



NPL REPORT IR 30

NPL Nuclear Industry Proficiency Test Exercise 2012

JULIAN DEAN

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NPL Nuclear Industry Proficiency Test Exercise 2012

Julian Dean
Acoustics and Ionising Radiation Division

ABSTRACT

A fourth Nuclear Industry Proficiency Test Exercise has been run by NPL. One sample was prepared, consisting of a nominal 200 L drum loaded with steel and Nylon sheets and plastic bottles containing coarse aggregate (with one containing ion exchange resin). The steel sheets and the resin bottle were spiked with known weights of standard solutions of ^{241}Am , ^{60}Co and ^{137}Cs . The activity concentrations (averaged across the drum contents) were approximately 2.8 Bq g^{-1} , 1.0 Bq g^{-1} and 1.0 Bq g^{-1} respectively.

The participants were required to report the activity concentrations of the individual radionuclides. Information disclosed to the participants initially included the radionuclides present, an activity concentration range, details of the empty drum (e.g. its mass and dimensions) and the percentage of each material type present. The drum was measured by 11 UK and 3 overseas laboratories. After the initial results deadline, further details of the distribution of materials and activity within the drum were disclosed and the participants were invited to submit additional data. It was pointed out that, during the transport process, the bottles in the drum had moved and it was concluded that the 'active' bottle could have been positioned anywhere in the base of the drum when measured by the participants (although probably within 25 cm of the base).

Approximately 44 % of the 'initial' results were statistically 'in agreement' with the NPL value. This was partly due to the large proportion of questionable and discrepant data submitted for ^{241}Am . As in earlier exercises, some of the results derived using Segmented Gamma Scanners were either low, questionable or discrepant. Four participants submitted additional results after NPL had disclosed the drum's internal matrix structure; however, the overall proportion of results 'in agreement' with NPL was only 27% (compared with 53% for the same four participants 'pre-disclosure').

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National Physical Laboratory
Hampton Road, Teddington, Middlesex, TW11 0LW

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Approved on behalf of the NPLML by Dr B Zeqiri, Knowledge Leader
Acoustics and Ionising Radiation Division

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1 INTRODUCTION

The accurate measurement of radioactivity in potentially active materials produced in nuclear site decommissioning is essential for correct waste categorisation. This is important for public safety, to reduce the industry's costs and to minimise LLW volumes. The National Physical Laboratory (NPL) runs Nuclear Industry Proficiency Test Exercises ('drum comparisons') [Dean, 2007, 2010, 2012] to enable laboratories involved in the clearance and sentencing of bulk γ -emitting waste to test their measurement procedures. The exercises provide a check on the modelling techniques used for calculating detection efficiencies and enable participants to demonstrate measurement capability to third parties.

This report describes the fourth PTE in this series, covering:

- the preparation of the 'standard drum';
- the circulation of the drum and reporting of data;
- the reported results and data analysis.

2 PREPARATION OF STANDARD DRUM

The following materials were procured / prepared:

- Standardised radionuclide solutions of ^{241}Am , ^{60}Co and ^{137}Cs
- 1 x 500 ml HDPE bottle containing ion-exchange resin;
- 29 x 500 ml HDPE bottles containing coarse aggregate;
- 3 x filter papers (80 mm x 80 mm);
- 1 x 200 L steel drum;
- Approximately 10 kg of Nylon 6-6 (in sheets);
- Approximately 4 kg of 0.9 mm BS 1449 stainless steel sheet;

The activity concentrations of the radionuclide solutions had been previously determined by assay in glass ampoules in a re-entrant secondary standard ionisation chamber. Each ampoule had been measured using a γ -spectrometer to check for the presence of any γ -emitting impurities.

The remaining activity was contained within the single bottle of ion-exchange resin which had been previously standardised and which contained all three radionuclides. A 'drum insert' was prepared (see Figure 1). The base and two opposite sides consisted of Nylon 6-6 and the other two sides consisted of stainless steel. This formed a box-like structure with the top of the 'box' open. Weighed amounts of the standardised solutions were drop-deposited onto the filter papers, and after drying the filters were taped to the outward-facing walls of the steel plates, as illustrated. Each filter was spiked with a different nuclide. The bottle of resin was spiked with a mixture of all three radionuclides and was positioned in a bottom corner of the box. The bottles of coarse aggregate were then placed in a single layer at the bottom of the box, adjacent to the active bottle.

The drum was certificated for the activity concentrations of each radionuclide present (see Table 1) and was designated source X12152.

3 CIRCULATION OF DRUM AND REPORTING OF DATA

An initial mailshot was prepared (see Appendix A) and circulated to potential participants.

A Reporting Form (Appendix B) was sent to the participants for reporting their data. Also, the participants were provided with the following details:

- The activity concentration range (1 - 10 Bq/g);
- Details of the empty drum from the manufacturer;
- The mass of the drum empty (18.3 kg nominal) and full (54.9 kg nominal);
- The percentage by mass of the drum's contents:
 - Coarse aggregate (56.1 % nominal)
 - Plastics (31.4 % nominal)
 - Metal (11.5 % nominal)
 - Ion-exchange resin (1.0 % nominal).

After the 'first deadline' (see Appendix A), participants were given details of the drum's 'internal structure' and locations of the activity, plus more details of the individual materials, which were:

- Coarse aggregate: 20.54 kg nominal
- Nylon: 9.78 kg nominal
- Steel: 4.19 kg nominal
- HDPE: 1.71 kg nominal
- Resin: 0.32 kg nominal

Unfortunately, the bottles of coarse aggregate and resin were found to have moved in transit and it was not clear at which stage of the circulation of the drum this had occurred. The active bottle could have been positioned anywhere in the base of the drum when measured by the participants (although probably within 25 cm of the base of the 'internal box'). However, the box structure and the filter papers had not moved in transit. Note also that the activity in the bottle was small compared with the total activity on the filter papers (< 10%).

Participants were invited to submit additional results based on the above information; four did so.

A list of participants is given in Appendix C.

4 RESULTS AND DATA ANALYSIS

To preserve anonymity, each participant was assigned a number, and their results were coded accordingly. Some of the laboratories had also participated in previous exercises and their numbers were changed for the current exercise.

On receipt of the results, NPL carried out data analyses using the method described below [Harms, 2009(a)].

Firstly, the deviation from the assigned (NPL) value of each laboratory value was calculated, given by:

$$D = 100 \frac{L - N}{N} = 100 \left(\frac{L}{N} - 1 \right) \quad [1]$$

where:

D = deviation from the NPL value (%)

L = the participant's value (Bq g⁻¹)

N = the NPL value (Bq g⁻¹)

The deviations are plotted in Figures 2 – 4 (results submitted prior to the first deadline, designated 'pre-disclosure') and Figures 8 – 10 (results submitted after first deadline, designated 'post-disclosure'). The error bars in the graphs represent the standard uncertainty ($k=1$) of the deviation:

$$u_D = 100 \frac{L}{N} \sqrt{\left(\frac{u_L}{L}\right)^2 + \left(\frac{u_N}{N}\right)^2} \quad [2]$$

where:

u_D = standard uncertainty of the deviation (%)

u_L = standard uncertainty of the participant's value (Bq g⁻¹)

u_N = standard uncertainty of the assigned value (Bq g⁻¹)

The results were evaluated using three tests:

$$\zeta = \frac{L - N}{\sqrt{u_L^2 + u_N^2}} \quad [3]$$

$$R_L = \frac{u_L}{L} \quad [4]$$

$$z = \frac{L - N}{\sigma_p} = \frac{L - N}{0.05823 N} \quad [5]$$

where:

ζ = zeta score

R_L = relative uncertainty of the participant's value

Z = z-score

σ_p = standard deviation for proficiency assessment

The standard deviation for proficiency assessment represents the level of performance that NPL would wish laboratories to be able to achieve. It corresponds to a deviation 'D' of 15% at the 99% confidence level.

The zeta and z-scores were used to determine whether the difference between the participant's value and the NPL value was significantly different from zero. An IQR (Inter-Quartile Range) outlier test was used to determine whether a particular R_L value was significantly larger than the other values in a data set; the IQR was used to calculate a limiting value of R_L , ' R_{lim} ', for each data set. The results are plotted in Figures 5 - 7. Note that no outlier test was carried out on the 'post-disclosure' data sets owing to the small numbers of results in each set – in these cases, all results are regarded as having passed the outlier test. The zeta scores, z-scores and outlier results are also given in Tables 2 - 7.

Results for which the absolute values of the zeta score and the z-score were both ≤ 2.576 (corresponding to a significance levels of $\alpha = 0.01$) and for which the relative uncertainty R_L was not significantly larger than the other values in the data set were regarded as being ‘in agreement’ with NPL. These are marked in dark blue in the deviation plots. If either (i) the relative uncertainty R_L was significantly larger than the other values in the data set, (ii) the result passes the zeta test but not the z-test (i.e. large deviation from the NPL value combined with a large uncertainty), or (iii) the result passes the z-test but not the zeta test (small deviation from the NPL value combined with a small uncertainty), the participant’s value is classified as ‘questionable’ (these are given in yellow in the deviation plots). If the absolute values of both the zeta score and the z-score are > 2.576 , then the participant’s value is classified as ‘discrepant’ from the NPL value (red points), regardless of the value of the relative uncertainty R_L .

5 DISCUSSION

Overall, 44% of the results submitted pre-disclosure were in agreement with the NPL Assigned Values. If the proportion in agreement with NPL is broken down by nuclide, the percentages are: ^{241}Am 14%, ^{60}Co 48% and ^{137}Cs 71%. Apart from one result, all the ^{241}Am data were higher than NPL (with positive deviations between 6 % and 196 %), and it is not clear why.

It is interesting that many of the discrepant data for ^{60}Co and ^{137}Cs were from measurements using either Segmented Gamma Scanners (SGSs) or collimated detectors. The lowest results reported for ^{60}Co (although mostly in agreement with NPL) were from SGS measurements and this is similar to the findings of previous exercises (Dean 2007, 2010, 2012).

Four participants submitted results post-disclosure. The overall proportion of results in agreement with NPL was only 27% (compared with 53% pre-disclosure for the same group of participants).

6 ACKNOWLEDGEMENTS

The author wishes to thank the participating organisations for the time and effort they have put into analysing the drum, and for the information provided. Also, thanks go to Daniel Ainsworth for organising the transport of the drum and Peter Ivanov for reviewing this report. Finally, the author gratefully acknowledges the financial support of the National Measurement System.

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8 TABLES

Table 1 - Principal radionuclides in X12152

Radionuclide	Decay mode	Activity concentration (averaged across contents of drum) @ 2012-07-01 1200 UTC* (Bq g ⁻¹)	Standard uncertainty ($k=1$) (Bq g ⁻¹)	Standard uncertainty ($k=1$) (%)
²⁴¹ Am	α/γ	2.762	0.010	0.4
⁶⁰ Co	β^-/γ	0.9649	0.0020	0.21
¹³⁷ Cs	$\beta^-, \beta^-/\gamma$	1.022	0.007	0.6

* Universal Time, Co-ordinated. This replaced Greenwich Mean Time in 1972. Format of date is YYYY-MM-DD.

Table 2 - Reported results for ^{241}Am ('pre-disclosure')NPL activity concentration = $(2.762 \pm 0.010) \text{ Bq g}^{-1}$ ($k=1$)

Reference time: 2011-03-01 1200 UTC

Participant code	Reported activity concentration (Bq/g)	Reported uncertainty (%)	Zeta score	Z score	D (%)	Outlier test result	Classification
1A	7.69	100	0.64	30.64	178.4	Outlier	Questionable
1B	3.35	12	1.46	3.66	21.29	Not outlier	Questionable
2	3.14	11	1.09	2.35	13.69	Not outlier	In agreement
3	3.94	18.9	1.58	7.32	42.65	Not outlier	Questionable
4	3.8	19	1.44	6.45	37.58	Not outlier	Questionable
5	3.36	50	0.36	3.72	21.65	Not outlier	Questionable
6A	0.38	15.8	-39.13	-14.81	-86.24	Not outlier	Discrepant
6B	5.58	95.93	0.53	17.52	102.0	Outlier	Questionable
7	6.32	17.9	3.14	22.12	128.8	Not outlier	Discrepant
8A	4.613	20.24	1.98	11.51	67.02	Not outlier	Questionable
8B	5.170	20.21	2.30	14.97	87.18	Not outlier	Questionable
8C	4.675	20.21	2.02	11.89	69.26	Not outlier	Questionable
9	2.93	5.5	1.04	1.04	6.083	Not outlier	In agreement
10A	5.44	25.5	1.93	16.65	96.96	Not outlier	Questionable
10B	5.04	25.4	1.78	14.16	82.48	Not outlier	Questionable
10C	5.03	25.4	1.78	14.10	82.11	Not outlier	Questionable
11A	8.19	10.20	6.50	33.75	196.5	Not outlier	Discrepant
11B	7.05	10.41	5.84	26.66	155.3	Not outlier	Discrepant
12	4.595	17.82	2.24	11.40	66.36	Not outlier	Questionable
13	3.09	33	0.32	2.04	11.88	Not outlier	In agreement
14	6.66	27.55	2.12	24.24	141.1	Not outlier	Questionable

Table 3 - Reported results for ^{60}Co ('pre-disclosure')NPL activity concentration = $(0.9649 \pm 0.0020) \text{ Bq g}^{-1}$ ($k=1$)

Reference time: 2011-03-01 1200 UTC

Participant code	Reported activity concentration (Bq/g)	Reported uncertainty (%)	Zeta score	Z score	D (%)	Outlier test result	Classification
1A	1.27	40	0.60	5.43	31.62	Outlier	Questionable
1B	2.36	12	4.93	24.83	144.6	Not outlier	Discrepant
2	1.23	7.3	2.95	4.72	27.47	Not outlier	Discrepant
3	1.04	2.7	2.67	1.34	7.783	Not outlier	Questionable
4	1.4	12	2.59	7.74	45.09	Not outlier	Discrepant
5	1.07	7	1.40	1.87	10.89	Not outlier	In agreement
6A	2.34	12.8	4.59	24.47	142.5	Not outlier	Discrepant
6B	1.08	14.79	0.72	2.05	11.93	Not outlier	In agreement
7	0.878	13.5	-0.73	-1.55	-9.006	Not outlier	In agreement
8A	1.101	14.44	0.86	2.42	14.11	Not outlier	In agreement
8B	1.069	14.40	0.68	1.85	10.79	Not outlier	In agreement
8C	1.049	14.39	0.56	1.50	8.716	Not outlier	In agreement
9	1.040	4.0	1.80	1.34	7.783	Not outlier	In agreement
10A	1.47	11.7	2.94	8.99	52.35	Not outlier	Discrepant
10B	1.38	11.6	2.59	7.39	43.02	Not outlier	Discrepant
10C	1.39	11.5	2.66	7.57	44.06	Not outlier	Discrepant
11A	0.92	10.03	-0.49	-0.80	-4.653	Not outlier	In agreement
11B	1.39	11.70	2.61	7.57	44.06	Not outlier	Discrepant
12	1.066	14.72	0.64	1.80	10.48	Not outlier	In agreement
13	1.08	8	1.33	2.05	11.93	Not outlier	In agreement
14	1.48	27.35	1.27	9.17	53.38	Not outlier	Questionable

Table 4 - Reported results for ^{137}Cs ('pre-disclosure')NPL activity concentration = $(1.022 \pm 0.007) \text{ Bq g}^{-1}$ ($k=1$)

Reference time: 2011-03-01 1200 UTC

Participant code	Reported activity concentration (Bq/g)	Reported uncertainty (%)	Zeta score	Z score	D (%)	Outlier test result	Classification
1A	0.965	30	-0.20	-0.96	-5.577	Not outlier	In agreement
1B	2.224	12	4.50	20.20	117.6	Not outlier	Discrepant
2	1.02	7.8	-0.03	-0.03	-0.1957	Not outlier	In agreement
3	1.45	6.2	4.75	7.19	41.88	Not outlier	Discrepant
4	1.1	12	0.59	1.31	7.632	Not outlier	In agreement
5	1.11	7	1.13	1.48	8.611	Not outlier	In agreement
6A	3.25	12.7	5.40	37.44	218.0	Not outlier	Discrepant
6B	1.12	17.07	0.51	1.65	9.589	Not outlier	In agreement
7	2.62	23.5	2.60	26.85	156.4	Not outlier	Discrepant
8A	0.933	20.36	-0.47	-1.50	-8.708	Not outlier	In agreement
8B	0.976	20.28	-0.23	-0.77	-4.501	Not outlier	In agreement
8C	0.925	20.32	-0.52	-1.63	-9.491	Not outlier	In agreement
9	0.907	4.1	-0.31	-1.93	-11.25	Not outlier	In agreement
10A	1.08	14.3	0.38	0.97	5.675	Not outlier	In agreement
10B	1.06	14.1	0.25	0.64	3.718	Not outlier	In agreement
10C	1.01	14.2	-0.08	-0.20	-1.174	Not outlier	In agreement
11A	1.96	11.09	4.31	15.76	91.78	Not outlier	Discrepant
11B	1.16	14.20	0.84	2.32	13.50	Not outlier	In agreement
12	0.9195	14.84	-0.75	-1.72	-10.03	Not outlier	In agreement
13	1.13	15	0.64	1.81	10.57	Not outlier	In agreement
14	1.33	27.36	0.85	5.18	30.14	Not outlier	Questionable

Table 5 - Reported results for ^{241}Am ('post-disclosure')NPL activity concentration = $(2.762 \pm 0.010) \text{ Bq g}^{-1}$ ($k=1$)

Reference time: 2011-03-01 1200 UTC

Participant code	Reported activity concentration (Bq/g)	Reported uncertainty (%)	Zeta score	Z score	D (%)	Outlier test result	Classification
4	1.9	15	-3.02	-5.36	-31.21	Not outlier	Discrepant
6B	3.60	48.7	0.48	5.21	30.34	Not outlier	Questionable
11A	10	10.20	7.10	45.00	262.06	Not outlier	Discrepant
11B	9.70	10.41	6.87	43.14	251.19	Not outlier	Discrepant
13	3.22	27	0.53	2.85	16.58	Not outlier	Questionable

Table 6 - Reported results for ^{60}Co ('post-disclosure')NPL activity concentration = $(0.9649 \pm 0.0020) \text{ Bq g}^{-1}$ ($k=1$)

Reference time: 2011-03-01 1200 UTC

Participant code	Reported activity concentration (Bq/g)	Reported uncertainty (%)	Zeta score	Z score	D (%)	Outlier test result	Classification
4	1.1	11	1.12	2.40	14.00	Not outlier	In agreement
6B	0.718	16.5	2.08	-4.39	-25.59	Not outlier	Questionable
11A	0.92	10.03	-0.49	-0.80	-4.653	Not outlier	In agreement
11B	1.41	11.70	2.70	7.92	46.13	Not outlier	Discrepant
13	1.09	11	1.04	2.23	12.97	Not outlier	In agreement

Table 7 - Reported results for ^{137}Cs ('post-disclosure')NPL activity concentration = $(1.022 \pm 0.007) \text{ Bq g}^{-1}$ ($k=1$)

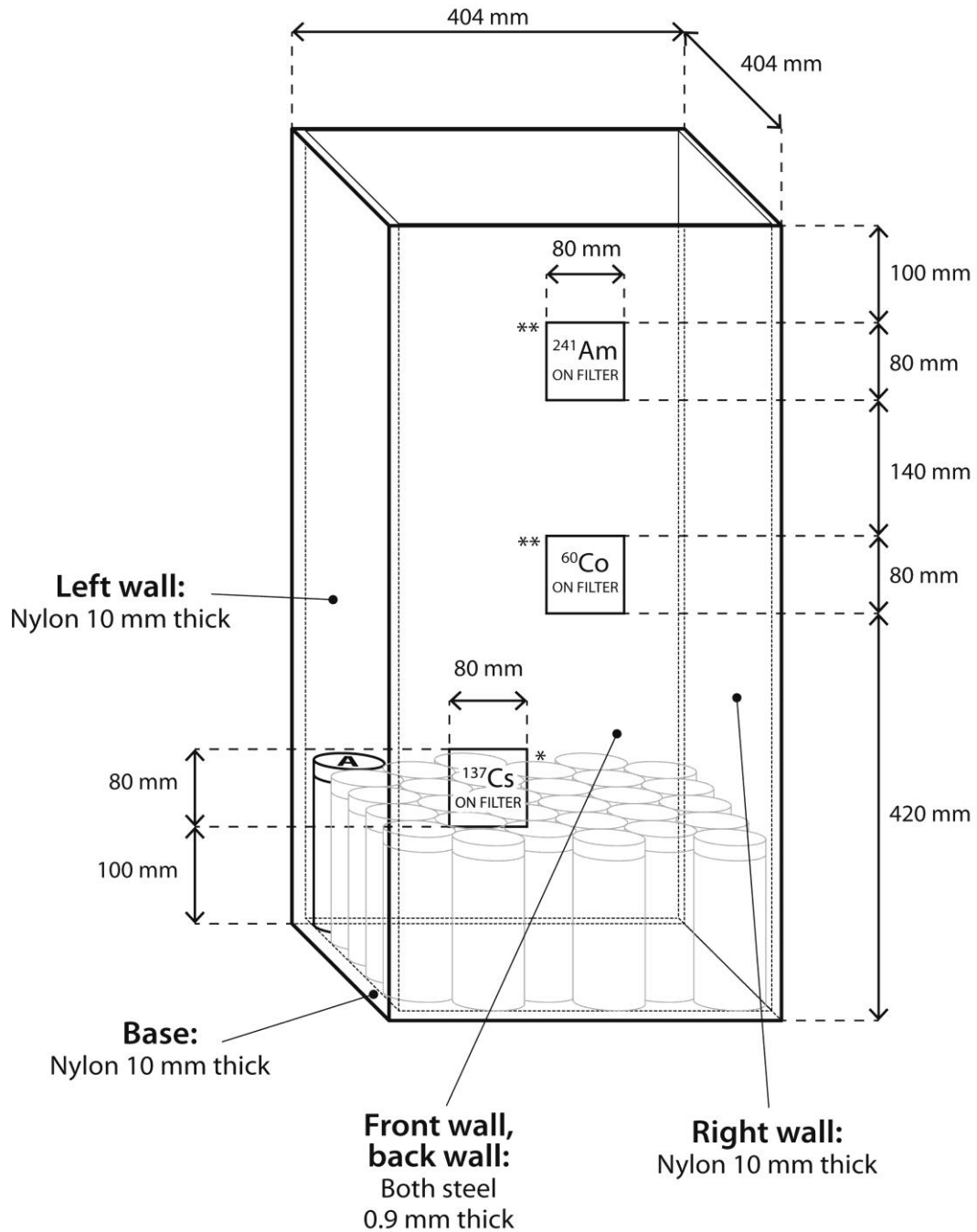
Reference time: 2011-03-01 1200 UTC

Participant code	Reported activity concentration (Bq/g)	Reported uncertainty (%)	Zeta score	Z score	D (%)	Outlier test result	Classification
4	0.83	11	-2.10	-3.23	-18.79	Not outlier	Questionable
6B	2.23	17.6	3.08	20.30	118.2	Not outlier	Discrepant
11A	1.96	11.09	4.31	15.76	91.78	Not outlier	Discrepant
11B	1.15	14.20	0.78	2.15	12.52	Not outlier	In agreement
13	1.77	21	2.01	12.57	73.19	Not outlier	Questionable

9 FIGURES

Figure 1 - Schematic diagram of 'drum insert'

**NPL Nuclear Industry PTE 2012
Dimensions of insert for standard drum X12152**



* ¹³⁷Cs filter on back wall, on rear face

** ²⁴¹Am and ⁶⁰Co filters on front wall, on front face

**Figure 2 - Deviation plot for ^{241}Am results, pre-disclosure
(6 results above area of plot)**

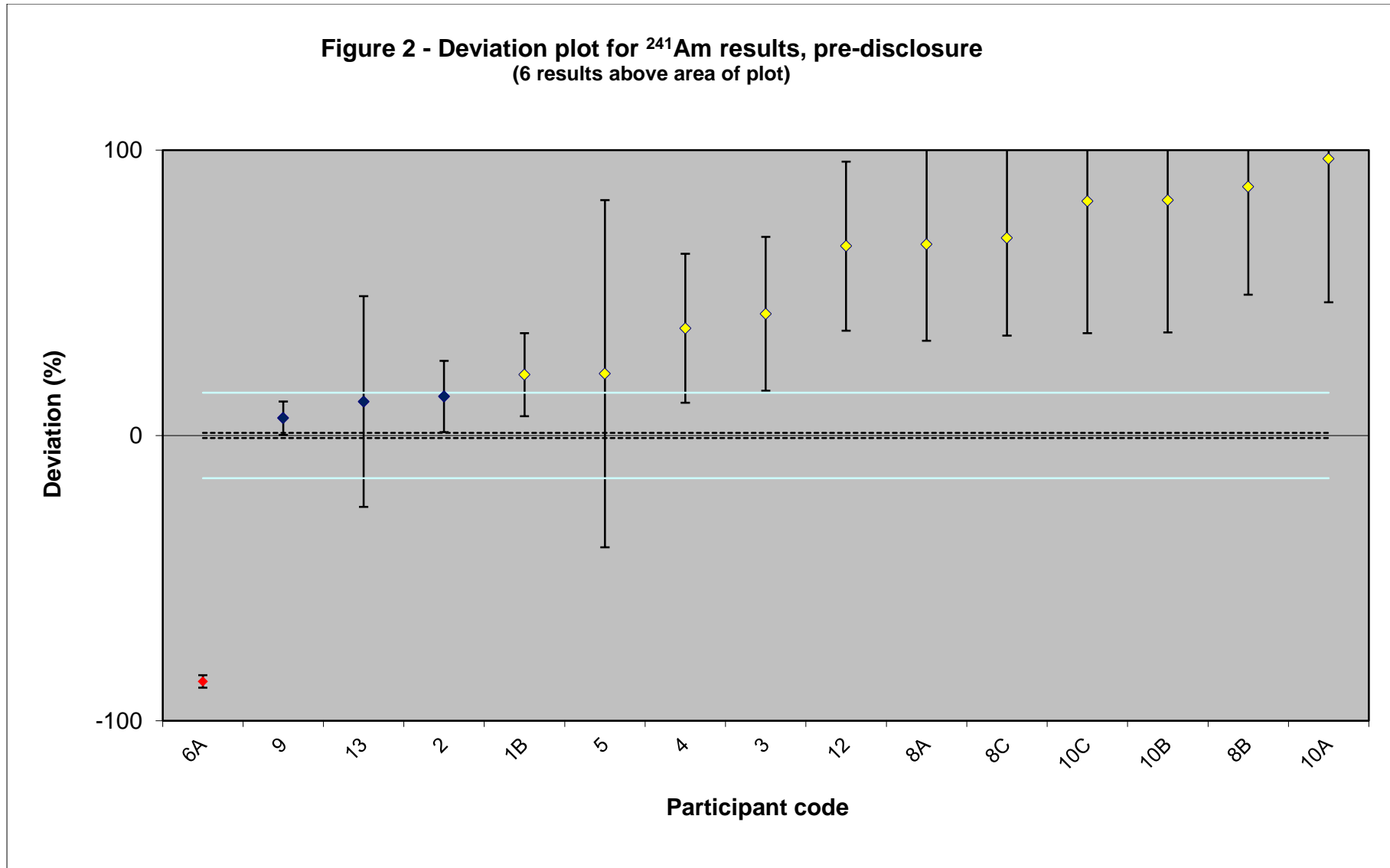


Figure 3 - Deviation plot for ⁶⁰Co results, pre-disclosure
 (2 results above area of plot)

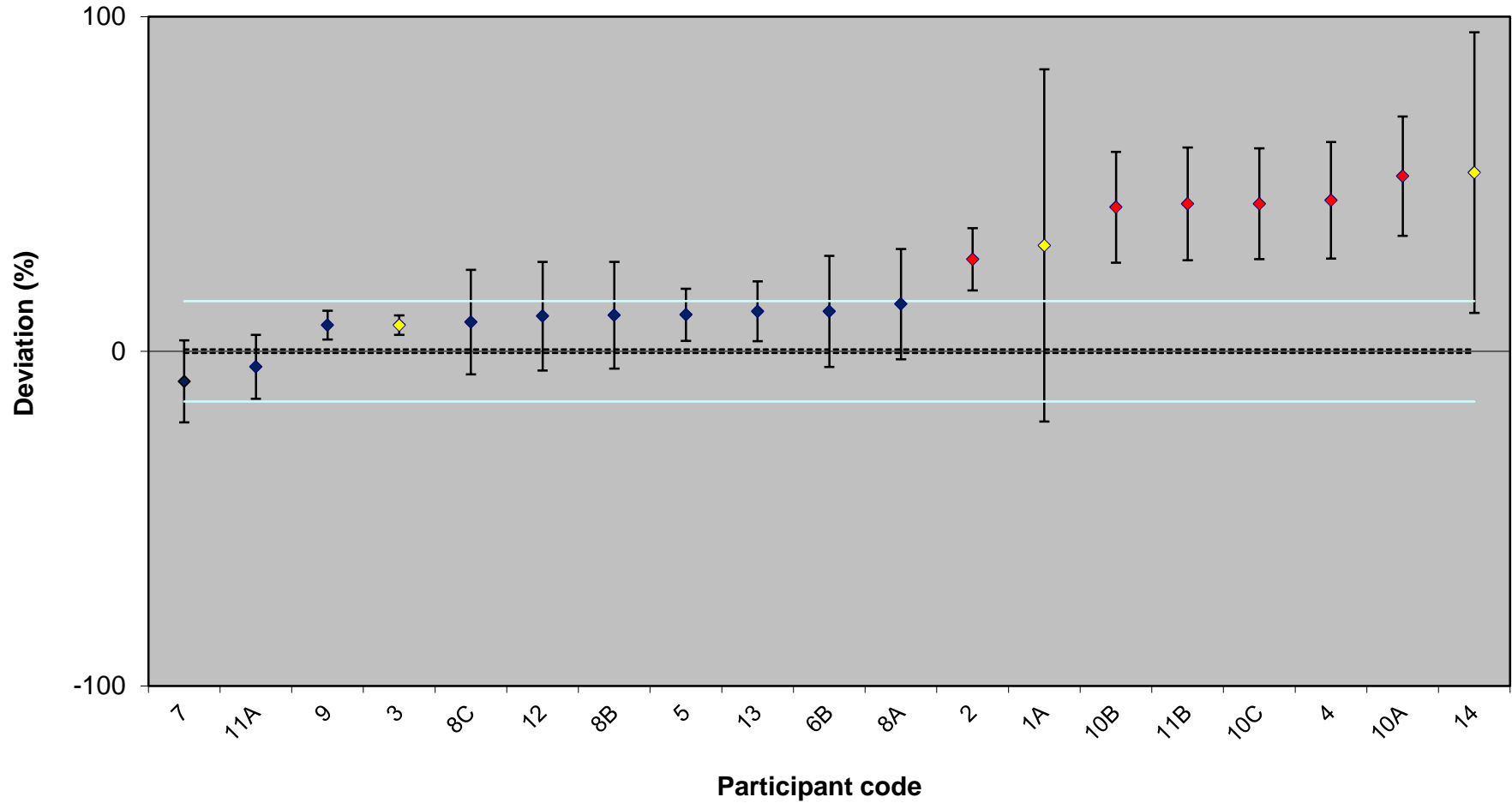


Figure 4 - Deviation plot for ¹³⁷Cs results, pre-disclosure
(3 results above area of plot)

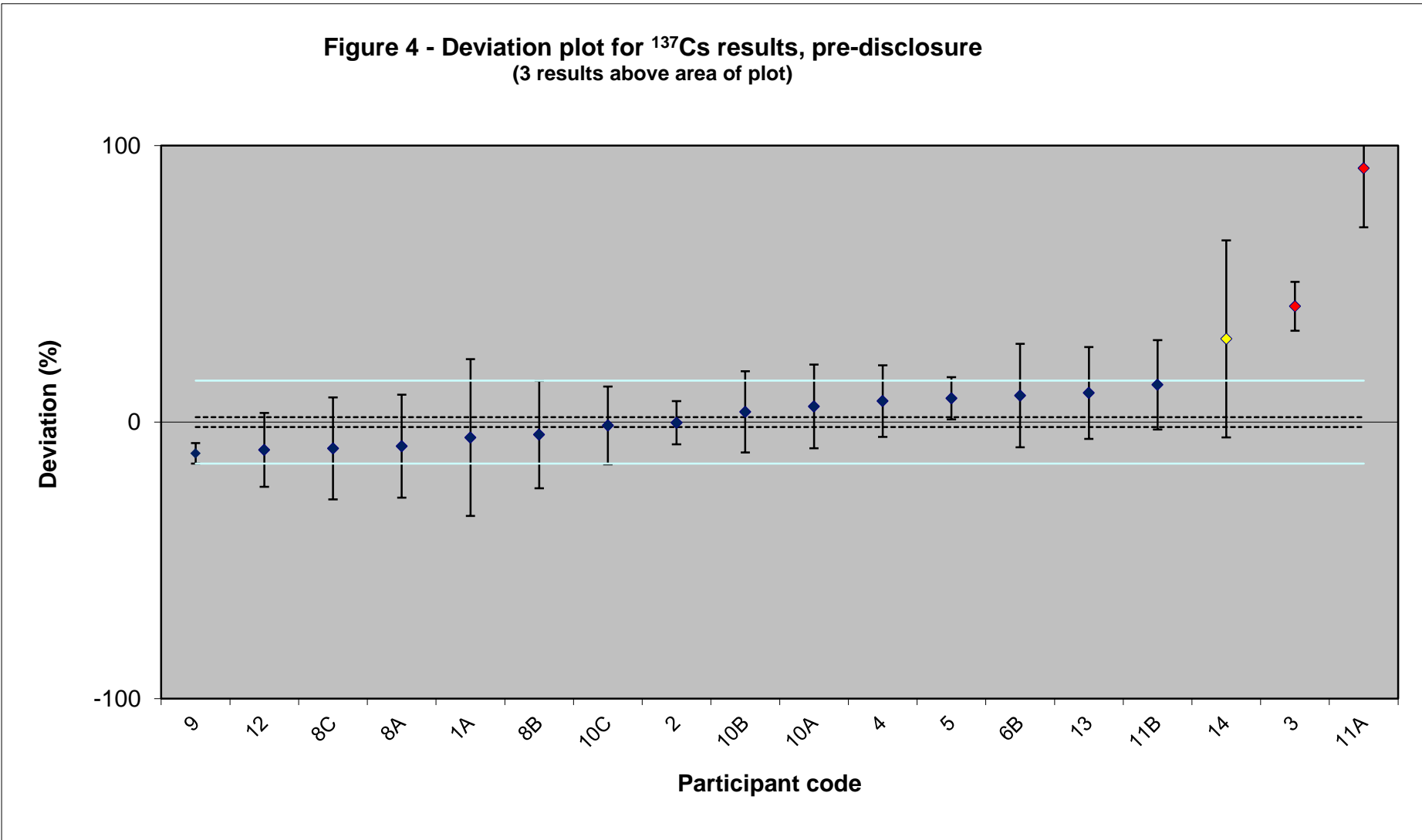


Figure 5 - Relative uncertainty plot for ^{241}Am results, pre-disclosure

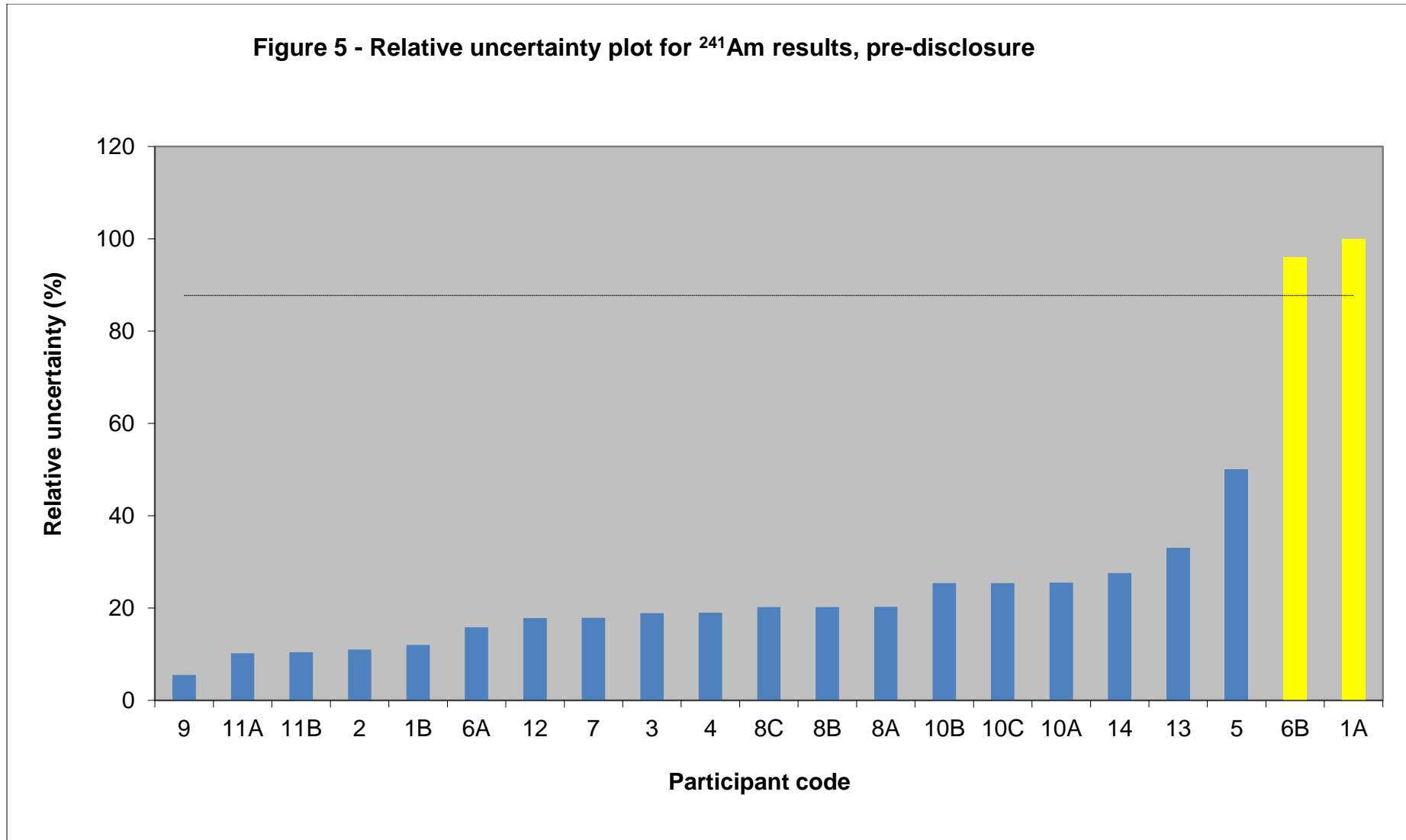


Figure 6 - Relative uncertainty plot for ⁶⁰Co results, pre-disclosure

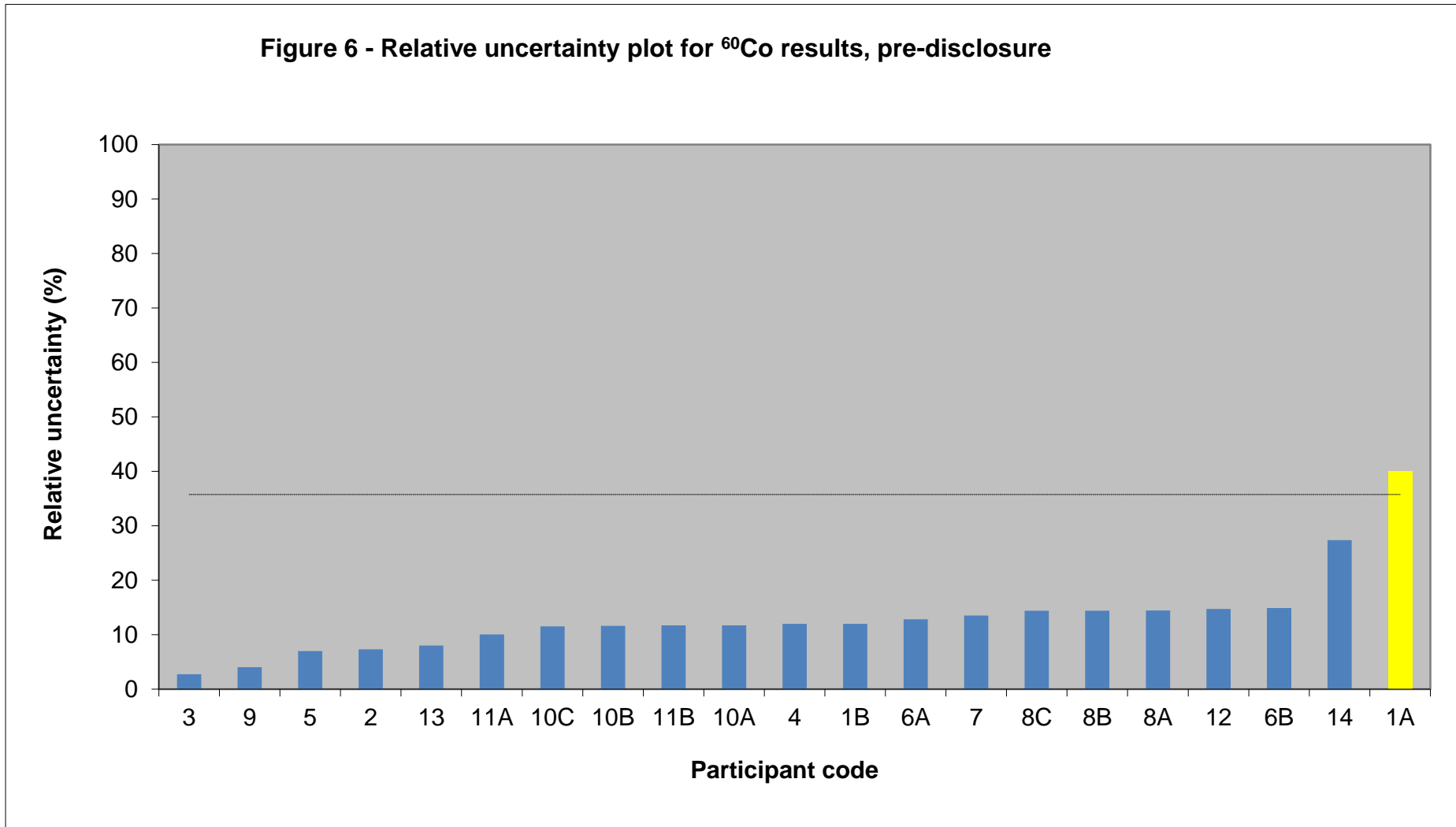
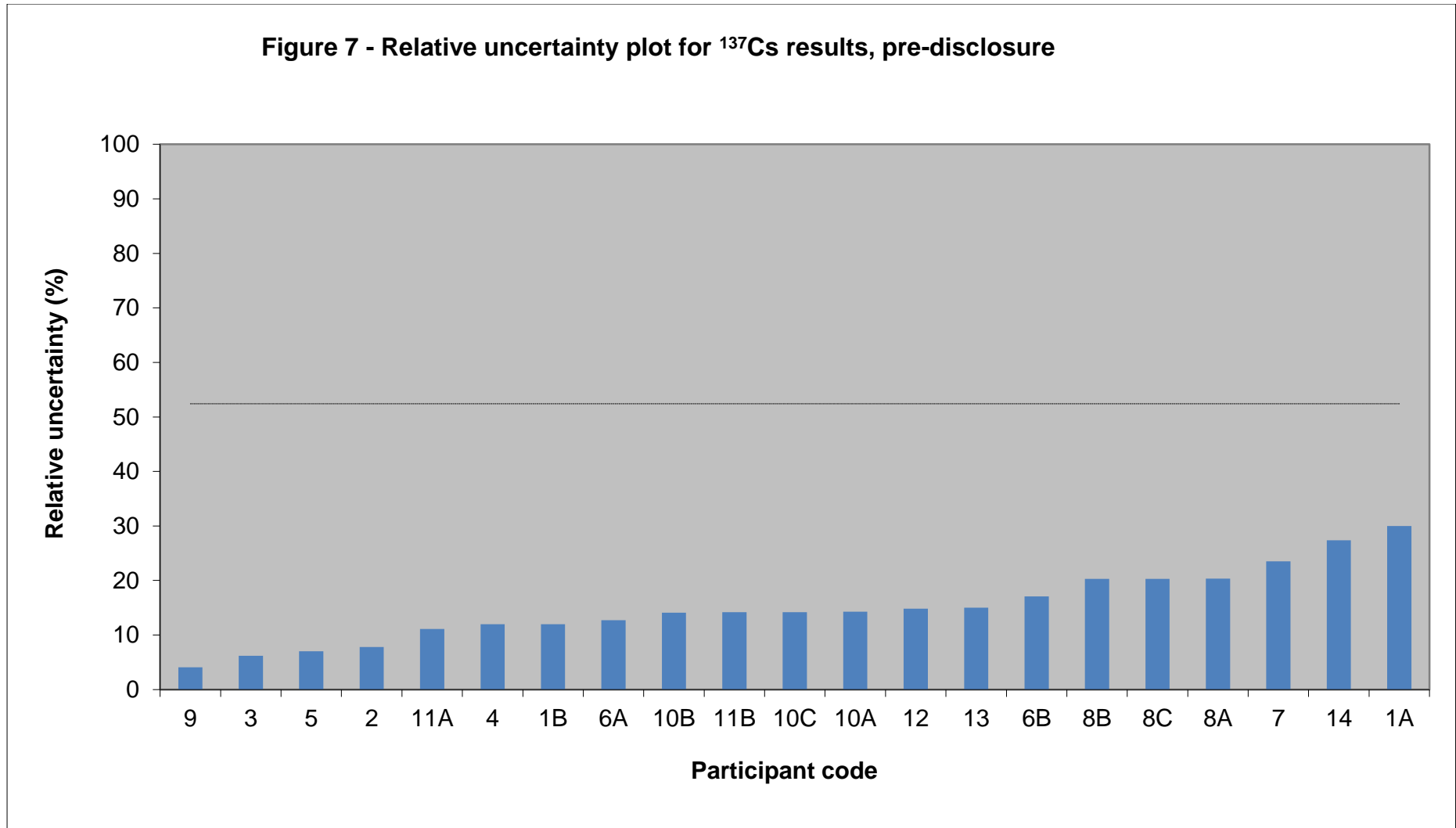


Figure 7 - Relative uncertainty plot for ¹³⁷Cs results, pre-disclosure



**Figure 8 - Deviation plot for ^{241}Am results, post-disclosure
(2 results above area of plot)**

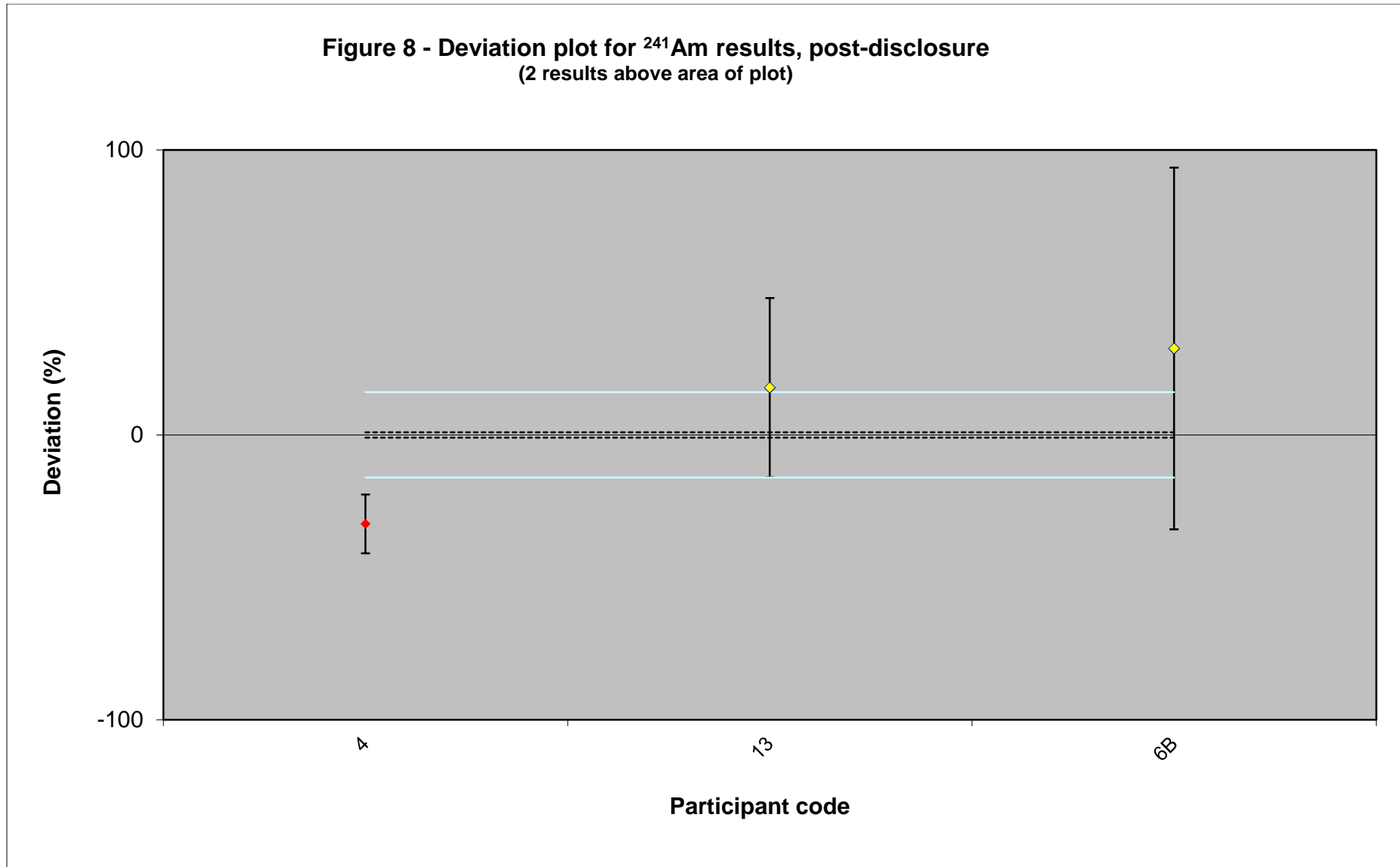


Figure 9 - Deviation plot for ⁶⁰Co results, post-disclosure

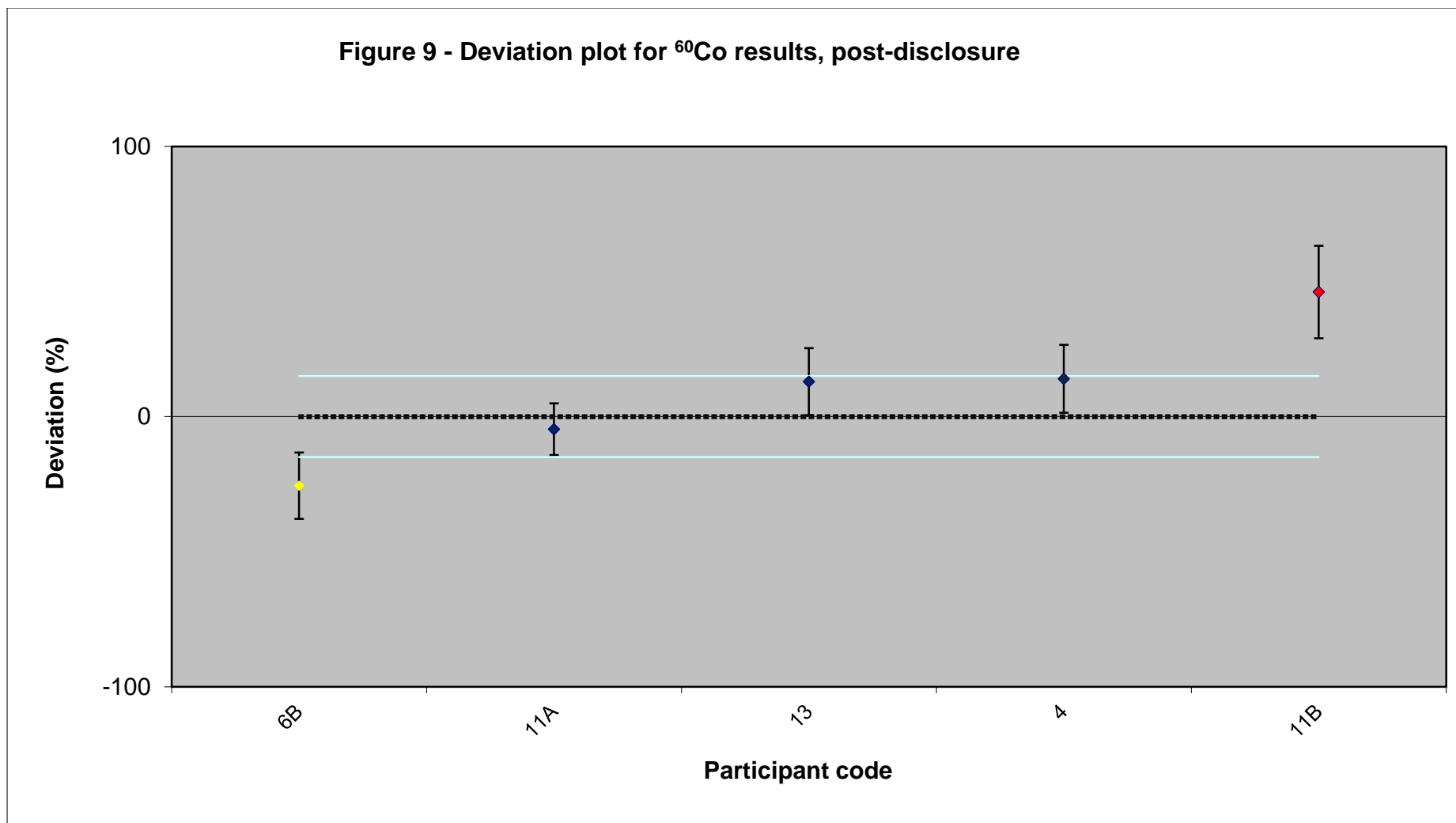
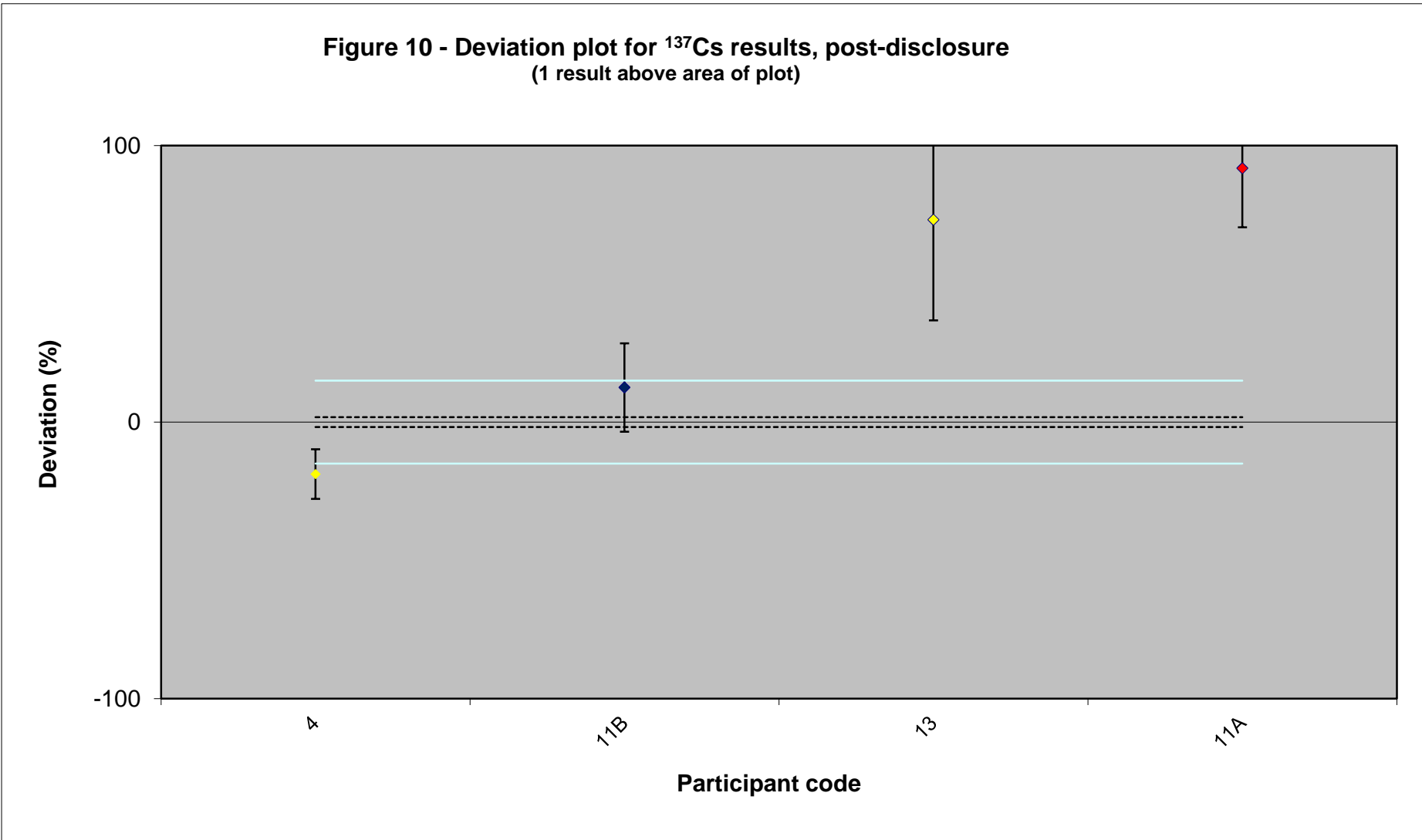


Figure 10 - Deviation plot for ¹³⁷Cs results, post-disclosure
(1 result above area of plot)



10 APPENDIX A – Initial Mailshot

Dear Colleague,

FOURTH NPL NUCLEAR INDUSTRY PROFICIENCY TEST EXERCISE

NPL is about to run its fourth bulk-waste proficiency test exercise ('drum comparison') to enable UK laboratories involved in decommissioning and site clearance to test their bulk-waste gamma measurement procedures. I am writing to invite you to participate in this exercise. As for previous exercises, the purpose is to provide the user community with a voluntary, independent and confidential test of their bulk waste measurement procedures.

In brief: NPL will prepare a single 'mock waste' sample in a 200-litre steel drum. The drum will contain metal, plastics, building material simulant (coarse aggregate) and ion-exchange resin. The radionuclides ^{241}Am , ^{60}Co and ^{137}Cs will be present and the overall activity concentration (activity/total mass of material in drum) will be in the range 1 – 10 Bq g⁻¹. The activity will be distributed in a heterogeneous manner. The drum will be available for measurement between early August 2012 and mid-February 2013 and participants will be asked to report the activity concentrations of the individual radionuclides. A short exercise report will be published in March 2013. All results will be coded and treated as confidential.

n.b. Please note that, due to limited available funding, there will be no post-exercise meeting.

If you are interested in participating, please read the full details given on pages 2 to 3 below and then complete and return the PTE Enquiry Form. Please note that requests to participate must be received by close of business on 3 July 2012.

We hope you are interested and that you will be able to participate.

Yours faithfully

Julian Dean

June 2012

A) Plan for Fourth NPL Nuclear Industry PTE

NPL will prepare a single ‘mock waste’ sample in a 200-litre steel drum. The drum will contain a mixture of metal, plastics, building material simulant (coarse aggregate) and ion-exchange resin. The radionuclides ^{241}Am , ^{60}Co and ^{137}Cs will be present and the overall activity concentration (activity/total mass of material in drum) will be in the range $1 - 10 \text{ Bq g}^{-1}$. The activity will be distributed in a heterogeneous manner within the drum.

The drum will be delivered to (and collected from) the participants on agreed dates. Participants will be given 2 working days to measure the drum (excluding arrival and dispatch days). The drum will be an Excepted package.

Note that, prior to measurement by the participants, NPL will disclose only the above information plus:

- **the percentage by mass of each material present;**
- **the dimensions of the drum;**
- **the mass of the drum (empty and full).**

Participants will be asked to report their measurements of the individual radionuclide activity concentrations along with details of calibration procedures and instrumentation used, by a ‘first deadline’ (see Timetable below). NPL will then disclose:

- more details of the materials (e.g. which metal) and the ‘internal structure’ of the drum;
- the location(s) of the activity present.

Participants will then have the opportunity to submit (by a ‘second deadline’) additional results based on this more detailed knowledge of the drum. Note that revisions to earlier results (i.e. those submitted before the first deadline) will not be accepted during this period.

NPL will then prepare a short draft report (including all results, coded for anonymity) and issue to all participants.

B) Timetable

Action	Dates
Interested laboratories to reply to this mailshot	By 3 July 2012
NPL to contact each laboratory, advise if they can be accommodated, and, if so, agree receipt and dispatch dates	By 27 July 2012
Participants to submit Purchase Orders	Within two weeks of notification of receipt and dispatch dates
Participants to measure drum	Within agreed dates in the period 6 August 2012 to 15 February 2013
Participants to submit results (<u>not knowing</u> details of drum contents)	By 1 March 2013 (First deadline)
NPL to declare further details of drum contents	4 March 2013
Participants to submit any additional results (<u>knowing</u> details of drum contents)	By 15 March 2013 (Second deadline)
NPL to issue report	By 29 March 2013

C) How to participate

Please complete the enclosed Enquiry Form and return it by close of business on **3 July 2012** to: radioactivity@npl.co.uk

Please indicate on the form which weeks in the period 6 August 2012 to 15 February 2013 you would prefer for delivery of the sample drum to your site. Note that you will be allocated two full working days to measure the drum (excluding the arrival and dispatch days).

IMPORTANT: If the exercise is oversubscribed we shall deal with requests for inclusion on a first-come-first-served basis, so please **PLEASE DO NOT SUBMIT A PURCHASE ORDER AT THIS STAGE**. We shall contact you in July to confirm whether or not we can accommodate you, and if so we will agree receipt and dispatch dates with you and ask you to submit your order at that time. Participants must ensure Purchase Orders are submitted within two weeks to ensure that they receive the drum on the allocated date.

D) Fees

The fees will be as follows:

- Participation: **£1075**
- Delivery: **To be advised**

NPL will arrange for a courier to deliver and pick-up on the agreed dates.

11 APPENDIX B – Reporting form

NUCLEAR INDUSTRY PTE 2012 REPORTING FORM	
Participating laboratory	
Contact person	
Address	
Submission date	

Radionuclide	Activity concentration (Bq g ⁻¹) RT 1200 UTC, 01/07/12	Type A uncertainty (% , k=1)	Type B uncertainty (% , k=1)	Combined standard uncertainty (% , k=1)
²⁴¹ Am				
⁶⁰ Co				
¹³⁷ Cs				

Please provide brief details of the following:

Detector type	
Scanning method used (including, e.g., detector collimation, segmented scanning and rotation of drum)	
Matrix density correction applied	
Calibration standards used	
Efficiency modelling and software	
Other	

12 APPENDIX C – List of Participants

Mr N M Baghini
MAHPG Laboratory
Imperial College London
Silwood Park Campus
Buckhurst Road
Ascot
Berkshire SL5 7TE

Dr H Beddow
Nuvia Ltd
B351.28
Fifteenth Street
Harwell Oxford
Didcot
Oxfordshire OX11 9AW

Mr W De Boeck
SCK-CEN
Boeretang 200
2400 Mol
Belgium

Mr J Cairns
Aurora Health Physics Services Ltd
3 The Terrace
Library Avenue
Harwell Oxford
Didcot OX11 0SG

Mr G Faulkner
Babcock International Group – Marine and Technology (Devonport)
Babcock International Group
PC956 N016
Devonport Royal Dockyard
Plymouth
Devon PL1 4SG

Mr T Hatt
ORTEC – Advanced Measurement Technology
Spectrum House
1 Millars Business Centre
Fishponds Close
Wokingham
Berkshire RG41 2TZ

Mr T Huys
Belgoprocess
Gravenstraat 73
2490 Dessel
Belgium

Mr R Major
AMEC

NPL Report IR 30

601 Faraday St
Birchwood
Warrington WA3 6GN

Mr A Waterfall
AWE
Aldermaston
Reading
Berkshire RG7 4PR

Mr N J O'Brien
AWE
Aldermaston
Reading
Berkshire RG7 4PR

Dr D Parvin
Babcock International Group
B14.1
Sellafield
Seascale
Cumbria

Mr M Rushby
Canberra UK Ltd
B528.10 Unit 1
Harwell Oxford
Didcot
Oxfordshire OX11 0DF

Mr G Simone
Nucleco S.p.A.
Via Anguillarese 301
Rome
Italy

Mr J Stephenson
D60
RSRL Winfrith
Winfrith Newburgh
Dorset DT2 8WG

Mr G Ward
Sizewell A Site - Magnox Ltd.
Nr Leiston
Suffolk IP16 4UE

Performance of a HPGe System for Surface and Container Measurements – 13582

Timothy R. Twomey* and Ronald M. Keyser**

*ORTEC – AMETEK, 801 South Illinois Avenue, Oak Ridge, TN 37830 USA

**Software & Information Services, 562 Bacon Springs Ln, Clinton, TN 37716 USA

ABSTRACT

The decommissioning of a nuclear facility or post-accident cleanup is an immense engineering effort requiring an array of specialist tools and techniques. The decommissioning and cleanup activities generate large quantities of low activity waste. For economic disposal, it is desirable to certify the waste as suitable for free release. Every container must be assayed to a sufficient degree of accuracy and sensitivity so that it may be certified to be or not to be suitable for “free release”.

In a previous work, the performance of a highly-automated system for free release of large numbers of containers was presented in which the spectroscopy hardware comprised four ORTEC Interchangeable Detector Module (IDM) mechanically cooled HPGe spectrometers in conjunction with ORTEC ISOPlus waste assay software. It was shown that the system was capable of assaying large containers to free release levels in reasonable measurement times.

Not all operations have enough waste to justify an automated system or rapid assay results may be required, perhaps in a remote location. To meet this need, a new mobile system has been developed for the assay of smaller objects (drums, boxes, and surfaces) *In-Situ*. The system incorporates the latest generation IDM-200 and ISOPlus software and a new variant of the ISOCart hardware.

This paper will describe the system and performance.

Keywords: Waste assay, In Situ, HPGe, Germanium detectors, MDA, MDC, Free release

INTRODUCTION

Large amounts of waste are produced in cleanup of accidents and during dismantling and decommissioning activities of unneeded nuclear facilities. While some of this waste contains radioactive material, which is controlled by regulatory bodies, much of the waste has no nuclear material present, but this must be demonstrated prior to disposal. Waste with nuclear material

levels below regulatory limits can be disposed of in ordinary waste streams as “below clearance limit” (CL) or “free release” material.

For free release, the contents of a waste container must be measured and certified to be below the specific activity limits (Bq/g) prescribed in the regulations. There is a much higher cost to dispose of waste which cannot be certified as free release. Manual systems for container assay using germanium detectors (both liquid nitrogen and mechanical coolers) and similar software was described in Refs. (1, 2). An automated system using the IDM and ISOPlus software was described in Ref. (3) and demonstrated that containers could be measured to a Minimum Detectable Concentration (MDC) level suitable for free release in reasonable measurement times.

This paper describes the development of a transportable assay system, capable of measuring waste containers of any size and determining their eligibility for free release.

EQUIPMENT

The equipment consisted of an IDM 200 mounted on a movable cart, prototype collimator, a laptop for control and data collection, calibration sources, a 200 l drum, and a back shield of lead with an average thickness of 40 cm. The measurements were made in an ordinary building with concrete floors and ceiling in a room with gypsum-board walls. The waste container was a standard 200 l, steel-walled drum of 21.4 kg empty weight including removable lid. It was filled with mixed density waste comprising paper, printed circuit boards, electronic instrument chassis, and computer parts. It was loosely filled with a net weight of 83 kg, thereby constituting an average density of ~ 0.3 g/cc. The drum was mounted on a lift jack and positioned so that the midpoint of the drum is in line with detector center height.

The IDM 200 (and mechanically identical Detective 200), see Ref. (4), is a fully integrated spectroscopy system consisting of a HPGe detector (85 mm diameter by 30 mm deep), cooled by a miniature Stirling cycle cooler, DSP MCA, high voltage supply and high speed USB communication port. A "hardened", all metal-sealed detector cryostat eliminates any possibility of damage to the detector due to partial warm up. The system is designed for low power operation and can be mains powered or will run for several hours on an internal battery. The detector is



Figure 1 IDM 200 with Prototype Collimator

shielded by 12.7 mm of steel up to the front surface of the detector cover. A 6.4 mm thick cylindrical lead collimator shield that extends from approximately the middle of the detector crystal to 25 cm in front of the front of the detector endcap was mounted on the steel shield. Figure 1 shows the prototype collimator in place on the unit. This collimator limits the field of view to the width (diameter) of the drum when the front edge of the collimator is 50 cm from the near surface of the drum.

The Field of View is calculated by the software from the operator entered detector-drum distance, detector diameter, collimator material, and collimator size. The calculation was verified by measuring the field of view using a multi-nuclide gamma-ray point source. The source was moved in front of the detector with collimator at a distance of 30 cm from the end of the collimator (55 cm from detector). The peak area vs horizontal position is shown in Fig. 2. The FOV was calculated as the FWHM for the peak area vs position to be 33 cm. The calculated FOV was 34 cm. The detector was energy and efficiency calibrated using a NIST-traceable mixed gamma ray source ranging from 59 keV to 1.8 MeV placed at 30 cm from the detector front face on the detector axis. Both the resolution and efficiency are in the MDA formula. Figure 3 shows the detector resolution as a function of energy for this detector. Figure 4 shows the efficiency vs energy curve for this detector. The ISOPlus software calculates the total efficiency of a volume source from a point source calibration. It also calculates the absorption correction based on the density of the contents (from the entered weight and volume) and type of material in the drum, assuming that,

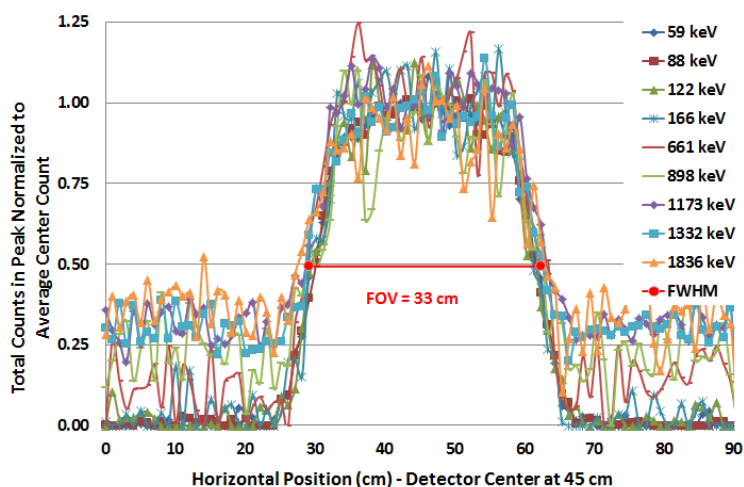


Figure 3 Normalized Count Rate vs Horizontal Position in Front of Detective 200 with Lead Collimator

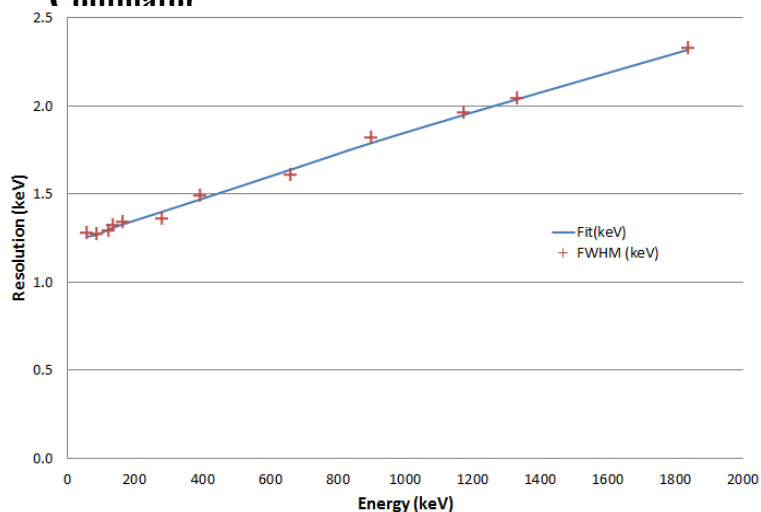


Figure 2 Resolution vs Energy

on average, the material and distribution of activity is homogeneous within the detector's field of view. To meet this assumption of homogeneous sample material, the drum can be rotated either by using a turntable or manually to multiple positions during the total count time. Multiple detectors can also be used and the spectra combined to obtain the final result.

The detector placement relative to the drum is shown in Fig. 5.

Nuclides and MDC

The MDCs were calculated for ^{54}Mn , ^{60}Co , ^{125}Sb , ^{134}Cs , ^{137}Cs , ^{152}Eu , ^{154}Eu , and ^{241}Am . These same nuclides used in Ref. (3) so that a comparison could be made to the previous results. The MDC method selected was the NuReg 4.16 Method as defined in Ref. (5). The background width was selected as 2.5 FWHM. This width was selected to be able to compatible with previous calculations. A smaller width, as given in ISO 11929 (Ref. 6) would give smaller (better) values.

Spectra

The system was operated in automatic mode to collect spectra over a two-day period. The collection times were 3600, 7200, 10000, 20000, 30000, 40000, 50000, and 60000 seconds. In addition, 36 spectra were collected for 1 hour each to measure the distribution of the results.

RESULTS

Background

Figure 6 shows a 50000 s background spectrum with the drum in front of the back shield. This is a typical background for rooms in concrete buildings.

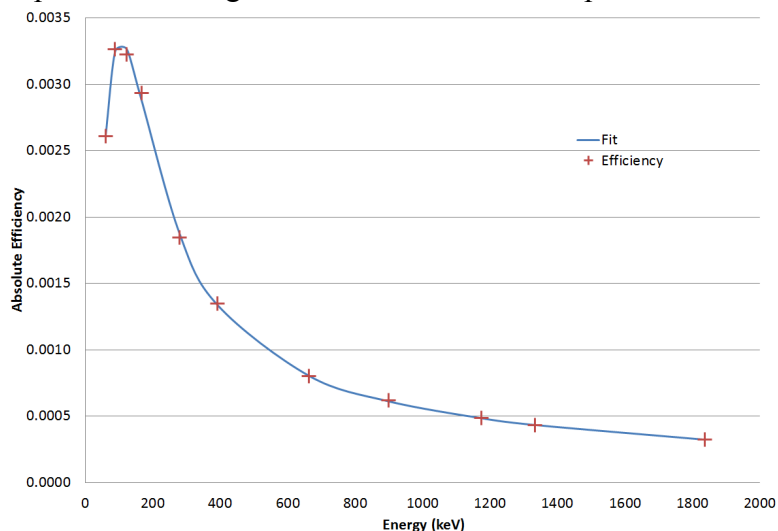


Figure 4 Efficiency vs Energy for Point Source at 30 cm

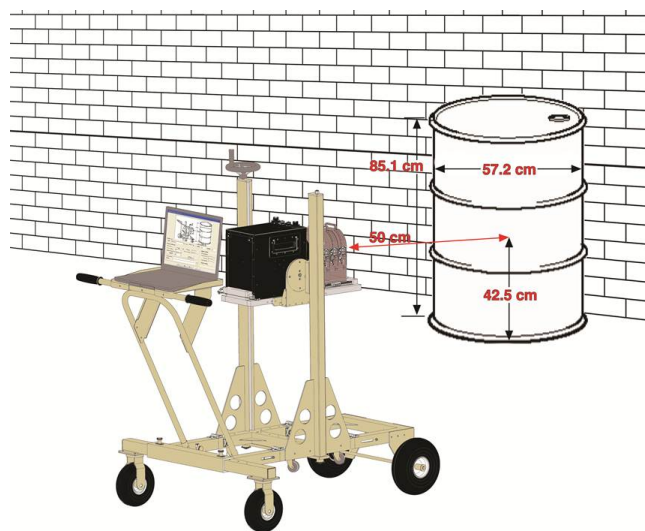


Figure 5 Detector and Drum Arrangement

Minimum Detectable Concentration

The MDC was calculated for the listed nuclides for each of the spectra of different counting times. The MDCs vs counting time for some of the nuclides are shown in Fig. 7. It shows the typical reduction with the square root of the time.

The MDCs for the IDM 200 are compared to the previous work for several counting times in Table I. It should be noted that different containers were used.

RESULTS

The results show that the single detector system using the IDM 200 can be used in the field on medium size containers to give results below the required limit in a count time of one to two hours for most nuclides of interest. Only low-density samples were counted. The attenuation correction is based on the measured density and the operator entered type of content.

The Sogin results are based on a single detector spectrum (one of the four detectors in the automated system) and show a lower level in a shorter time due to the significantly thicker collimator (10 cm vs 4 mm) and larger volume (1000 l vs 200 l). The clearance levels are taken from Refs. 7, 8, and 9. These results show that the clearance level MDCs can be met in 10,000 s or less for the measurement configuration used. The achieved MDCs are generally higher than those achieved with a single detector in the SOGIN system. This

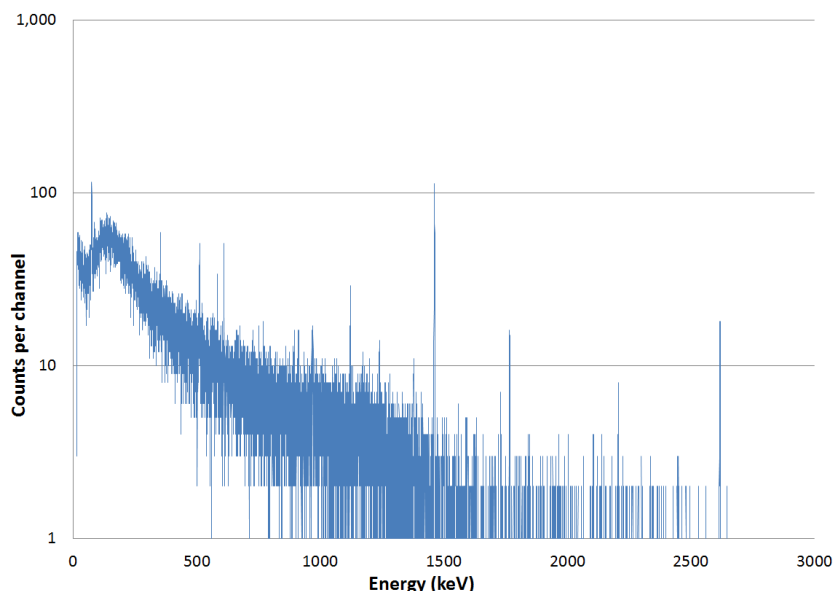


Figure 6 Long Time Background with Drum

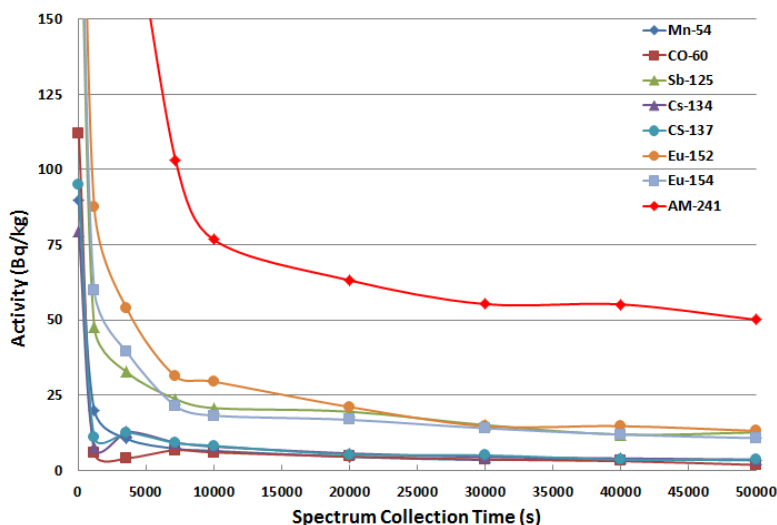


Figure 7 MDC vs Collection Time

is attributable to the much deeper collimation chosen in the present system, which lowers the background, but also the absolute detection efficiency for extended sources. A thicker side wall but less deep collimator would further reduce background due to radiation from the side of the system, while improving the absolute efficiency. It is suited for small numbers of containers or containers in remote locations where the use of a larger system is impractical.

Table I MDCs (Bq/g) for Waste Density ~ 0.3 to 0.4 g/cc					
Nuclide	3600 s	7200 s	10000 s	Representative Clearance level (Refs. 7, 8, 9)	Sogin System (2400 s)
⁵⁴ Mn	0.011	0.0072	0.0065	1.0, 0.1, 0.1	0.0030
⁶⁰ Co	0.004	0.0067	0.0060	1.0, 0.1, 0.1	0.0019
¹²⁵ Sb	0.033	0.0237	0.0207	10.0, 1.0, 1.0	0.0102
¹³⁴ Cs	0.013	0.0093	0.0079	1.0, 0.1, 0.1	0.0032
¹³⁷ Cs	0.013	0.0091	0.0082	1.0, 1.0, 1.0	0.0037
¹⁵² Eu	0.054	0.0312	0.0295	1.0, 0.1, 0.1	0.0131
¹⁵⁴ Eu	0.039	0.0214	0.0182	1.0, 0.1, 0.1	0.0080
²⁴¹ Am	0.194	0.1030	0.0767	1.0, 0.1, 0.1	0.0655

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Radiological Performance of an Automated HPGe Assay System for Bulk Containers of Decommissioning Waste Intended for Free Release

Timothy R. Twomey, Ronald M. Keyser, and Davide Sacchi

ORTEC

801 South Illinois Avenue
Oak Ridge, TN, 37831 USA

Email: ron.keyser@ametek.com, tim.twomey@ametek.com, davide.sacchi@ametek.com

Giuseppe Merlino and Paolo Grignani

EL-SE S.r.l.

Via Pier della Francesca 26,
20090 Trezzano sul Naviglio (MI)
Italy

Email: giuseppe.merlino@el-se.com, paolo.grignani@el-se.com

Gianluigi Migliore, Nunzia Radatti and Sabrina Romani

Sogin S.p.A.

Via Torino, 6
00184 Roma

Italy

Email: migliore@sogin.it, radatti@sogin.it, romani@sogin.it

ABSTRACT

The decommissioning of a nuclear power plant is an immense engineering effort requiring an array of specialist tools and techniques. The decommissioning activities generate large quantities of low-activity waste. For economic disposal, it is desirable to certify the waste as suitable for free release. Every container must be assayed to a sufficient degree of accuracy and sensitivity so that it may be certified as “free release”. The more reliable the analysis, the lower the total cost of decommissioning because of the high cost of radioactive waste disposal. Since the waste quantities are large, a suitable measurement system must be highly automated, reliable, and sensitive enough to reliably demonstrate that the free release criteria have been met. The automated system is required to measure a variety of sample sizes and forms: bags, boxes, and B25 containers, with densities approximately in the range 100 kg/m^3 to 2000 kg/m^3 . This paper gives the radiological performance (detection limits) of a commercial system designed for this application, installed at the SOGIN decommissioning sites at Caorso, Trino and Latina, Italy. The assay systems were developed by El.Se. Srl (ITALY) in collaboration with ORTEC. Each system uses four ORTEC Interchangeable Detector Module (IDM) mechanically cooled HPGe spectrometers. The IDMs simplify the mechanical design and improve the serviceability. Analysis of spectra is performed using the ORTEC ISOPlus waste assay software under control of a user interface developed using National Instruments LabView. A new “average MDA” algorithm has been developed and implemented. The system will be fully described and performance data will be presented.

Keywords: Waste assay, box counters, HPGe, Germanium detectors, MDA, Free release

INTRODUCTION

Free release of Nuclear Waste, such as is produced in large quantities during dismantling and decommissioning activities in redundant nuclear facilities, is controlled by regulatory bodies. For free release the contents of a waste container must be certifiably below the specific activity limits in Bq/g or equivalent prescribed in the regulations. There is a severe cost penalty in disposing of waste which cannot be certified as “below clearance limit” (CL) or “free release”. This paper describes the joint development of a container assay system, capable of handling large waste containers and determining their suitability for free release.

The system was developed by El-SE s.r.l. in conjunction with ORTEC, who provided spectroscopic components, for the Italian company Sogin S.p.A. which manages the decommissioning of Italy’s nuclear power plants. Sogin has deployed three examples of this system at the decommissioning sites in Caorso, Trino, and Latina.

OVERVIEW

The system is highly automated for measurement of a variety of samples sizes and forms: bags, boxes, and B25 containers, with densities approximately in the range 100 kg/m^3 to 2000 kg/m^3 , generally loaded by the use of a fork lift or overhead crane.



The system hardware comprises the following major sub-systems:

- Mechanical Hardware: Container conveyor and Detector Support and positioning mechanism.
- System control: Operator Console, personal computer, and PLC
- Germanium Detectors: 4 ORTEC IDMs (Interchangeable Detector Modules)

A computer-controlled automatic Cart-On-Track (Rail) conveyor capable of handling weights of up to 6000 kg moves the container past the four HPGe detector systems in two “tower” structures positioned on either side of the container (Fig 1). An automatic weigh scale with a resolution of 1 kg is integrated within the conveyor.

The vertical positioning of the detectors is also carried out under computer control with a resolution of +/- 1 mm to handle different container sizes, while detector-to-container distance can be adjusted manually. All machinery movements are implemented and controlled locally by a PLC and are managed remotely by a System Control Computer which is a PC providing the system operator interface.

Electrical hardware control, with the exception of the spectroscopy system electronics, is provided by means of a PLC from the operator console. The PLC firmware supports a local MMI (Man Machine Interface) and an ethernet interface allowing remote control of the system from the system control computer. A touch-screen LCD, mounted on the operator console allows system set-up and calibration (for example, test of the scale accuracy), plus manual positioning of the container platform and pre-calibration of detector positions. For calibration/setup purposes, each detector may be moved to the desired position by the operator console and then the system software can read the position information and save it for future use as part of a “learning” process. As part of this process the software warns the user if the computed detector coordinates are out of range or would lead to a detector collision when in operation.

The local interface is locked when the PLC is executing remote procedures, in order to avoid conflicts between automatic and manual operations. The PLC firmware also manages all the system safety features (light barriers, anti-collision sensors, etc), immediately stopping any running motor if a security input is triggered. Diagnostic messages are issued and archived by the PLC whenever anomaly conditions occur.

HPGe Detectors

The spectroscopy system hardware is implemented using a fundamental gamma-ray detection “building block,” the ORTEC IDM. The IDM consists of an 85 mm x 30 mm HPGe Detector, Stirling cooler, DSP MCA, high voltage supply, and high speed USB communication. It uses standard, low-current mains power.

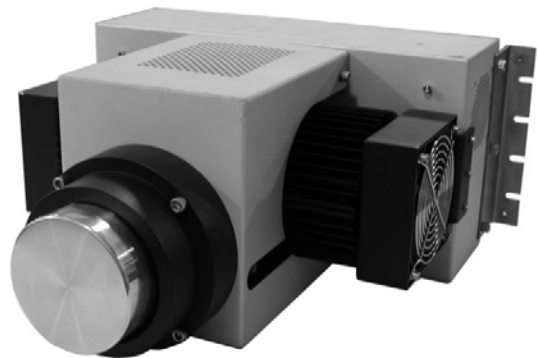


Figure 2 Interchangeable Detector Module (IDM)

The large diameter detector gives excellent efficiency in the range ~40 to ~3000 keV, contributing to low MDAs and short count times. Standardized detector crystal dimensions mean that all IDMs will perform similarly. Relative efficiency is approximately 55%. A complete description is given in [1]. Digital filtering techniques reduce the effect of low frequency noise from mechanical vibration [2].

Each IDM is provided with a 10 cm deep lead rectangular shield which provides cylindrical collimation. The minimum lateral wall thickness is 10 cm. Each collimator is provided with a 1mm thick copper liner along the internal curved surfaces. The collimator depth is variable between 0.5 cm and 3 cm to vary the field of view for different containers.

Software description

In routine operation, the system is controlled by the operator through the system control PC. The underlying activity calculations are performed by ORTEC Isotopic-32 version 4.1 [3, 4] operating in “container mode” under a user interface program, written by EL-SE in National Instruments LabVIEW which provides hardware control, analysis set-up, and measurement process management. Operator and password protected setup modes are provided.

Calibration

Each detector (IDM) is first characterized by a single point source measurement and knowledge of detector crystal dimensions and dead-layer, and the end cap thickness.

This primary calibration, which can be traceable if a traceable standard is used, is then extrapolated to match the physical situation of the sample: container geometry, material, and matrix composition. The entire measurement problem is broken down into multiple source/matrix voxels and their contribution to the composite spectrum are calculated and summed.



Figure 3 Collimator Detail

No special separate measurements are needed to characterize the detector other than the above point-source calibration. The container or item is modeled, based on its physical dimensions, material, and the average density of the waste matrix. The method amounts to an “efficiency transfer” method in which an efficiency measured with a standard in one (calibration) geometry is transformed by calculation to the efficiency which would be measured in a second (sample) configuration.

Under control of the automatic process, the item is moved to the first pre-programmed counting position. Each selected detector (usually all four) counts to the chosen preset time and then the item is moved to the second position and counted. This process repeats until all measurements in all

counting positions have been made. For a 3 m³ container, typically 3 sets of measurements are made each of 4 spectra, one from each detector. Twelve results are obtained for the total activity which can be examined individually or as the average. When all spectra have been counted, analysis takes place and final reports are generated.

Averaged MDAs are also available according to the NUREG 4.16 which can be extended, in the case of four similar detectors to:

$$MDA_{SUM} = \frac{2.71 + 4.66 \cdot \sqrt{\sigma_{B1}^2 + \sigma_{B2}^2 + \sigma_{B3}^2 + \sigma_{B4}^2}}{\gamma \cdot (LT_1 + LT_2 + LT_3 + LT_4) \cdot \bar{\epsilon}_c}$$

Where: σ_{Bi} is the uncertainty in the background in peak area i
 γ is the branching ratio or gamma-ray yield
 LT_i is the live time of the spectrum from detector i
 $\bar{\epsilon}_c$ is the corrected average efficiency (absorption and geometry)

If the background term $4.66 \cdot \sqrt{\sigma_{B1}^2 + \sigma_{B2}^2 + \sigma_{B3}^2 + \sigma_{B4}^2}$ is much larger than 2.71, then for identical detectors and backgrounds this reduces to:

$$MDA_{SUM} = \frac{MDA_1}{\sqrt{4}} = \frac{MDA_1}{2}$$

Where MDA_1 is the MDA for a single detector.

Tabulated scaling factors are used to calculate the activities of non gamma-emitters or very weak emitters, including correction for the different half-lives of the vector and correlated nuclides.

Tables of release limits are used to compute percentage of limit for individual nuclides.

Operator process

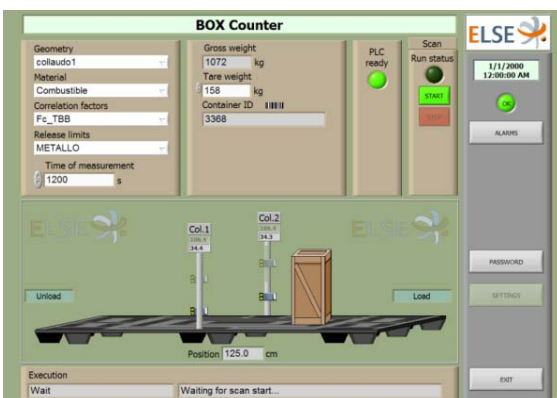


Figure 4 Main Operator Screen

The main operator screen is shown in Figure 3. Extensive use is made of LabVIEW Graphics in order to make the system user friendly. The setup process is similarly graphical and is used to pre-define container type measurement parameters, such as horizontal and vertical measurement positions, container data (materials, thicknesses, and dimensions), and to build data tables such as release limits and scaling factor tables. Any subset of the available four detectors can be programmed to be used for a measurement.

After Setup, only five choices are required for an operator to start a routine scan:

- The measurement geometry (defines the container type and the measurement positions)
- The material in the container (chosen from a dropdown list of database materials)
- The correlation factor table (which may vary depending on the waste material type and origin)
- The concentration limit table (which may vary depending on the material type (e.g., metal, concrete))
- The preset time for the spectrometric measurement in each position

After these data are entered, the system proceeds to automatically take data at the pre-programmed positions and preset times, and then performs an activity analysis of each spectrum. After the initial analysis by ISOTOPIC, the operator program generates reports, including activities, MDAs and “release index” reports showing the percentage of maximum allowed release activities for specific nuclides.

Testing and Performance Results

On site testing was carried out at Latina, Trino and Caorso Nuclear Power Plants by Sogin personnel to demonstrate compliance with EU directive 96/29 EURATOM and EC Recommendation: Radiation Protection RP89, RP113, RP122.

MDA Testing

In order to determine the MDA of the system for the nuclides specified, a long background run was made (typically 58000 seconds over night), then a representative “blank” container and matrix was counted. The MDAs were then calculated from the spectrum after correction for background peaks. The measured MDAs were compared with the Sogin performance specification requirements and the with the clearance limits in references [5-7]. These are presented in Tables I and II.

Table I MDA on single spectrum

Radionuclide	MDA low density Bq/g		MDA high density materials Bq/g			Clearance Limit Bq/g		
	Required 0.3 g/cc 40 min	Measured ^a 0.4 g/cc 40 min	Required 2 g/cc 4hr	Measured ^b 1.5 g/cc 4hr	Measured ^c 1.8 g/cc 4hr	RP 89 [5]	RP 113 [6]	RP 122 [7]
Mn-54	0.05	0.0030	0.005	0.0008	0.0004	1.0	0.1	0.1
Co-60	0.05	0.0019	0.005	0.0006	0.0003	1.0	0.1	0.1
Sb-125	0.05	0.0102	0.010	0.0038	0.0013	10.0	1.0	1.0
Cs-134	0.05	0.0032	0.005	0.0009	0.0005	1.0	0.1	0.1
Cs-137	0.05	0.0037	0.005	0.0011	0.0005	1.0	1.0	1.0
Eu-152	0.05	0.0131	0.010	0.0040	0.0019	1.0	0.1	0.1
Eu-154	0.05	0.0080	0.010	0.0021	0.0013	1.0	0.1	0.1
Am-241	1.00	0.0655	0.500	0.0203	0.0066	1.0	0.1	0.1

^a Trino NPP 1m³ container, 1mm wall. 4 detectors fixed position Matrix: LECA

^b Trino NPP 1m³ container, 1mm wall. 4 detectors fixed position. Matrix: gravel

^c Caorso NPP 1m³ NO container. 2 detectors fixed position Matrix: concrete block

Table II MDA averaged on multiple spectra

Radionuclide	MDA low density Bq/g		MDA high density materials Bq/g			Clearance Limit Bq/g		
	Required 0.3 g/cc 40 min	Measured ^a 0.4 g/cc 40 min	Required 2 g/cc 4hr	Measured ^b 1.5 g/cc 4hr	Measured ^c 1.8 g/cc 4hr	RP 89 [5]	RP 113 [6]	RP 122 [7]
Mn-54	0.01	0.0011	0.001	0.0003	0.0003	1.0	0.1	0.1
Co-60	0.01	0.0007	0.001	0.0002	0.0002	1.0	0.1	0.1
Sb-125	0.01	0.0039	0.002	0.0012	0.0009	10.0	1.0	1.0
Cs-134	0.01	0.0013	0.001	0.0004	0.0003	1.0	0.1	0.1
Cs-137	0.01	0.0014	0.001	0.0004	0.0004	1.0	1.0	1.0
Eu-152	0.01	0.0049	0.002	0.0015	0.0013	1.0	0.1	0.1
Eu-154	0.01	0.0028	0.002	0.0008	0.0007	1.0	0.1	0.1
Am-241	0.50	0.0270	0.100	0.0097	0.0037	1.0	0.1	0.1

^a Trino NPP 1m³ container, 1mm wall. 4 detectors fixed position Matrix: LECA

^b Trino NPP 1m³ container, 1mm wall. 4 detectors fixed position. Matrix: gravel

^c Caorso NPP 1m³, NO container. 2 detectors fixed position Matrix: concrete block

Accuracy Testing



Accuracy tests were carried out using 1 m x 1 m x 1 m steel containers filled with matrix and with plastic source tubes aligned along the container diagonals; uniform source distributions were simulated by regularly spaced point sources along the diagonal sample tubes. The hot spot was simulated by placing all sources at the extreme end on one diagonal.

Fig 5 Accuracy test containers

Tables III and IV provide the results of the tests of uniform source distributions and Table V provides the results of non-uniform (“hot spot”) testing.

UNIFORM SOURCE DISTRIBUTIONS:

Table III Accuracy test 1: Measured at Caorso NPP - volume = 1 m ³ . 2 detectors. Matrix: paper, plastic 0.3 g/cc, 2400 sec live time (2-sigma uncertainty)			
Nuclide (number of sources)	Reference Source Activity (kBq)	Averaged Measured Activity Values (kBq)	Δ %
Co-60 (4)	720.2	689,5±19,6%	-4,2
Eu-152 (4)	1102.7	1185,0±19,6%	-7,5
Cs-137 (4)	1351.2	1354,0±20,0%	-0,2

Table IV Accuracy test 2: Measured at Trino. NPP volume = 1 m ³ . 4 detectors. Matrices: LECA Lightweight aggregate 0.4 g/cc and gravel 1.5 g/cc, 1200 sec live time (1-sigma uncertainty)					
Nuclide (number of sources)	Reference Source Activity (kBq)	0.4 g/cc Averaged Measured Activity (kBq)	Δ %	1.5 g/cc Averaged Measured Activity (kBq)	Δ %
Eu-152 (5)	1022.8	1178,0±7,3%	+13,2	991,3±7,3%	-3

Non-UNIFORM SOURCE (Hot spot) DISTRIBUTIONS:

Table V Accuracy Test 3: Measured at Latina NPP volume = 0.5 m ³ . 4 detectors. Matrices: paper 0.5 g/cc 4500 sec live time and gravel 1.5 g/cc 2000 sec live time (1-sigma uncertainty)					
Nuclide (number of sources)	Total Reference Source Activity (kBq)	0.5 g/cc Measured Activity Values (kBq)	Δ %	1.5 g/cc Measured Activity Values (kBq)	Δ %
Eu-152 (6)	1224 kBq	959±7.8%	-21.8	1390±11.8%	+13.5

Susceptibility to vibration and electrical noise:

The ORTEC IDM incorporates digital filtering to minimize resolution degradation due to low frequency noise. In addition, the system was designed to minimize the electrical noise generated by the motors and the associated drivers through the study of the layout, the use of shielded cables and ferrite and EMC filters. Tests were performed to assess the level of immunity of the spectroscopy acquisition system. The measured results of the FWHM and background measurements, carried out in different operating conditions of the machine (Static mode, Conveyor in operation, Detector moving), show the high level of electrical noise immunity reached.

Table VI FWHM (keV) Measurements using Eu-152 reference source

Reference Conditions	Real Time (s)	Live Time (s)	Dead Time %	FWHM @ 121.78 keV	FWHM @ 344.28 keV	FWHM @ 778.9 keV	FWHM @ 1112.11 keV	FWHM @ 1408 keV	Integral Total Counts
Static	300	206.1	31.27	1.12	1.28	1.58	1.79	1.95	2.18E+06
Conveyor in motion	300	205.6	31.45	1.12	1.28	1.59	1.78	1.97	2.17E+06
Detector Housing in motion	300	208.8	31.71	1.11	1.27	1.56	1.73	2.04	2.13E+06

Discussion and Conclusions

The test data show that the automated measurement system is capable of meeting below clearance limit or “free release” requirements for the nuclides under consideration as required by the system specification. It also demonstrates compliance with the cited EU recommendations.

The average MDA calculation reduces the container MDA by approximately a factor of two when all four detectors are used instead of a single detector. Testing has shown reasonable accuracy for uniform and non-uniform source distributions. The spectroscopic performance has been shown to be unaffected by operation of the heavy electromechanical systems associated with movement of the items to be measured.

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Reference 4

208-liter and B-25 Box MDA Values for a 28% GEM detector /Collimated

Counting time = 1.0 hr; MDA method = Nureg 4.16

October 17, 2003

Diameter: 59 mm

Length: 47 mm

208-Liter Drum Detector positioned 46 cm (18 inches) from drum							
Nuclide	Ref Energy (keV)	Combustible Density 0.2 g/cc Wt = 4.16E+4 g			Metal Density = 1.0 g/cc Wt = 2.08E+5 g		
		Grams	pCi/g	Bq/kg	Grams	pCi/g	Bq/kg
Co-60	1332.5		6.36E-01	2.35E+01		2.62E-01	9.71E+00
Cs-137	661.6		2.43E-01	8.98E+00		1.22E-01	4.50E+00
Ra-226	609.3		5.24E-01	1.94E+01		2.66E-01	9.86E+00
U-235	185.7	7.96E-03	3.72E-01	1.37E+01	3.08E-02	2.88E-01	1.06E+01
U-238	1001.0	3.54E+00	2.55E+01	9.43E+02	8.00E+00	1.15E+01	4.26E+02
Np-237	312.2	2.80E-05	4.28E-01	1.58E+01	8.24E-05	2.50E-01	9.26E+00
Pu-238	152.7	7.16E-05	2.64E+04	9.78E+05	3.33E-04	2.46E+04	9.12E+05
Pu-239	413.7	8.44E-03	1.13E+04	4.19E+05	2.31E-02	6.20E+03	2.29E+05
Pu-240	160.31	1.19E-02	5.84E+04	2.16E+06	5.28E-02	5.16E+04	1.91E+06
Pu-241	208.0	2.02E-05	4.28E+04	1.58E+06	7.16E-05	3.03E+04	1.12E+06
Am-241	59.5		3.46E+00	1.28E+02		1.75E+01	6.47E+02
Cm-243	277.6		1.53E+00	5.67E+01		9.36E-01	3.46E+01
Cm-244	152.6	1.45E-05	2.54E+04	9.40E+05	6.76E-05	2.37E+04	8.76E+05

B-25 Box (183 x 122 x 122 cm - 72 x 48 x 48 in) Detector positioned 91 cm (36 inches) from box							
Nuclide	Ref Energy (keV)	Combustible Density 0.2 g/cc Wt = 5.44 E+5 g			Metal Density = 1.0 g/cc Wt = 2.72E+6 g		
		Grams	pCi/g	Bq/kg	Grams	pCi/g	Bq/kg
Co-60	1332.5		3.54E-01	1.31E+01		2.37E-01	8.76E+00
Cs-137	661.6		1.53E-01	5.65E+00		1.18E-01	4.37E+00
Ra-226	609.3		8.64E-01	3.20E+01		2.60E-01	9.61E+00
U-235	185.7	7.48E-02	2.97E-01	1.10E+01	3.82E-01	3.04E-01	1.12E+01
U-238	1001.0	2.43E+01	1.49E+01	5.51E+02	8.80E+01	1.08E+01	3.98E+02
Np-237	312.2	2.38E-04	3.09E-01	1.14E+01	9.80E-04	6.56E-01	2.43E+01
Pu-238	152.7	7.04E-04	7.76E+03	2.87E+05	4.24E-03	2.68E+04	9.90E+05
Pu-239	413.7	6.80E-02	2.41E+04	8.91E+05	2.71E-01	6.16E+03	2.28E+05
Pu-240	160.31	1.15E-01	4.84E+04	1.79E+06	6.64E-01	1.08E+05	3.98E+06
Pu-241	208.0	1.85E-04	3.33E+04	1.23E+06	8.80E-04	3.17E+04	1.17E+06
Am-241	59.5		6.20E+00	2.29E+02		3.78E+01	1.40E+03
Cm-243	277.6		1.13E+00	4.19E+01		9.56E-01	3.54E+01
Cm-244	152.6	1.43E-04	2.13E+04	7.87E+05	8.64E-04	2.57E+04	9.52E+05

For a 15-minute count increase the MDA by $\text{Sqrt}(3600\text{sec}/900\text{sec}) = \text{Sqrt}(4) = 2.0$

208-liter and B-25 Box MDA Values for a 78% GMX detector /Collimated

Counting time = 1.0 hr; MDA method = Nureg 4.16

Weight of the container is not included in the pCi/g (Bq/kg) estimate.

October 17, 2003

Diameter: 70.2 mm

Length: 89.9 mm

208-Liter Drum Detector positioned 46 cm (18 inches) from drum							
Nuclide	Ref Energy (keV)	Combustible Density 0.2 g/cc Wt = 4.16E+4 g			Metal Density = 1.0 g/cc Wt = 2.08E+5 g		
		Grams	pCi/g	Bq/kg	Grams	pCi/g	Bq/kg
Co-60	1332.5		4.80E-02	1.78E+00		1.99E-02	7.36E-01
Cs-137	661.6		1.58E-01	5.85E+00		7.94E-02	2.94E+00
Ra-226	609.3		3.82E-01	1.41E+01		1.94E-01	7.19E+00
U-235	185.7	6.03E-03	2.81E-01	1.04E+01	2.34E-02	2.18E-01	8.07E+00
U-238	1001.0	2.72E+00	1.97E+01	7.27E+02	6.16E+00	8.86E+00	3.28E+02
Np-237	312.2	2.05E-05	3.12E-01	1.15E+01	6.01E-05	1.83E-01	6.77E+00
Pu-238	152.7	2.31E-05	8.51E+03	3.15E+05	1.07E-04	7.92E+03	2.93E+05
Pu-239	413.7	7.40E-03	9.91E+03	3.67E+05	2.02E-02	5.41E+03	2.00E+05
Pu-240	160.31	6.49E-03	3.20E+04	1.18E+06	2.87E-02	2.83E+04	1.05E+06
Pu-241	208.0	1.54E-05	3.25E+04	1.20E+06	5.48E-05	2.32E+04	8.57E+05
Am-241	59.5		1.20E+00	4.43E+01		6.07E+00	2.25E+02
Cm-243	277.6		1.28E+00	4.72E+01		7.80E-01	2.88E+01
Cm-244	152.6	4.66E-06	8.14E+03	3.01E+05	2.17E-05	7.58E+03	2.81E+05

B-25 Box (183 x 122 x 122cm - 72 x 48 x 48 in) Detector positioned 91 cm (36 inches) from box							
Nuclide	Ref Energy (keV)	Combustible Density 0.2 g/cc Wt = 5.44 E+5 g			Metal Density = 1.0 g/cc Wt = 2.72E+6 g		
		Grams	pCi/g	Bq/kg	Grams	pCi/g	Bq/kg
Co-60	1332.5		2.68E-02	9.91E-01		1.79E-02	6.61E-01
Cs-137	661.6		9.98E-02	3.69E+00		7.71E-02	2.85E+00
Ra-226	609.3		2.44E-01	9.03E+00		1.90E-01	7.02E+00
U-235	185.7	5.66E-02	2.25E-01	8.32E+00	2.89E-01	2.31E-01	8.53E+00
U-238	1001.0	1.88E+01	1.14E+01	4.22E+02	6.77E+01	8.29E+00	3.07E+02
Np-237	312.2	1.74E-04	2.26E-02	8.36E-01	7.15E-04	1.85E-01	6.86E+00
Pu-238	152.7	2.26E-04	7.12E+03	2.63E+05	1.37E-03	8.60E+03	3.18E+05
Pu-239	413.7	5.97E-02	6.80E+03	2.52E+05	2.36E-01	5.40E+03	2.00E+05
Pu-240	160.31	6.29E-02	2.64E+04	9.78E+05	1.88E-01	3.04E+04	1.12E+06
Pu-241	208.0	1.41E-04	2.54E+04	9.41E+05	6.71E-04	2.42E+04	8.95E+05
Am-241	59.5		2.15E+00	7.94E+01		1.31E+01	4.85E+02
Cm-243	277.6		9.44E-01	3.49E+01		7.97E-01	2.95E+01
Cm-244	152.6		2.68E-02	9.91E-01	2.77E-04	8.23E+03	3.04E+05

For a 15-minute count increase the MDA by $\text{Sqrt}(3600\text{sec}/900\text{sec}) = \text{Sqrt}(4) = 2.0$