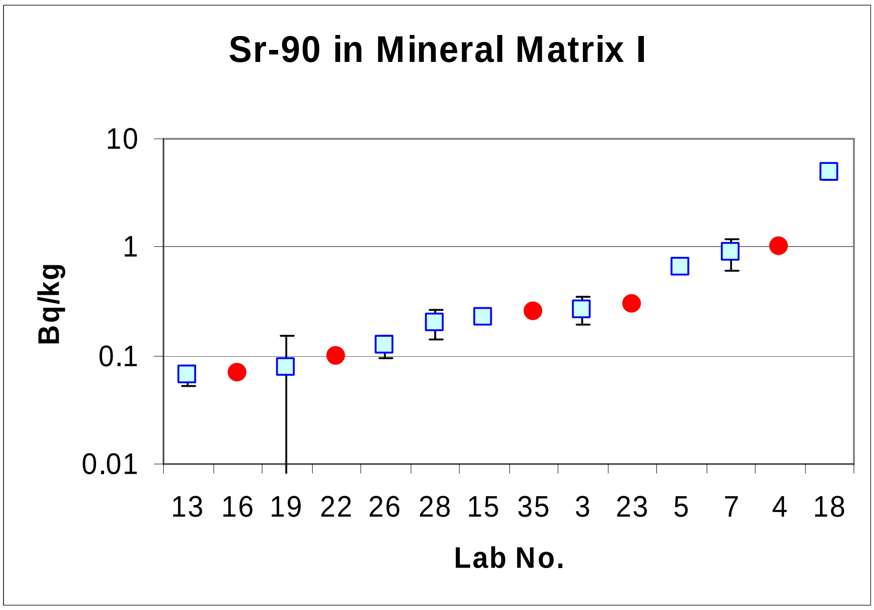




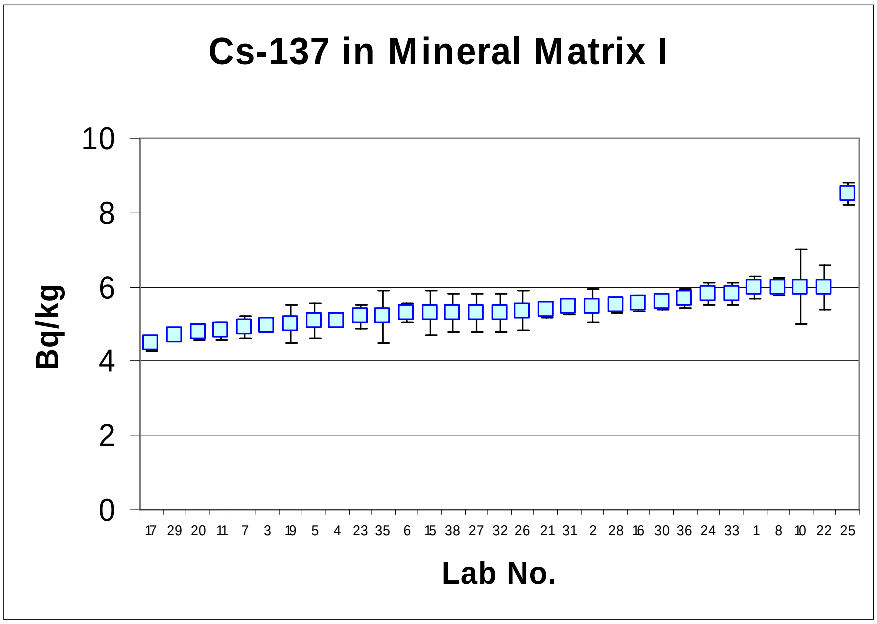
Mineral matrix I

Table 6. Results reported on radionuclides in sediment (mineral matrix I).

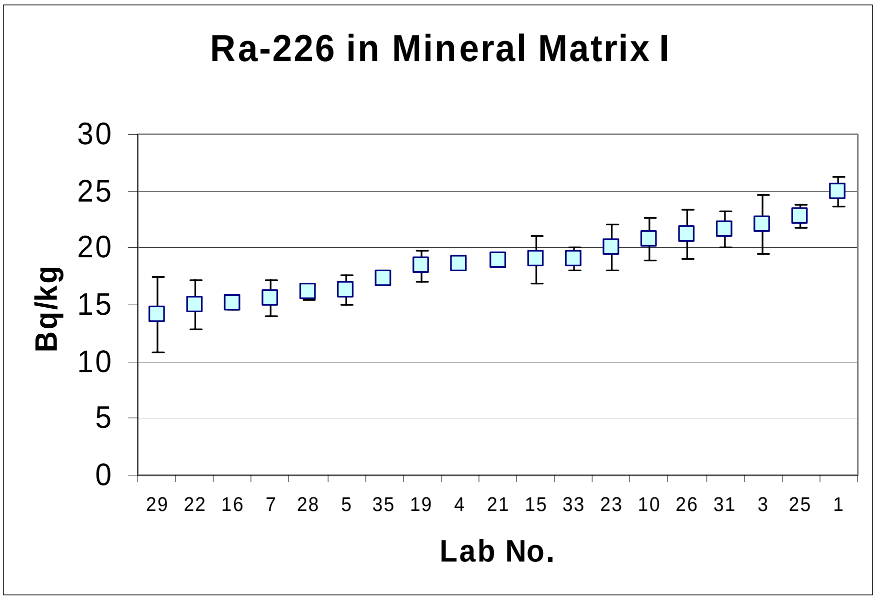
Lab No.	Sr-90 (Bq/kg)	1sd (Bq/kg)	Cs-137 (Bq/kg)	1sd (Bq/kg)	Pu-239,240 (Bq/kg)	1sd (Bq/kg)	Pu-238 (Bq/kg)	1sd (Bq/kg)	Am-241 (Bq/kg)	1sd (Bq/kg)	Ra-226 (Bq/kg)	1sd (Bq/kg)	Th-232 (Bq/kg)	1sd (Bq/kg)	K-40 (Bq/kg)	1sd (Bq/kg)	Pb-210 (Bq/kg)	1sd (Bq/kg)
1			6.00	0.30	0.095	0.021	< 0.008		0.060	0.016	25.0	1.3	25.5	1.3	426	22		
2			5.49	0.45											403	18		
3	0.27	0.08	4.96	0.15	0.110	0.010	0.0100	0.0030			22.0	2.6	14.9	1.2	370	30		
4	< 1		5.10	0.19					< 2.2		18.6	0.4	19.0	0.5	403	8	< 400	
5	0.65	0.07	5.08	0.47	0.103	0.014	0.0060	0.0043			16.3	1.3	17.1	1.7	433	17		
6			5.30	0.27											415	21		
7	0.91	0.30	4.90	0.30							15.6	1.6	17.8	0.8	358	18		
8			6.00	0.25											438	40		
10			6.00	1.00							20.8	1.9	20.8	1.8	395	20	37.0	16.0
11			4.81	0.23														
13	0.07	0.02																
15	0.23		5.30	0.60							19.0	2.1	21.0	2.3	384	30		
16	< 0.07		5.56	0.21	0.079	0.007					15.2	0.6	20.6	1.1	428	12	25.6	4.0
17			4.47	0.18									16.1	0.5	328	8		
18	4.84	0.60																
19	0.08	0.08	5.00	0.50							18.4	1.4	20.2	1.6	406	17		
20			4.79	0.20														
21			5.40	0.21							18.9	0.6	20.2	0.8	362	10		
22	< 0.1		6.00	0.60	0.080	0.022	< 0.08				15.0	2.1	25.0	2.8	410	33		
23	< 0.30		5.20	0.31							20.0	2.0	22.0	1.3	390	20		
24			5.80	0.30														
25			8.51	0.30							22.8	1.0	25.1	0.8	507	13		
26	0.12	0.02	5.36	0.54	0.103	0.010	0.0033	0.0013	0.043	0.005	21.2	2.1	21.0	2.1	446	45	25.5	2.6
27			5.30	0.50	0.095	0.010			0.080	0.020								
28	0.20	0.06	5.50	0.20	0.290	0.050	0.0310	0.0120			16.1	0.7	20.4	0.7	412	14		
29			4.71	0.11							14.1	3.3	18.7	3.5	354	3		
30			5.60	0.20											396	5	26.8	2.6
31			5.48	0.21							21.6	1.6	19.7	0.7	392	14	31.4	3.5
32			5.30	0.50											408	10		
33			5.80	0.30							19.0	1.0	20.5	0.8	365	12		
35	< 0.256		5.20	0.70	< 0.15				< 0.05		17.3	0.5	17.2	1.3	383	20	68.0	12.0
36			5.67	0.26											402	7		
38			5.30															
Median	0.23		5.30		0.099		0.0080		0.060		18.9		20.3		403		29.1	

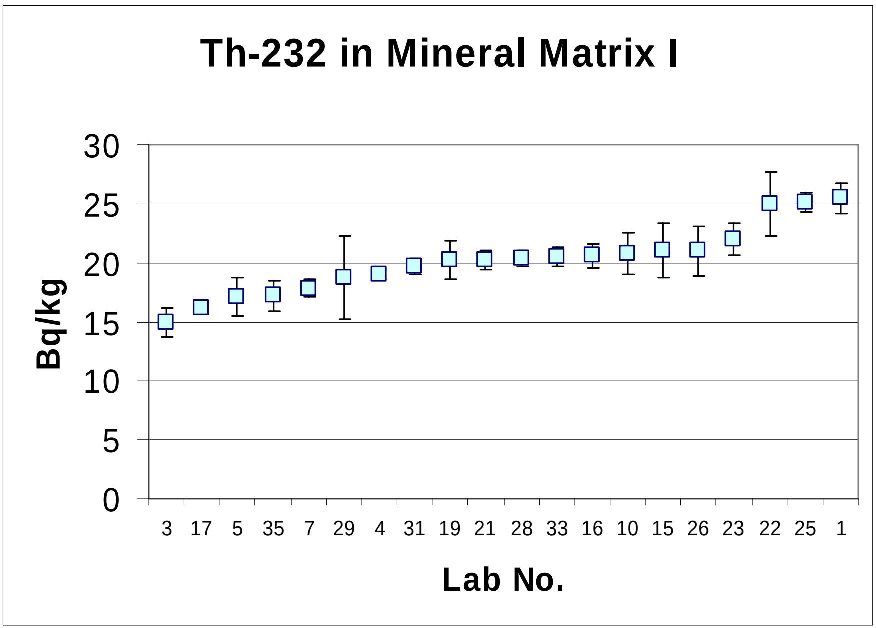


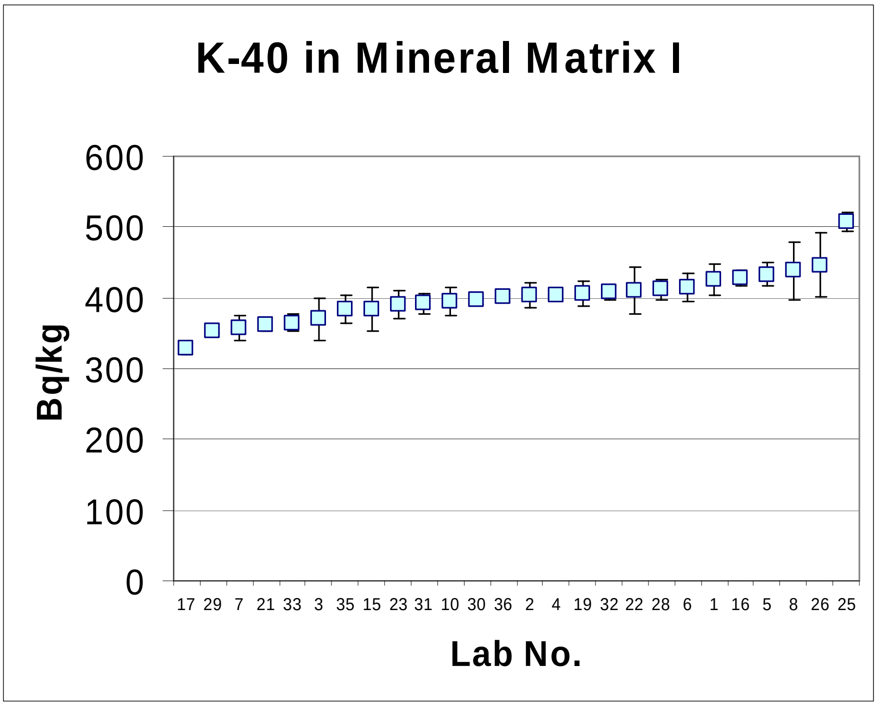
Sr-90 in Mineral Matrix I
10
1
0.1
0.01
Bq/kg
13 16 19 22 26 28 15 35 3 23 5 7 4 18
Lab No.

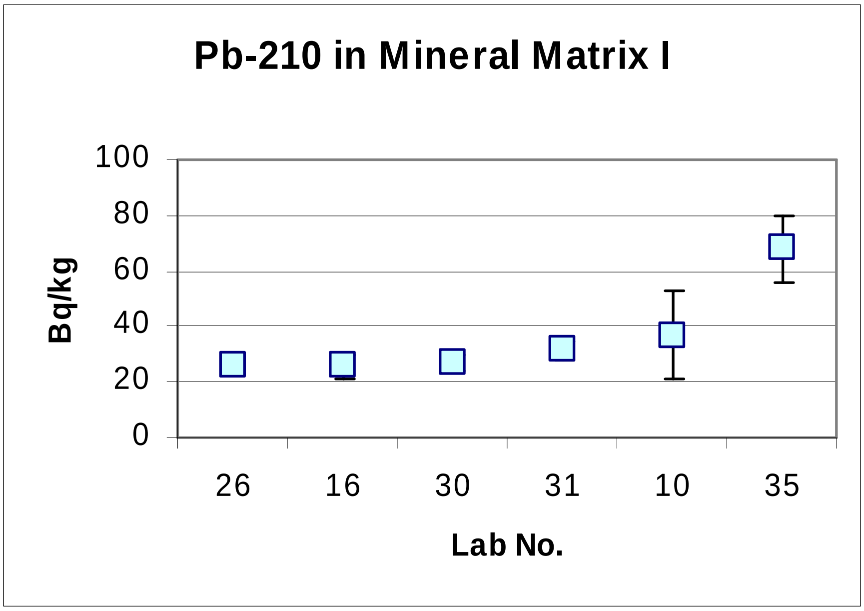


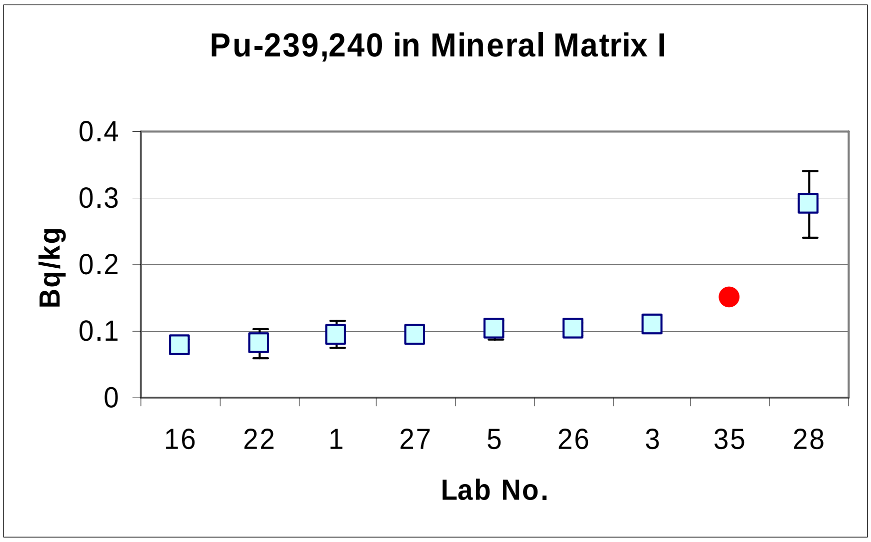
Cs-137 in Mineral Matrix I
10
8
6
4
2
0
Bq/kg
17 29 20 11 7 3 19 5 4 23 35 6 15 38 27 32 26 21 31 2 28 16 30 36 24 33 1 8 10 22 25
Lab No.

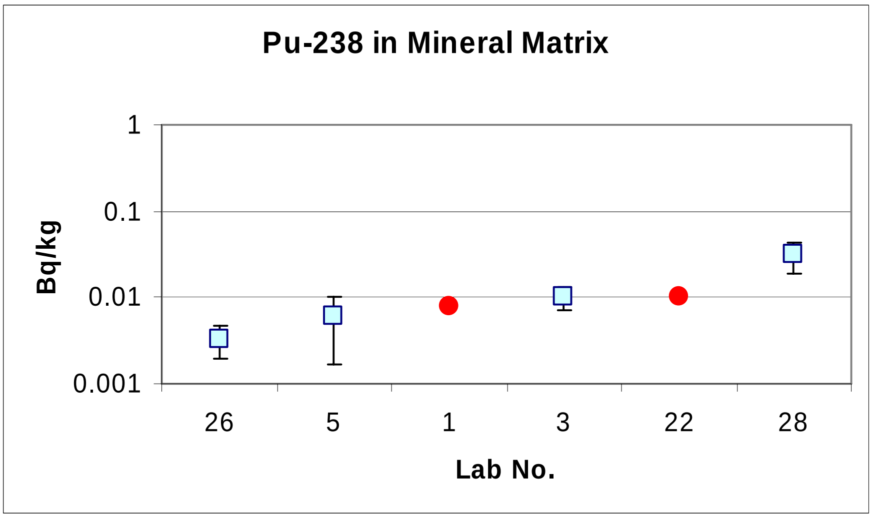

Ra-226 in Mineral Matrix I
Bq/kg
30
25
20
15
10
5
0
29 22 16 7 28 5 35 19 4 21 15 33 23 10 26 31 3 25 1
Lab No.

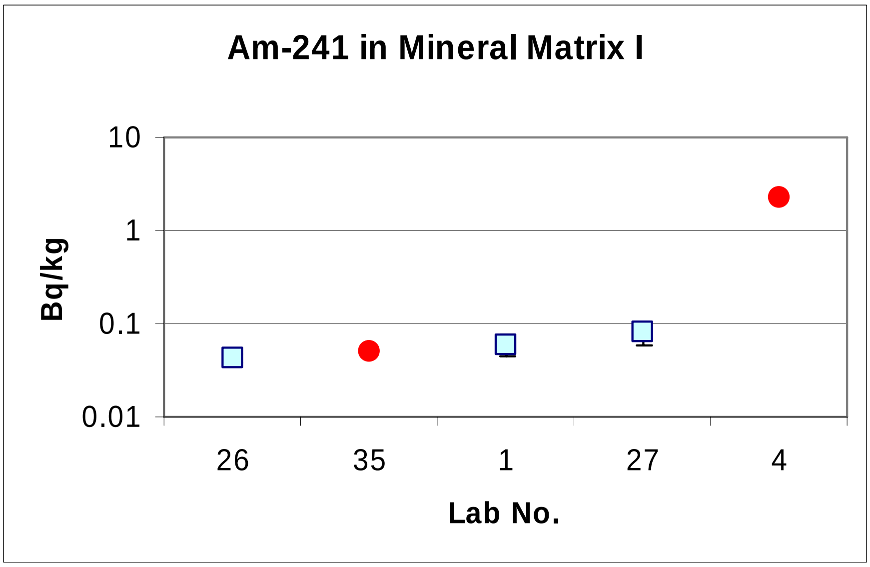

Th-232 in Mineral Matrix I
Bq/kg
30
25
20
15
10
5
0
3 17 5 35 7 29 4 31 19 21 28 33 16 10 15 26 23 22 25 1
Lab No.


K-40 in Mineral Matrix I
600
500
400
300
200
100
0
Bq/kg
17 29 7 21 33 3 35 15 23 31 10 30 36 2 4 19 32 22 28 6 1 16 5 8 26 25
Lab No.


Pb-210 in Mineral Matrix I
100
80
60
40
20
0
Bq/kg
26 16 30 31 10 35
Lab No.


Pu-239,240 in Mineral Matrix I
Bq/kg
0.4
0.3
0.2
0.1
0
16
22
1
27
5
26
3
35
28
Lab No.

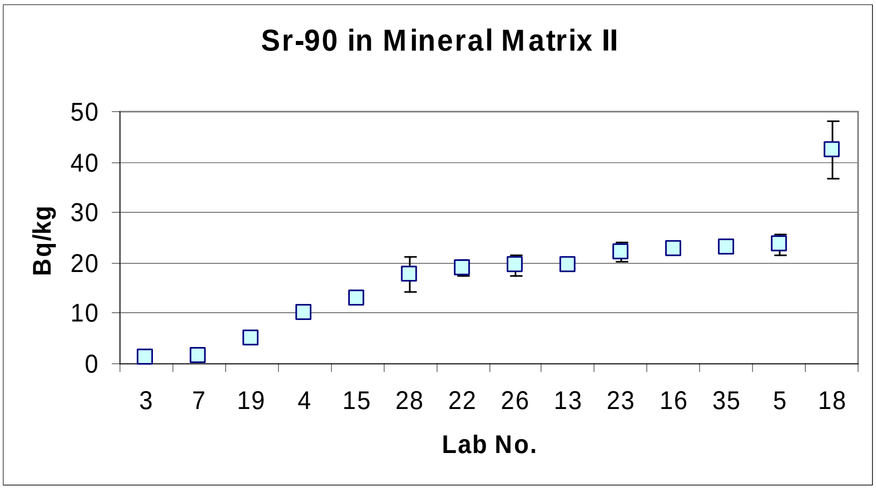

Pu-238 in Mineral Matrix
Bq/kg
1
0.1
0.01
0.001
26
5
1
3
22
28
Lab No.

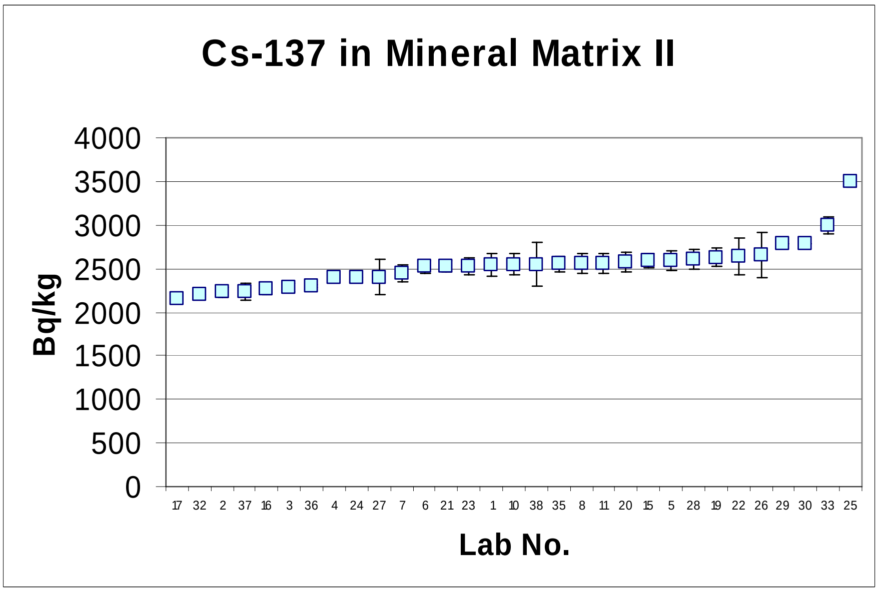

Am-241 in Mineral Matrix I
Bq/kg
10
1
0.1
0.01
26
35
1
27
4
Lab No.

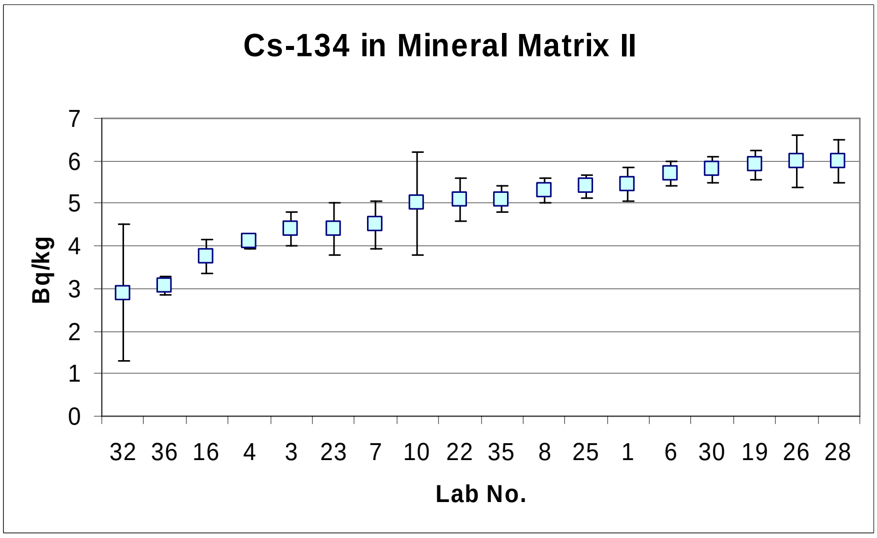
Mineral matrix II

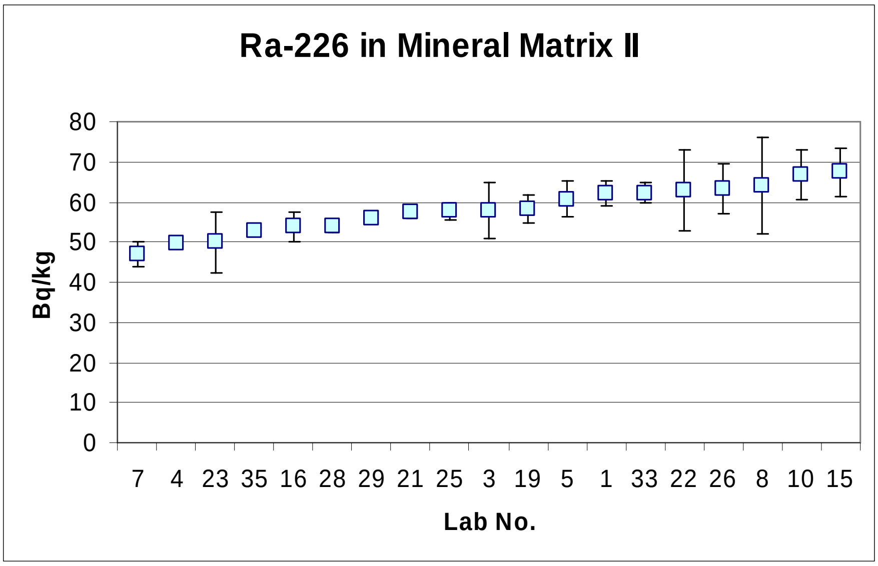
Table 7. Results reported on radionuclides in soil (mineral matrix II).

Lab No.	Sr-90	1sd	Cs-137	1sd	Cs-134	1sd	Pu-239,240	1sd	Pu-238	1sd	Am-241	1sd	Ra-226	1sd	Th-232	1sd	K-40	1sd	Pb-210	1sd
	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
1			2542	127	5.46	0.40	0.983	0.094	0.038	0.013	0.418	0.055	62.1	3.1	40.9	2.0	728	37		
2			2231	55													763	47		
3	1.4	0.3	2290	50	4.40	0.40	1.100	0.200	0.060	0.020	1.000	0.300	58.0	7.0	30.0	2.4	660	40	156	16
4	10.0	0.9	2393	19	4.10	0.15					< 5.8		49.8	0.8	39.9	0.7	737	13	< 250	
5	23.6	2.1	2593	114			1.300	0.060	0.047	0.009			60.7	4.4	27.8	2.0	828	46		
6			2520	76	5.70	0.29											727	36		
7	1.4	0.3	2440	98	4.50	0.55							47.0	3.0	38.0	5.0	655	64		
8			2556	110	5.30	0.30							64.0	12.0	45.5	0.6	725	40		
10			2546	120	5.00	1.20							66.7	6.2	40.3	3.5	699	22	138	30
11			2564	115																
13	19.6	0.6																		
15	13.0	1.0	2590	80									67.4	5.9	39.6	4.7	709	39		
16	22.8	1.0	2260	55	3.76	0.40	0.412	0.023					53.8	3.7	43.4	2.8	680	14	103	3
17			2150	50			< 1.2		< 1.0		< 0.74				31.6	0.5	584	13		
18	42.4	5.6																		
19	5.0	0.4	2630	106	5.91	0.35							58.4	3.5	42.5	3.2	790	33		
20			2577	113																
21			2526	63									57.5	1.6	42.5	1.4	673	18		
22	19.0	1.7	2640	211	5.10	0.51	0.950	0.067	0.030	0.008			63.0	10.1	40.0	6.4	700	56		
23	22.2	2.0	2530	101	4.40	0.62	1.080	0.108	0.030	0.012	0.330	0.063	50.0	7.5	42.0	2.9	680	34	112	9
24			2398	5																
25			3490	52	5.40	0.27							57.7	2.0	46.6	1.7				
26	19.5	2.0	2654	265	5.99	0.60	1.145	0.115	0.042	0.004	0.468	0.047	63.3	6.3	42.3	4.2	813	81	141	14
27			2400	200			1.100	0.100			0.300	0.060								
28	17.6	3.5	2610	114	6.00	0.50	1.400	0.200	0.060	0.030			54.0	1.5	43.7	1.9	736	36		
29			2790	3									55.9	1.3	54.3	1.4	795	7		
30			2790	3	5.80	0.30	0.77	0.02	0.05	0.004	0.48	0.01					751	8	163	15
32			2200	10	2.90	1.60											736	17		
33			2990	96									62.2	2.5	42.3	2.2	780	25		
35	23.2	1.1	2552	85	5.10	0.30	1.250	0.070			< 0.08		52.7	0.7	37.6	0.8	717	39	394	61
36			2302	19	3.07	0.22											708	12		
37			2237	103																
38			2550	255																
Median	19.3		2546		5.10		1.100		0.044		0.44		58.0		41.5		726		141	

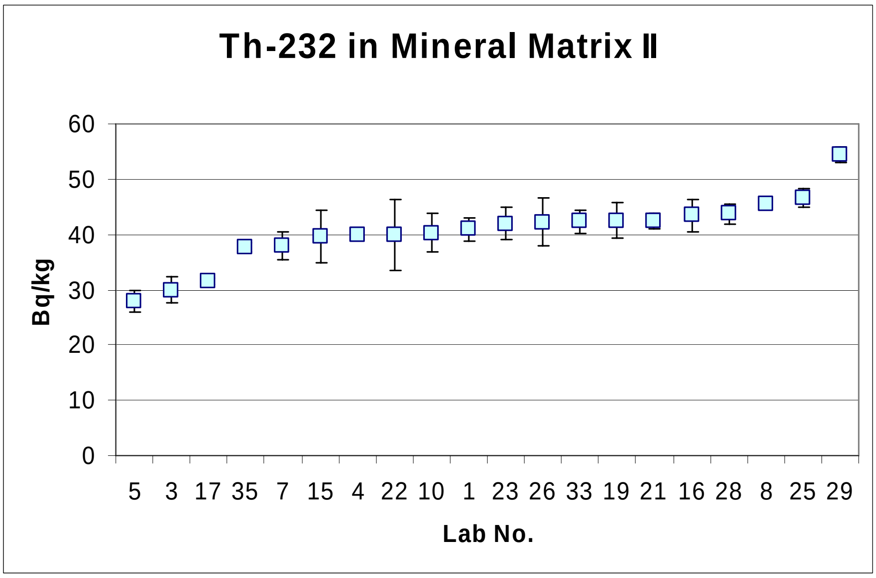

Sr-90 in Mineral Matrix II
Bq/kg
50
40
30
20
10
0
3 7 19 4 15 28 22 26 13 23 16 35 5 18
Lab No.


Cs-137 in Mineral Matrix II
Bq/kg
4000
3500
3000
2500
2000
1500
1000
500
0
17 32 2 37 16 3 36 4 24 27 7 6 21 23 1 10 38 35 8 11 20 15 5 28 19 22 26 29 30 33 25
Lab No.

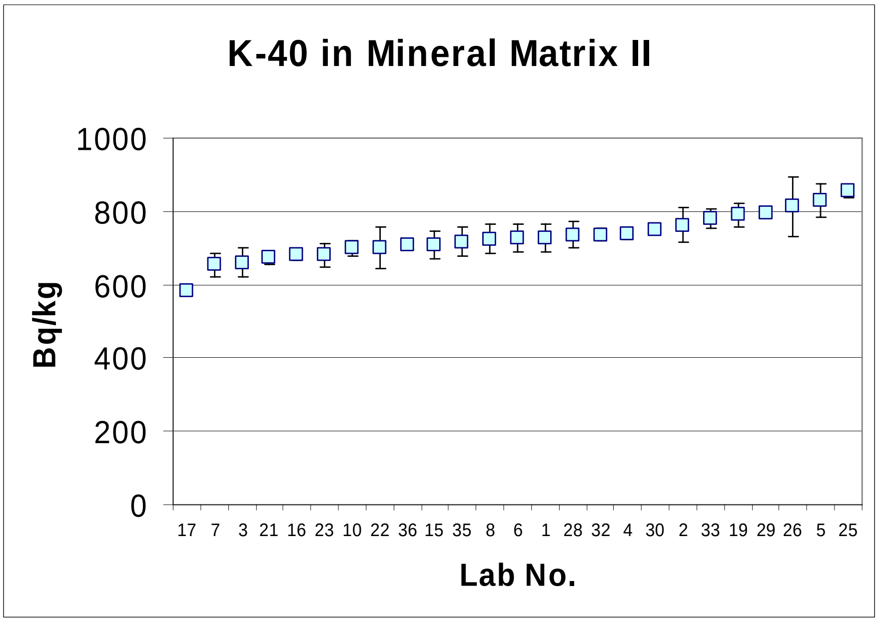

Cs-134 in Mineral Matrix II
Bq/kg
7
6
5
4
3
2
1
0
32 36 16 4 3 23 7 10 22 35 8 25 1 6 30 19 26 28
Lab No.

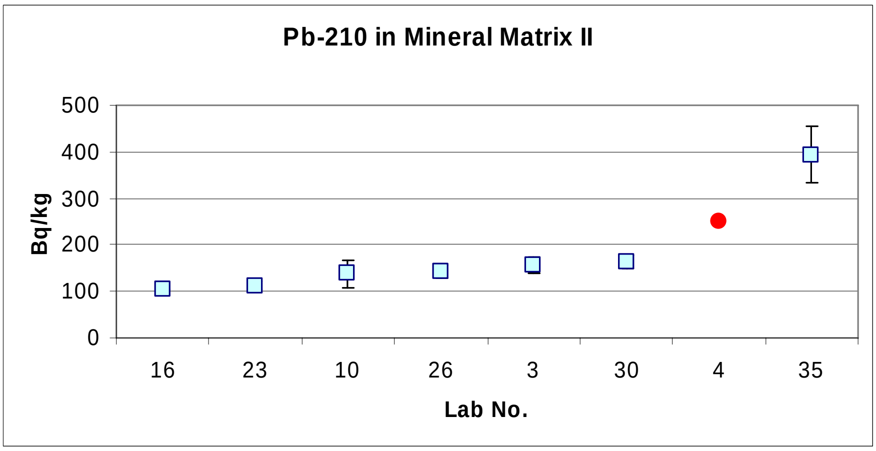


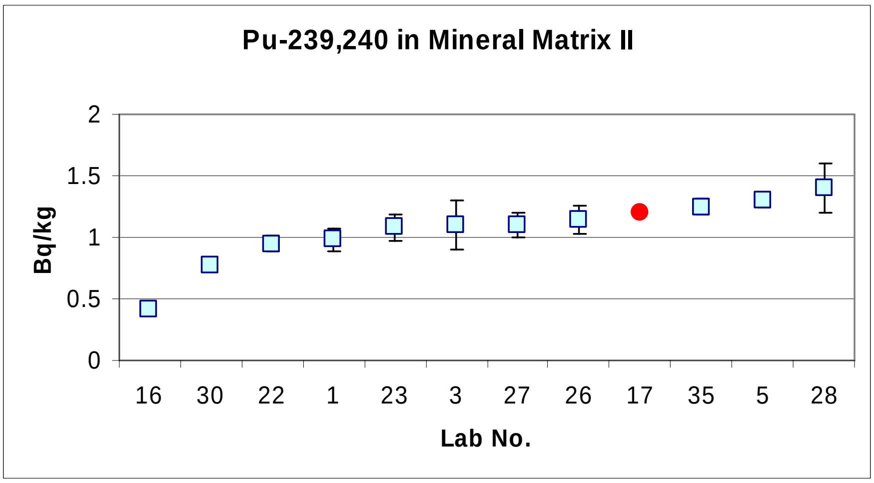
Ra-226 in Mineral Matrix II
Bq/kg
0
10
20
30
40
50
60
70
80
7 4 23 35 16 28 29 21 25 3 19 5 1 33 22 26 8 10 15
Lab No.

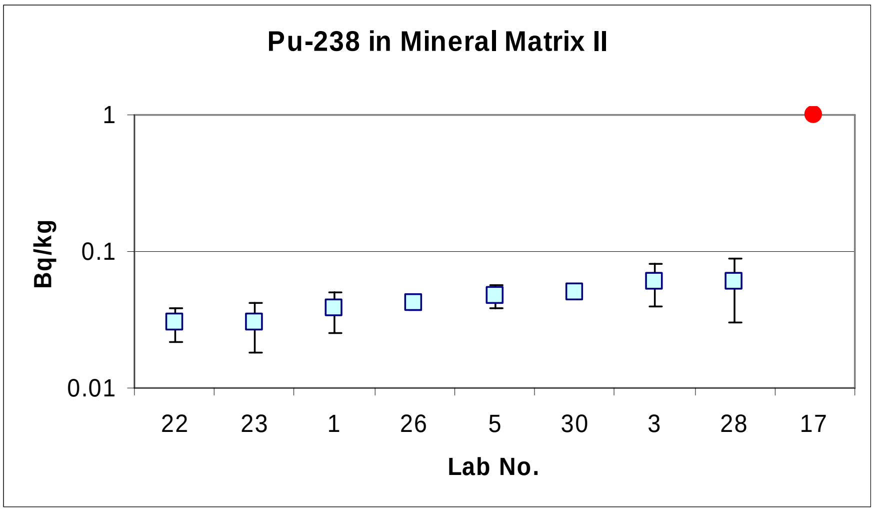


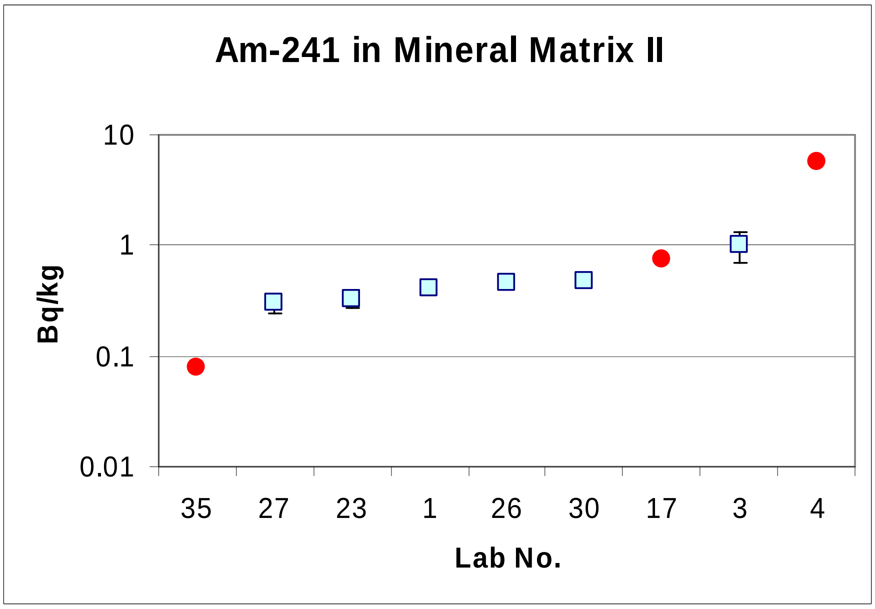
Th-232 in Mineral Matrix II
Bq/kg
0
10
20
30
40
50
60
5 3 17 35 7 15 4 22 10 1 23 26 33 19 21 16 28 8 25 29
Lab No.


K-40 in Mineral Matrix II
Bq/kg
1000
800
600
400
200
0
17 7 3 21 16 23 10 22 36 15 35 8 6 1 28 32 4 30 2 33 19 29 26 5 25
Lab No.


Pb-210 in Mineral Matrix II
Bq/kg
500
400
300
200
100
0
16 23 10 26 3 30 4 35
Lab No.


Pu-239,240 in Mineral Matrix II
Bq/kg
2
1.5
1
0.5
0
16 30 22 1 23 3 27 26 17 35 5 28
Lab No.

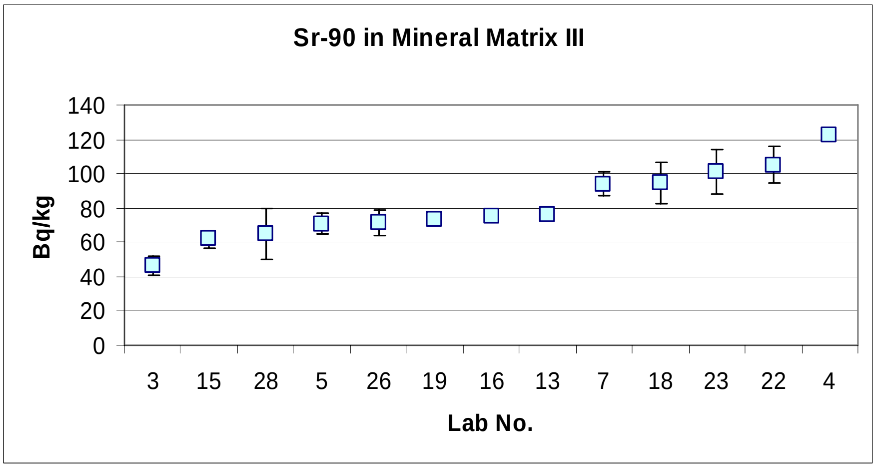

Pu-238 in Mineral Matrix II
Bq/kg
1
0.1
0.01
22
23
1
26
5
30
3
28
17
Lab No.

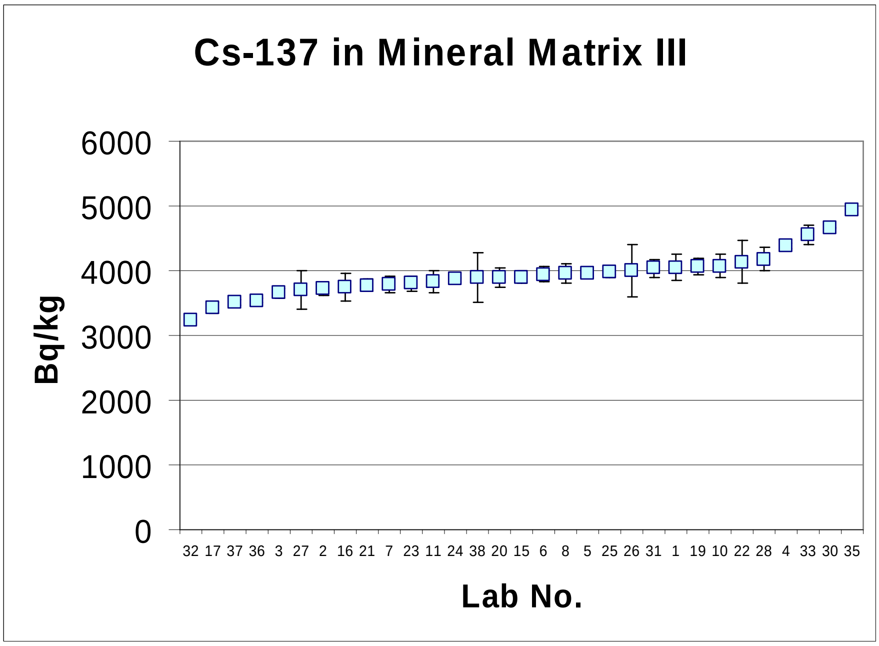

Am-241 in Mineral Matrix II
Bq/kg
10
1
0.1
0.01
35
27
23
1
26
30
17
3
4
Lab No.

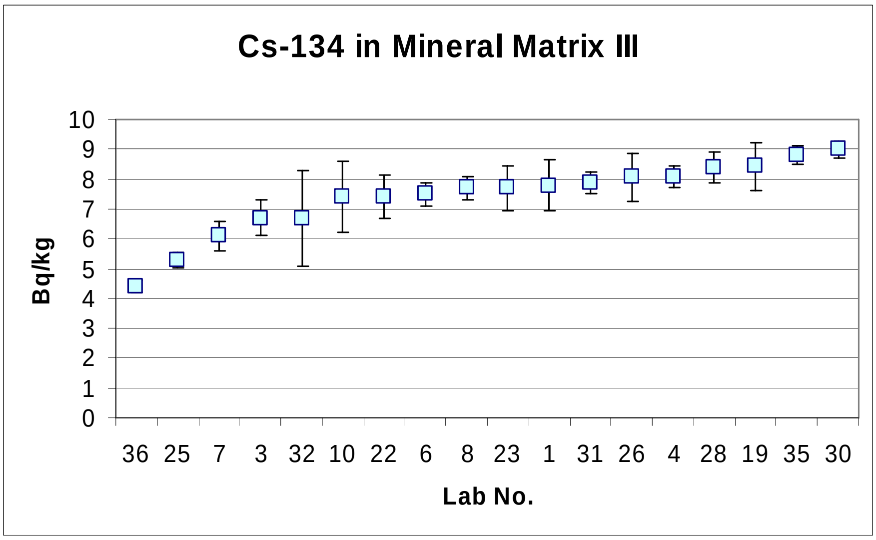
Mineral matrix III

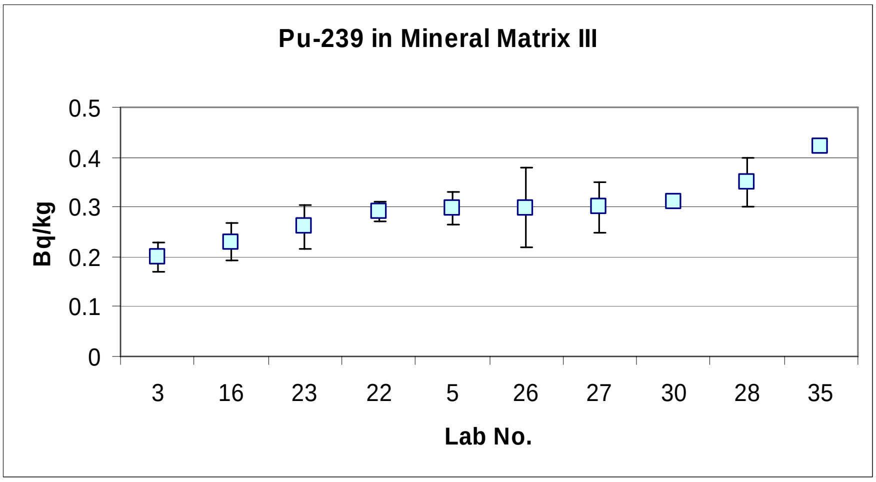
Table 8. Results reported on radionuclides in a certified reference material, soil (mineral matrix III).

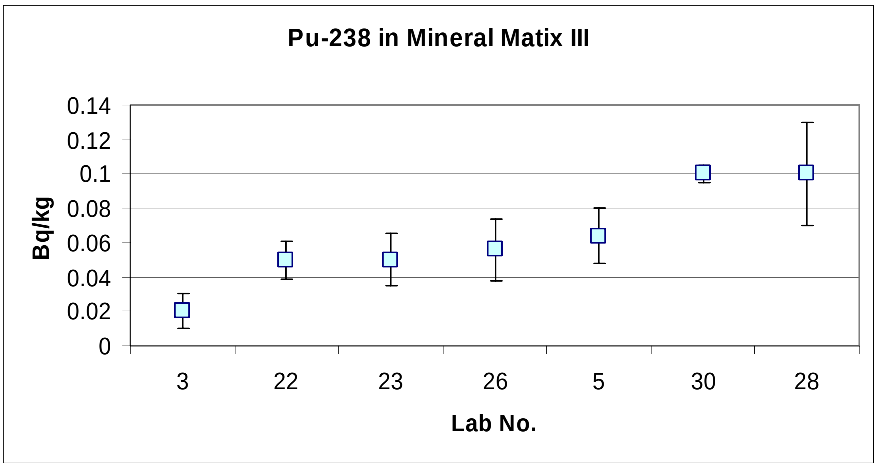
Lab No.	Sr90	1sd	Cs137	1sd	Cs134	1sd	Pu239	1sd	Pu238	1sd	Am241	1sd	Ra226	1sd	Th232	1sd	K40	1sd	Pb210	1sd
	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
1			4045	203	7.8	0.9											421	21		
2			3715	94													426	37		
3	46.2	5.4	3650	80	6.7	0.6	0.200	0.030	0.020	0.010			24.4	2.9	17.9	1.4	400	30		
4	122.5	1.9	4382	35	8.1	0.4					< 13.6		2.2	0.1	25.0	1.2	459	12	< 400	
5	70.8	5.8	3968	43			0.297	0.032	0.064	0.016			20.1	2.1	16.6	1.9	429	24		
6			3945	118	7.5	0.4											430	22		
7	94.0	7.0	3779	127	6.1	0.5									20.0	2.5	364	25		
8			3959	140	7.7	0.4									20.9	1.8	418	22		
10			4069	180	7.4	1.2							24.4	2.9	21.2	2.2	420	17		
11			3821	172																
13	76.2	2.2																		
15	62.0	5.0	3900	100													405	16		
16	75.1	3.0	3740	210			0.230	0.037					22.1	3.4	24.4	2.0	420	25		
17			3420	90																
18	94.5	12.3																		
19	73.5	3.0	4065	134	8.4	0.8							21.0	2.7	19.7	2.8	404	26		
20			3892	140																
21			3769	94									21.3	1.8	25.4	1.8	368	11		
22	105.0	10.5	4130	330	7.4	0.7	0.290	0.020	0.050	0.011							390	39		
23	101.0	13.1	3800	114	7.7	0.8	0.260	0.044	0.050	0.015			17.2	2.6	18.8	1.7	360	18	19.3	2.4
24			3877	6																
25			3981	80	5.3	0.3							19.4	1.0	18.0	0.8	479	14		
26	71.3	7.1	3997	400	8.1	0.8	0.299	0.081	0.056	0.018	0.228	0.074	23.4	2.3	21.7	2.2	457	46	27.0	2.7
27			3700	300			0.300	0.050			0.180	0.030								
28	65.0	15.0	4180	180	8.4	0.5	0.350	0.050	0.100	0.030			22.9	1.5	22.6	1.1	420	20		
30			4660	4	9.0	0.3	0.31	0.01	0.100	0.005	0.44	0.01					457	6	42.5	7.8
31			4034	141	7.9	0.4							17.9	0.6	21.2	0.7	403	15	29.8	2.0
32			3230	10	6.7	1.6											427	11		
33			4560	146									25.1	1.5	23.3	1.6	414	17		
35			4938	9	8.8	0.3	0.421	0.010			0.120	0.050	21.3	0.6	24.3	1.4	483	16	104.0	17.0
36			3537	28	4.4	0.2											387	8		
37			3510	41																
38			3890	389																
Median	75.1		3900		7.7		0.298		0.056		0.204		21.3		21.2		420		29.8	
Ref	75 - 85		3913 - 4034		7.2 – 7.4		0.26 – 0.34		0.056 – 0.085		0.11 – 0.15		18 - 22		19 - 22		417 - 432			

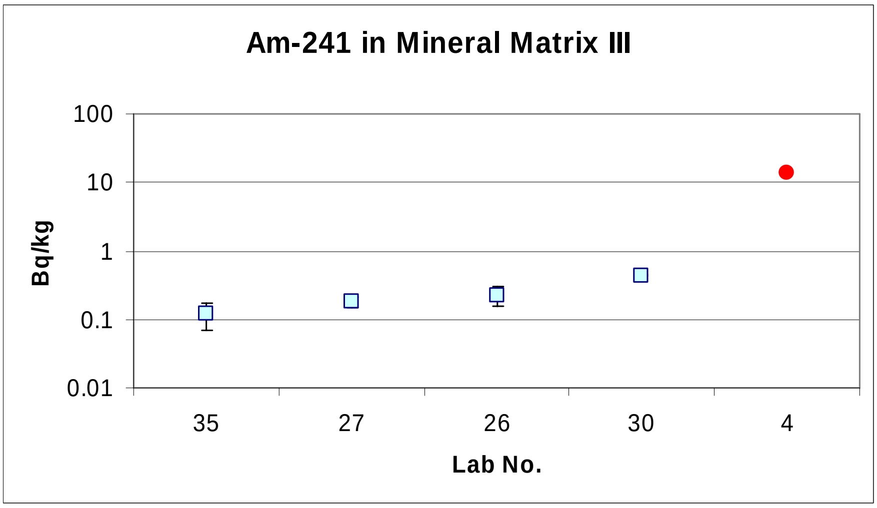

Sr-90 in Mineral Matrix III
Bq/kg
140
120
100
80
60
40
20
0
3 15 28 5 26 19 16 13 7 18 23 22 4
Lab No.

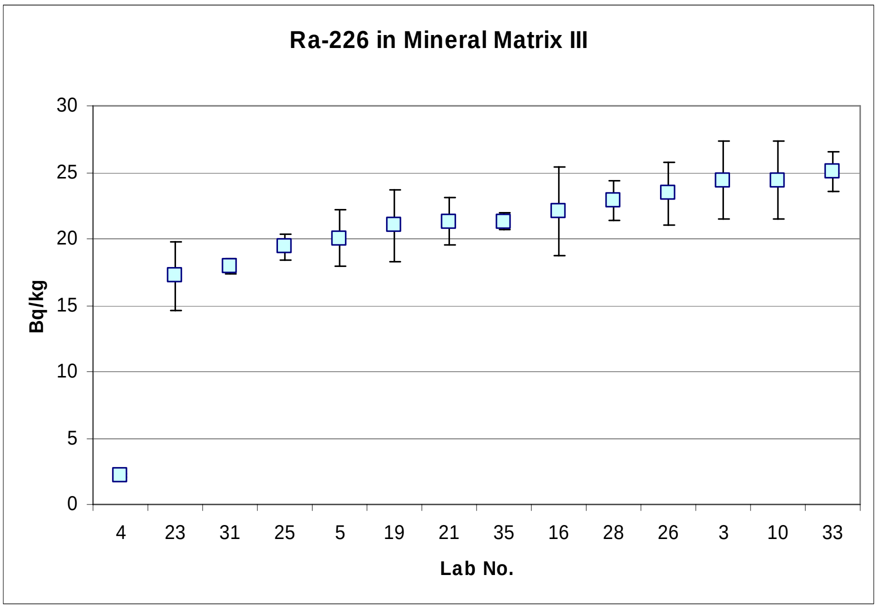

Cs-137 in Mineral Matrix III
Bq/kg
6000
5000
4000
3000
2000
1000
0
32 17 37 36 3 27 2 16 21 7 23 11 24 38 20 15 6 8 5 25 26 31 1 19 10 22 28 4 33 30 35
Lab No.

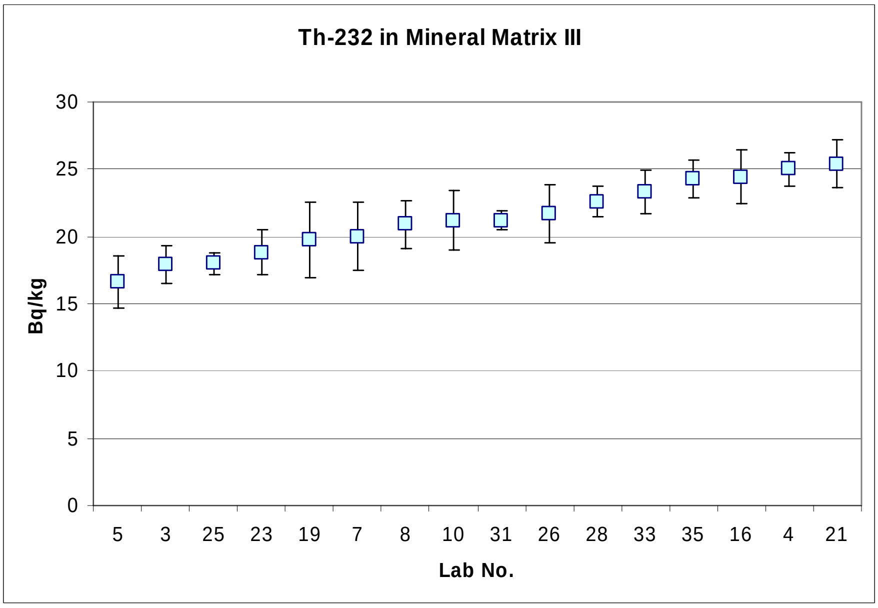

Cs-134 in Mineral Matrix III
Bq/kg
10
9
8
7
6
5
4
3
2
1
0
36 25 7 3 32 10 22 6 8 23 1 31 26 4 28 19 35 30
Lab No.

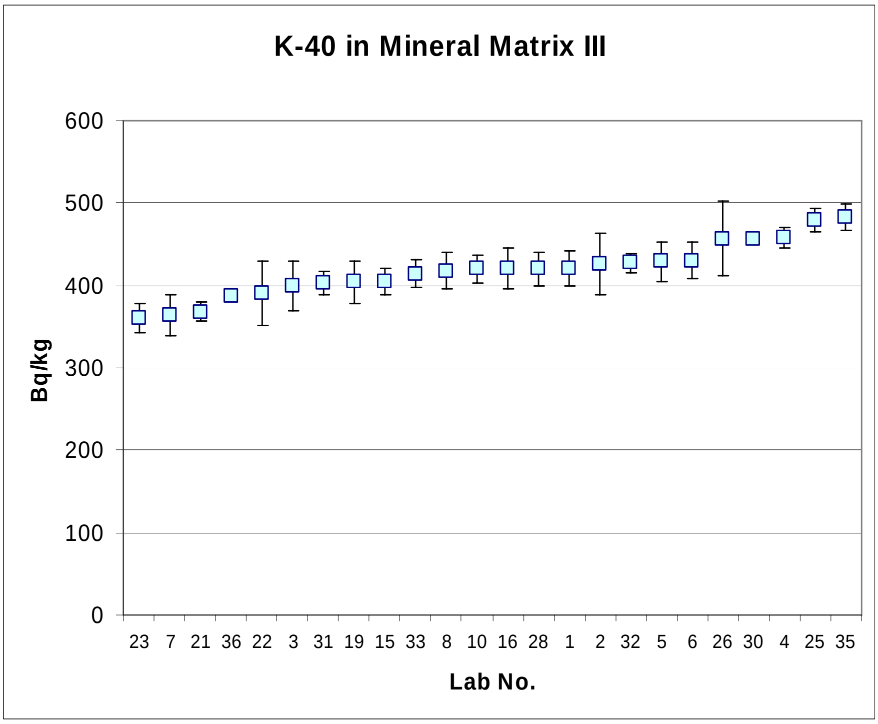

Pu-239 in Mineral Matrix III
Bq/kg
0.5
0.4
0.3
0.2
0.1
0
3
16
23
22
5
26
27
30
28
35
Lab No.

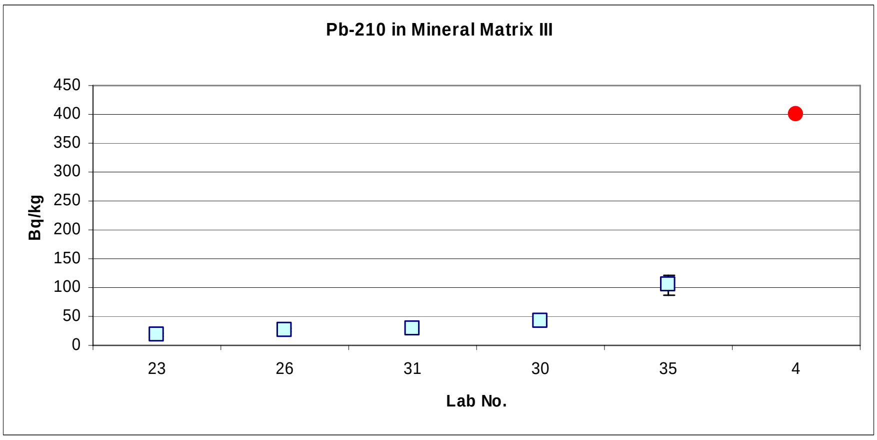

Pu-238 in Mineral Matix III
Bq/kg
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
3
22
23
26
5
30
28
Lab No.


Am-241 in Mineral Matrix III
Bq/kg
100
10
1
0.1
0.01
35
27
26
30
4
Lab No.


Ra-226 in Mineral Matrix III
Bq/kg
0
5
10
15
20
25
30
4
23
31
25
5
19
21
35
16
28
26
3
10
33
Lab No.


Th-232 in Mineral Matrix III
Bq/kg
0
5
10
15
20
25
30
5
3
25
23
19
7
8
10
31
26
28
33
35
16
4
21
Lab No.

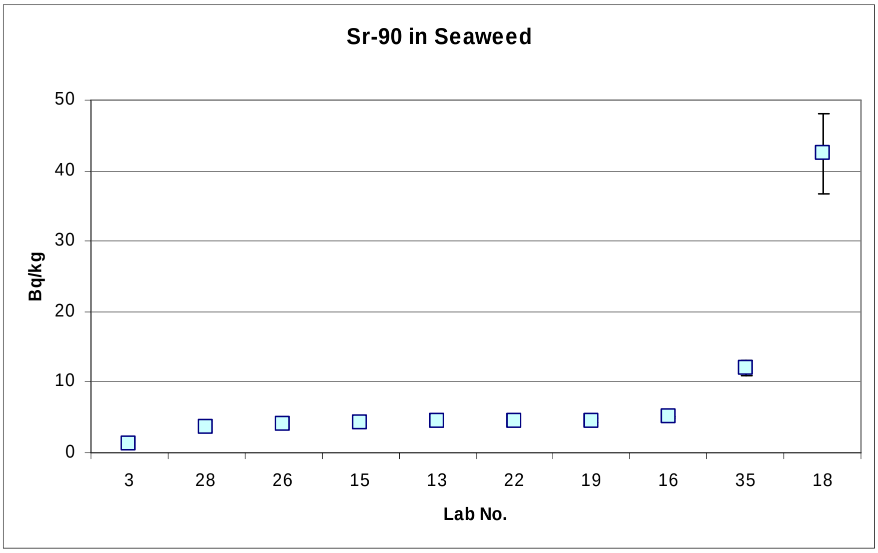

K-40 in Mineral Matrix III
Bq/kg
600
500
400
300
200
100
0
23 7 21 36 22 3 31 19 15 33 8 10 16 28 1 2 32 5 6 26 30 4 25 35
Lab No.

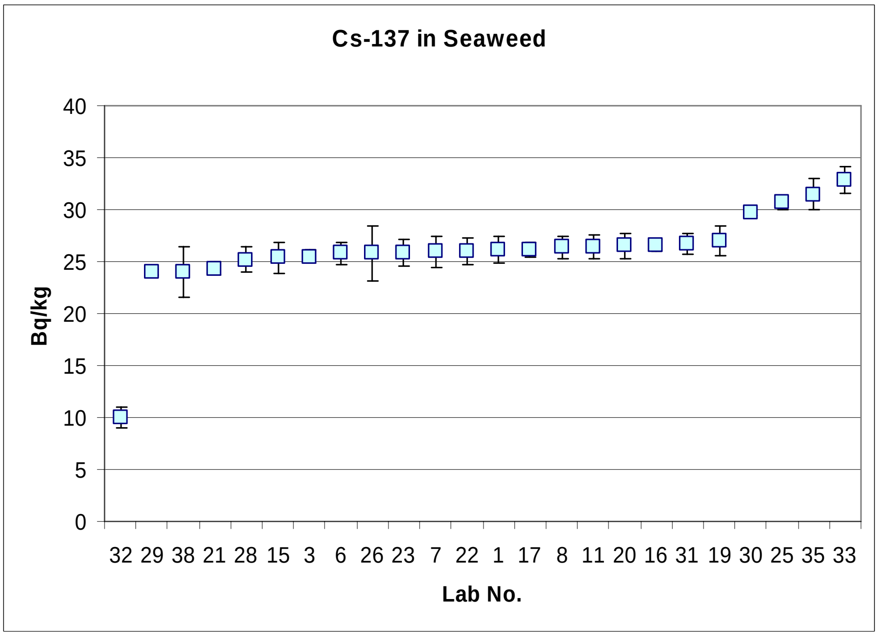

Pb-210 in Mineral Matrix III
Bq/kg
450
400
350
300
250
200
150
100
50
0
23 26 31 30 35 4
Lab No.

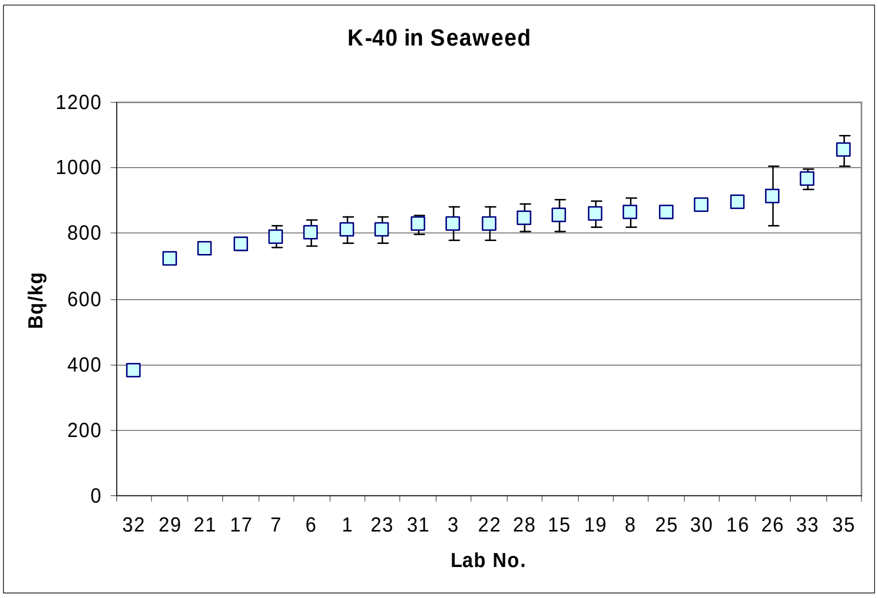
Seaweed

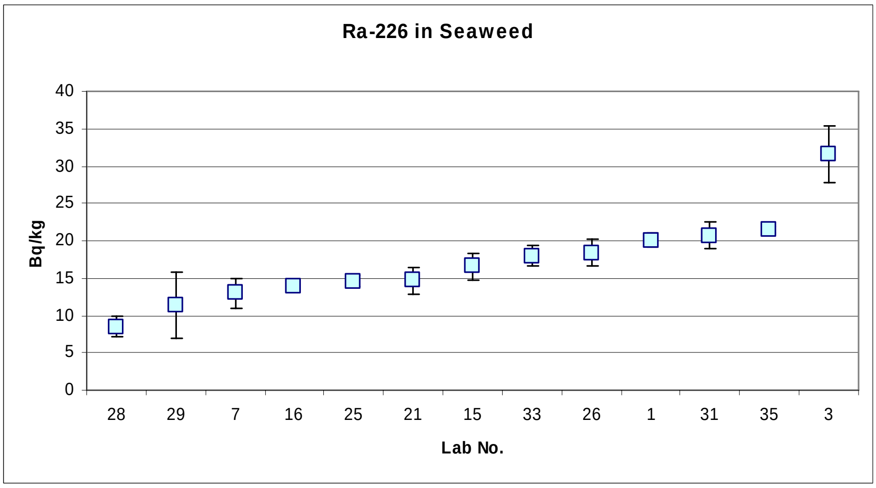
Table 9. Results reported on radionuclides in seaweed.

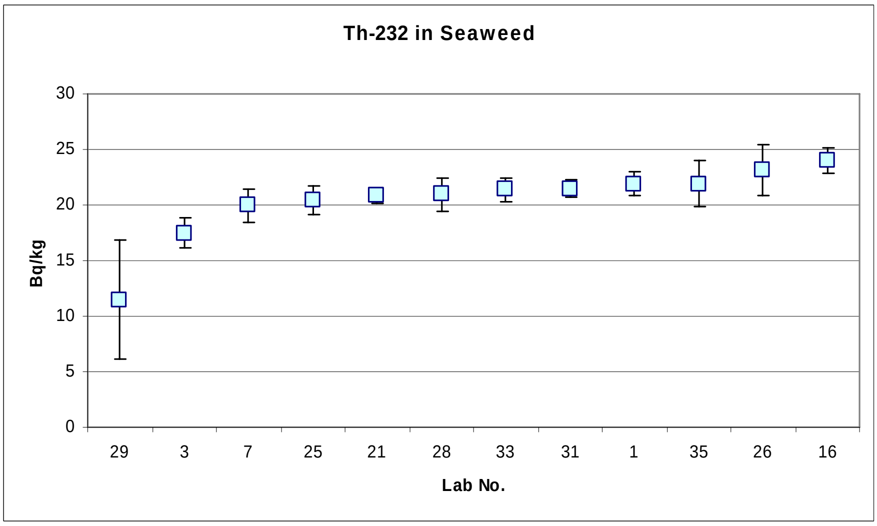
Lab No.	Sr-90	1sd	Cs-137	1sd	K-40	1sd	Ra-226	1sd	Th-232	1sd	Be-7	1sd	Pu-239	1sd	Pu-238	1sd	Am241	1sd	Tc-99	1sd	Pb-210	1sd	Po-210	1sd
	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
1			26.1	1.3	810	41	20.1	1.0	21.9	1.1	54.9	5.0	0.040	0.012	< 0.007		0.041	0.015	27.0	2.7				
3	1.3	0.3	25.5	0.7	830	50	31.6	3.8	17.5	1.4	63.0	7.0	0.060	0.010	0.010	0.005	0.200	0.040						
6			25.8	1.0	803	40																		
7			26.0	1.5	790	33	13.0	2.0	20.0	1.5														
8			26.4	1.1	862	45													28.1	3.1				
11			26.5	1.1																				
13	4.5	0.1																						
15	4.2	0.4	25.4	1.5	855	49	16.6	1.8																
16	5.1	0.2	26.6	0.6	894	12	13.9	0.5	24.0	1.2			0.032	0.003							20.8	4.5	17.5	0.6
17			26.2	0.7	767	19					57.0	8.0												
18	42.4	5.6																						
19	4.6	0.4	27.0	1.4	860	41																		
20			26.5	1.2																				
21			24.3	0.6	753	19	14.7	1.8	20.8	0.7														
22	4.5	0.6	26.0	1.3	830	50																		
23			25.9	1.3	810	41					56.0	6.2	0.054	0.011	< 0.02		0.020	0.008			13.0	2.3	20.0	2.5
25			30.7	0.6	865	18	14.6	0.7	20.4	1.3														
26	4.0	0.4	25.8	2.6	913	91	18.4	1.8	23.1	2.3			0.047	0.005	0.002	0.001	0.013	0.003	24.7	2.5	16.5	1.7	80.0	8.0
28	3.7	0.7	25.2	1.2	847	43	8.5	1.4	21.0	1.5			0.130	0.030	0.033	0.013								
29			24.0	0.3	721	7	11.4	4.4	11.5	5.4														
30			29.7	0.3	887	6					69.1	13.1									33.9	4.2		
31			26.7	1.0	827	30	20.7	1.7	21.5	0.7											27.8	3.1		
32			10.0	1.0	379	4													34.6	1.2				
33			32.9	1.3	966	31	18.0	1.3	21.4	1.1														
35	12.0	1.1	31.5	1.5	1052	47	21.5	0.4	21.9	2.1			0.068	0.017			< 0.02				93.0	12.0		
37																			25.0	8.0				
38			24.0	2.4																				
Median	4.5		26.1		830		16.6		21.2		57		0.054		0.010		0.031		27.0		24.3		20.0	

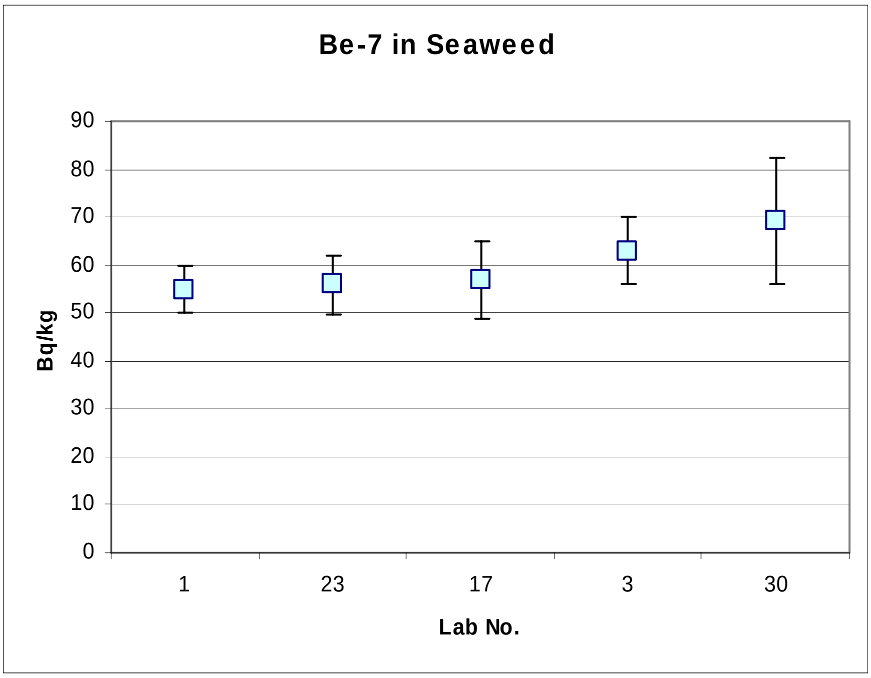

Sr-90 in Seaweed
Bq/kg
50
40
30
20
10
0
3
28
26
15
13
22
19
16
35
18
Lab No.

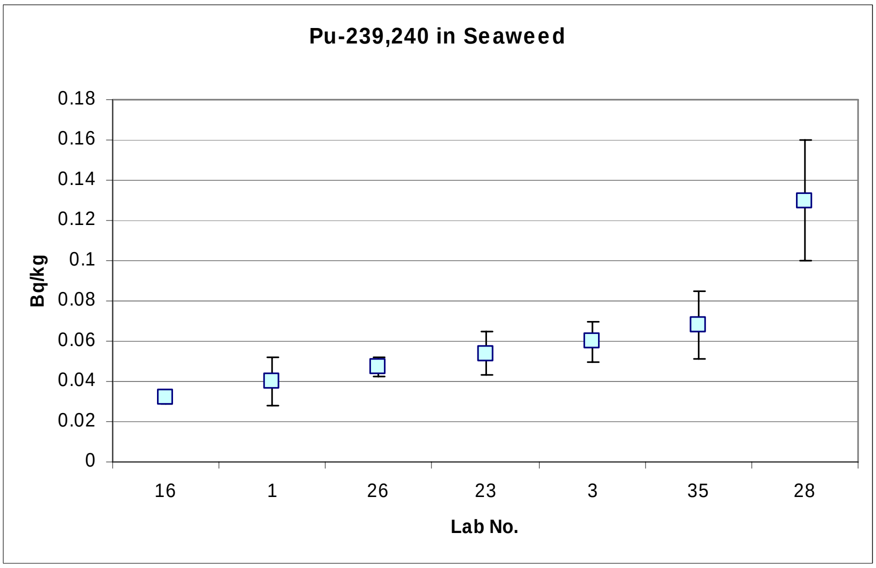

Cs-137 in Seaweed
Bq/kg
40
35
30
25
20
15
10
5
0
32 29 38 21 28 15 3 6 26 23 7 22 1 17 8 11 20 16 31 19 30 25 35 33
Lab No.

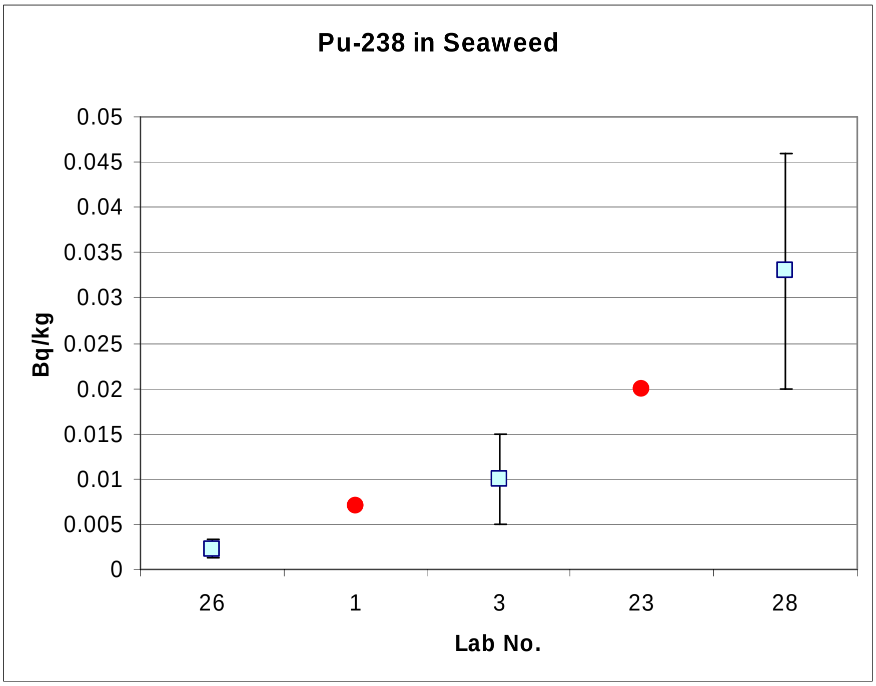

K-40 in Seaweed
Bq/kg
1200
1000
800
600
400
200
0
32 29 21 17 7 6 1 23 31 3 22 28 15 19 8 25 30 16 26 33 35
Lab No.

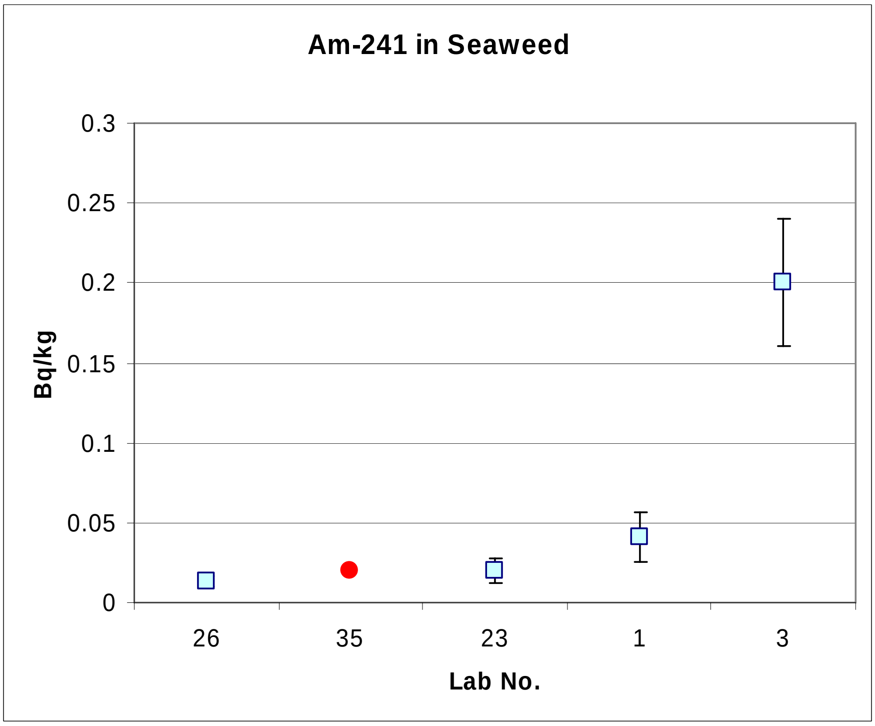

Ra-226 in Seaweed
Bq/kg
40
35
30
25
20
15
10
5
0
28 29 7 16 25 21 15 33 26 1 31 35 3
Lab No.

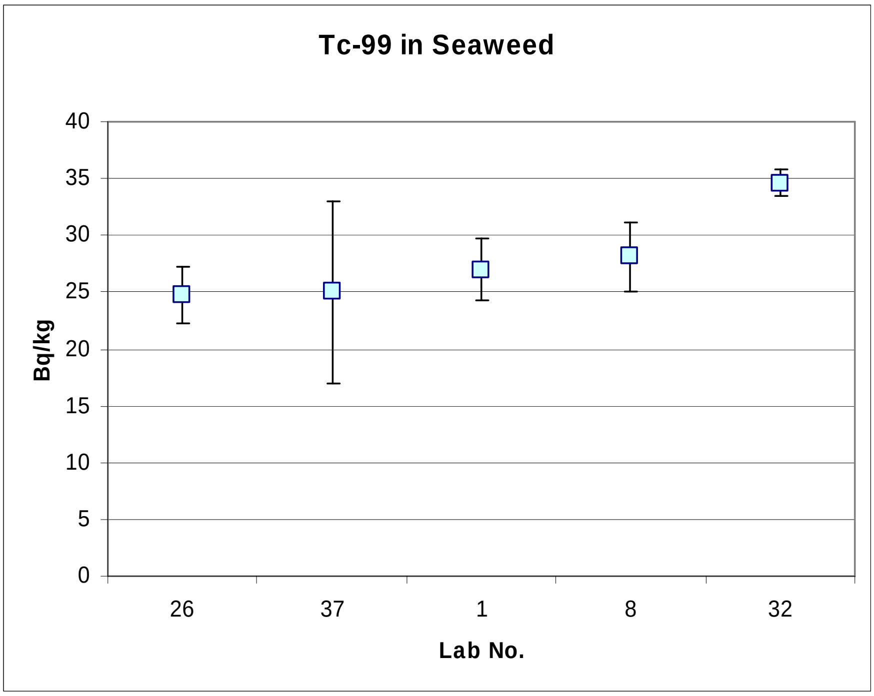

Th-232 in Seaweed
Bq/kg
30
25
20
15
10
5
0
29 3 7 25 21 28 33 31 1 35 26 16
Lab No.

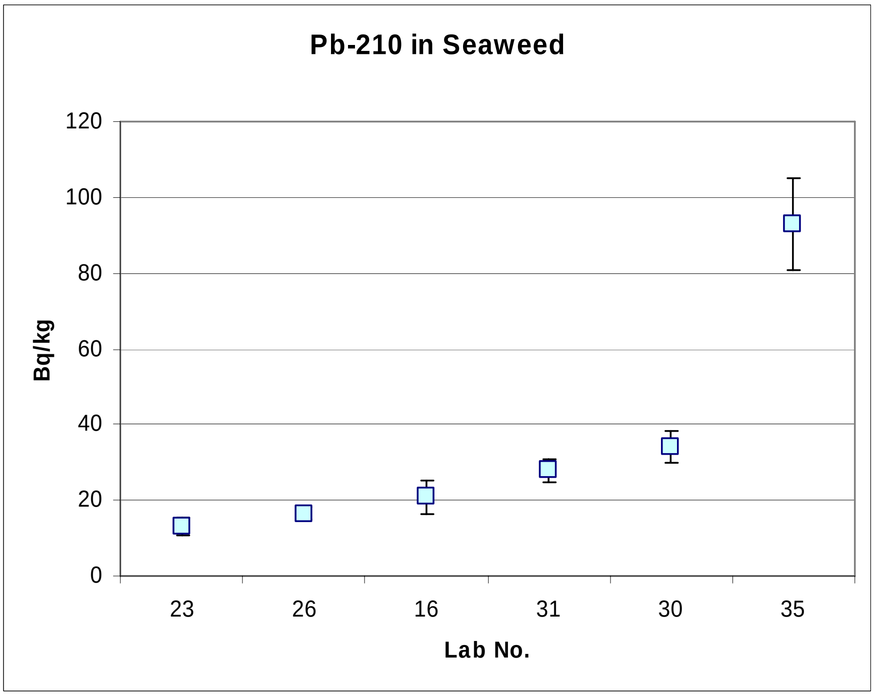

Be-7 in Seaweed
Bq/kg
90
80
70
60
50
40
30
20
10
0
1
23
17
3
30
Lab No.

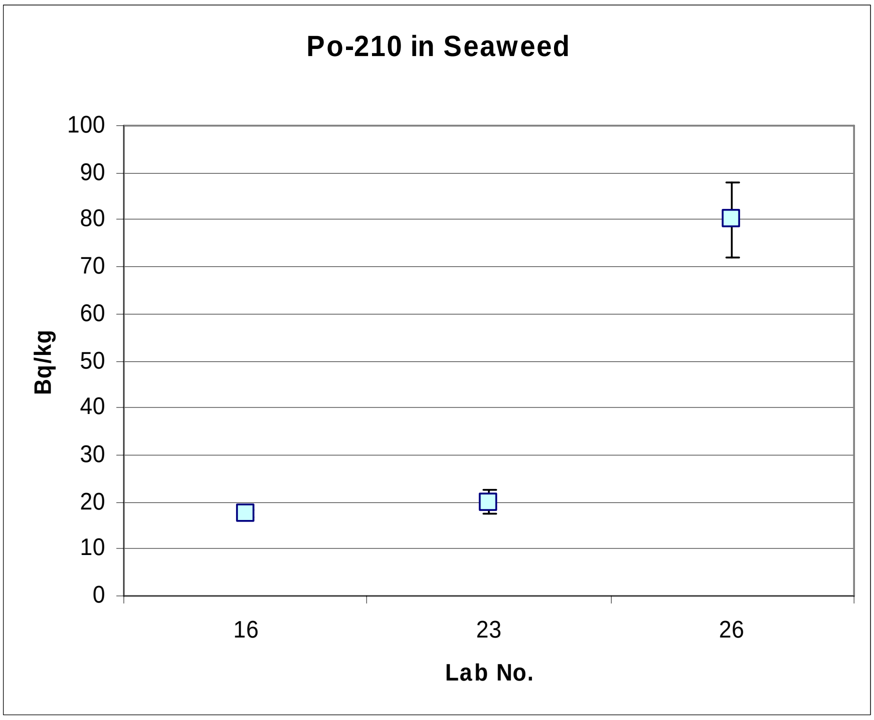

Pu-239,240 in Seaweed
Bq/kg
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
16
1
26
23
3
35
28
Lab No.


Pu-238 in Seaweed
Bq/kg
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
26
1
3
23
28
Lab No.


Am-241 in Seaweed
Bq/kg
0.3
0.25
0.2
0.15
0.1
0.05
0
26
35
23
1
3
Lab No.


Tc-99 in Seaweed
40
35
30
25
20
15
10
5
0
Bq/kg
26
37
1
8
32
Lab No.

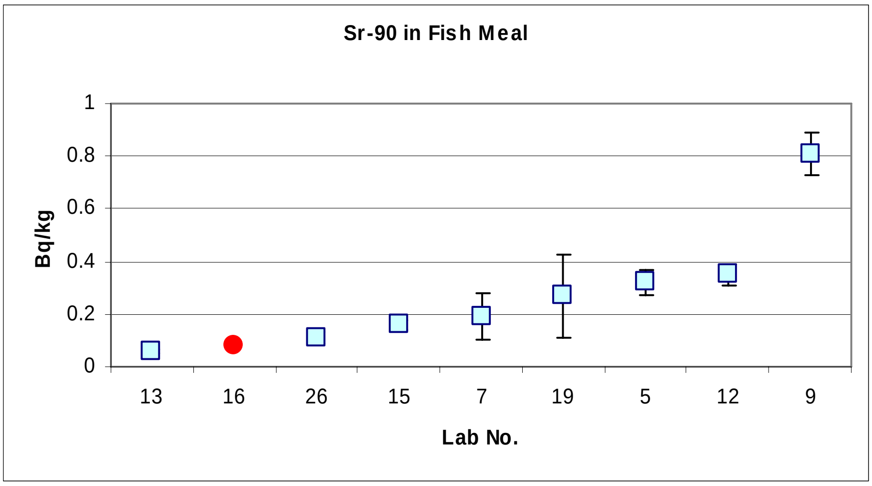

Pb-210 in Seaweed
120
100
80
60
40
20
0
Bq/kg
23
26
16
31
30
35
Lab No.

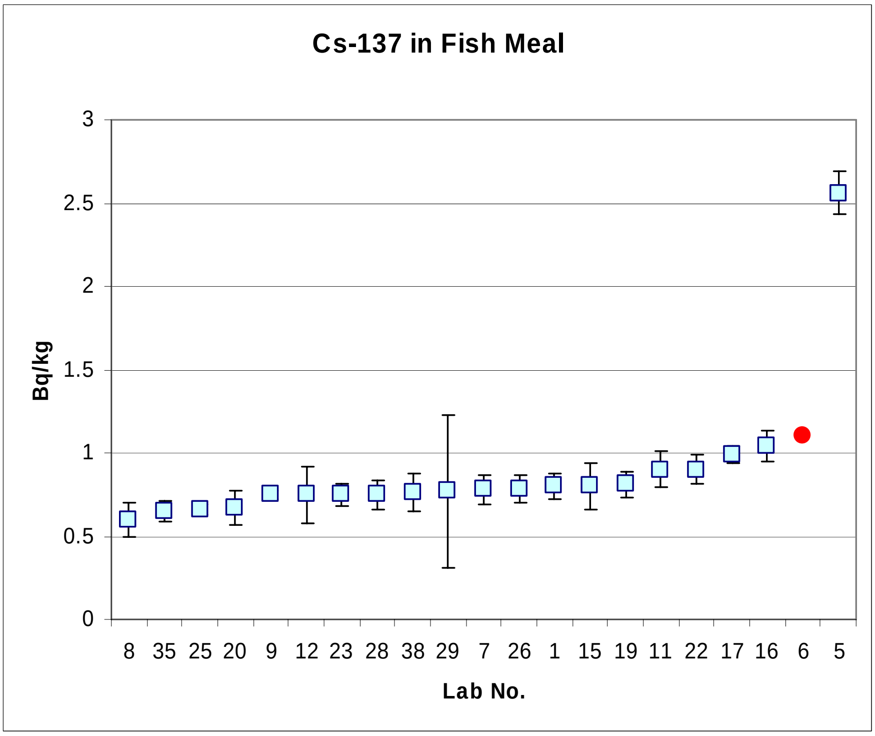

Po-210 in Seaweed
100
90
80
70
60
50
40
30
20
10
0
Bq/kg
16
23
26
Lab No.

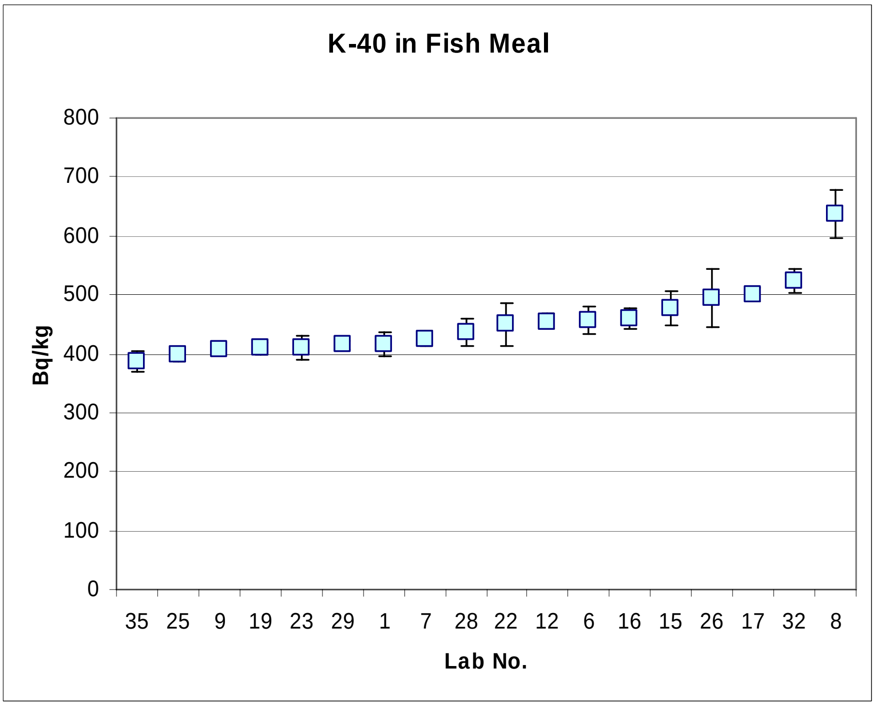
Fish meal

Table 10. Results reported on radionuclides in fish meal.

Lab No.	Sr-90	1sd	Cs-137	1sd	K-40	1sd
	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
1			0.80	0.08	416	21
5	0.32	0.05	2.56	0.13		
6			< 1.1		457	23
7	0.19	0.09	0.78	0.09	426	12
8			0.60	0.10	637	40
9	0.81	0.08	0.75	0.03	408	10
11			0.90	0.11		
12	0.35	0.04	0.75	0.17	455	13
13	0.061	0.007				
15	0.16	0.02	0.80	0.14	478	29
16	< 0.08		1.04	0.10	460	18
17			0.99	0.05	500	11
19	0.27	0.16	0.81	0.08	410	10
20			0.67	0.10		
22			0.90	0.09	450	36
23			0.75	0.07	410	21
25			0.66	0.03	398	11
26	0.11	0.02	0.79	0.08	495	50
28			0.75	0.09	436	23
29			0.77	0.46	415	7
32					524	20
35			0.65	0.06	387	17
38			0.76	0.11		
Median	0.23		0.78		443	



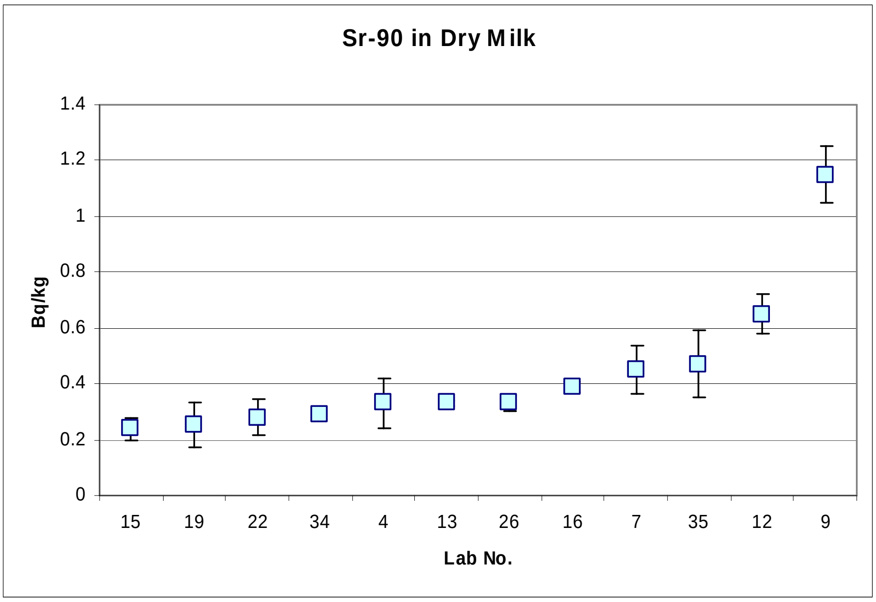

Cs-137 in Fish Meal
Bq/kg
3
2.5
2
1.5
1
0.5
0
8 35 25 20 9 12 23 28 38 29 7 26 1 15 19 11 22 17 16 6 5
Lab No.

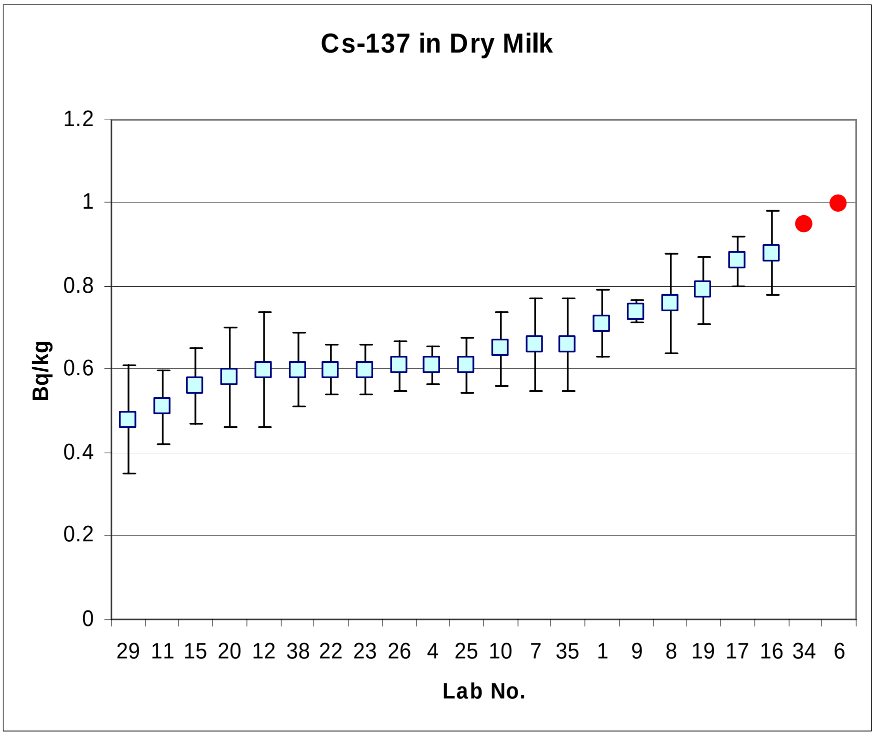

K-40 in Fish Meal
Bq/kg
800
700
600
500
400
300
200
100
0
35 25 9 19 23 29 1 7 28 22 12 6 16 15 26 17 32 8
Lab No.

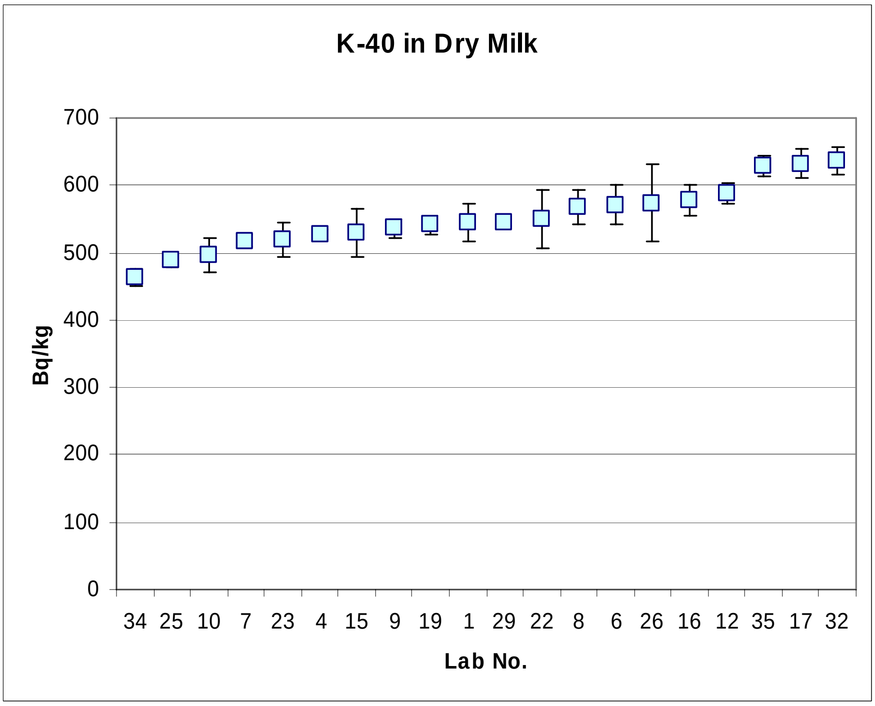
Dry milk

Table 11. Results reported on radionuclides in dry milk.

Lab No.	Sr-90	1sd	Cs-137	1sd	K-40	1sd
	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
1			0.71	0.08	544	28
4	0.33	0.09	0.61	0.04	527	7
6			< 1.0		571	29
7	0.45	0.09	0.66	0.11	518	10
8			0.76	0.12	567	25
9	1.15	0.1	0.74	0.03	536	13
10			0.65	0.09	497	26
11			0.51	0.09		
12	0.65	0.07	0.6	0.14	588	15
13	0.33	0.01				
15	0.24	0.04	0.56	0.09	530	35
16	0.39	0.02	0.88	0.10	577	23
17			0.86	0.06	632	21
19	0.25	0.08	0.79	0.08	541	14
20			0.58	0.12		
22	0.28	0.06	0.6	0.06	550	44
23			0.6	0.06	520	26
25			0.61	0.07	489	11
26	0.33	0.03	0.61	0.06	573	57
29			0.48	0.13	544	5
32					637	21
34	0.29	0.02	< 0.949		463	13
35	0.47	0.12	0.66	0.11	628	15
38			0.60	0.09		
Median	0.33		0.61		544	



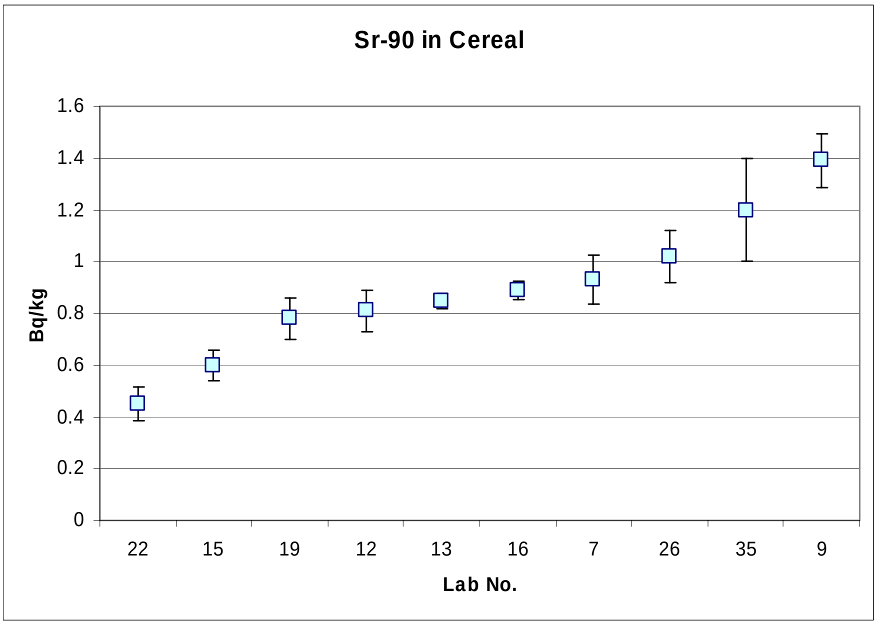

Cs-137 in Dry Milk
1.2
1
0.8
0.6
0.4
0.2
0
Bq/kg
29 11 15 20 12 38 22 23 26 4 25 10 7 35 1 9 8 19 17 16 34 6
Lab No.

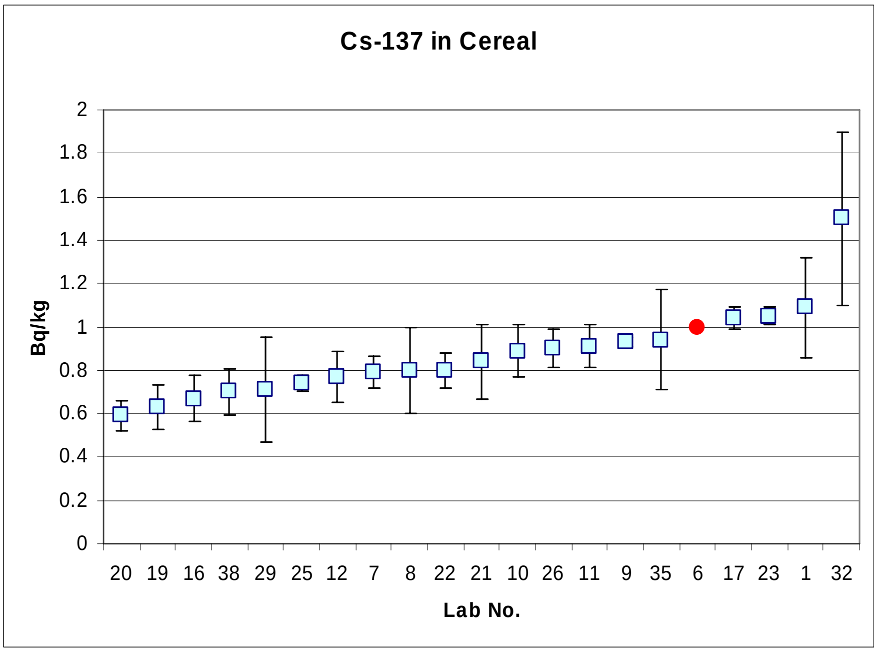

K-40 in Dry Milk
700
600
500
400
300
200
100
0
Bq/kg
34 25 10 7 23 4 15 9 19 1 29 22 8 6 26 16 12 35 17 32
Lab No.

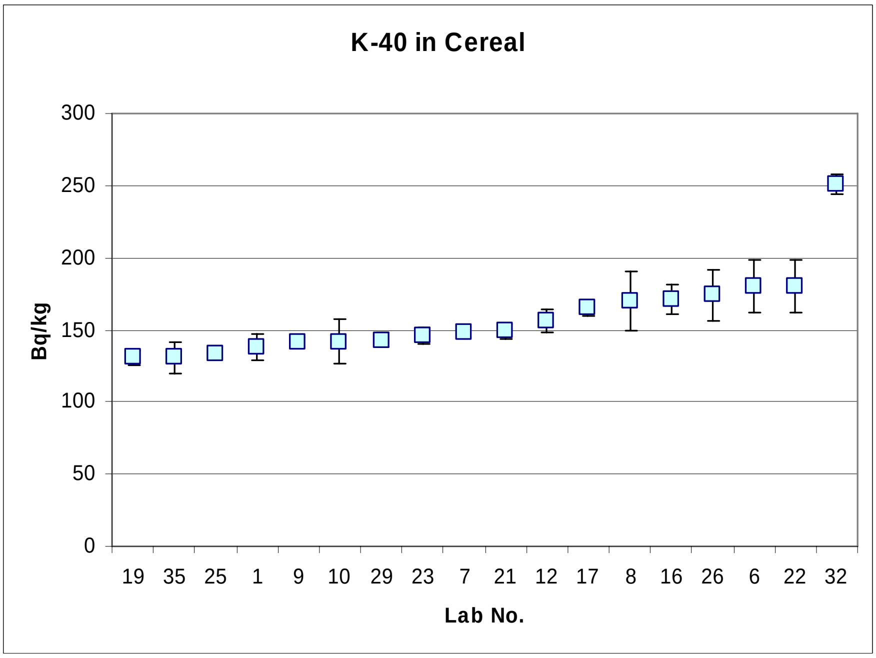
Cereal

Table 12. Results reported on radionuclides in cereal.

Lab No.	Sr-90	1sd	Cs-137	1sd	K-40	1sd
	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
1			1.09	0.23	138	9
6			< 1.0		180	18
7	0.93	0.10	0.79	0.08	148	4
8			0.80	0.20	170	20
9	1.39	0.11	0.93	0.03	141	4
10			0.89	0.12	142	15
11			0.91	0.10		
12	0.81	0.08	0.77	0.12	156	8
13	0.85	0.03				
15	0.60	0.06				
16	0.89	0.04	0.67	0.11	171	10
17			1.04	0.05	165	5
19	0.78	0.08	0.63	0.10	131	5
20			0.59	0.07		
21			0.84	0.17	149	5
22	0.45	0.06	0.80	0.08	180	18
23			1.05	0.04	146	6
25			0.74	0.03	134	4
26	1.02	0.10	0.90	0.09	174	17
29			0.71	0.24	143	5
32			1.50	0.40	251	7
35	1.20	0.20	0.94	0.23	131	11
38			0.70	0.11		
Median	0.87		0.82		149	



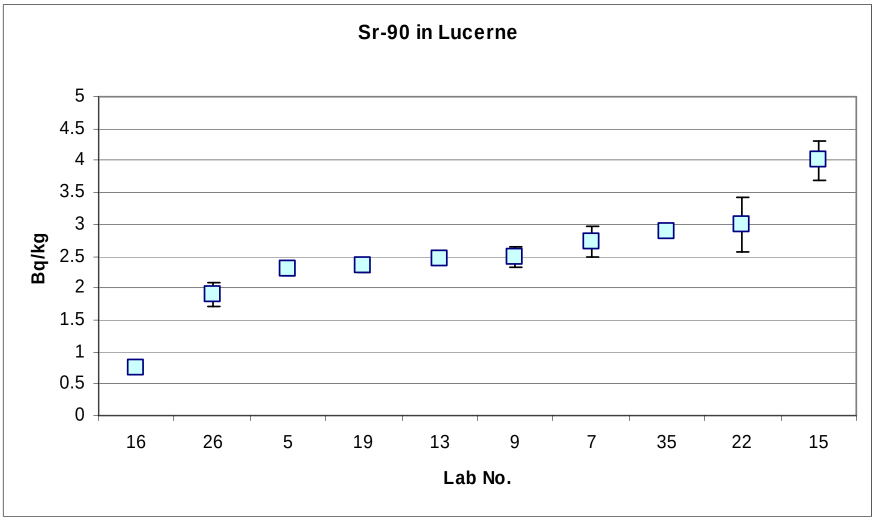

Cs-137 in Cereal
Bq/kg
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
20 19 16 38 29 25 12 7 8 22 21 10 26 11 9 35 6 17 23 1 32
Lab No.

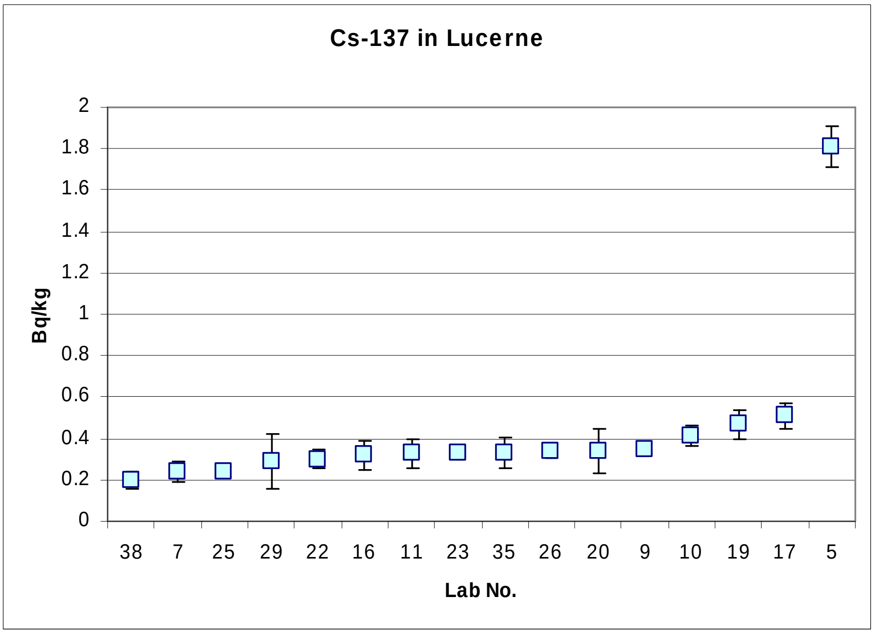

K-40 in Cereal
Bq/kg
300
250
200
150
100
50
0
19 35 25 1 9 10 29 23 7 21 12 17 8 16 26 6 22 32
Lab No.

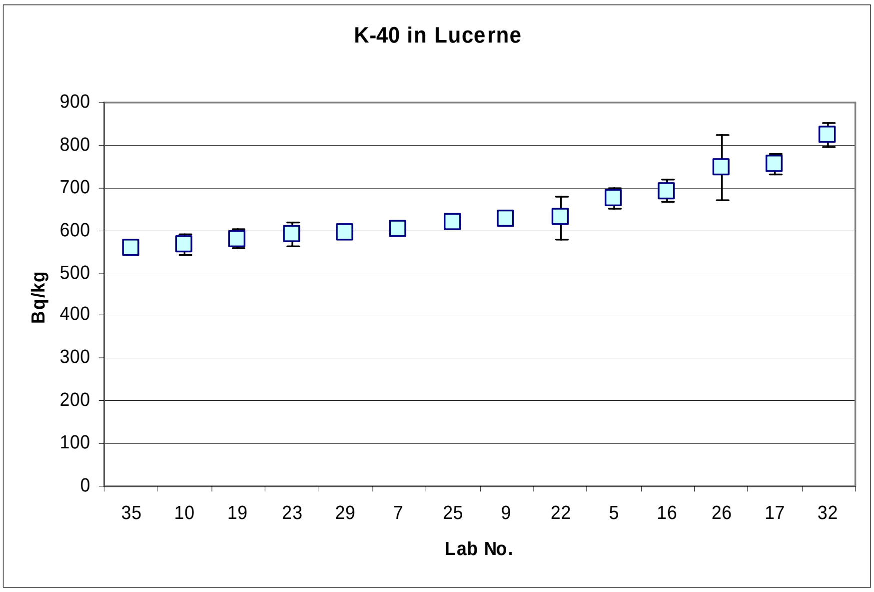
Lucerne

Table 13. Results reported on radionuclides in lucerne.

Lab No.	Sr-90	1sd	Cs-137	1sd	K-40	1sd
	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg	Bq/kg
5	2.29	0.10	1.81	0.10	675	23
7	2.73	0.24	0.24	0.05	602	6
9	2.48	0.16	0.35	0.02	626	16
10			0.41	0.05	567	25
11			0.33	0.07		
13	2.47	0.07				
15	4.00	0.30				
16	0.75	0.03	0.32	0.07	693	27
17			0.51	0.06	756	25
19	2.34	0.10	0.47	0.07	580	23
20			0.34	0.11		
22	3.00	0.42	0.30	0.05	630	50
23			0.33	0.02	590	30
25			0.24	0.03	620	13
26	1.90	0.19	0.34	0.03	748	75
29			0.29	0.13	596	5
32					824	29
35	2.90	0.10	0.33	0.07	558	14
38			0.20	0.04		
Median	2.48		0.33		623	




Cs-137 in Lucerne
Bq/kg
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
38 7 25 29 22 16 11 23 35 26 20 9 10 19 17 5
Lab No.


K-40 in Lucerne
Bq/kg
900
800
700
600
500
400
300
200
100
0
35 10 19 23 29 7 25 9 22 5 16 26 17 32
Lab No.

Evaluation

The evaluation procedure involves a comparison of the result x from each participant (radionuclide activity concentration) for a single radionuclide and sample type with the median of the results x_m across laboratories. From this a z-score value is calculated according to $z = (x-x_m)/\sigma$, where σ is a target standard deviation, for which a value of 10% has been assumed throughout for this intercomparison. Values of z-scores are combined across sample types into rescaled sums of z-scores according to $RSZ = (\Sigma z)/n^{½}$, where n is the number of sample types. The RSZ-value is an indicator of analytical bias for the radionuclide in question and used for a test in the normal distribution. When tested at a 99% level of significance, values of RSZ lower than -2.6 indicate analytical bias on the low side exceeding the target standard deviation of 10% and RSZ values higher than 2.6 indicate analytical bias on the high side larger than 10%.

Table 14. Summary of the performance tests.

Radionuclide	Laboratories submitting results	Laboratories passing evaluation criteria	
^{90}Sr	20	3	15%
^{99}Tc	5	4	80%
^{134}Cs	19	16	84%
^{137}Cs	35	27	77%
^{238}Pu	8	2	25%
^{239,240}Pu	11	8	73%
^{241}Am	7	1	14%
^{226}Ra	20	14	70%
^{232}Th	21	16	76%
^{40}K	29	26	90%
^{210}Pb	8	3	38%
^{210}Po	3	2	67%
^{7}Be	5	5	100%
Tritium	17	12	71%
Total alpha	6	2	33%
Total beta	7	3	43%

Furthermore, values of z-scores for individual radionuclides are combined across sample types into sums of squares of z-scores according to $SSZ = \Sigma z^2$. The SSZ-value is an indicator of analytical accuracy and used for a test in the chi-square distribution. If tested at the 99% significance level and in case that a participant has submitted results on concentrations of a certain radionuclide in 4 sample types, SSZ values in the range from 0.2 to 14.9 indicate that the analytical accuracy is consistent with the assumption of an analytical uncertainty corresponding to a 10% standard deviation. If the SSZ-value is lower than 0.2, this indicates that the accuracy corresponds to an analytical uncertainty smaller than 10%. Correspondingly, if the SSZ-value is higher than 14.9, this indicates that the accuracy corresponds to an analytical uncertainty, which is greater than 10%.

The results of the tests are summarised by radionuclide across sample types in Table 14 listing the number of participants submitting analytical results, the number of those whose performance matches the target standard deviation or better. The tests were made at the 99% significance level. The detailed results of the evaluation are shown in the appendix, which lists the test parameters and significance levels for the radionuclides across sample types for each participant. In addition graphs show column charts for each radionuclide of the sums of z-scores for each participant with information on contributions from each sample type.

Conclusions

Thirty-eight laboratories participated in an intercomparison exercise carried out in 2004 and 2005 on laboratory analyses of radionuclides in environmental samples and food. The sample types included seawater, lake water, tap water, sediment, seaweed, fish meal, soil, dry milk, cereal and lucerne and the exercise involved artificial and naturally occurring radionuclides including total alpha and beta radioactivity.

The evaluation of analytical performance was based on comparison with median values, a 10% target standard deviation and statistical tests at the 99% level. More than half of the laboratories passed the evaluation criteria for ^{99}Tc, ^{134}Cs, ^{137}Cs, ^{239,240}Pu, ^{226}Ra, ^{232}Th, ^{40}K, ^{210}Po, ^{7}Be and tritium while less than half of the participants passed the criteria for ^{90}Sr, ^{238}Pu, ^{241}Am, ^{210}Pb, total alpha and total beta radioactivity.

The analytical results compare well across many of the laboratories. However, the results indicate that there is room for improvement of the analytical quality at most laboratories. It is also noteworthy that the results on total alpha and beta radioactivity in lake water show quite poor agreement, which is a matter of implication for national screening programmes of radioactivity in drinking water.

It is important, to recognise the subjective components of the evaluation that include the choice of using median values to represent the true values and the choice of a target standard deviation of 10%. However, for one certified reference material included in the exercise, the median and the reference values were in good agreement.

Acknowledgement

This work was sponsored by the Nordic Nuclear Safety Research, NKS (http://www.nks.org).

References

Nielsen, S.P., 1996. An Intercomparison Exercise on radionuclides in Sediment Samples. Risø-R-914(EN). Risø National Laboratory, Roskilde, Denmark

Fogh, C.L., 2000. NKS 1999 intercomparison of measurements of radioactivity. NKS-19. Nordic nuclear safety research, Roskilde, Denmark

Fogh, C.L., Nielsen, S.P. and Keith-Roach, M., 2002. Intercomparison of Radionuclides in Environmental Samples 2000-2001. Nordic nuclear safety research, Roskilde, Denmark

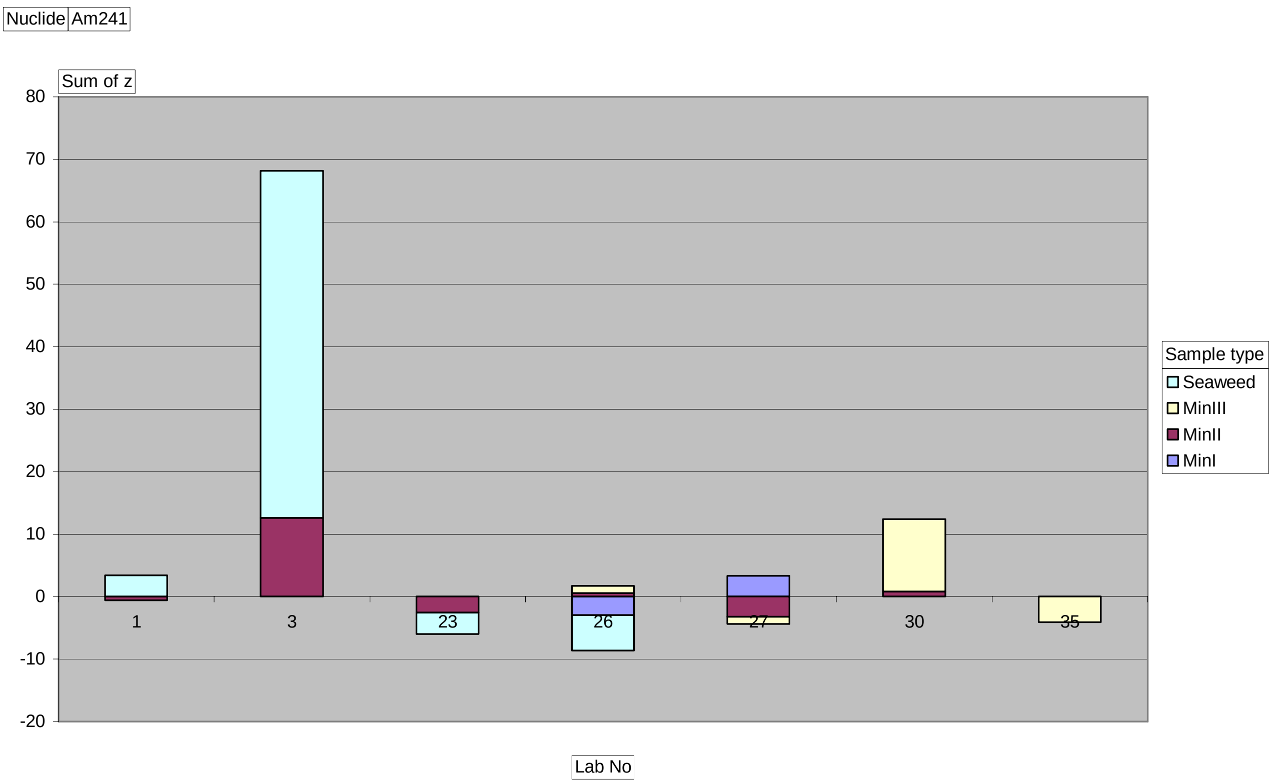
Appendix

The evaluation of the results from each participant is shown in the following tables and graphs for individual radionuclides across samples. The evaluation is based on the methods described previously, where n indicates the number of results submitted, RSZ the rescaled sum of z-scores, SSZ the sum of squares of z-scores, and Sign the associated levels of significance ("ns" denotes not significant, "*" significant at the 95% level, "**" significant at the 99% level, and "***" significant at the 99.9% level).

Americium-241

Table A 1. Statistical evaluation of the results for ^{241}Am.

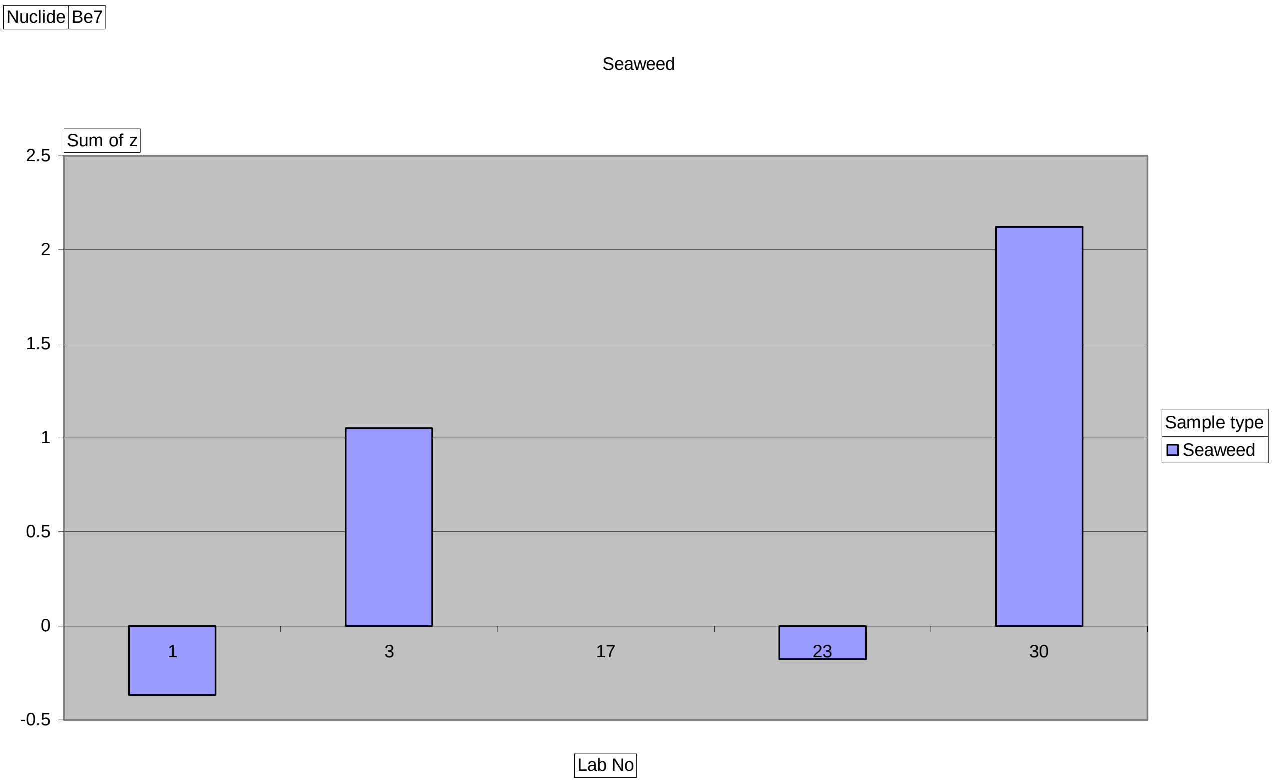
Lab No	n	RSZ	Sign	SSZ	Sign
1	3	1.7	ns	12.2	*
3	2	48.2	***	3246.9	***
23	2	-4.2	***	18.3	***
26	4	-3.4	**	42.7	***
27	3	-0.6	ns	22.9	***
30	2	8.8	***	134.5	***
35	1	-4.1	***	17.0	***



Beryllium-7

Table A 2. Statistical evaluation of the results for ^{7}Be.

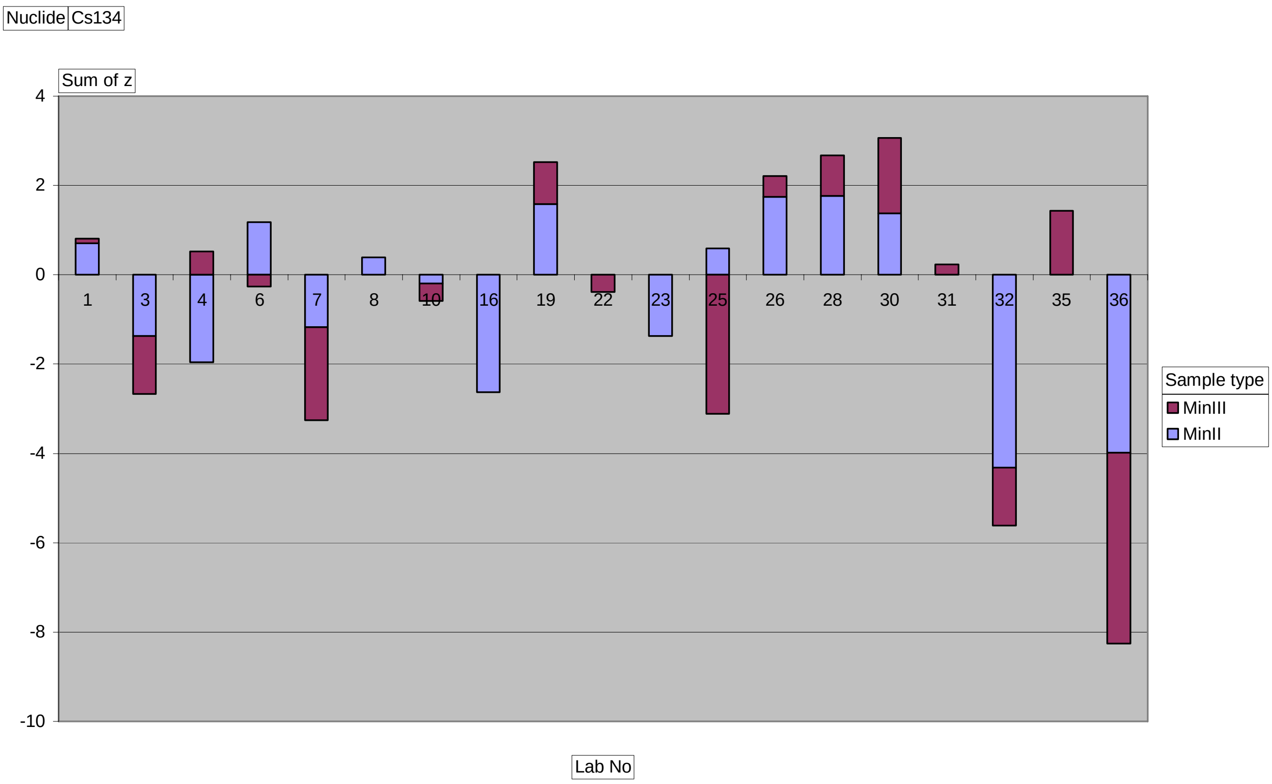
Lab No	n	RSZ	Sign	SSZ	Sign
1	1	-0.4	ns	0.1	ns
3	1	1.1	ns	1.1	ns
17	1	0.0	ns	0.0	***
23	1	-0.2	ns	0.0	ns
30	1	2.1	*	4.5	ns



Caesium-134

Table A 3. Statistical evaluation of the results for ^{134}Cs.

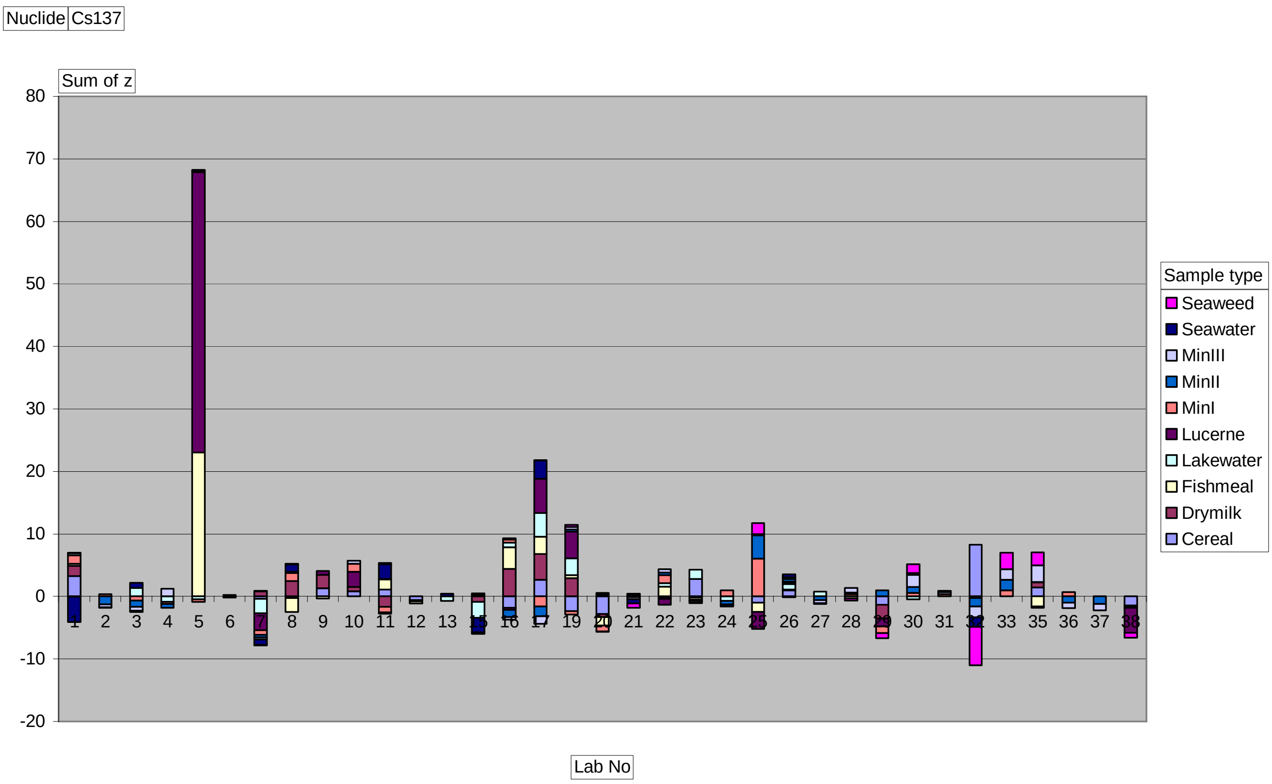
Lab No	n	RSZ	Sign	SSZ	Sign	Lab No	n	RSZ	Sign	SSZ	Sign
1	2	0.6	ns	0.5	ns	23	2	-1.0	ns	1.9	ns
3	2	-1.9	ns	3.6	ns	25	2	-1.8	ns	10.1	*
4	2	-1.0	ns	4.1	ns	26	2	1.6	ns	3.3	ns
6	2	0.6	ns	1.5	ns	28	2	1.9	ns	3.9	ns
7	2	-2.3	*	5.7	ns	30	2	2.2	*	4.7	ns
8	2	0.3	ns	0.2	ns	31	1	0.2	ns	0.1	ns
10	2	-0.4	ns	0.2	ns	32	2	-4.0	***	20.3	***
16	1	-2.6	**	6.9	*	35	2	1.0	ns	2.0	ns
19	2	1.8	ns	3.4	ns	36	2	-5.8	***	34.1	***
22	2	-0.3	ns	0.2	ns						



Caesium-137

Table A 4. Statistical evaluation of the results for ^{137}Cs.

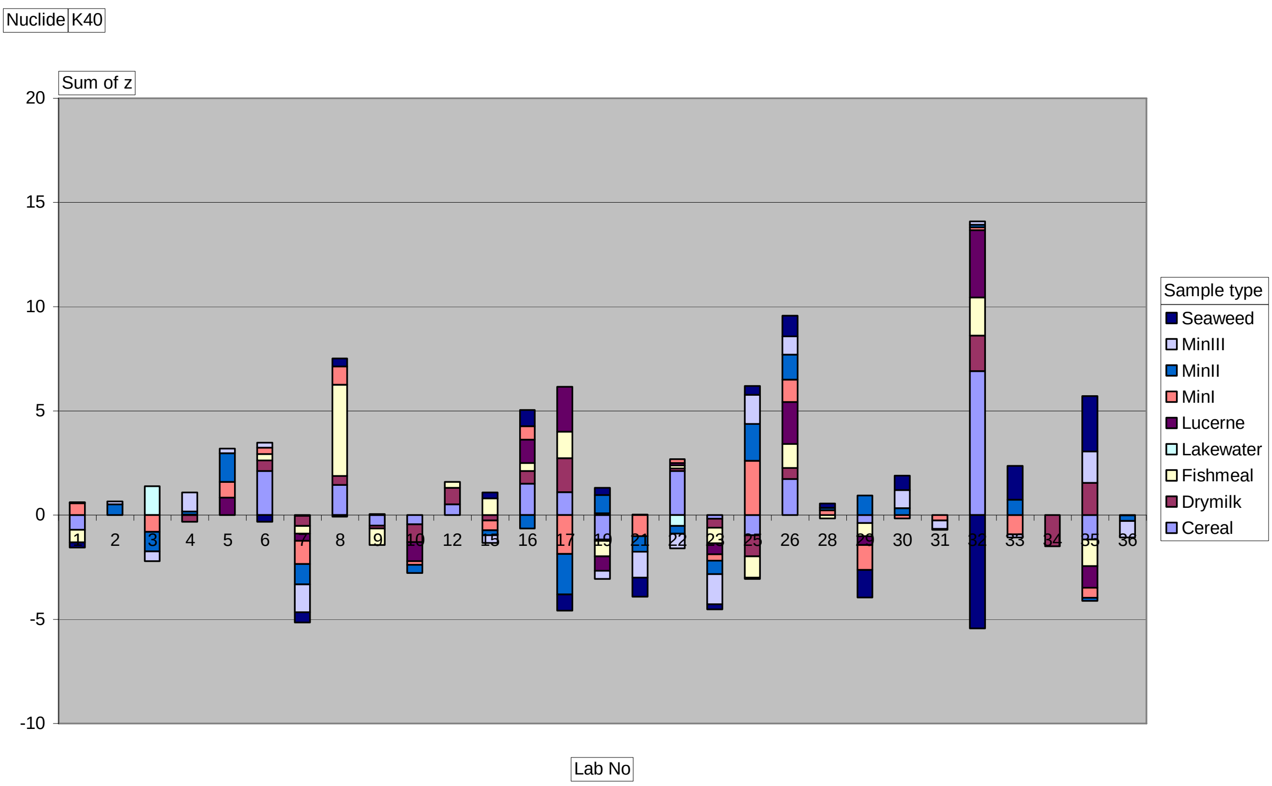
Lab No	n	RSZ	Sign	SSZ	Sign	Lab No	n	RSZ	Sign	SSZ	Sign
1	8	1.0	ns	32.3	***	21	6	-0.5	ns	1.1	*
2	5	-0.7	ns	1.9	ns	22	9	1.0	ns	6.0	ns
3	6	-0.1	ns	4.4	ns	23	9	1.1	ns	10.4	ns
4	5	-0.3	ns	2.7	ns	24	5	-0.3	ns	1.8	ns
5	6	27.5	***	2542.3	***	25	8	2.3	*	64.3	***
6	5	0.0	ns	0.0	***	26	10	1.1	ns	2.4	*
7	10	-2.2	*	15.1	ns	27	5	-0.2	ns	1.2	ns
8	8	1.0	ns	14.2	ns	28	5	0.3	ns	0.9	ns
9	4	1.9	ns	6.8	ns	29	7	-2.2	*	10.6	ns
10	6	2.3	*	9.0	ns	30	6	1.9	ns	7.3	ns
11	9	0.9	ns	13.3	ns	31	3	0.5	ns	0.3	ns
12	3	-0.6	ns	0.5	ns	32	7	-1.0	ns	113.9	***
13	2	-0.2	ns	0.7	ns	33	4	3.5	***	13.7	*
15	8	-1.9	ns	13.0	ns	35	8	1.9	ns	16.9	ns
16	9	1.9	ns	37.0	***	36	3	-0.7	ns	2.3	ns
17	10	5.5	***	91.1	***	37	2	-1.6	ns	2.5	ns
19	9	2.9	**	40.4	***	38	8	-2.3	*	18.3	*
20	8	-1.8	ns	11.0	ns						



Potassium-40

Table A 5. Statistical evaluation of the results for ^{40}K.

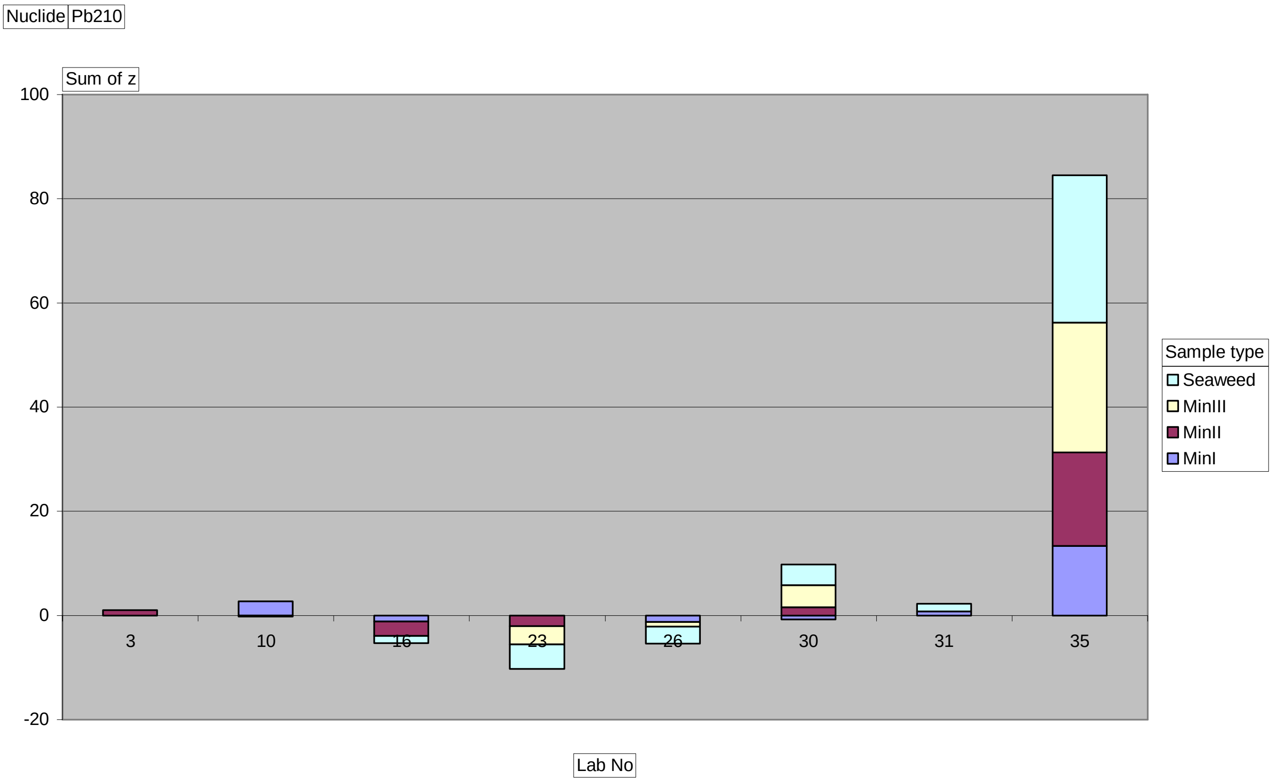
Lab No	n	RSZ	Sign	SSZ	Sign	Lab No	n	RSZ	Sign	SSZ	Sign
1	7	-0.4	ns	1.3	*	21	5	-1.7	ns	4.0	ns
2	3	0.4	ns	0.3	ns	22	9	0.4	ns	5.5	ns
3	5	-0.4	ns	3.6	ns	23	9	-1.5	ns	3.7	ns
4	4	0.4	ns	1.0	ns	25	8	1.1	ns	15.0	ns
5	4	1.6	ns	3.2	ns	26	8	3.4	***	13.0	ns
6	7	1.2	ns	5.1	ns	28	5	0.2	ns	0.1	***
7	8	-1.8	ns	4.7	ns	29	7	-1.1	ns	4.8	ns
8	7	2.8	**	22.4	**	30	4	0.9	ns	1.4	ns
9	4	-0.7	ns	0.9	ns	31	3	-0.4	ns	0.2	ns
10	6	-1.1	ns	1.9	ns	32	8	3.1	**	93.9	***
12	3	0.9	ns	1.0	ns	33	4	0.6	ns	4.1	ns
15	6	-0.1	ns	1.2	*	34	1	-1.5	ns	2.2	ns
16	8	1.6	ns	5.5	ns	35	8	0.6	ns	16.1	ns
17	7	0.6	ns	17.9	*	36	3	-0.6	ns	0.7	ns
19	8	-0.6	ns	3.5	ns						



Lead-210

Table A 6. Statistical evaluation of the results for ^{210}Pb.

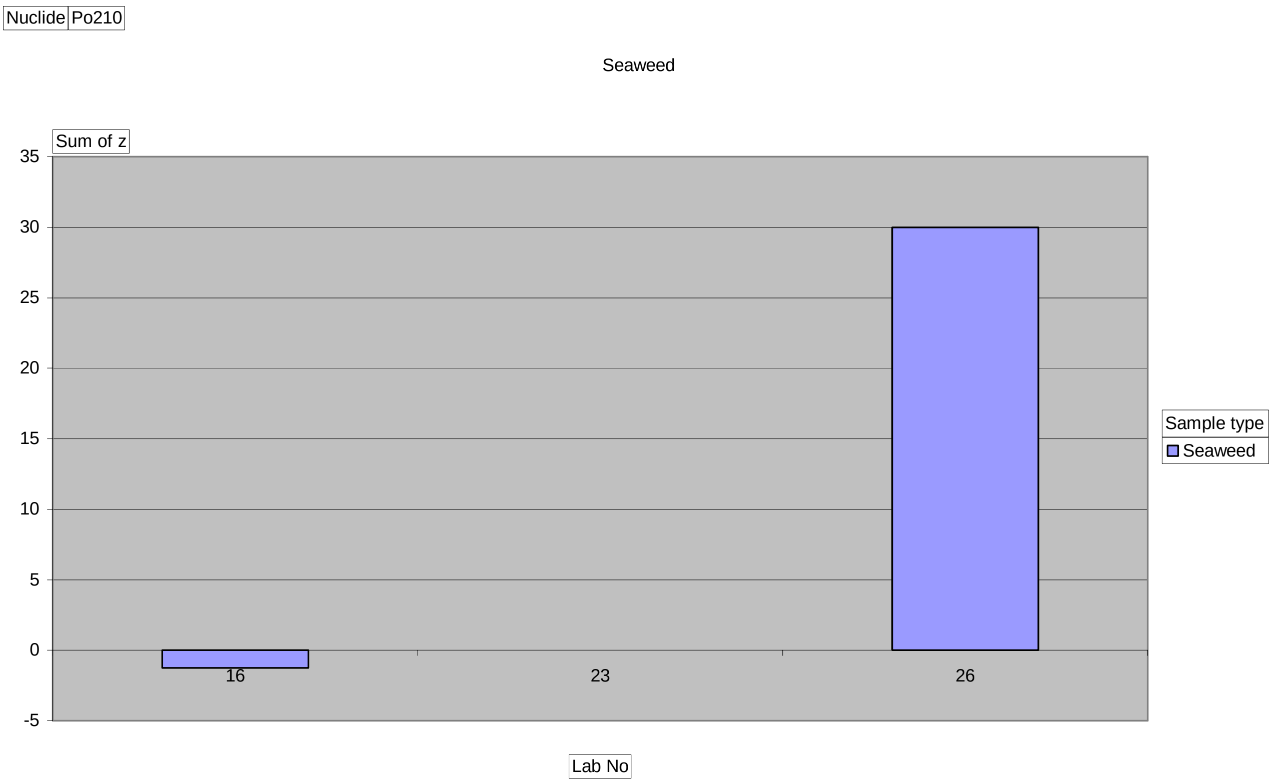
Lab No	n	RSZ	Sign	SSZ	Sign
3	1	1.1	ns	1.1	ns
10	2	1.8	ns	7.4	*
16	3	-3.1	**	10.7	*
23	3	-5.9	***	38.3	***
26	4	-2.7	**	12.7	*
30	4	4.5	***	36.8	***
31	3	1.3	ns	2.7	ns
35	4	42.2	***	1919.9	***



Polonium-210

Table A 7. Statistical evaluation of the results for ^{210}Po.

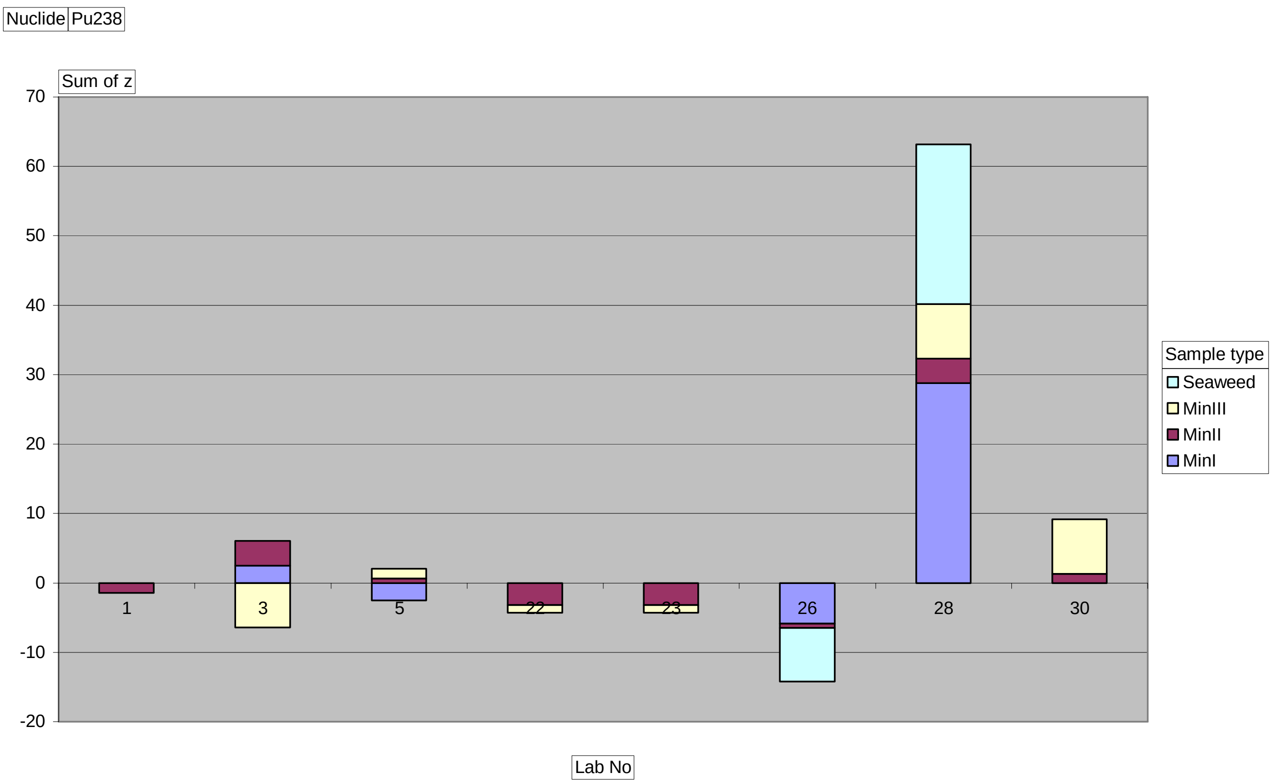
Lab No	n	RSZ	Sign	SSZ	Sign
16	1	-1.3	ns	1.6	ns
23	1	0.0	ns	0.0	***
26	1	30.0	***	900.0	***



Plutonium-238

Table A 8. Statistical evaluation of the results for ^{238}Pu.

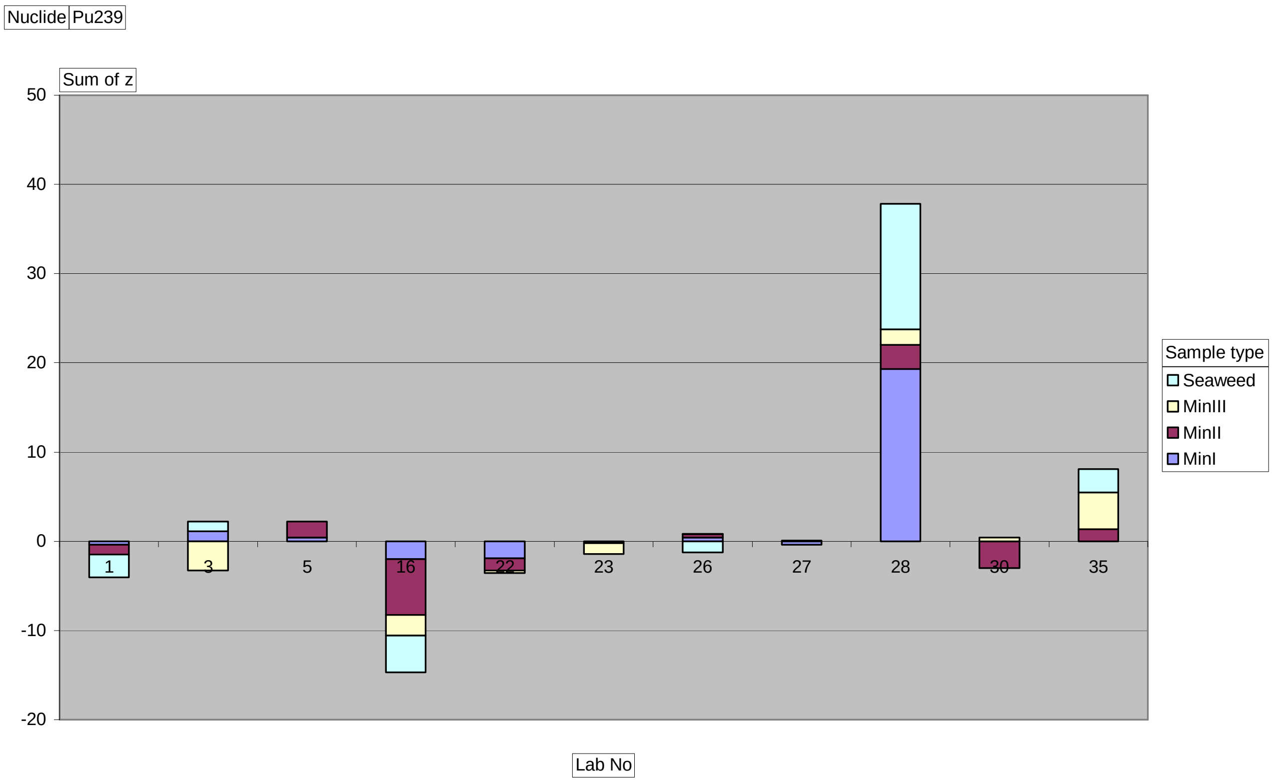
Lab No	n	RSZ	Sign	SSZ	Sign
1	1	-1.4	ns	2.0	ns
3	4	-0.2	ns	60.2	***
5	3	-0.3	ns	8.7	ns
22	2	-3.0	**	11.5	**
23	2	-3.0	**	11.5	**
26	4	-7.1	***	94.2	***
28	4	31.6	***	1430.0	***
30	2	6.5	***	63.4	***



Plutonium-239,240

Table A 9. Statistical evaluation of the results for $^{239,240}Pu$.

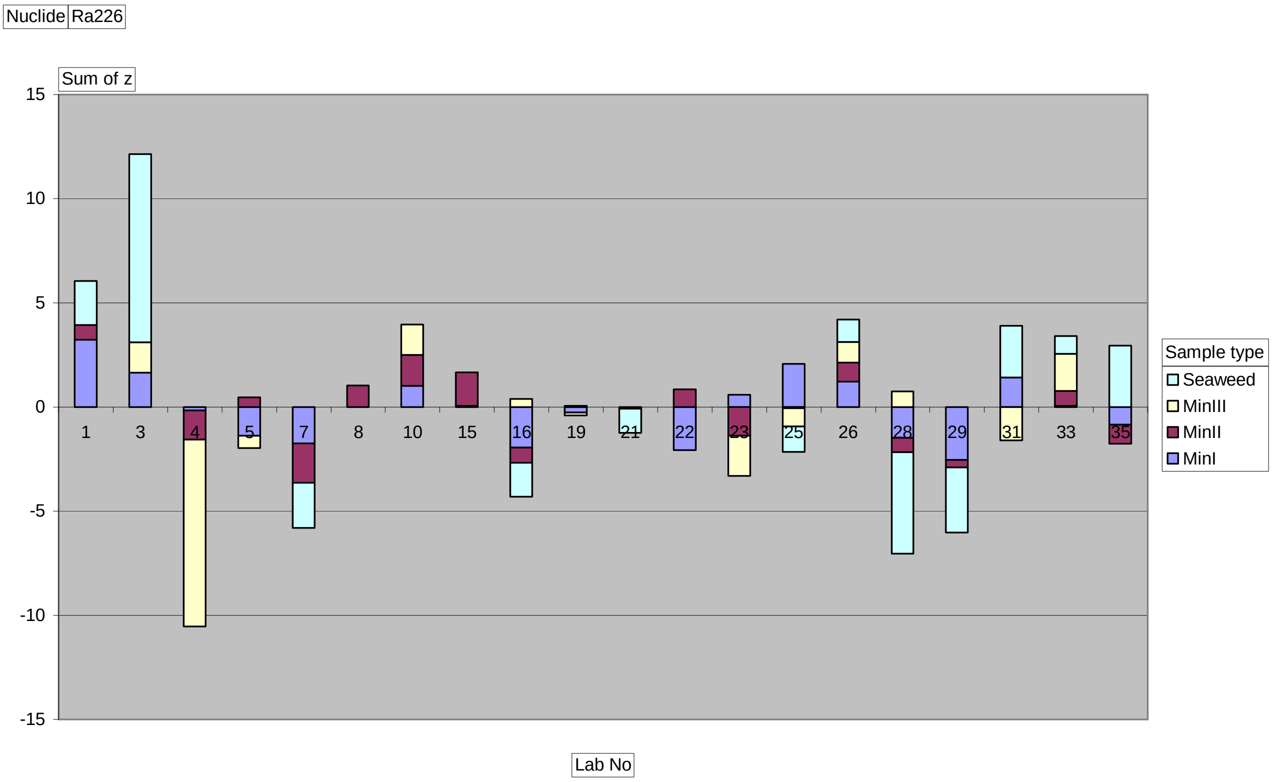
Lab No	n	RSZ	Sign	SSZ	Sign
1	3	-2.3	*	8.0	ns
3	4	-0.5	ns	13.3	*
5	3	1.3	ns	3.5	ns
16	4	-7.3	***	65.5	***
22	3	-2.1	*	5.6	ns
23	3	-0.8	ns	1.7	ns
26	4	-0.2	ns	1.8	ns
27	3	-0.2	ns	0.2	*
28	4	18.9	***	580.8	***
30	2	-1.8	ns	9.2	*
35	3	4.7	***	25.6	***



Radium-226

Table A 10. Statistical evaluation of the results for ^{226}Ra.

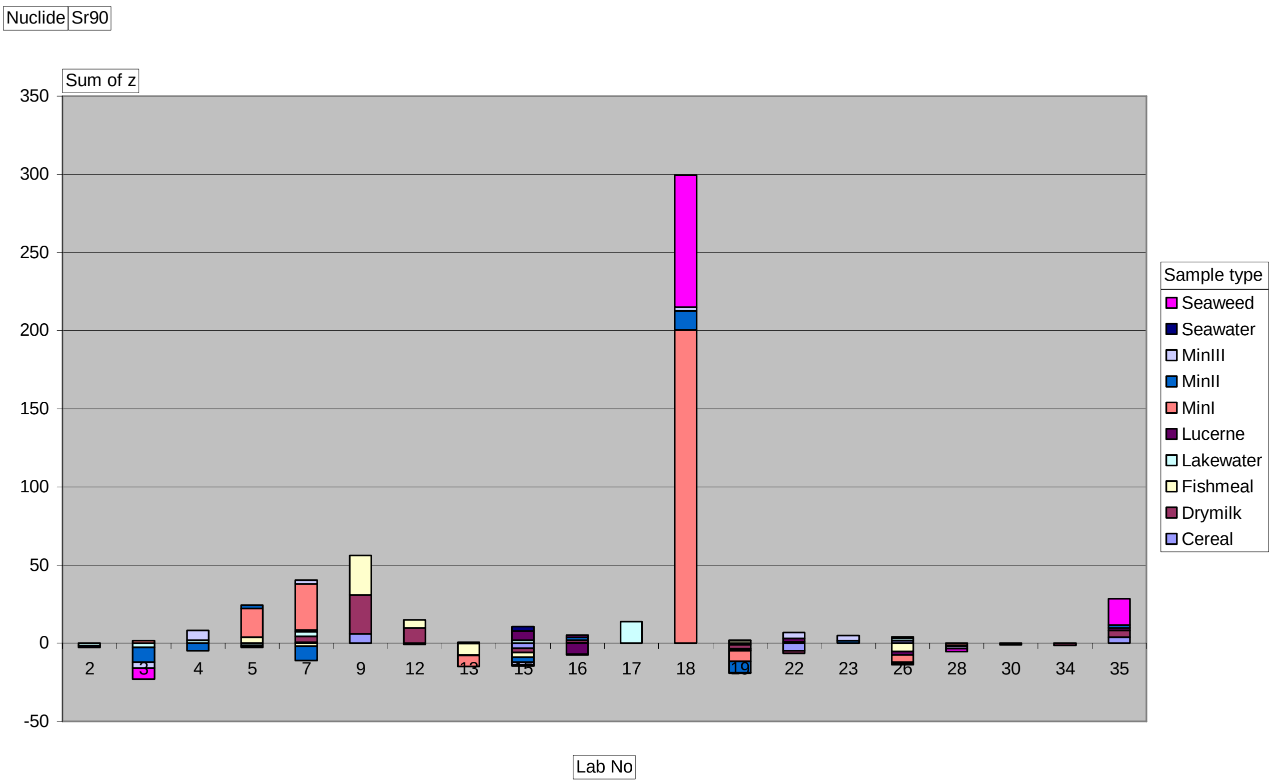
Lab No	n	RSZ	Sign	SSZ	Sign	Lab No	n	RSZ	Sign	SSZ	Sign
1	3	3.5	***	15.4	**	21	4	-0.6	ns	1.3	ns
3	4	6.1	***	86.5	***	22	2	-0.8	ns	5.0	ns
4	3	-6.1	***	82.4	***	23	3	-1.6	ns	5.9	ns
5	3	-0.9	ns	2.5	ns	25	4	0.0	ns	6.5	ns
7	3	-3.4	***	11.3	*	26	4	2.1	*	4.5	ns
8	1	1.0	ns	1.1	ns	28	4	-3.1	**	27.0	***
10	3	2.3	*	5.4	ns	29	3	-3.5	***	16.4	**
15	3	1.0	ns	2.6	ns	31	3	1.3	ns	10.7	*
16	4	-2.0	*	7.1	ns	33	4	1.7	ns	4.4	ns
19	3	-0.2	ns	0.1	*	35	4	0.6	ns	10.3	ns



Strontium-90

Table A 11. Statistical evaluation of the results for ^{90}Sr.

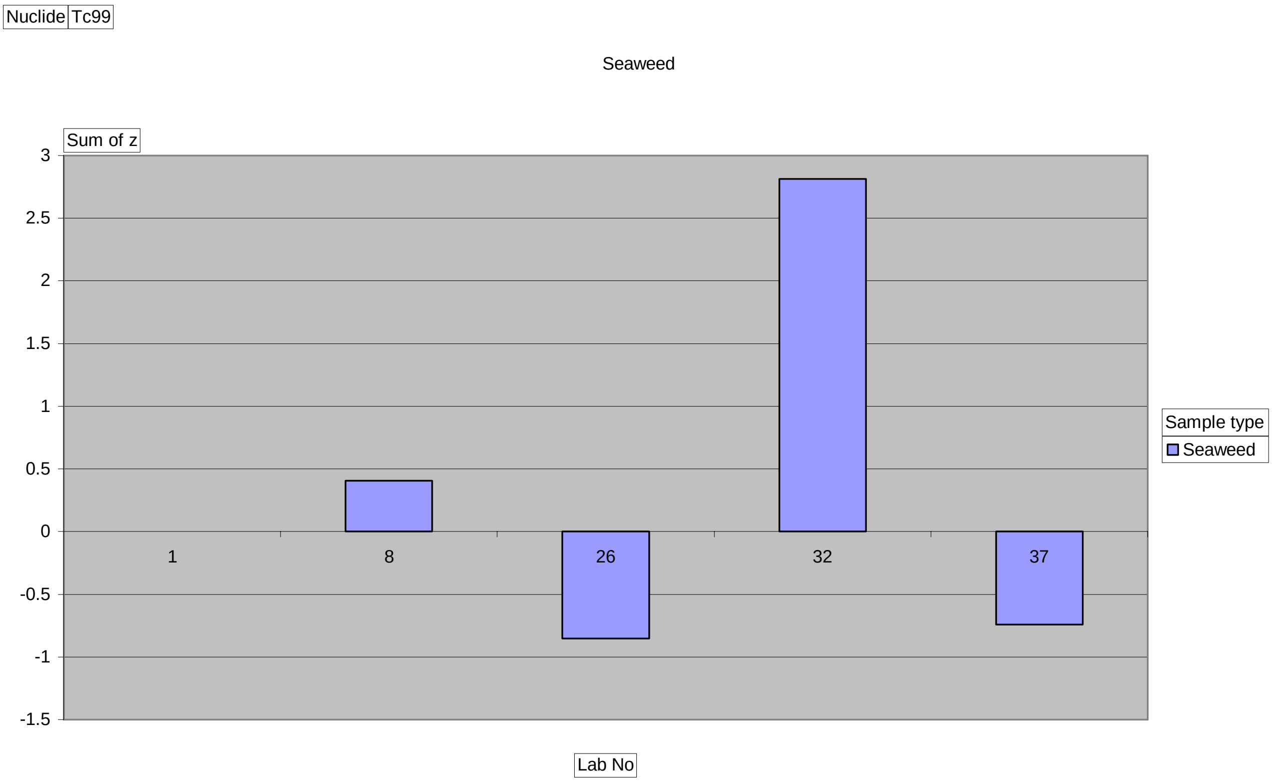
Lab No	n	RSZ	Sign	SSZ	Sign	Lab No	n	RSZ	Sign	SSZ	Sign
2	2	-1.9	ns	3.6	ns	17	1	14.0	***	195.3	***
3	5	-9.5	***	162.0	***	18	4	149.6	***	47418.8	***
4	4	1.7	ns	66.6	***	19	9	-5.7	***	110.1	***
5	6	8.9	***	356.7	***	22	7	0.2	ns	46.5	***
7	8	10.4	***	992.7	***	23	3	2.9	**	14.2	**
9	4	28.0	***	1289.4	***	26	10	-3.1	**	60.9	***
12	3	8.2	***	121.7	***	28	4	-2.6	**	7.4	ns
13	10	-4.5	***	104.4	***	30	2	-0.6	ns	0.4	ns
15	10	-1.3	ns	88.0	***	34	1	-1.2	ns	1.5	ns
16	8	-0.8	ns	57.4	***	35	5	12.7	***	317.5	***



Technetium-99

Table A 12. Statistical evaluation of the results for ^{99}Tc.

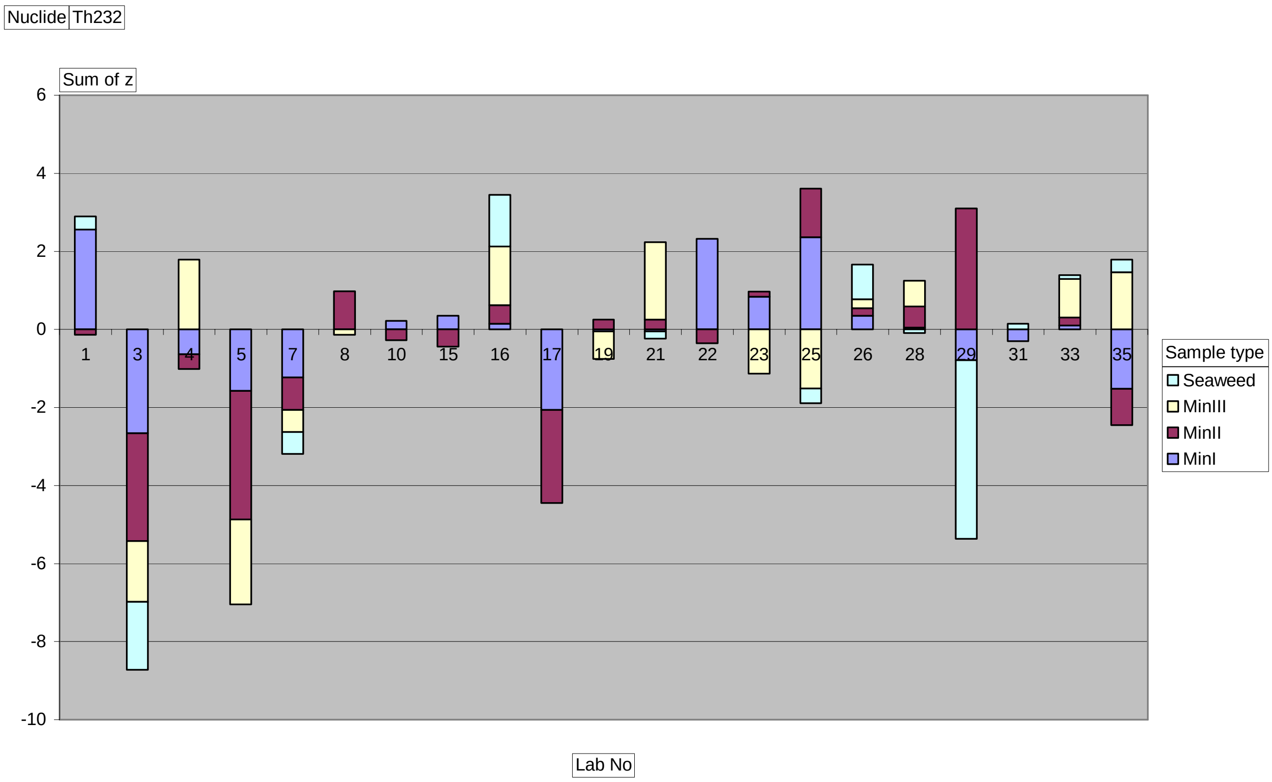
Lab No	n	RSZ	Sign	SSZ	Sign
1	1	0.0	ns	0.0	***
8	1	0.4	ns	0.2	ns
26	1	-0.9	ns	0.7	ns
32	1	2.8	**	7.9	**
37	1	-0.7	ns	0.5	ns



Thorium-232

Table A 13. Statistical evaluation of the results for ^{232}Th.

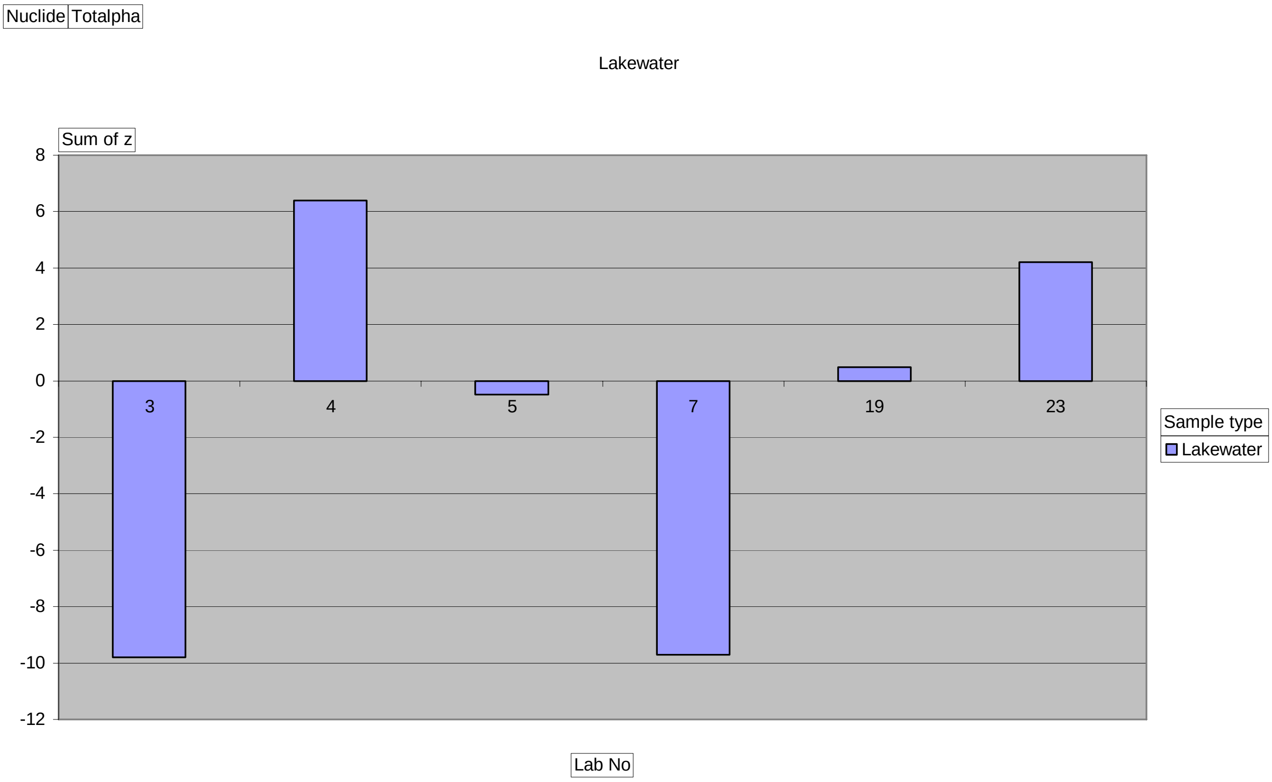
Lab No	n	RSZ	Sign	SSZ	Sign	Lab No	n	RSZ	Sign	SSZ	Sign
1	3	1.6	ns	6.7	ns	21	3	1.2	ns	4.0	ns
3	2	-6.2	***	20.2	***	22	2	1.4	ns	5.5	ns
4	2	0.6	ns	3.8	ns	23	2	-0.1	ns	2.0	ns
5	2	-5.0	***	18.0	***	25	1	1.7	ns	9.6	**
7	3	-1.8	ns	2.9	ns	26	2	1.2	ns	1.0	ns
8	1	0.8	ns	1.0	ns	28	3	0.7	ns	0.7	ns
10	2	0.0	ns	0.1	ns	29	3	-1.3	ns	31.2	***
15	2	-0.1	ns	0.3	ns	31	3	-0.1	ns	0.1	*
16	3	2.0	*	4.3	ns	33	2	1.0	ns	1.0	ns
17	2	-3.1	**	9.9	*	35	3	-0.4	ns	5.4	ns
19	2	-0.4	ns	0.6	ns						



Total alpha radioactivity

Table A 14. Statistical evaluation of the results for total alpha radioactivity.

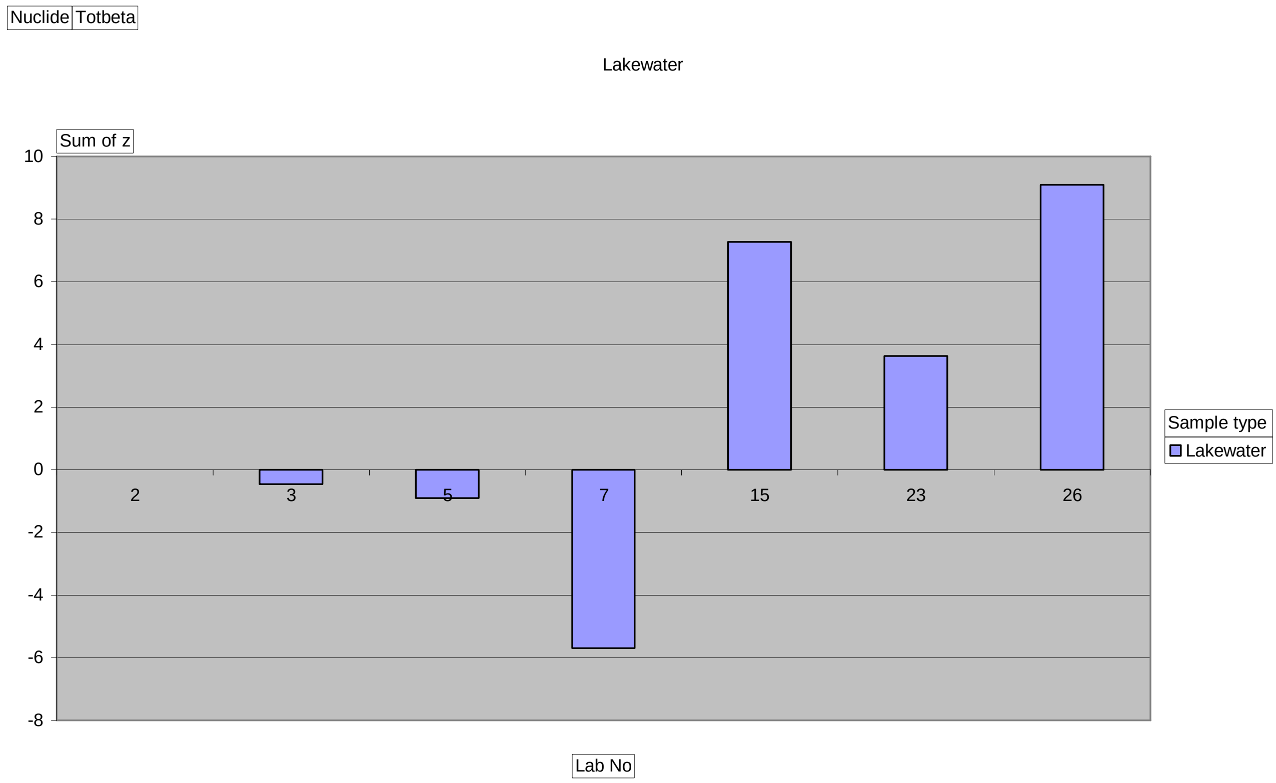
Lab No	n	RSZ	Sign	SSZ	Sign
3	1	-9.8	***	95.9	***
4	1	6.4	***	40.9	***
5	1	-0.5	ns	0.2	ns
7	1	-9.7	***	94.2	***
19	1	0.5	ns	0.2	ns
23	1	4.2	***	17.7	***



Total beta radioactivity

Table A 15. Statistical evaluation of the results for total beta radioactivity.

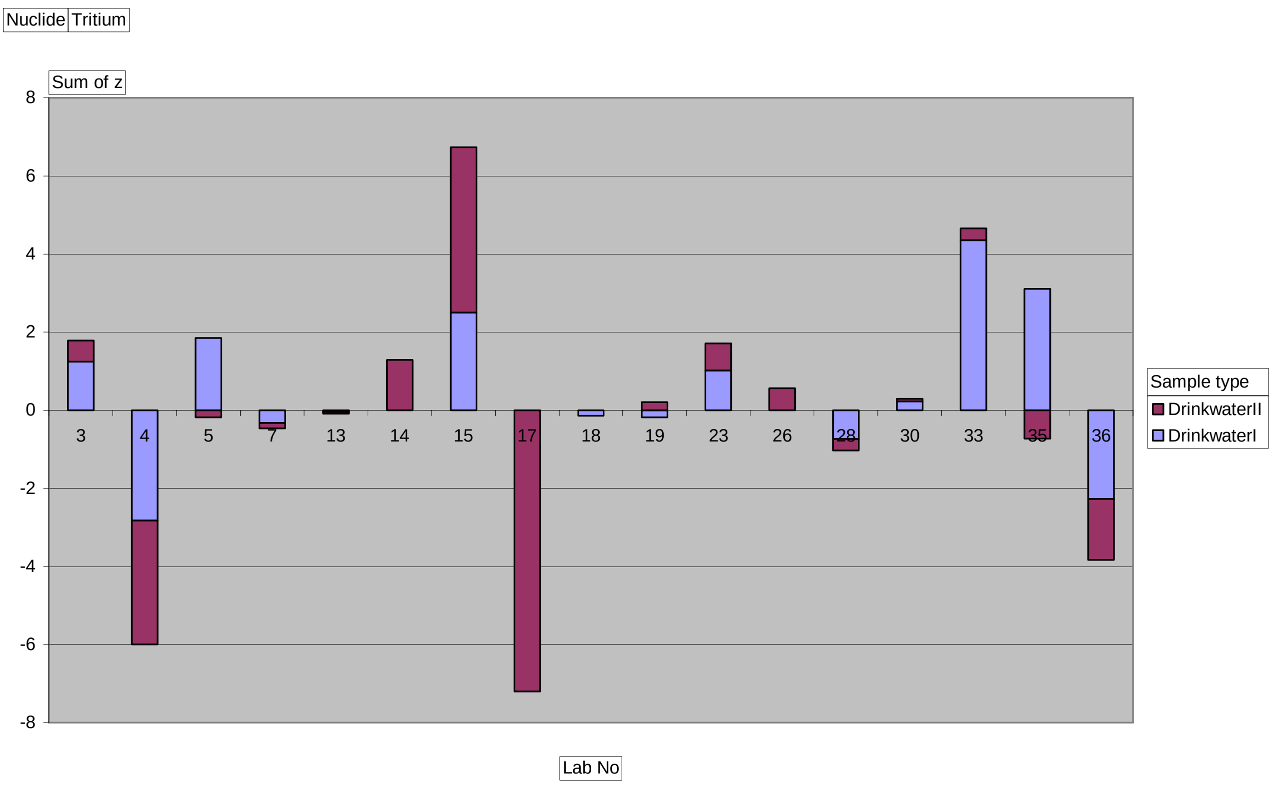
Lab No	n	RSZ	Sign	SSZ	Sign
2	1	0.0	ns	0.0	***
3	1	-0.5	ns	0.2	ns
5	1	-0.9	ns	0.8	ns
7	1	-5.7	***	32.4	***
15	1	7.3	***	52.9	***
23	1	3.6	***	13.2	***
26	1	9.1	***	82.6	***



Tritium

Table A 16. Statistical evaluation of the results for tritium.

Lab No	n	RSZ	Sign	SSZ	Sign
3	2	1.3	ns	1.8	ns
4	2	-4.2	***	18.1	***
5	2	1.2	ns	3.5	ns
7	2	-0.3	ns	0.1	ns
13	2	-0.1	ns	0.0	**
14	1	1.3	ns	1.7	ns
15	2	4.8	***	24.1	***
17	1	-7.2	***	51.9	***
18	2	-0.1	ns	0.0	*
19	2	0.0	ns	0.1	ns
23	2	1.2	ns	1.5	ns
26	2	0.4	ns	0.3	ns
28	2	-0.7	ns	0.6	ns
30	2	0.2	ns	0.1	ns
33	2	3.3	***	19.0	***
35	2	1.7	ns	10.1	*
36	2	-2.7	**	7.6	*



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Abstract

Thirty-eight laboratories participated in an intercomparison exercise carried out in 2004 and 2005 on laboratory analyses of radionuclides in environmental samples and food. The sample types included seawater, lake water, tap water, sediment, seaweed, fish meal, soil, dry milk, cereal and lucerne and the exercise involved artificial and naturally occurring radionuclides including total alpha and beta radioactivity. The evaluation of analytical performance was based on comparison with median values, a 10% target standard deviation and statistical tests at the 99% level. More than half of the laboratories passed the evaluation criteria for 99Tc, 134Cs, 137Cs, 239,240Pu, 226Ra, 232Th, 40K, 210Po, 7Be and tritium while less than half of the participants passed the criteria for 90Sr, 238Pu, 241Am, 210Pb, total alpha and total beta radioactivity. The analytical results compare well across many of the laboratories. However, the results indicate that there is room for improvement of the analytical quality at most laboratories. It is also noteworthy that the results on total alpha and beta radioactivity in lake water show quite poor agreement, which is a matter of implication for national screening programmes of radioactivity in drinking water. It is important, to recognise the subjective components of the evaluation that include the choice of using median values to represent the true values and the choice of a target standard deviation of 10%. However, for one certified reference material included in the exercise, the median and the reference values were in good agreement.

Key words: Radionuclides, intercomparison, environment, food

Available on request from the NKS Secretariat, P.O.Box 49, DK-4000 Roskilde, Denmark.
Phone (+45) 4677 4045, fax (+45) 4677 4046, e-mail nks@nks.org, www.nks.org