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Second IRMF Comparison of Surface Contamination Monitor Calibrations 2000 - 2001

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ABSTRACT

The Ionising Radiations Metrology Forum (IRMF) organised a second comparison of surface contamination monitor calibrations in which twenty establishments in the UK participated. The exercise involved the circulation of three surface contamination monitors for calibration using large area reference sources available in the participants' laboratories.

The instruments used were a Mini Instruments EP15, a Berthold LB122 and an Electra ratemeter with DP6AD probe. The instrument responses were calculated by the individual participants and submitted to the authors for analysis along with details of the reference sources used. Details of the estimated uncertainties were also reported.

The results are compared and demonstrate generally satisfactory agreement between the participating establishments.

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Approved on behalf of Managing Director, NPL, by
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CONTENTS

		Page
1	INTRODUCTION	1
2	PARTICIPANTS	1
3	INSTRUMENTATION	2
4	MEASUREMENT PROTOCOL	2
5	RESULTS	3
	5.1 EP15	3
	5.2 LB122	4
	5.3 DP6AD	5
6	DISCUSSION	6
	6.1 Setting up of DP6AD	6
	6.2 Use of Contiguous Portions Technique	7
	6.3 Uncertainties	8
7	CONCLUSIONS	9
8	ACKNOWLEDGEMENTS	9
9	REFERENCES	10

APPENDIX 1: Members of the IRMF Working Group	11
APPENDIX 2: Participants	12
APPENDIX 3: Measurement Protocol	13
APPENDIX 4: Amendments to Submitted Data	27

Table 1	Additional Data Submitted for EP15	29
Table 2	Spread in Results for EP15 Calibrations	29
Table 3	Additional Data Submitted for LB122	30
Table 4	Spread in Results for LB122 Calibrations	30
Table 5	Additional Data Submitted for DP6AD	31
Table 6	Spread in Results for DP6AD Calibrations	31
Table 7	DP6AD Settings Used	32
Table 8	Uncertainty Contributions Reported	33

Figure 1	Mini EP15 – ^{14}C	35
Figure 2	Mini EP15 – ^{14}C plotted by source age	36
Figure 3	Mini EP15 – ^{36}Cl	37

Figure 4	Mini EP15 – $^{90}Sr+^{90}Y$	38
Figure 5	Mini EP15 – ^{241}Am	39
Figure 6	LB122 – ^{14}C	40
Figure 7	LB122 – ^{14}C plotted by source age	41
Figure 8	LB122 – ^{36}Cl	42
Figure 9	LB122 – $^{90}Sr+^{90}Y$	43
Figure 10	LB122 – ^{241}Am	44
Figure 11	DP6AD – ^{36}Cl	45
Figure 12	DP6AD – ^{36}Cl plotted by HT setting	46
Figure 13	DP6AD – $^{90}Sr+^{90}Y$	47
Figure 14	DP6AD – $^{90}Sr+^{90}Y$ plotted by HT setting	48
Figure 15	DP6AD – ^{241}Am	49
Figure 16	DP6AD – ^{241}Am plotted by HT setting	50
Figure 17	Comparison of methods used for HT determination DP6AD – ^{36}Cl	51
Figure 18	Comparison of methods used for HT determination DP6AD – ^{241}Am	52

1 INTRODUCTION

The calibration of surface contamination monitors is performed on an annual basis as part of the regulatory requirements[1] governing any organisation undertaking work with unsealed sources of ionising radiation. The quality of these calibrations was examined in a comparison exercise organised by the Ionising Radiations Metrology Forum in 1993[2]. This exercise concluded that review of the current guidance on the calibration of surface contamination monitors was needed as the main two sources available were contradictory and confusing.

In the years following the comparison exercise in 1993, much work has been undertaken in the field of monitor calibrations. This work has included a study of the use of the Contiguous Portions method[3] and the production of a measurement Good Practice Guide[4] on the calibration of portable instruments. A measurement Good Practice Guide on the evaluation of uncertainties in radiological measurement is also in preparation. All of this work bears directly on the ability of the measurement and user communities to perform accurate calibrations of surface contamination monitors.

In 2000 the IRMF embarked on a second comparison exercise of contamination monitor calibrations; the findings of that exercise are presented in this report. Amongst the aims of this repeat exercise is the desire to ascertain whether there has been an improvement in the calibrations of surface contamination monitors since the 1993 exercise and since the publication of new guidance. Members of the working party that organised this comparison exercise are listed in Appendix 1.

2 PARTICIPANTS

Participation in this exercise was open to all members of the IRMF, including those organisations that had taken part in 1993. To optimise the benefit of this comparison and to generate some overlap with a similar IPEM exercise that is conducted from time to time in the UK, members of the IPEM Radiation Protection special interest group were invited to participate as well.

In accordance with IRMF policy[5], participants were allowed to choose whether to take part on an open or anonymous basis. Decisions on disclosure of results were made before an organisation performed measurements for the comparison and could not be reversed later. Anyone wishing to revise their data, once submitted, was allowed to do so but on the understanding that the nature of the changes made would be published in this report.

Appendix 2 contains a list of the participants (in the order in which measurements were made) and the codes that have been used in this report to represent each organisation.

3 INSTRUMENTATION

Instruments for the exercise were selected to incorporate some of the types most widely used and to afford an overlap with the 1993 exercise. The Mini EP15 (a Geiger-Müller detector), Berthold LB122 $\beta-\gamma$ (gas-filled proportional counter) and the DP6AD (scintillation detector) with an Electra ratemeter were chosen to be included in the comparison.

The EP15 and LB122 require little in the way of setting up and after an initial inspection and check source measurement to confirm they are operating correctly, could be calibrated immediately. The DP6 however was circulated with the accompanying Electra settings in a completely scrambled state. Participants were required to determine the optimum operating voltage and retrieve the other parameters needed from the manufacturer's operating manual.

All of the equipment for the exercise was circulated in a hard backed suitcase to protect it during transport. Participants were asked to inspect the instruments upon arrival at their organisation and report any breakages to the comparison organiser. A check source and typical instrument responses were provided to help identify any internal damage to the instruments.

4 MEASUREMENT PROTOCOL

The protocol for this exercise was written by the IRMF working party paying particular attention to the 1993 exercise and the difficulties that were experienced in analysing the results due to variations and ambiguities in the reporting of data. Reporting sheets were designed to encourage the participants to provide as much relevant information as possible that could be useful in identifying sources of errors when the results were analysed later.

This exercise covered only the calibration of surface contamination monitors and did not include the calibration of wide area reference sources. Reference sources for the calibration of the monitors were not provided, the participants were asked to use sources available in their establishments to cover as many radionuclides as possible but to attempt at least ^{14}C, ^{36}Cl or ^{90}Sr+^{90}Y and ^{238}U or ^{241}Am.

Participants were asked to report the instrument response (in terms of emissions), and its uncertainty, of each of the instruments to a range of reference sources.

$$\text{Instrument Response (Emissions)} = \frac{\sum_{i=1}^{n}(R_i - B)}{SER}$$

Conversion of that instrument response to an activity response and the P-factor used were also requested (see GPG14[4] for an explanation of P-factors).

$$\text{Instrument Response (Activity)} = \frac{\sum_{i=1}^{n}(R_i - B)}{SER.P}$$

where R_i is the observed reading at source position i (s^{-1})
B is the background count rate (s^{-1})
SER is the surface emission rate per unit area of the source (s^{-1} cm^{-2})
n is the number of source positions
P is the appropriate P-factor.

Spaces for background and check source measurement results were included on the reporting sheet.

Overall uncertainties in emission response for each instrument with each radionuclide were included on the main reporting sheet. In addition to these, a full breakdown of the uncertainty budget was requested for each instrument but with only one of the reference sources. A table containing some of the possible sources of uncertainty was provided; extra rows were included for additional uncertainty contributions identified by the participants.

Since the wide area reference sources being used for the calibrations were not provided for the exercise and varied for each organisation, a table was provided for participants to enter details of the source type, dimensions, emission rate and its last calibration.

The protocol was issued to each of the participating organisations and a copy was circulated in the trunk with the instruments. The complete measurement protocol is reproduced in Appendix 3.

5 RESULTS

The results presented in this section indicate the final submissions made by each organisation. A significant amount of effort was made by both the participants and the working party to explain, recalculate and/or eliminate anomalous results before these final data sets resulted. Summaries of the amendments made to each laboratories data can be found in Appendix 4.

5.1 EP15

Figures 1 to 5 show graphical presentations of the data reported using this instrument for ^{14}C, ^{36}Cl, ^{90}Sr and ^{241}Am. Additional data were reported by some organisations for ^{55}Fe, ^{60}Co, ^{99}Tc, ^{125}I, ^{137}Cs, ^{147}Pm, ^{204}Tl, ^{234}U, ^{238}U and ^{238}Pu; these are presented in Table 1 but, as there were insufficient data points to produce figures, no further analysis of these data has been made. Table 2 shows the spread of results obtained for each radionuclide and compares these values with the outcome of the 1993 exercise.

The ^{14}C data has a large spread of 46%; this is similar to the result obtained in 1993. The large uncertainty reported by NIRMPA (FGH) is dominated by the low gross countrate observed using their ^{14}C source; the Working Group recommends that the purchase of a more active source be considered. Since participating in this comparison NRPB Radiation Metrology (RM), have procured a new ^{14}C reference source and made their own comparison measurements, these have shown a deviation for the old source similar to that obtained in this exercise. Figure 2 shows the data for this instrument plotted according to the age of the ^{14}C source; no evidence can be seen of an effect due to source age and hence manufacturing process for the anodised aluminium sources used by these organisations.

The ^{36}Cl data reported has a spread of 42% which is significantly greater than that observed in the 1993 exercise. The value submitted by anonymous Lab C (LBC) is highly discrepant. This is likely to be due to their use of a 'home made' filter paper source for which the determination of surface emission rate must have been extremely difficult and is almost certainly not traceable to national standards of radioactivity. When the Lab C value is eliminated from the data set, a spread of 22% can be achieved.

The results obtained using the EP15 with ^{90}Sr+^{90}Y yield a spread of 31%. Explanations can be offered for a number of discrepant values for this instrument – radionuclide combination. Anonymous Lab B (LBB) performed this calibration using the contiguous portions technique over 45 source positions; while this must have been extremely time consuming and impractical for general calibrations, it is unnecessary for this combination where the data clearly showed only 2 or 3 positions at most gave a significant response. Lab C (LBC) again used a 'home made' filter paper source. When Lab B and Lab C results are removed from the data set, a spread of 26% is obtained. BNFL Berkeley (BER) and RRPPS Birmingham (QEH) results were acknowledged to be in areas of the EP15 scale where it was awkward to read. BNFL Berkeley (BER) used a resin-bead source; all other participants (except Lab C, already discussed) used anodised aluminium type sources. Considering the higher energy of this radionuclide, better results were expected for the EP15.

The ^{241}Am data submitted has a spread of 28% compared to a spread of 15% observed in 1993. No further discussion of these results is necessary as all of the participants' data fell within ± 20% of the mean value.

5.2 LB122

Figures 6 to 10 contain the data reported using this instrument for ^{14}C, ^{36}Cl, ^{90}Sr and ^{241}Am. Additional data were reported by some organisations for ^{55}Fe, ^{60}Co, ^{99}Tc, ^{125}I, ^{129}I, ^{137}Cs, ^{147}Pm, ^{204}Tl, ^{234}U, and ^{238}Pu; these are presented in Table 3 but, as there were insufficient data points to produce figures, no further analysis of these data has been made. Table 4 shows the spread of results obtained for each radionuclide. As this instrument was not included in the 1993 exercise, no comparison of results is possible.

Variations in the reported instrument responses for the LB122 were significantly greater than those for the EP15 and DP6AD. The main reason for this lies in the use of the contiguous portions technique. Only two laboratories, RWE Nukem at Harwell (RNH) and at Winfrith (RNW) possessed reference sources with dimensions greater than those of this detector. The remaining organisations calibrated this instrument using a single calibration source position, a single position with a scaling/correction factor applied or the contiguous portions technique using multiple source positions.

The ^{14}C data submitted has a spread of 50% from the mean value. The value reported by Laboratory A (LBA) was based on a single source position; no scaling or correction factor was applied to this. Lab B (LBB) used 45 contiguous portions. Lab D (LBD) used a single source position and applied a correction factor as recommended in GPG14[4] to obtain the semi-infinite response. Since this method resulted in a discrepancy of 22% from the mean value, the Working Group suggest that Lab D revisit their derivation of this correction factor. BNFL Berkeley (BER) also adopted a single source position but used a scaling factor to account for the area of the detector that had not been covered by the source. While the BNFL Berkeley (BER) result for ^{14}C compares well with the mean value, the results become progressively more discrepant as the beta energy increases (see the data for ^{36}Cl and $^{90}Sr+^{90}Y$). No effect has been observed in Figure 7 due to the age of the ^{14}C sources used.

A very large spread of 65% was observed for the ^{36}Cl data using the LB122. If Labs A (LBA) and C (LBC) are excluded from the results due to using too few source positions and a filter paper source respectively, this spread can be reduced to only 16%.

The $^{90}Sr+^{90}Y$ data submitted has a spread of 48% when all data points are considered. If only the organisations that performed an appropriate number of contiguous portions measurements are included in the analysis, the spread becomes 10%. Lab B (LBB) used 45 source positions. Lab C (LBC) used a filter paper source and BNFL Berkeley used a resin-bead source. If the scaling factor used by BNFL Berkeley (BER) is removed from their data, the result obtained is similar to that reported by Lab A (LBA) for a single source position measurement.

The results obtained using the LB122 with ^{241}Am yield a spread of 48%. NIRMPA (FGH) reported using a circular source to calibrate the LB122 using the contiguous portions technique; this must have been extremely difficult to say the least and is not recommended due to the inability to achieve adjacent but not overlapping source positions. The value reported by BNFL Berkeley (BER) is a clear outlier; the Working Group believe this to be due to the use of a scaling factor to account for the area of the detector not covered by the reference source. If the detector itself is non-uniform, the use of a scaling factor will generate an error as it assumes the response is equal over the whole surface. It is likely that the response of this LB122 was lower at the edges and the scaling factor over-estimated the response that might have been achieved using a source of larger area; this effect would be more pronounced for α-emitting sources hence the largest discrepancy being observed for ^{241}Am.

5.3 DP6AD

Figures 11 to 13 show the data reported using this instrument for ^{36}Cl, ^{90}Sr and ^{241}Am. Additional data were reported by some organisations for ^{60}Co, ^{137}Cs, ^{147}Pm, ^{204}Tl, ^{234}U, ^{238}U and ^{238}Pu; these are presented in Table 5 but, as there were insufficient data points to produce figures, no further analysis of these data has been made. Further data was submitted for ^{14}C but as this instrument is unsuitable for the detection of low energy β-emitters it has been excluded from this report. Table 6 shows the spread of results obtained for each radionuclide and compares these values with the outcome of the 1993 exercise.

The data reported for the DP6 was generally better than those submitted for the EP15 and LB122; a number of reasons for this are possible. Although the DP6 had to be set up by the participants, the procedure for this is relatively simple and was described thoroughly in the manual provided. The Electra ratemeter provides a digital reading and can be used in the 'integrate' mode, which eliminates the need for eye averaging over the period of measurement; the EP15 had the complications of a needle pointer and a logarithmic scale to deal with. The smaller size of the DP6 resulted in the need for fewer source positions and hence reduced use of the contiguous portions technique compared to the LB122. Finally, since this detector is often used for the detection of α-emitters it is not commonly used in hospitals. Many of the anonymous labs from the medical sector therefore did not submit data, for the other instruments it has often been these organisations that generated out-lying data.

The ^{36}Cl results produced a spread of 22% with all submitted values falling within 15% of the mean value. The reduced scale on the y-axis of Figure 11 should be noted.

The results obtained using the DP6 with ^{90}Sr+^{90}Y yield a spread of 24%. If the Lab B (LBB) value is eliminated from the data set (due to the use of too many source positions), a spread of 17% is achieved, this spread is half of that observed in the 1993 exercise.

The ^{241}Am data has a spread of 31% however this is dominated by a high value submitted by DRPS DERA (DRP). The Working Group discussed the DRPS value at length but no reasonable explanation for its disagreement could be agreed. The DRPS reporting sheet suggests that the DP6AD was operated in the α+β mode while most other organisations used the α only setting for this calibration. NIRMPA (FGH) used a similar HT setting as DRPS and made measurements on both settings; while their α+β value is closer than their α only value to that of DRPS, they are not comparable. Measurements made by AWE in the separate α and β modes support the NIRMPA data.

6 DISCUSSION

6.1 Setting up of DP6AD

Participants were asked to set up the DP6AD and Electra ratemeter from scratch to test their ability to determine and set the appropriate HT voltage and to retrieve other ratemeter settings from the instruction manual.

The manufacturer describes two approaches for the determination of the operating voltage. The first method involves setting the detector to measure α's while exposing it to a ^{90}Sr+^{90}Y source, the counts are observed while the HT is increased from 600V, the HT is set to the position where the α response is ≤ 0.1% of the β response to the same source. The alternative is to observe the instrument reading in the β setting while exposing the detector to an α source, as the HT is increased the countrate increases, decreases and then increases again, the HT is set to the dip in the curve.

Despite the measurement protocol requesting details of the method used to determine the HT setting, many laboratories did not provide this information. Some other organisations gave limited information about the procedure used but it was insufficient to be used in comparing the methods. Of the remaining laboratories, NIRMPA (FGH), DRaStaC (AWE), RRPPS (QEH) and RWE Nukem at Harwell (RNH) used the first method described above and Thermo Electron (TE), NRPB Radiation Metrology (RM), NRPB at Nycomed Amersham (NA) and RWE Nukem Winfrith (RNW) employed method 2. Figures 17 and 18 show the results submitted by these organisations for ^{36}Cl and ^{241}Am; although there are insufficient data points to draw firm conclusions, it appears the method employed to determine the HT setting has made no difference to the calibrations.

Figures 12, 14 and 16 show the data reported for ^{36}Cl, ^{90}Sr+^{90}Y and ^{241}Am plotted in order of ascending HT voltage. Collectively the charts show that lower instrument responses were generally obtained when the HT used was lower and higher responses obtained when greater HT was employed. This trend is most apparent in the ^{36}Cl data and was to be expected.

Table 7 gives details of the Electra settings used where these deviated from those recommended in the instruction manual.

Considering the need to set up this instrument, the overall results obtained for the DP6AD and Electra were very good.

6.2 Use of Contiguous Portions Technique

The contiguous portions technique was originally described in HSE Guidance document 49 (now withdrawn). Further investigations into the technique were made at NPL[3] in 1997 and its' use was recommended in GPG14[4]. For the purpose of this comparison exercise, the technique was widely used, however this was not without problems.

In the analysis of the data for this exercise, many of the values that were resubmitted were necessary due to mistakes occurring in the use of the contiguous portions technique. The most common errors occurring were in the subtraction of background contributions; the number of background countrate contributions subtracted did not correspond to the number of source positions employed. One organisation initially reported highly discrepant instrument responses for all of their calibrations when corrections for the active area were omitted in obtaining the emission rate per unit area of the sources.

The use of detector profiles to determine the number of source positions necessary for a contiguous portions measurement may not have been adopted in all cases. Two laboratories reported contiguous portions calibrations that had included too many source positions; one of these had made measurements in 45 source positions.

The use of correction and scaling factors proved to be unsuccessful in this exercise. The only laboratory that had derived a correction factor based on a detector profile to reduce the number of source positions required for a contiguous portions calibration showed discrepant results for ^{14}C with the LB122. One laboratory calibrated the LB122 using a single source position and a scaling factor to correct for the area of the detector not covered by the source; this resulted in a discrepant value for ^{241}Am and was probably due to non-uniformity in efficiency at the edges of the detector. Additional measurements performed at NPL using a scaling factor in the same way yielded similar results.

Considering the difficulties observed in achieving agreement between organisations in calibrations performed using the contiguous portions technique, it would appear possible that it is not widely used in routine calibrations of surface contamination monitors and additional effort was made for this exercise. More experience of the method may improve understanding of the technique and result in fewer mistakes in its implementation; including a large area detector in the next IRMF comparison and seeking better agreement in the results could test this.

6.3 Uncertainties

Participants were required to submit one full uncertainty budget for each instrument used in the exercise, an example budget was included in the measurement protocol for guidance. It is clear from the reports submitted that participants gave a great deal of thought to their uncertainty contributions however a general lack of understanding was still demonstrated by many.

The sources of uncertainty and their magnitudes varied greatly between the organisations that submitted budgets. Table 8 contains a varied selection of the uncertainty contributions submitted by the participants.

Uncertainties quoted for instrument response (emissions) often took the form of a fixed value that was applied for a particular instrument regardless of the radionuclide being measured. This approach is perfectly acceptable when the fixed value has been derived by suitable methods and has been demonstrated not to change significantly with nuclide or if the worst-case radionuclide value has been adopted. Some laboratories failed to include an uncertainty contribution due to the instrument reading in their budget; the uncertainties reporting sheet had deliberately excluded this significant source of uncertainty to test those performing the calibrations. In some cases, the value of an uncertainty contribution identified was reasonable however, the failure to apply a sensitivity co-efficient to that value led to an inappropriate uncertainty contribution being included in the budget.

Where organisations are calculating expanded uncertainties of the order of ± 30%, they need to question their ability to adequately calibrate that particular instrument in accordance with the criterion contained in GPG14[4].

It is clear that the inclusion of the example uncertainty budget in the protocol was inappropriate as the terms used in this example were often contradictory with those used in the latest guidance[4]. While the example encouraged participants to consider their uncertainties more thoroughly and demonstrated some techniques to quantify sources of uncertainty, it was also confusing. An IRMF working group has recently prepared a draft Good Practice Guide on Uncertainty in Radiological Measurement, it is hoped that this guidance will clarify the determination of uncertainties and might result in more realistic uncertainties being observed in future exercises.

As a general note, it is good practice when deriving uncertainties to always round the values up; this does not appear to be common practice amongst the organisations participating in this exercise.

7 CONCLUSIONS

After explaining and eliminating some outlying data, the results for most instruments are improved or comparable to the exercise in 1993 despite there being many more participating organisations.

Some organisations should consider purchasing new sources. For example where 'home-made' filter paper sources have been used, traceability to national standards has not been achieved. Where the surface emission rate of a reference source used is particularly low a high uncertainty results, this could be improved with sources of greater emission rate.

Some organisations, particularly in the medical sector need to recalibrate their reference sources. Some sources had not been calibrated in more than 15 years despite the recommendation of 4 years in GPG14[4].

There is no evidence from the results of this comparison to show that older ^{14}C sources should not be used. Although some of these sources have lost carbon to the atmosphere if left in strong sunlight, it is recommended that they are recalibrated regularly rather than replaced.

While the contiguous portions technique has been widely adopted, more attention to detector profiles is needed to ensure an appropriate number of source positions are used.

Greater care is required to ensure the correct number of background contributions is subtracted from contiguous portions data.

Some quoted uncertainty contributions appear to be inappropriate. For example, 4.1% for the effect of inaccurate voltage setting on the EP15 (this is set by the manufacturer) and 10% for source to detector positioning (accurate 3 mm spacers were provided).

Some organisations didn't consider all of the significant contributions to the uncertainty in the calibrations; this resulted in a low overall uncertainty.

The forthcoming publication of a Good Practice Guide on Uncertainty in Radiological Measurement is much needed.

In general, the comparison exercise was very successful with almost all of the calibrations performed agreeing with the mean value to within ± 30%.

8 ACKNOWLEDGEMENTS

The Ionising Radiations Metrology Forum is supported under the Ionising Radiation Metrology Programme of the National Measurement System, funded by the Department of Trade and Industry.

The organisers and participants are grateful to Thermo Electron Corp for the loan of the DP6AD and Electra and to RWE Nukem for providing the check source.

Thanks are also due to AWE for performing the initial instrument characterisations before the exercise began.

9 REFERENCES

1 *Ionising Radiations Regulations* 1999 (London HMSO).

2 Woods M J and Hedley R P. *IRMF Intercomparison of Calibration of Large Area Reference Sources and Portable Alpha and Beta Surface Contamination Monitors 1993/4 – Part 1*, NPL Report CIRA(EXT)002, 1996.

3 Scott C J and Woods M J. *The Use of Relatively Small Sources for the Calibration of Area Survey Meters*, NPL Report CIRM 6, 1997.

4 Scott C J, Burgess P H and Woods M J. *The Examination, Testing and Calibration of Portable Radiation Protection Instruments*, Measurement Good Practice Guide, NPL 1999.

5 Lewis V E. *Minutes of Fifteenth IRMF Meeting*, NPL, April 1998.

10 APPENDICES

Appendix 1 Members of the IRMF Working Party

Alan Edwards	DRaStaC, AWE
Duncan McClure	NRPB
Jan McClure	NRPB
Max Pottinger	BNFL Berkeley
Tony Richards	Consultant, formerly of Leeds University
Clare Scott	NPL
John Simpson	RWE Nukem (formerly AEA Technology)
Mike Woods	IRMC (formerly NPL)

Appendix 2 Participants

Organisation	Organisation Code	Contact Person	UKAS Accredited
DRaStaC, AWE	AWE	Alan Edwards	Yes
Health Physics, NPL	NPL	Caroline Felgate	No
RWE Nukem, Winfrith	RNW	John Simpson	Yes
NIRMPA, Forster Green Hospital	FGH	Kieran Cranley	No
RPS, Velindre Hospital	VH	Wyn Thomas	No
DRPS, DERA	DRP	John Bennett	Yes
Anonymous – Hospital	LBA	-	No
Anonymous – Hospital	LBB	-	No
BNFL, Berkeley	BER	Max Pottinger	No
Anonymous – Hospital	LBC	-	No
RRPPS, Queen Elizabeth's Hospital	QEH	Stuart Green	No
Johnson Controls	JCL	Don Mackenzie	Yes
RWE Nukem, Harwell	RNH	Reg Bosley	No
NRPB, Radiation Metrology	RM	Duncan McClure	No
NRPB, Southern Centre	SC	Andrew Wright	No
NRPB at Amersham	RMA	Duncan McClure	No
Anonymous – Hospital	LBD	-	No
Thermo Electron	TE	Jen Barnes	No
Anonymous – Nuclear industry	LBE	-	No
Bristol General Hospital	BGH	Jenny Oduko	No

Appendix 3 Measurement Protocol

Measurement Protocol

Introduction

This intercomparison has been organised by the Ionising Radiation Metrology Forum (IRMF) and the National Physical Laboratory (NPL) to assess the standard of calibrations of surface contamination monitors performed in the UK. Three instruments will be circulated to fifteen organisations for routine calibration. The results of these calibrations will be collated and reported by NPL.

Participants in the intercomparison must decide in advance whether they will take part anonymously or whether their results will be disclosed. It is necessary to complete, sign and return a form to the technical co-ordinator (contact details are given at the end of the protocol) indicating the level of disclosure required prior to the start of the intercomparison. It is not possible for organisations to change their decision on disclosure once the exercise has commenced. This policy is in accordance with the disclosure scheme agreed by the IRMF in April 1998.

A similar intercomparison exercise conducted in 1993[1] concluded that 'significant problems exist' in this field and there was a need to update the HSE guidance and practical advice to the user community in general. Since that time, a measurement good practice guide[2] (GPG 14) on the calibration of radiation protection instruments has been published which provides detailed guidance on techniques that can be employed to calibrate surface contamination monitors.

Schedule

Laboratories will be given a period of two weeks in which to perform the required measurements and to forward the instruments to the next participant. After every three participants, one week will be allowed for any necessary maintenance and to absorb any slippage of the schedule that may have occurred. A proposed timetable will be distributed at the start of the intercomparison, every effort should be made to adhere to this timetable in the interests of completing the intercomparison within a reasonable time (approx. one year).

It may be possible to rearrange the timetable if sufficient notice is given - please contact the administrative co-ordinator to arrange this (contact details are given at the end of the protocol). If a laboratory completes their work before their deadline, they are encouraged to transport the instruments to the next participant early (with the agreement of the next

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[1] Woods M J and Hedley R P. IRMF intercomparison of calibration of large area reference sources and portable alpha and beta surface contamination monitors 1993/4 - Part 1. NPL Report CIRA (EXT)002, January 1996.

[2] Scott C J, Burgess P H and Woods M J. The Examination, Testing and Calibration of Portable Radiation Protection Instruments. Measurement Good Practice Guide 14, NPL, March 1999.

participant). It is also possible that additional participants could be included in the exercise if it proves that time is available.

Participation in the intercomparison is free of charge. Participants are however responsible for arranging and meeting the cost of transporting the equipment to the next laboratory. The following carrier is recommended:

Echo plc Head Office Unit 1, Ferro Fields Scaldwell Industrial Estate Brixworth Northants NN6 9UA	Contact person: Grant Bees Tel: 01604 880 888 Fax: 01604 881 037

Equipment

The equipment will be circulated in a single hard-faced suitcase, a list of contents will be enclosed. The suitcase should be transported locked and the key sent to the next participant in the post. If keys are lost, spares are available from the administrative co-ordinator.

Instruments

Berthold LB122 (β, γ) : a large area xenon filled proportional counter. For the purpose of this intercomparison it should be operated in cps-B mode. Manual provided.

Mini EP15 : a halogen quenched Geiger-Müller tube. Manual provided.

NE DP6 and Electra Ratemeter : a dual phosphor probe that can be used in conjunction with the Electra Ratemeter. To assess the ability of the participants to set up these instruments, the Electra will be circulated with the programmed settings fixed to 'nonsense' values (see Appendix 1). It will be necessary to reset the Electras parameters according to the manual or the procedures of the participating organisation. Manual and cable provided.

Check Source

The check source provided contains a mixture of Am-241, Sr-90 and Cs-137 which mimics the emissions of U-238. For the purpose of transport documentation, the following nominal data can be used:

Source identifier:	FU 850
Am-241 activity:	140 Bq
Sr-90 activity:	2 kBq
Cs-137 activity:	15 kBq

Miscellaneous

Positioning jigs to hold each of the detectors in a fixed geometry, 3 mm from the surface of the check source.

A variety of spacers which may be used to provide 3 mm separation for detector positioning during the calibrations. It is recommended that spacers are only used as a guide whilst setting up the measurement geometry and are removed before calibrations are performed.

Calibration Procedure

Check Source Measurements

A mock U-238 source has been supplied as a check source to help identify any damage to the instruments that may have occurred in transit. Positioning jigs (one for each monitor) have been provided to aid reproducibility of the source and detector geometry and minimise positioning errors. The jigs are marked to indicate which end of the probe (e.g. the handle end of the DP6) should be positioned at each end of the jig. Where it is possible to move the probe around within the jig, the handle end should always be pulled tight against the edge of the jig.

The check source measurement for the EP15 should be made with a stainless steel mask in place between the source and the detector - this mask reduces the source emissions to a level that can be recorded by this instrument. The mask is marked to indicate which face should be in contact with the source.

The response of each instrument to the check source has been measured prior to the intercomparison. The responses observed by the participants should be recorded in Table A.1 and compared to the values below:

Berthold LB122 observed net cps	=	496 ± 50 cps
Mini EP15 (with mask) observed net cps	=	64 ± 20 cps

If the response observed does not agree with these values within the tolerances stated, contact should be made with the technical co-ordinator before proceeding with the calibrations.

An expected check source response has not been provided for the DP6 detector as this is to be set up by the individual laboratories and the response will vary. An observed check source reading should still be entered into Table A.1 once the detector has been set as required.

Instrument Calibrations

The instruments should be calibrated according to the procedures routinely used in the participating organisations. All measurements should be made with a source to detector separation of 3 mm.

Sufficient measurements should be made to determine the instrument response in terms of source emissions and activity. The equations defined below can be used to calculate the instrument response; these equations apply for calibrations performed using a single source position (where n = 1) as well as contiguous portions calibrations where a number of source positions are used (n > 1).

$$\text{Instrument Response (Emissions)} = \frac{\sum_{i=1}^{n}(R_i - B)}{SER}$$

$$\text{Instrument Response (Activity)} = \frac{\sum_{i=1}^{n}(R_i - B)}{SER.P}$$

where R_i is the observed reading at source position i (s^{-1})
B is the background count rate (s^{-1})
SER is the surface emission rate per unit area of the source (s^{-1} cm^{-2})
n is the number of source positions
P is the appropriate P-factor.

Please note that n does not correspond to a number of repeated measurements with the reference source in the same measurement position. If repeated measurements are made, R_i should be the mean observed reading for a particular source position.

The results of these calibrations, their associated uncertainties and the value of the P-factor used should be recorded in Table A.1. In addition to the calibration results, participants should also complete Table A.2 regarding the settings that are used for the DP6 and Electra, a copy of the data used to derive the operating voltage should also be supplied when the results are reported.

It is recommended that the monitors are calibrated for as many nuclides as possible but as a minimum one of each of the following should be used:

Low energy β - emitter (e.g. C-14)
High energy β - emitter (e.g. Sr-90+Y-90 or Cl-36)
α - emitter (e.g. Am-241).

Space has been provided in Table A.1 for details of calibrations performed using radionuclides other than those suggested. If calibrations are made using photon reference sources, additional information regarding the materials and furniture of the laboratory will be requested once the results have been submitted. A contiguous portions type of calibration should be performed if necessary; full details of the measurements made and the calculations to derive the instrument response should be reported on separate sheets.

Details of the uncertainty budget for one of the calibrations for each of the instruments should be entered into Table A.3. The method usually employed to quantify uncertainties should be used, however, an example uncertainty derivation has been included in Appendix A.2.

Details of each of the reference sources used during the calibrations should be given in Table A.4. It is important to provide as much of this information as possible even if the table cannot be fully completed.

If one of the instruments provided is not appropriate for the nature of the work carried out in a particular organisation or reference sources of suitable radionuclides are not available, it is not essential to perform the calibration.

Reporting of Results

To encourage consistency in the data reported and to ensure that sufficient information is provided, tables have been supplied for recording the results. These tables should be copied as many times as necessary for the number of calibrations performed. Additional sheets can be used for any further comments or information to be reported.

Completed results tables should be sent to the administrative co-ordinator at NPL as soon as possible after the calibrations are performed or within 4 weeks at the latest.

Progress of the intercomparison will be presented and discussed at IRMF meetings. The results will be published in an NPL report once the analysis is complete.

Useful Contacts

Administrative Contact:

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All general enquires should be addressed to Elizabeth Engel in the first instance.

IRMF Intercomparison of Surface Contamination Monitor Calibrations

Table A.1 **Calibration Results**

Laboratory : Contact Person : Operator Name :

Instrument Type : Serial No. : Calibration Date :

Background Reading Check Source Reading (not background corrected)

Before : After : Before : After :

NUCLIDE	SOURCE IDENTIFIER	GROSS READING cps	NET READING cps	INSTRUMENT RESPONSE (Emissions) $cps/(s^{-1}cm^{-2})$	UNCERTAINTY IN INSTRUMENT RESPONSE (Emissions)	INSTRUMENT RESPONSE (Activity) $cps/(Bqcm^{-2})$	P - FACTOR APPLIED
^{14}C							
^{36}Cl							
^{90}Sr + 90Y							
^{238}U							
^{241}Am							

Signed……………… Print Name ……………… Date ………………..

Table A.2

Settings used for the DP6 and Electra

Laboratory : Contact Person :

Number	Parameter	Setting
0	Battery voltage	
1	Alarm level	
3	High voltage setting	
4	Overload current	
5	Dead time	
6	Upper level discriminator	
8	Units	
A	Inhibit background subtraction	
b	Inhibit integrate facility	
C	Rate monitoring algorithm	
E	Pulse counting mode	
F	GM or scintillation	

A copy of the measurements made to determine the operating voltage should also be submitted with the calibration results.

Signed……………… Print Name ……………… Date ………………..

Table A.3

Uncertainty Budget

Laboratory : Contact Person : Operator Name :

Detector : Reference Source ID:

SOURCE OF UNCERTAINTY	METHOD OF ESTIMATION	MAGNITUDE OF UNCERTAINTY (k=1)
Detector Window Area		
H T Setting		
Dead Time (if applicable)		
Background Countrate		
Source - Detector Separation		
Surface Emission Rate of Reference Source		
Non - Uniformity of Reference Source		
Backscatter		
	Combined Uncertainty (k=1)	

Please provide details of your uncertainty budget for one source - detector combination.
Please use additional sheets if necessary to provide as much information as possible.

Signed……………… Print Name ……………… Date ………………..

IRMF Intercomparison of Surface Contamination Monitor Calibrations

Table A.4

Reference Source Details

Laboratory : Contact Person :

Source identifier	
Nuclide	
Surface emission rate (s^{-1}) and reference date	
Uncertainty in surface emission rate (k=2)	
Half - life used if decay calculated	
Calibration date and laboratory	
Nominal activity	
Active dimensions (mm)	
Outer dimensions (mm)	
Source construction eg. anodised aluminium	
Substrate material and thickness (mm)	
Source manufacturer	
Date of purchase	
Manufacturers drawing number	

Signed……………… Print Name ……………… Date ………………..

Please photocopy this form as required to provide details of all the reference sources that have been used in this exercise.

Appendix A.1

Nonsense Settings for the DP6 Probe

As part of this exercise participants are asked to set up the DP6 probe and Electra ratemeter from scratch. The Electra should therefore be circulated with the following nonsense settings:

Number	Parameter	Setting
0	Battery Voltage	View only
1	Alarm Level	OFF
3	High voltage setting	370V
4	Overload current	10 µA
5	Dead time	30µs
6	Upper level discriminator	1.50V
8	Units	cpm
A	Inhibit background subtraction	ON
b	Inhibit integrate facility	OFF
C	Rate monitoring algorithm	Auto
E	Pulse counting mode	int
F	GM or scintillation	G

Note: the numbers listed correspond to those described in the Electra manual.

Appendix A.2

Example Uncertainty Budget

The following example is being drafted by an IRMF working party. The terms used in this draft do not correspond to those contained in GPG 14 or in this intercomparison protocol. The uncertainty budget below should only be used as a guide for the techniques to estimate uncertainty contributions.

The nomenclature of this example may change before it is published.

1. Calibration of surface contamination monitors

1.1 Surface contamination monitors are calibrated in terms of their response to known rates of radioactive emissions. In practice this is achieved by using large-area, planar sources which have a defined area and whose emission rates have been determined in a traceable manner. The calibration is normally determined in terms of response/(emission rate per unit area). The calibration factor is defined by:

$$CF_{\mathrm{E}} = (M - B)/(E/A) f_V \; f_d \; f_u f_{bs}$$

where:

CF_E	-	calibration factor,
M	-	observed monitor reading,
B	-	background reading,
E	-	emission rate of the calibration source,
A	-	area of the active portion of the calibration source
f_V	-	plateau voltage factor,
f_d	-	source-detector separation factor,
f_u	-	source uniformity factor,
f_{bs}	-	back-scatter factor.

Under normal conditions, the factors f_V, f_d, f_u and f_{bs} are each assumed to have a value of 1.

1.2 For the purpose of this example consider a monitor with a detector area of 50 cm^2, having an analogue display and a facility to set the detector voltage. Consider also a calibration source with an active area of 10 cm x 10 cm, having an anodised layer of ^{14}C on a thick aluminium substrate.

1.3 Several techniques can be used to determine the mean observed monitor reading, M, and its uncertainty. Assume a snap-shot technique is used whereby six successive but randomly timed readings are recorded, giving 350, 400, 400, 325, 350, 350 s^{-1}. The mean and standard deviation of the mean become 362.5 $\pm$ 12.5 s^{-1}.

1.4 The background rate, B, may be determined in the same types of ways as those used for the source count rate, M. Assume an eye-averaging technique is used whereby the highest and lowest count rates are recorded over a given period of time. These are 40 and 25 s^{-1} respectively, giving a mean value of 32.5 s^{-1}. The uncertainty has a rectangular distribution with a width of 15 s^{-1}. The resultant Type B standard uncertainty is calculated as the semi-width, 7.5 s^{-1}, divided by $\sqrt{3}$, giving ± 4.3 s^{-1} (or ± 13 % in B).

1.5 The emission rate, E, of the source and its uncertainty are provided on the calibration certificate by the laboratory that calibrated the source using a windowless proportional counter. From the previous example, the statement on the certificate may well be of the form:

The measured value of the emission rate is:

$$E = 2732 \pm 21\ s^{-1}$$

The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor of k=2, which provides a level of confidence of approximately 95%.

The standard uncertainty at 1σ, u_i, is therefore ± 10.5 s^{-1} or ± 0.38 %.

1.6 In the absence of any uncertainty statement by the manufacturer, the only information available for the source area is the product drawing which shows the active area dimensions to be 100 mm x 100 mm. On the assumption that the outer bounds of these lengths are 99 and 101 mm, the uncertainty on the linear dimensions may be taken to be of a rectangular distribution with a semi-width of 0.1 cm. The standard uncertainty on the linear dimension becomes $0.1/\sqrt{3} = 0.06$ cm, which is equivalent to 0.6%. The corresponding uncertainty on the area becomes 2 x 0.6 % = 1.2 %.

1.7 The plateau voltage factor, f_V, only applies to those monitors where manual alterations are possible. If the setting is not to be checked and/or adjusted between calibrations, then this has no effect. If, however, the user is allowed to do this, the setting may not be returned to exactly that used during the calibration exercise. The slope of the response curve in this region may be 10 % / 50 v. It is assumed that an operator is more likely to set the voltage nearer to the optimum than to the extremes and that ± 50 v represents the 95% confidence level. Accordingly, a triangular distribution is assumed with a standard uncertainty calculated as the semi-width (10%) divided by $\sqrt{6}$, giving ± 4.1 %.

1.8 The source-detector separation factor, f_d, is the result of the uncertainty in mounting the calibration source exactly 3 mm from the detector face. Experimental evidence has shown that, for a particular ^{14}C source at a 3 mm source-detector separation, the relative change in response was 2.6 % / mm. It is assumed that the deviation from the declared 3 mm separation is no greater than 0.5 mm but that all values are equally probable between 2.5 and 3.5 mm. The standard uncertainty on the separation, therefore, is ± 0.5 / √3 = ± 0.29 mm = 9.7 %. Combining this with the response factor gives a sensitivity coefficient, c_i, of 0.026 (mm^{-1}) x 3 (mm) = 0.078.

1.9 Large area sources suffer from non-uniformity of the activity distribution. For Class I ^{14}C sources, the uniformity shall be better than ± 10%. For a typical monitor with a detector area of 50 cm^2 and a calibration source area of 100 cm^2, if the distribution of activity is not known, a worst case condition is that the area under the detector could have an activity per unit area which is 7% greater or less than the value for the whole source. Assuming a rectangular distribution, this represents a standard uncertainty of ± 7 / √3 % = ± 4.0% arising from f_u, the source uniformity factor.

1.10 Variations in backscatter effects arise from factors such as the nature of the surface on which the calibration source is resting and the proximity to scattering surfaces such as walls. This effect can be quite marked for photon emitters but for ^{14}C on Class I substrates the effect is negligible.

1.11 Uncertainty budget

Symbol	Source of uncertainty	Value ± %	Probability distribution	Divisor	c_i	u_i ± %	v_i or v_{eff}
M	Standard deviation of mean	3.5	normal	1	1.0	3.5	5
B	Background	13	rectangular	√3	32.5/362.5	1.3	∞
E	Emission rate	0.38	normal	1	1.0	0.38	∞
A	Source area	1.2	rectangular	√3	1.0	1.2	∞
f_V	Plateau voltage	4.1	triangular	√6	1.0	4.1	∞
f_d	Source-detector separation	9.7	rectangular	√3	0.078	0.75	∞
f_u	Source uniformity	4.0	rectangular	√3	1.0	4.0	∞
f_{bs}	Backscatter	n/a	n/a	n/a	n/a	n/a	n/a
u_c	Combined uncertainty	---	normal	---	---	7.0	∞
U	Expanded uncertainty	---	normal (k=2)	---	---	14.0	∞

Note: v_i and v_{eff} refer to the number of degrees of freedom.

1.12 Reported result:

Using the formula above, the calibration factor in terms of emission rate becomes:

$$CF_E = (362.5 - 32.5) / (2732 / 100)$$
$$= 12.1 \left(counts.s^{-1} \right) / \left(s^{-1}.cm^{-2} \right)$$

and the calibration certificate will state:

The measured value of the calibration factor for is:

$$CF_E = 12.1 \pm 1.7 \left(counts.s^{-1} \right) / \left(s^{-1}.cm^{-2} \right)$$

The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor of $k = 2$, which provides a level of confidence of approximately 95%.

Appendix 4 Amendments To Submitted Data

Participants were given the opportunity to amend their submitted data even after the relative results of the comparison were available. This allowed any obvious errors to be corrected. Approximately one third of participants elected to amend their results. Details of the amendments made by each organisation are detailed in the remainder of this Appendix.

DRaStaC, AWE

Insufficient background countrate contributions were subtracted from the total instrument reading when calibrating the LB122 using a ^{14}C source and the Contiguous Portions technique. LB122 measurements with other nuclides were not amended. All data for ^{14}C has been amended to reflect measurements of a newer reference source (see Discussion section).

Health Physics, NPL

Incorrect and insufficient number of background countrate contributions were subtracted from the total instrument reading when calibrating the LB122 using the Contiguous Portions technique. Uncertainties revised.

RWE Nukem, Winfrith (RNW)

All uncertainties in instrument response values were increased. The original values related to the instrument reading for each measurement, the revised values had a component for the emission rate of the reference sources added.

NIRMPA, Forster Green Hospital (FGH)

Uncertainties revised.

DRPS, DERA (DRP)

All original instrument responses were corrected to account for the area of the reference sources used in the measurements, the calculations made had used the total emission rate of the source rather than the emission rate per unit area. Insufficient background countrate contributions were subtracted from the total instrument reading when calibrating the LB122 and DP6 using the Contiguous Portions technique.

Thermo Electron (TE)

All data for ^{14}C was revised after this reference source was recalibrated. All instrument responses for LB122 were revised following a reduction in the number of contiguous portions source positions included in the analysis.

No revisions were made by: BNFL Berkeley (BER); Bristol General Hospital (BGH); Johnson Controls (JCL); Lab A (LBA); Lab B (LBB); Lab C (LBC); Lab D (LBD); Lab E (LBE); NRPB, Radiation Metrology (RM); NRPB, Radiation Metrology at Amersham (RMA); NRPB, Southern Centre (SC); RPS, Velindre Hospital (VH); RRPPS, Queen Elizabeth's Hospital (QEH) and RWE Nukem, Harwell (RNH).

Table 1

Additional Data Submitted for EP15

Nuclide	Organisation	Instrument Response (Emissions)	Uncertainty (% at k=2)	Mean Value
^{55}Fe	QEH	0.28	42	-
^{60}Co	DRP	6.268	10.76	6.3
	BER	7.03	20	
	JCL	5.6	15	
^{99}Tc	LBC	4.8	26.6	-
^{125}I	FGH	0.2	23.62	-
^{137}Cs	FGH	7.88	18.16	7.8
	DRP	7.653	10.1	
	LBE	7.91	-	
^{147}Pm	NPL	3.32	3.24	3.4
	VH	3.36	11.9	
	DRP	4.233	10.52	
	BGH	2.86	-	
^{204}Tl	FGH	7.66	27.08	-
^{234}U	RNW	4.1	13	4.3
	RNH	4.5	20	
^{238}U	DRP	11.97	14	-
^{238}Pu	DRP	5.323	9.88	5.2
	SC	5	18	

Table 2

Summary of Results for EP15 Calibrations

Nuclide	Mean Instrument Response (Emissions) 2001	Spread in 2001	Spread in 1993
^{14}C	2.9	46%	40%
^{36}Cl	8.7	42%	19%
^{90}Sr+^{90}Y	8.8	31%	16%
^{241}Am	5.7	28%	15%

Table 3

Additional Data Submitted for LB122

Nuclide	Organisation	Instrument Response (Emissions)	Uncertainty (% at k=2)	Mean Value
^{55}Fe	QEH	4.83	22	-
^{57}Co	LBC	2.29	26.8	-
^{60}Co	DRP	37.28	9.16	43
	BER	53	15.2	
	JCL	39.6	15	
^{99}Tc	LBC	32.98	23.4	-
^{125}I	FGH	14.86	10.14	-
^{129}I	QEH	7.07	18	-
^{137}Cs	DRP	58.3	9.14	57
	BGH	55.2	-	
^{147}Pm	NPL	17	3.28	15
	VH	12.99	5.6	
	DRP	18.5	9.14	
	BGH	12.3	-	
^{234}U	RNH	14	8	-
^{238}Pu	RM	23.7	8	22
	SC	20	20	

Table 4

Summary of Results for LB122 Calibrations

Nuclide	Mean Instrument Response (Emissions) 2001	Spread in 2001
^{14}C	9.0	50%
^{36}Cl	67	65%
^{90}Sr+^{90}Y	73	48%
^{241}Am	29	48%

Note: this instrument was not included in the 1993 exercise so no data is available for comparison.

Table 5

Additional Data Submitted for DP6AD

Nuclide	Organisation	Instrument Response (Emissions)	Uncertainty (% at k=2)	Mean Value
^{60}Co	DRP	15.14	9.92	17
	BER	19.58	14.8	
^{137}Cs	FGH	35.16	17.52	34
	DRP	32.77	9.8	
^{147}Pm	NPL	1.8	3.26	3.5
	VH	4.96	31.10	
	DRP	3.83	9.90	
^{204}Tl	FGH	47.15	18.58	-
^{234}U	RNW	25	12	24
	RNH	23	8	
^{238}U	AWE	15.12	14	-
	DRP	63.29	9.8	
^{238}Pu	DRP	39.36	9.8	37
	RM	35	8	
	SC	37.6	18	
	LBE	35.9	14	

Table 6

Spread in Results for DP6AD Calibrations

Nuclide	Mean Instrument Response (Emissions) 2001	Spread in 2001	Spread in 1993
^{36}Cl	40	22%	18%
^{90}Sr+^{90}Y	45	24%	34%
^{241}Am	35	31%	30%

Table 7

DP6AD Settings Used

The DP6AD and Electra ratemeter settings used by the majority of the participants were those listed in the manufacturer's manual, where the settings used differed, these have been listed in the table.

Parameter	Manufacturer's Setting	Setting Used	Organisation
Overload Current	3 µA	10 µA	BER
			RNW
Rate Monitoring Algorithm	AUTO	PRES	AWE
Pulse Counting Mode	DUAL	INT	LBA

Table 8

Uncertainty Contributions Reported

Abbreviations used in the table:

a	semi-width	B	background
c_i	sensitivity co-efficient	cps	counts per second
d_i	divisor	HT	HT setting used for DP6
R	observed instrument reading	SD	standard deviation
SDOM	standard deviation of the mean	SER	surface emission rate

Source of uncertainty	Values reported (k=1)	Method of estimation
Background countrate	-	'Not taken into account' (BGH)
	0.04%	Variation on eye average for LB122 (RNH)
	0.11%	SD of repeat measurements, c_i=B/R for EP15 (LBB)
	13%	1 cps for 7.5 cps reading (TE)
Backscatter	-	Unlikely to have affect since bench is low density material (QEH)
	-	Taken into account in SER measurement by NPL (AWE)
Dead time	-	Scale already corrected (QEH)
	0.04%	Ignoring dead time error would give 0.4%, dead time held to <10% (TE)
Detector window area	0.58%	From manufacturer's quoted dimensions for LB122 (RNH)
	0.77%	a=0.1cm, d=√3, multiply by 2 for 2 dimensions, expressed as % of area for EP15 (LBC)
	1.2%	Engineering tolerances for DP6 (TE)
HT setting	-	Fixed on LB122 (DRP)
	0.3%	6% per 200V for DP6 (SC)
	2.38%	±20V/HT x100% (LBB)
	4.1%	Based on a triangular distribution for LB122 (LBC)
Instrument reading	0.8%	Poisson distribution for LB122 (BER)
	5.9%	√R, c_i=1 for LB122 (QEH)
	10.8%	SDOM for EP15 (LBD)
Linearity	4%	SDOM – due to 'wobbly needle and poorly marked portion of scale (RM)

Table 8 continued

Source of uncertainty	Values reported (k=1)	Method of estimation
Non-uniformity of source	Negligible	As source is entirely covered by detector for LB122 (VH)
	3.5%	12% variation over whole source, c_i=0.5 as source rotated, d=√3 for LB122 (QEH)
	5.77%	± 10% measured uniformity for ^{14}C, d=√3 (JCL)
	9.2%	3 measurements in different positions for ^{14}C (BER)
Occlusion of source due to spacers	Negligible	RM
Source area	1%	a=1mm, d=√3, ∴ 0.6% and 0.4% in 100 x 150 mm source, uncertainty on area is 1% (JCL)
	1.2%	± 1mm on each dimension (BER)
	2.3%	±1mm, max 4% in area, d=√3, c_i=1 (QEH)
Source – detector separation	0	Fixed jig ∴ accurate (BGH)
	1.0%	Relative change in response for ^{14}C is 3.6% per mm, assume ± 0.5 mm, d=√3, ∴ 0.29mm x 3.6 (RNH)
	4.27%	±3.7%, d=√3, c_i=2, ⇒ 4.27% for DP6AD (AWE)
Source position during contiguous portions	2%	1mm in 100mm, twice (RM)
	5%	Based on local studies using jig (QEH)
Surface emission rate of reference source	0.6% - 5%	From calibration certificate, various labs
	2.75%	Determined by local measurements using masks (RNH)
	-	Not known (LBC)

Figure 1

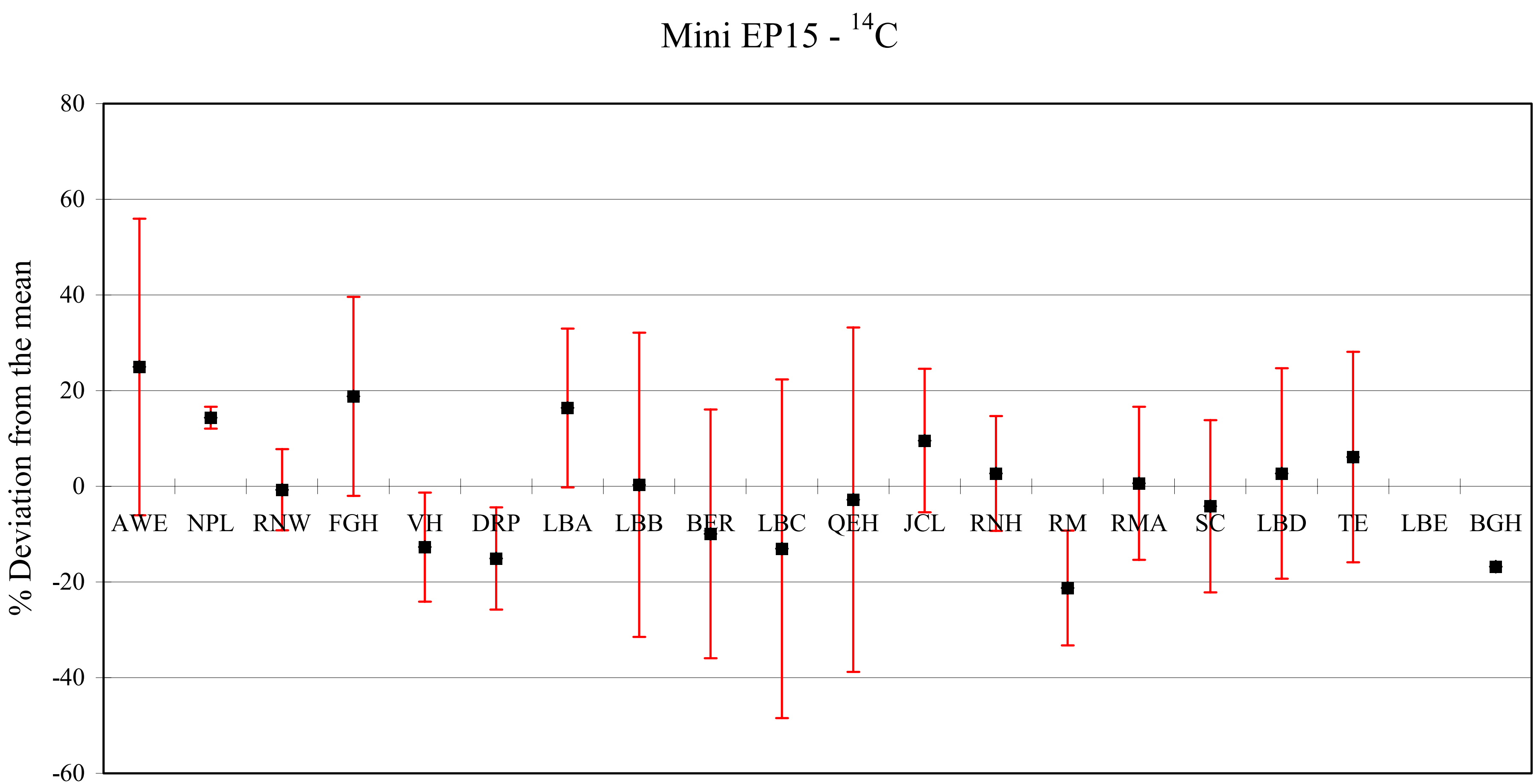

Mini EP15 - ^{14}C
% Deviation from the mean
80
60
40
20
0
-20
-40
-60
AWE
NPL
RNW
FGH
VH
DRP
LBA
LBB
BER
LBC
QEH
JCL
RNH
RM
RMA
SC
LBD
TE
LBE
BGH

Figure 2

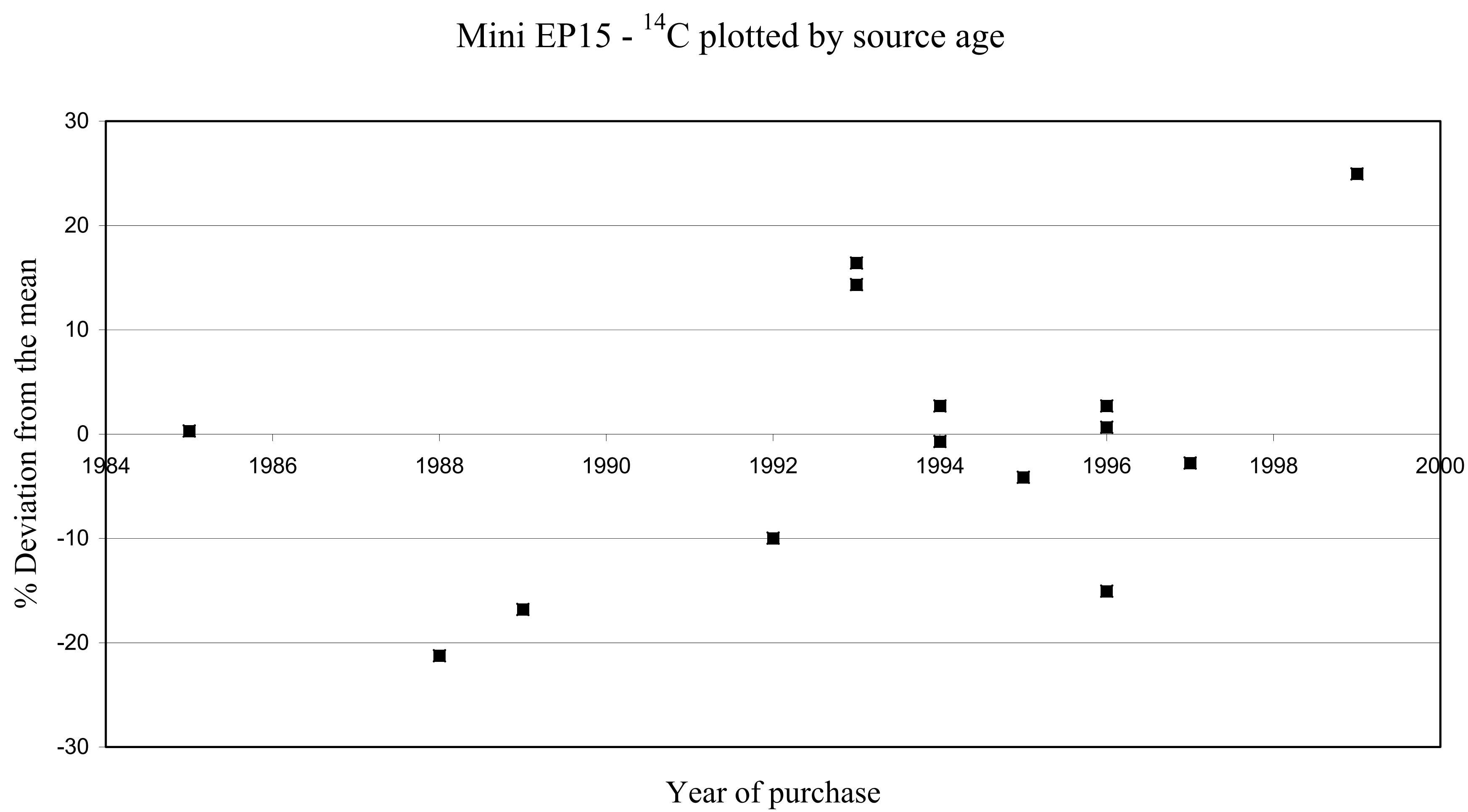

Mini EP15 - 14C plotted by source age
30
20
10
0
-10
-20
-30
1984
1986
1988
1990
1992
1994
1996
1998
2000
% Deviation from the mean
Year of purchase

Figure 3

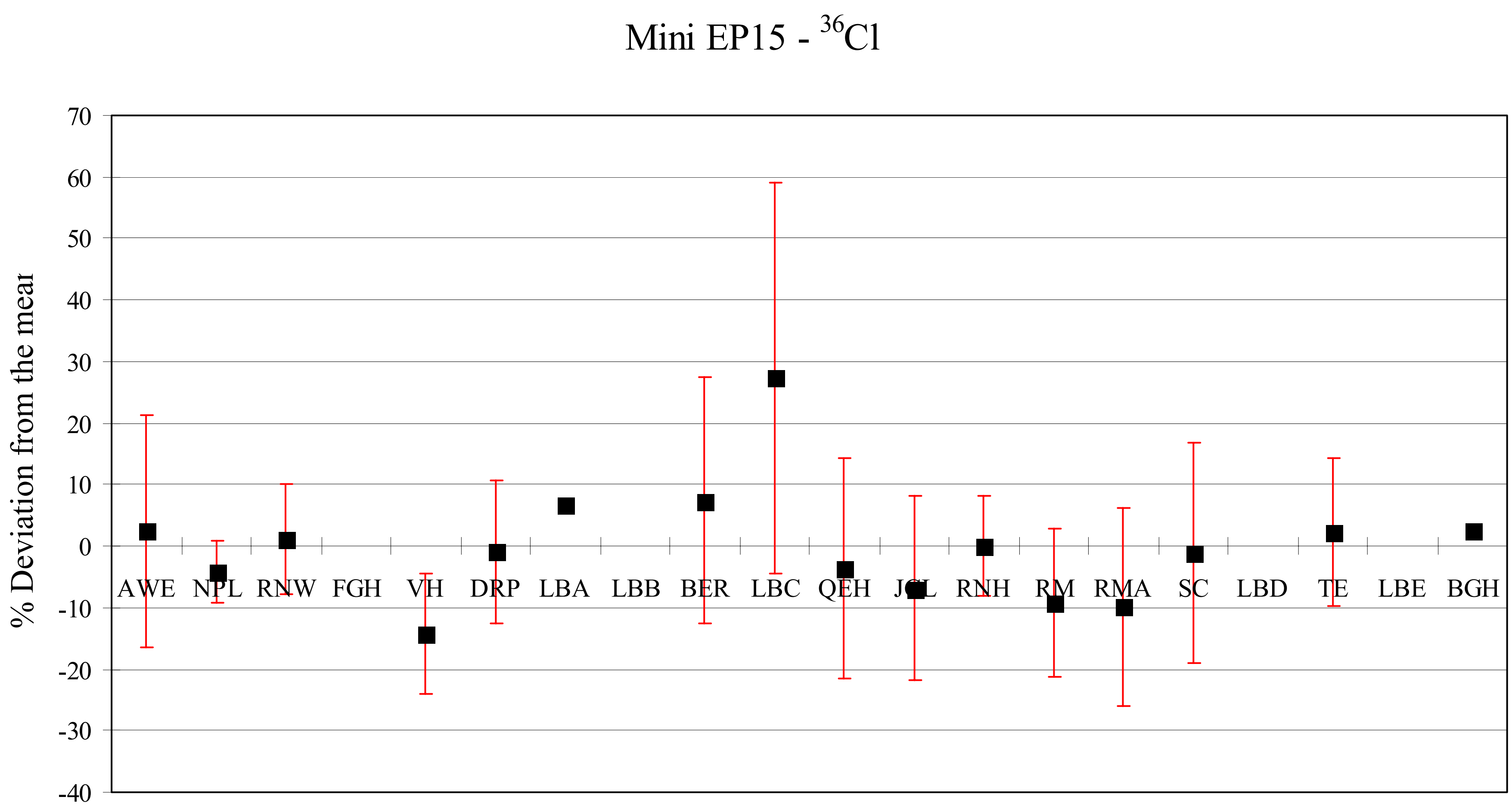

Mini EP15 - ^{36}Cl
% Deviation from the mear
70
60
50
40
30
20
10
0
-10
-20
-30
-40
AWE
NPL
RNW
FGH
VH
DRP
LBA
LBB
BER
LBC
QEH
JCL
RNH
RM
RMA
SC
LBD
TE
LBE
BGH

Figure 4

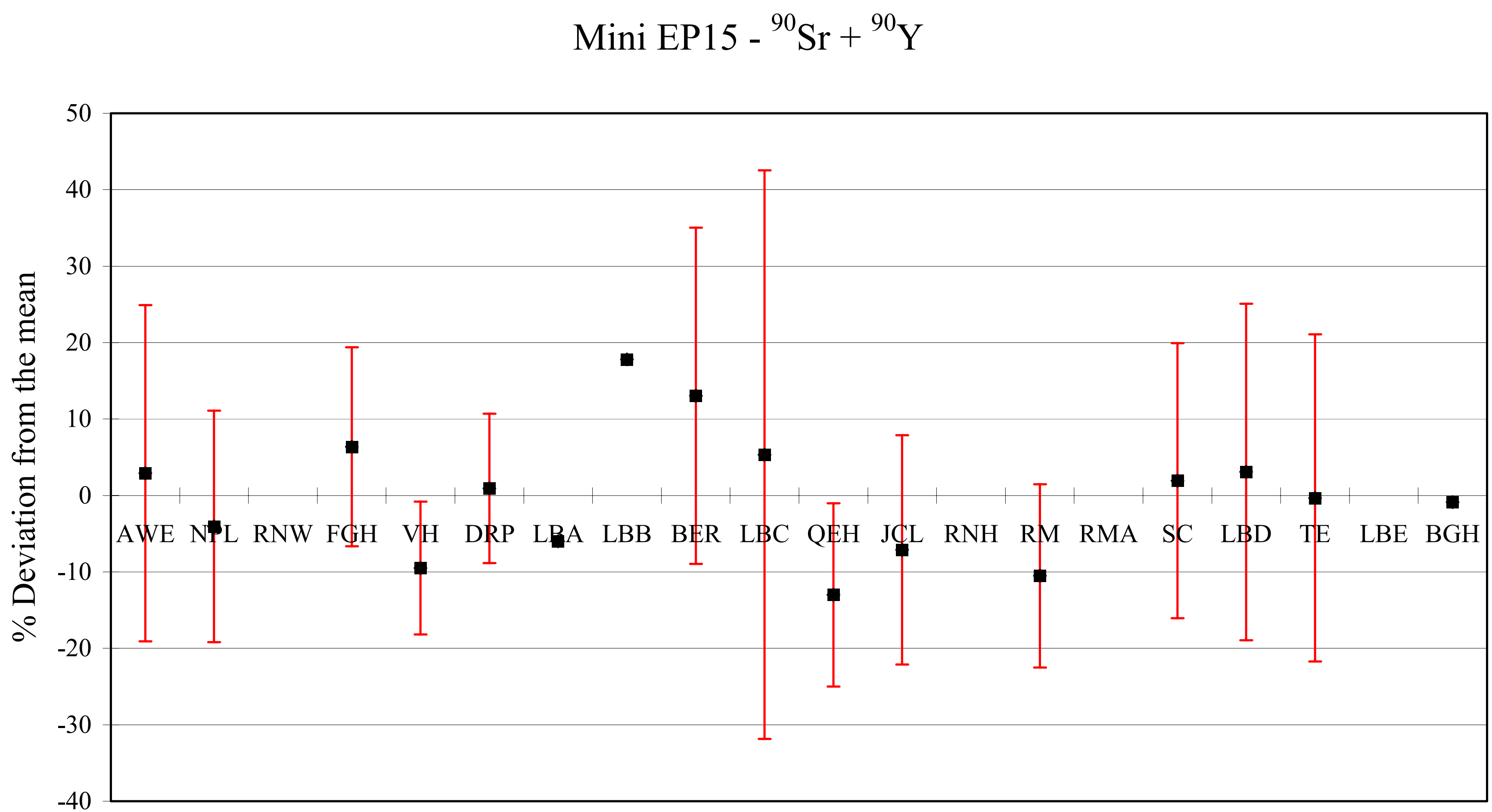

Mini EP15 - ^{90}Sr + ^{90}Y
% Deviation from the mean
50
40
30
20
10
0
-10
-20
-30
-40
AWE
NPL
RNW
FGH
VH
DRP
LBA
LBB
BER
LBC
QEH
JCL
RNH
RM
RMA
SC
LBD
TE
LBE
BGH

Figure 5

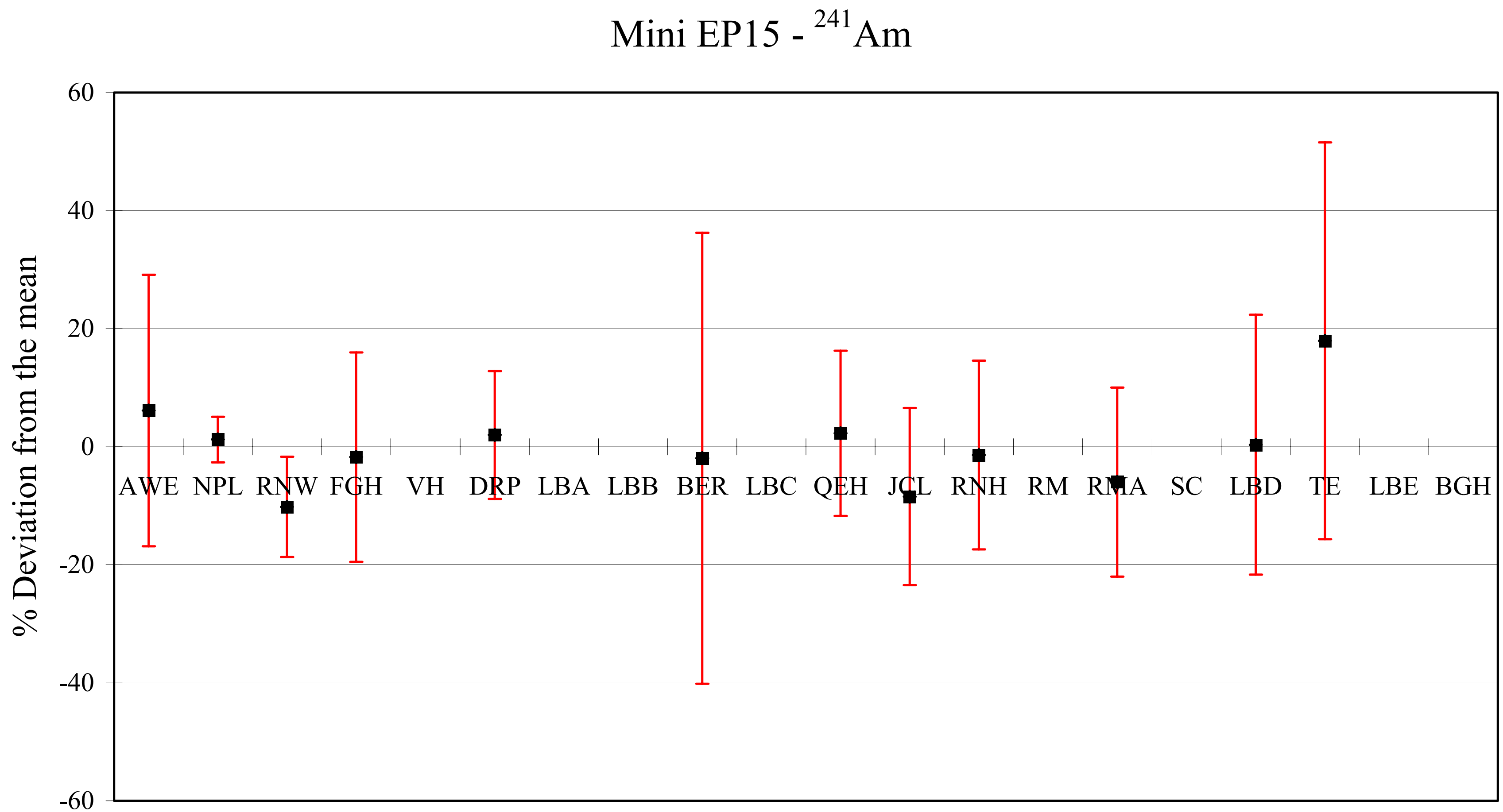

Mini EP15 - 241Am
% Deviation from the mean
60
40
20
0
-20
-40
-60
AWE
NPL
RNW
FGH
VH
DRP
LBA
LBB
BER
LBC
QEH
JCL
RNH
RM
RMA
SC
LBD
TE
LBE
BGH

Figure 6

LB122 - ^{14}C

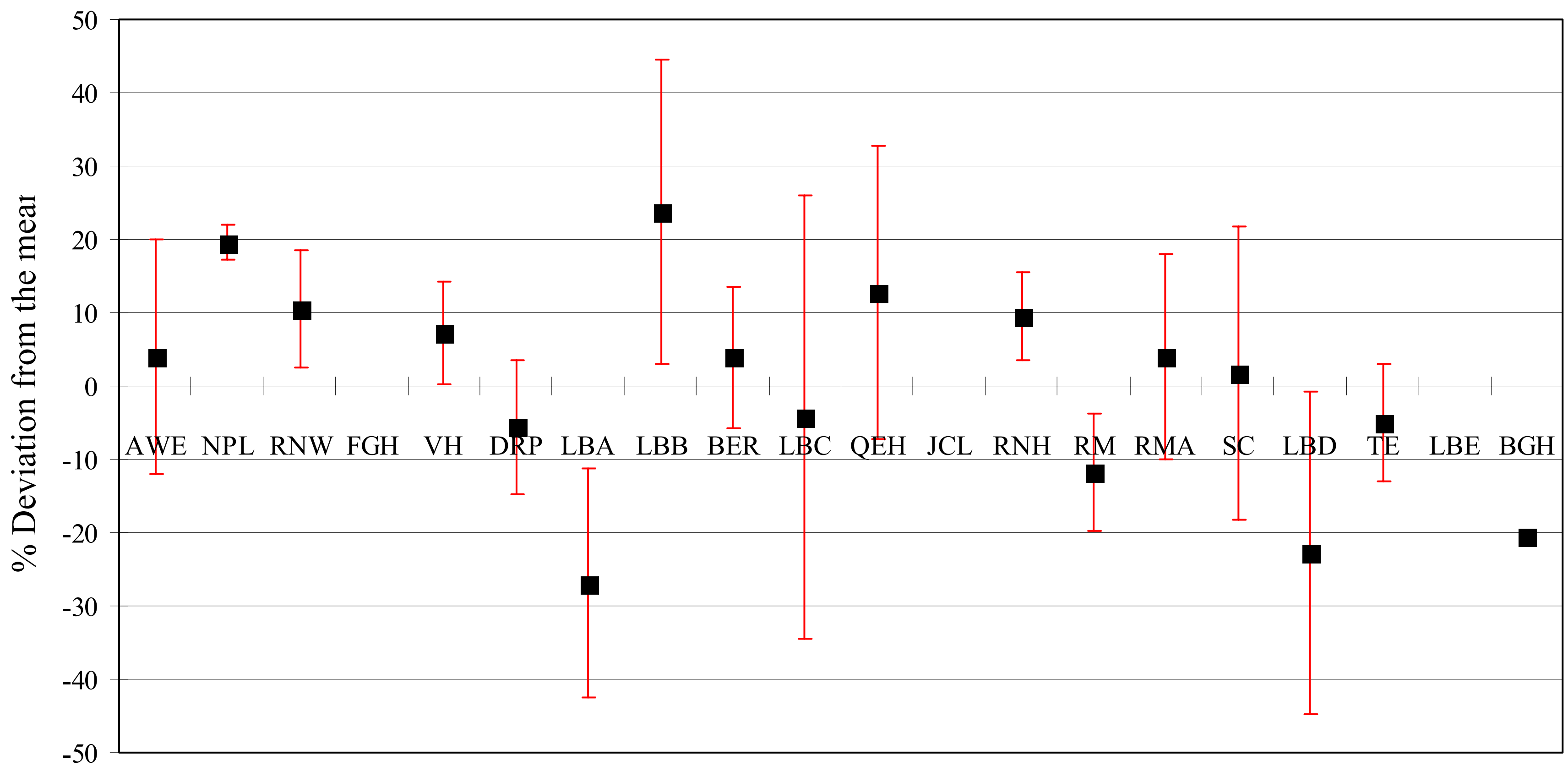


Figure 7

LB122 - ^{14}C plotted by age of source

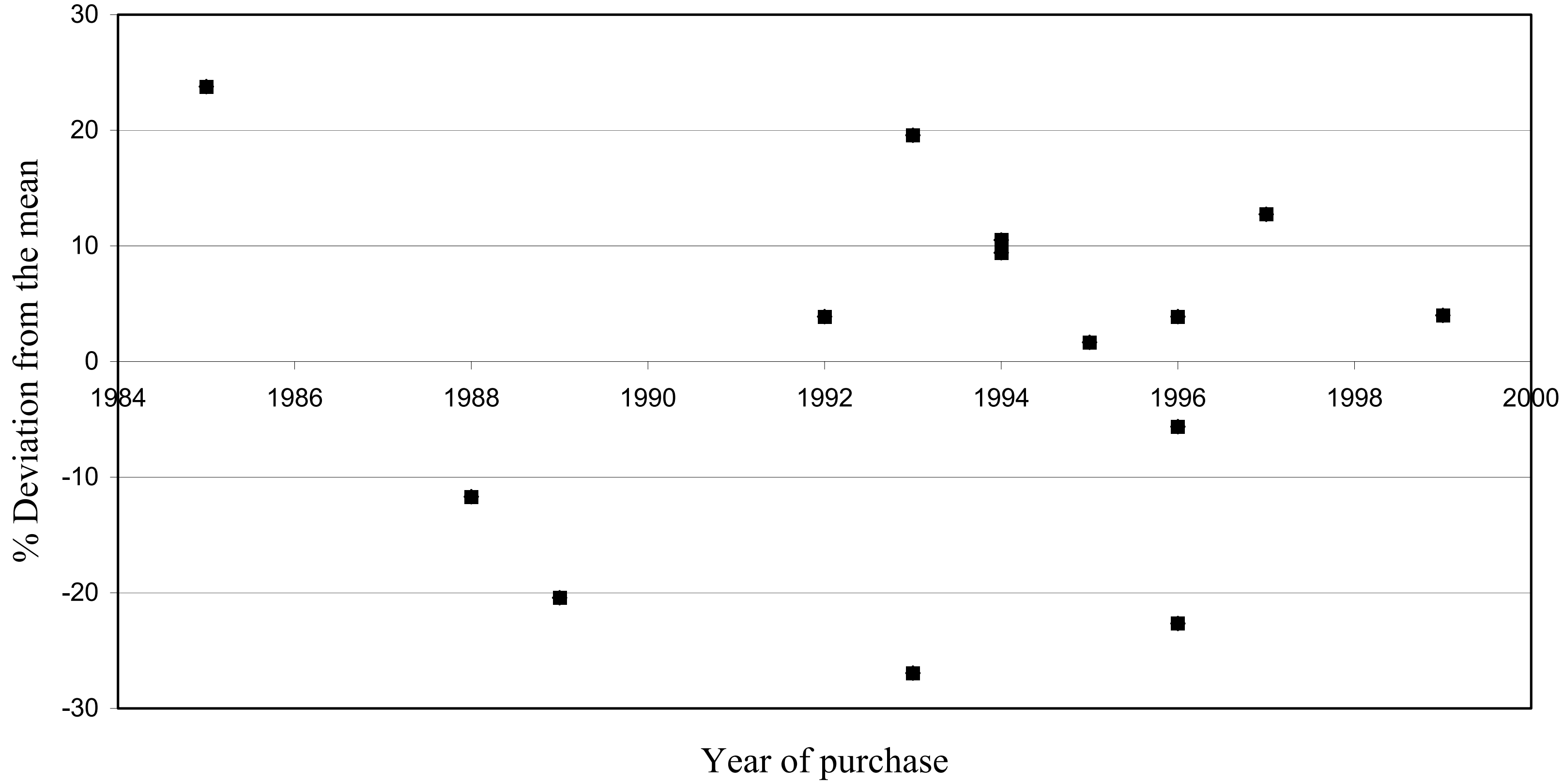


Figure 8

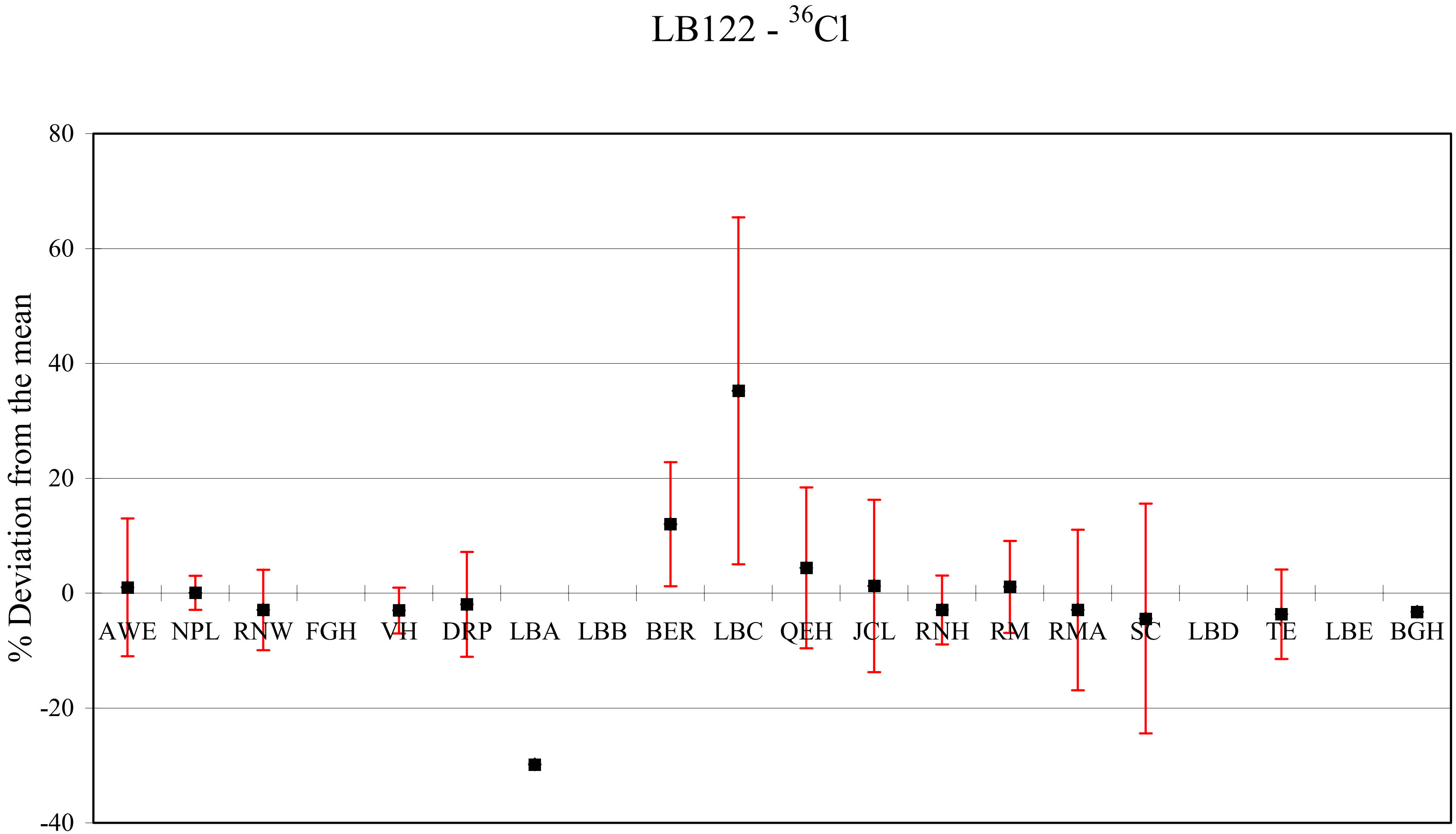

LB122 - ^{36}Cl
% Deviation from the mean
80
60
40
20
0
-20
-40
AWE NPL RNW FGH VH DRP LBA LBB BER LBC QEH JCL RNH RM RMA SC LBD TE LBE BGH

Figure 9

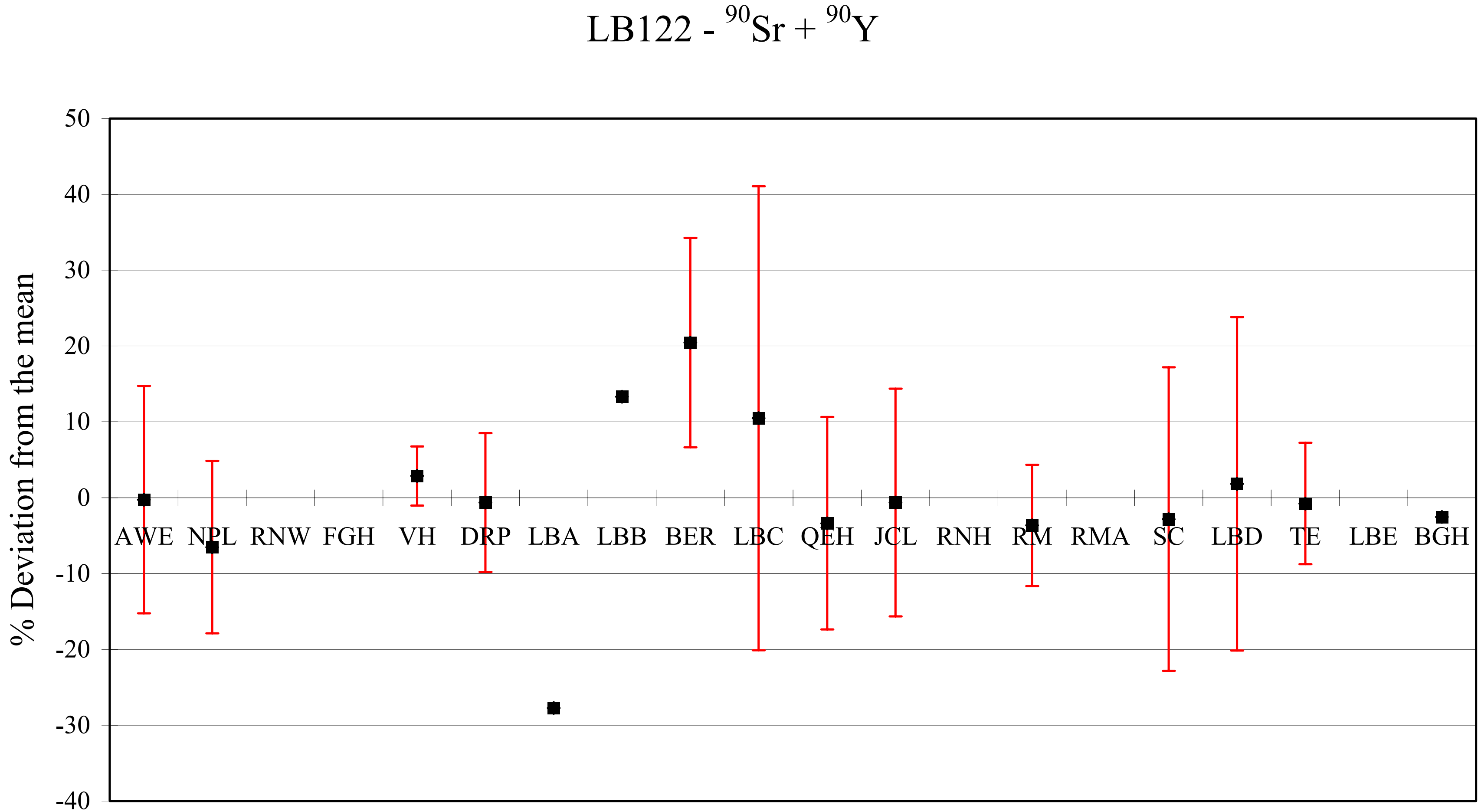

LB122 - $^{90}Sr + ^{90}Y$
% Deviation from the mean
50
40
30
20
10
0
-10
-20
-30
-40
AWE NPL RNW FGH VH DRP LBA LBB BER LBC QEH JCL RNH RM RMA SC LBD TE LBE BGH

Figure 10

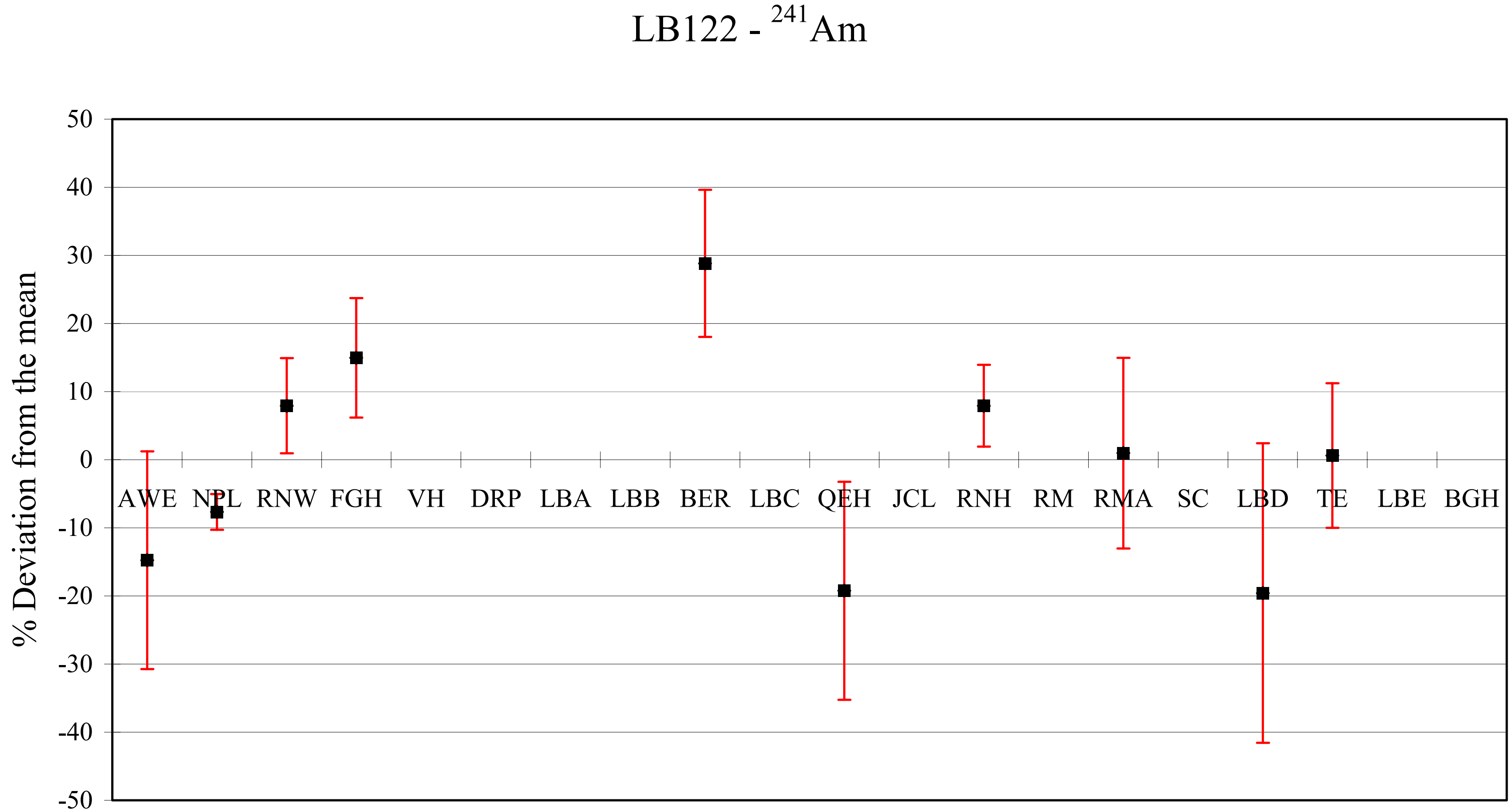

LB122 - ^{241}Am
% Deviation from the mean
50
40
30
20
10
0
-10
-20
-30
-40
-50
AWE
NPL
RNW
FGH
VH
DRP
LBA
LBB
BER
LBC
QEH
JCL
RNH
RM
RMA
SC
LBD
TE
LBE
BGH

Figure 11

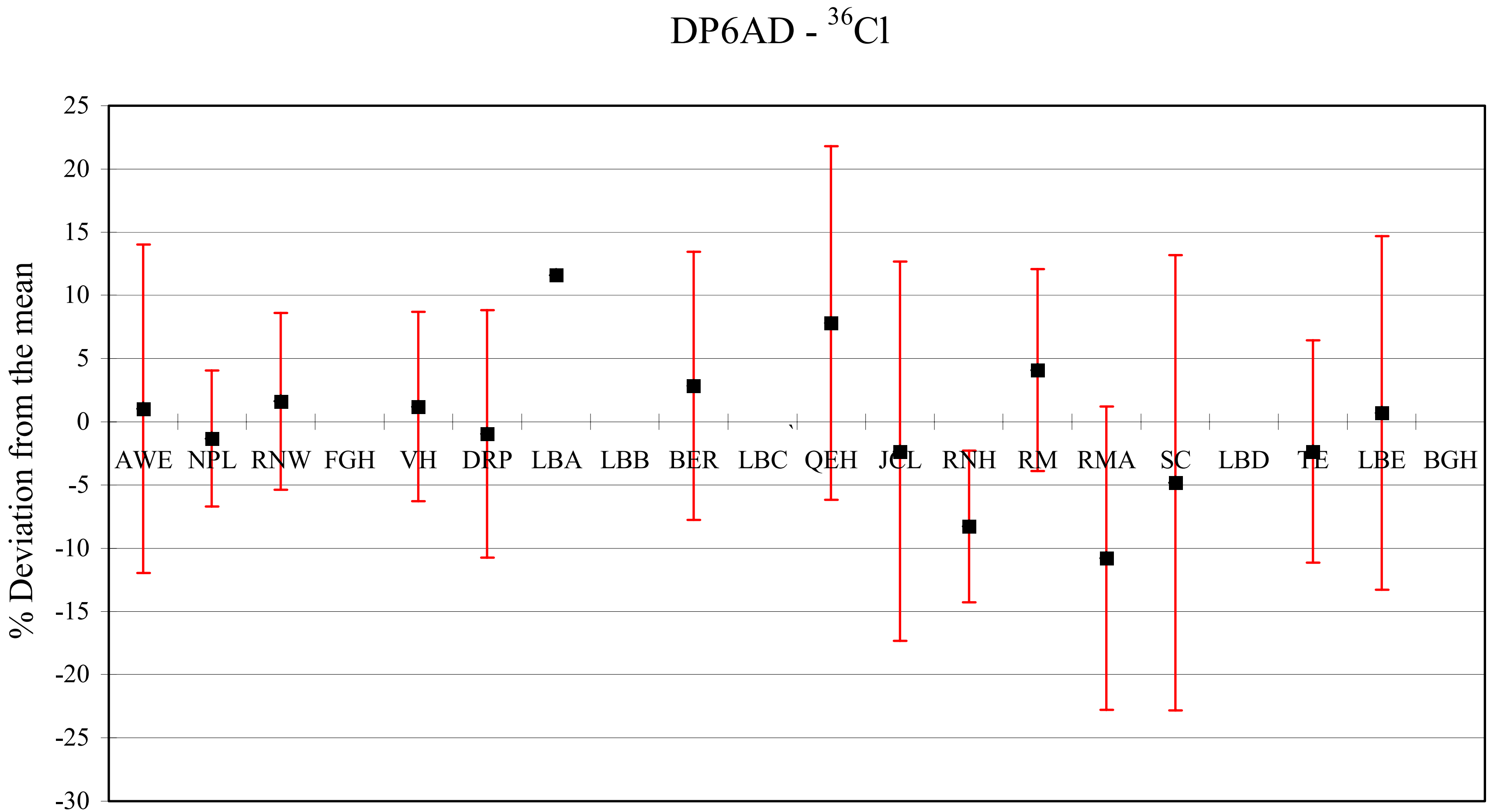

DP6AD - ^{36}Cl
% Deviation from the mean
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
AWE
NPL
RNW
FGH
VH
DRP
LBA
LBB
BER
LBC
QEH
JCL
RNH
RM
RMA
SC
LBD
TE
LBE
BGH

Figure 12

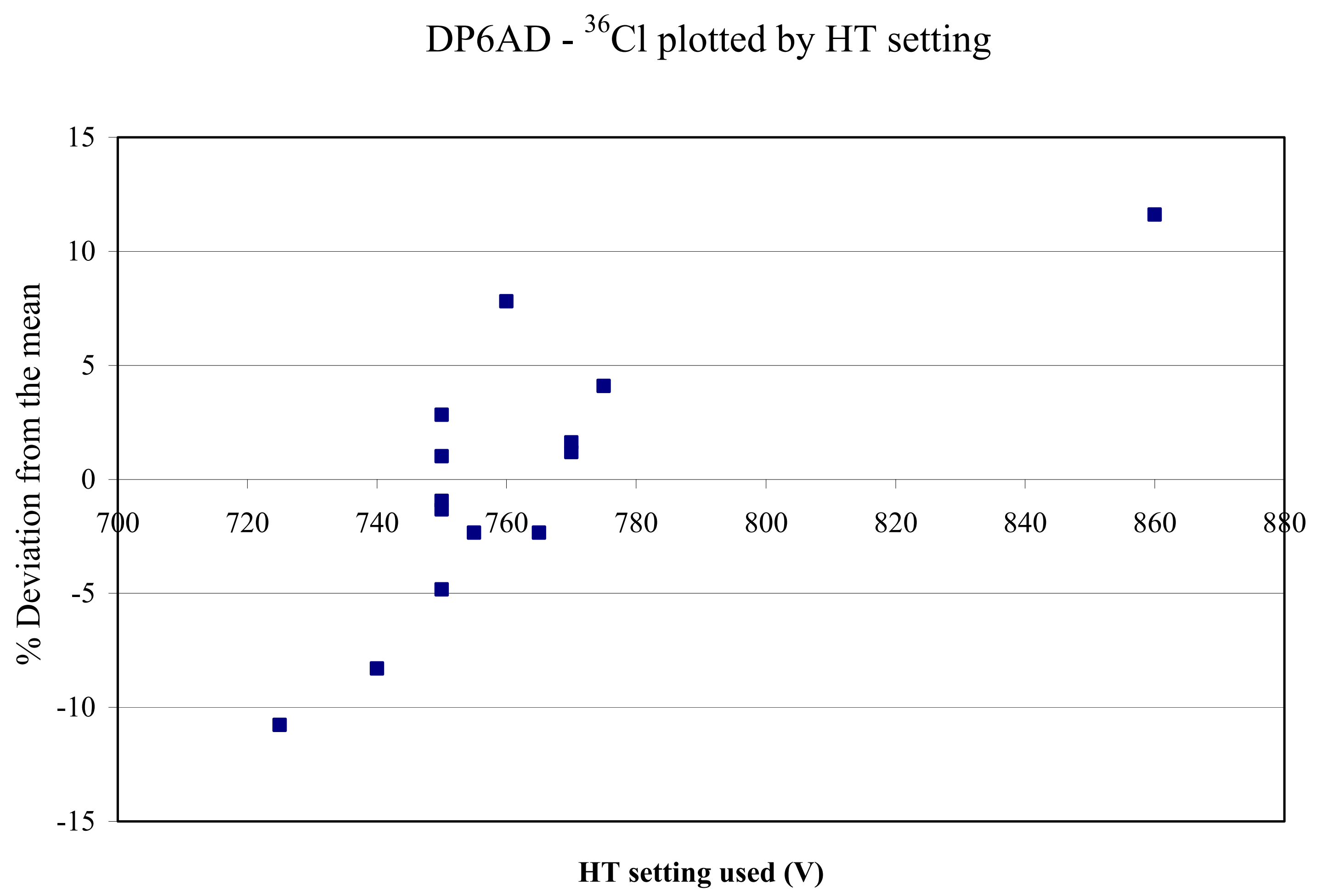

DP6AD - 36Cl plotted by HT setting
15
10
5
0
-5
-10
-15
700
720
740
760
780
800
820
840
860
880
% Deviation from the mean
HT setting used (V)

Figure 13

DP6AD - $^{90}Sr + ^{90}Y$

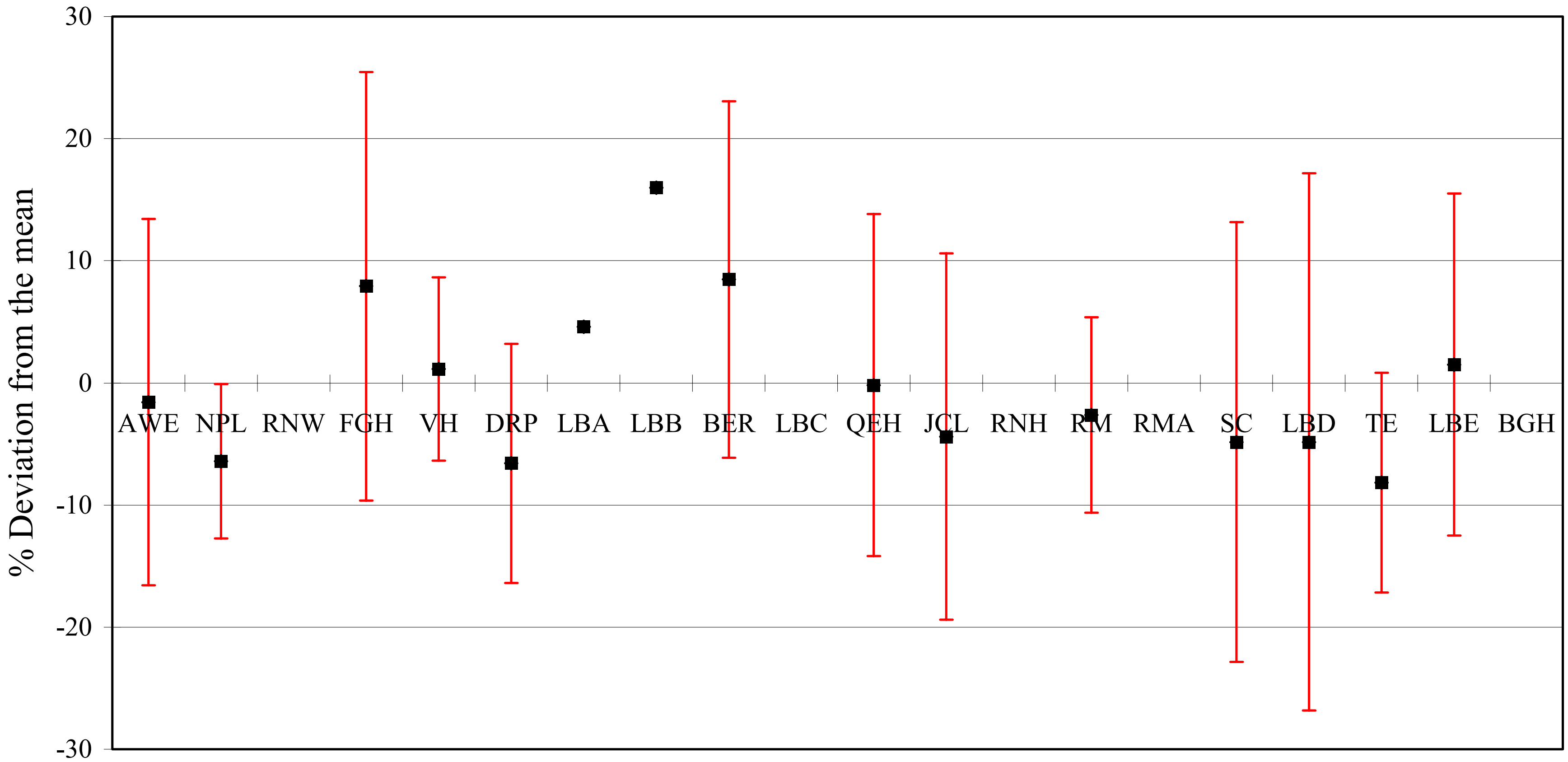


Figure 14

DP6AD - $^{90}Sr+^{90}Y$ plotted by HT setting

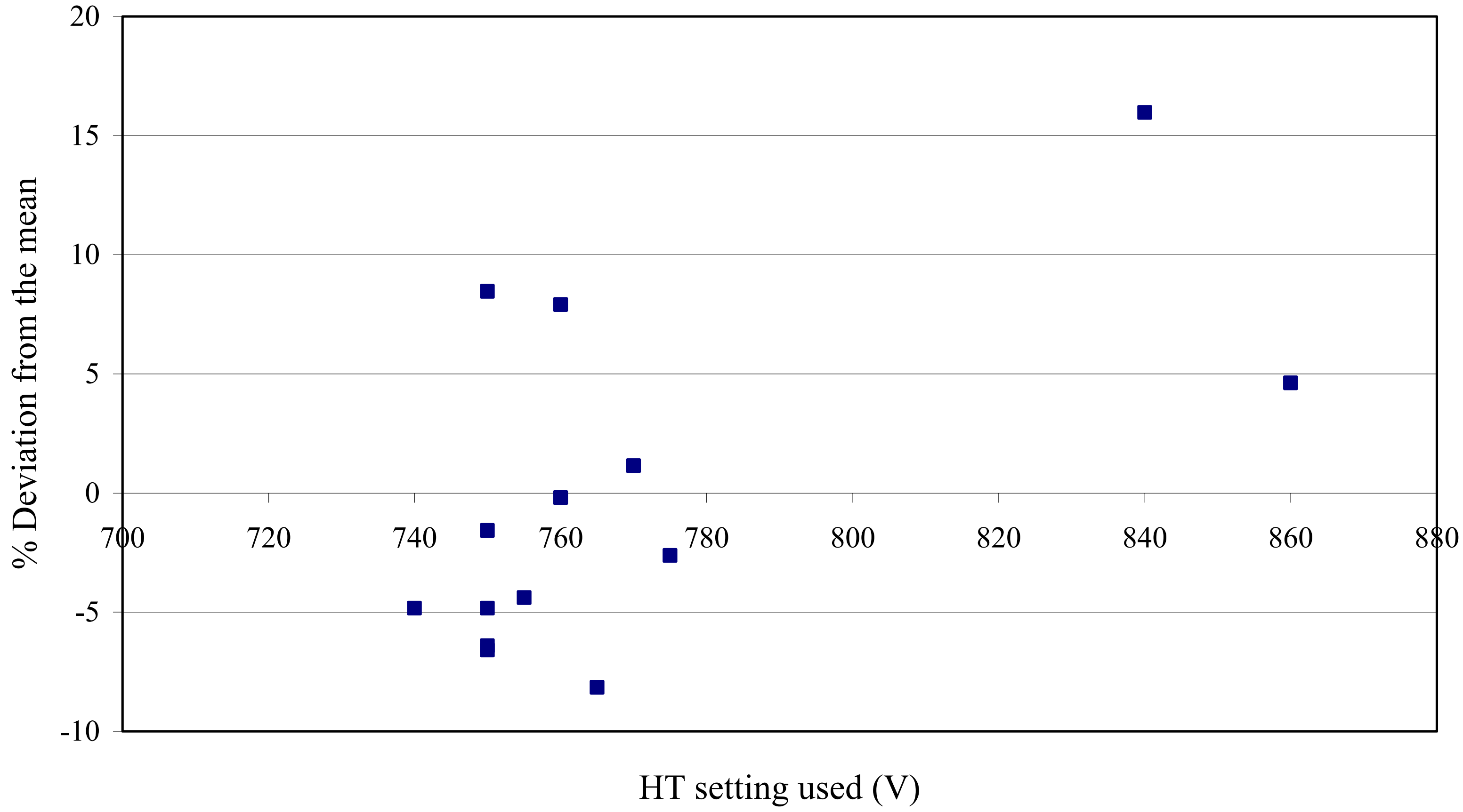


Figure 15

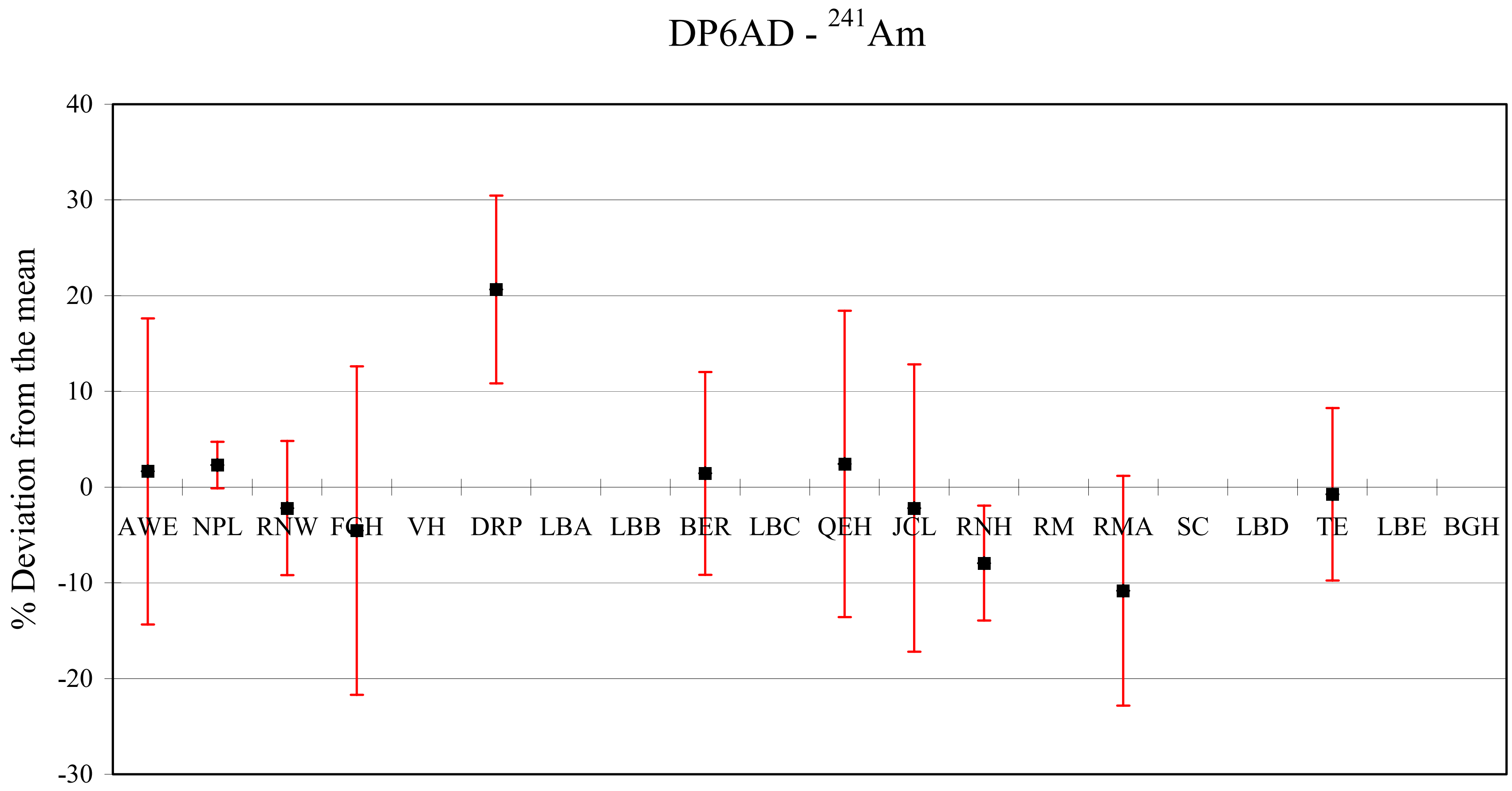

DP6AD - 241Am
% Deviation from the mean
40
30
20
10
0
-10
-20
-30
AWE NPL RNW FGH VH DRP LBA LBB BER LBC QEH JCL RNH RM RMA SC LBD TE LBE BGH

Figure 16

DP6AD - ^{241}Am plotted by HT setting

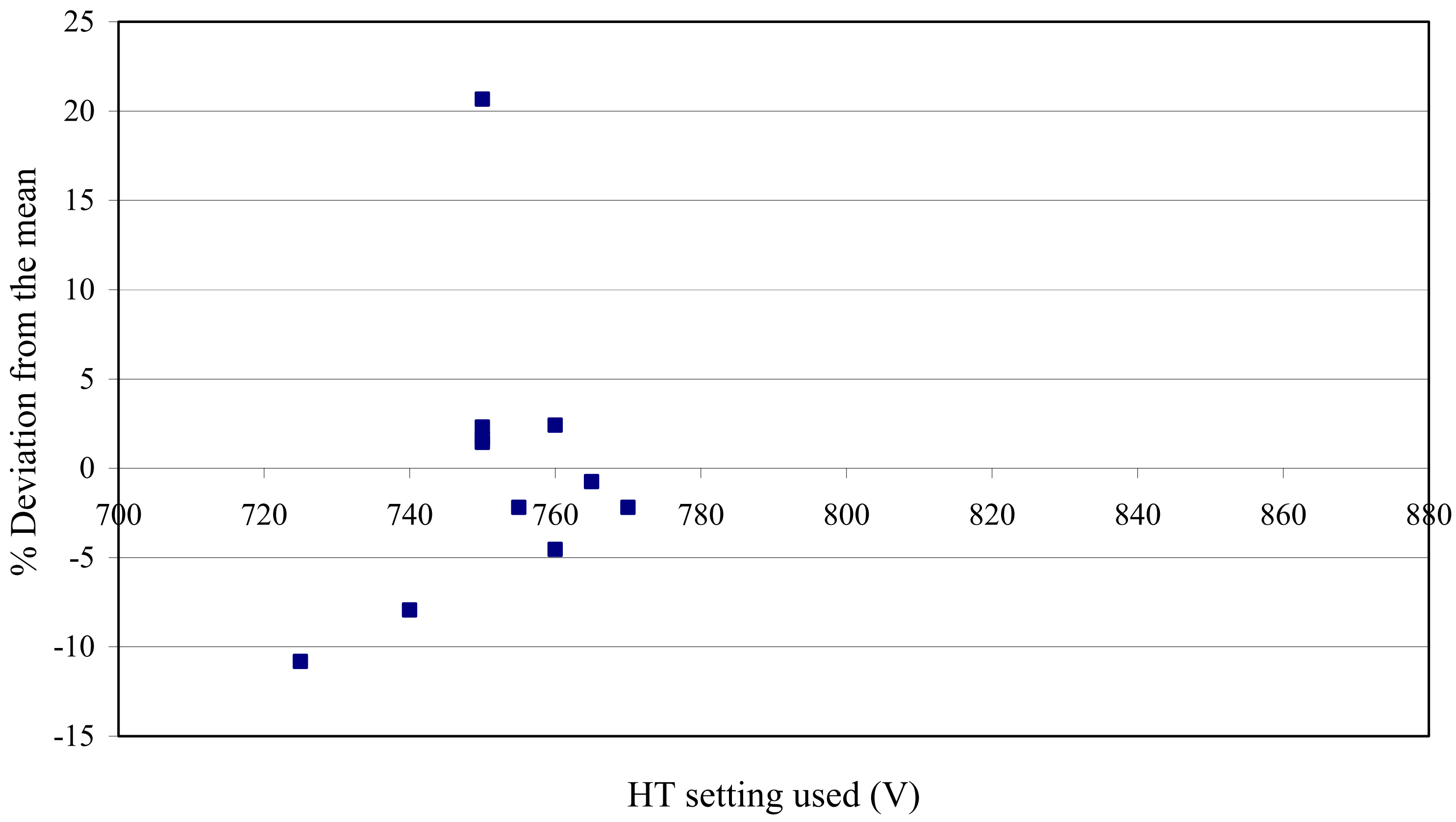


Figure 17

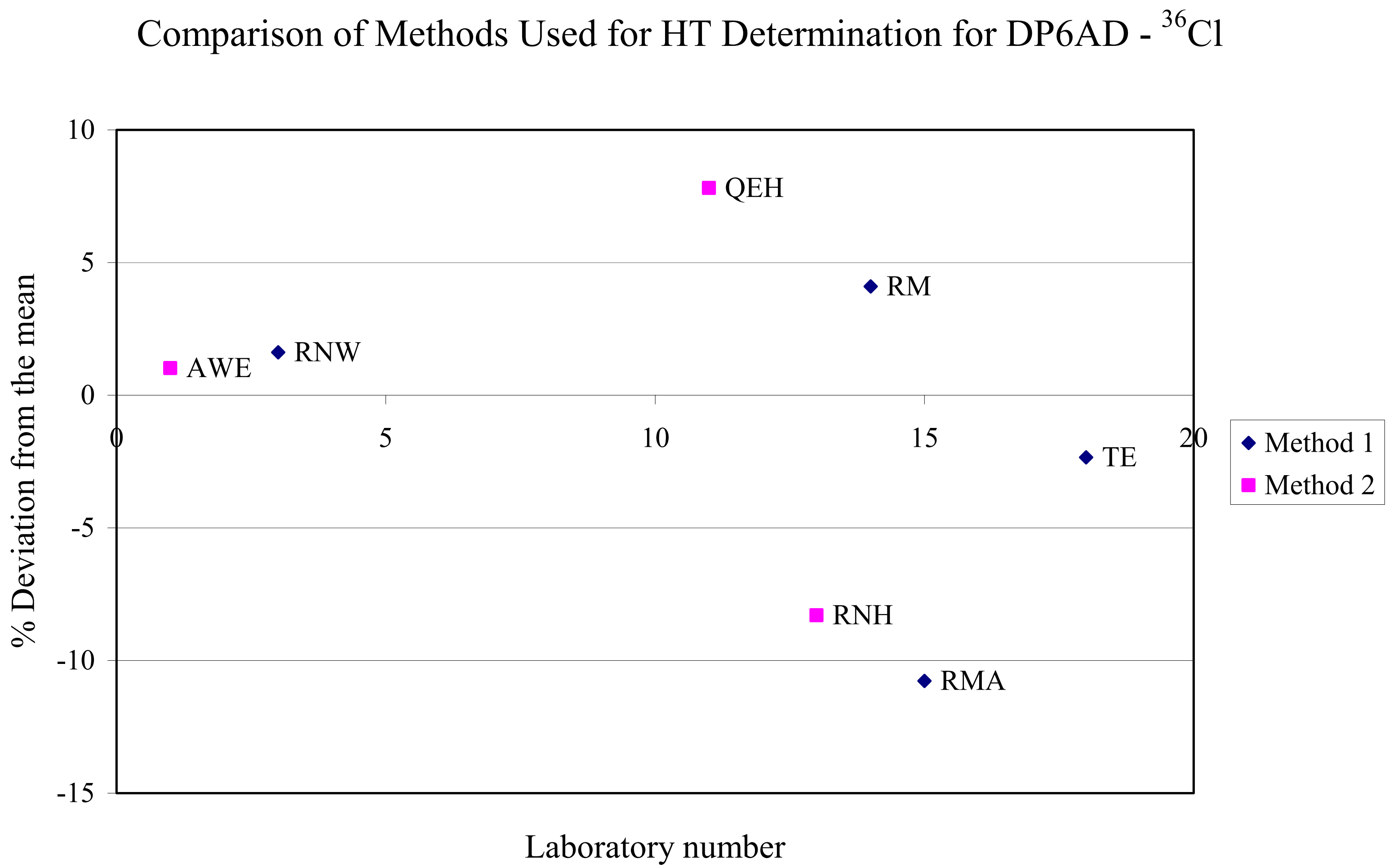
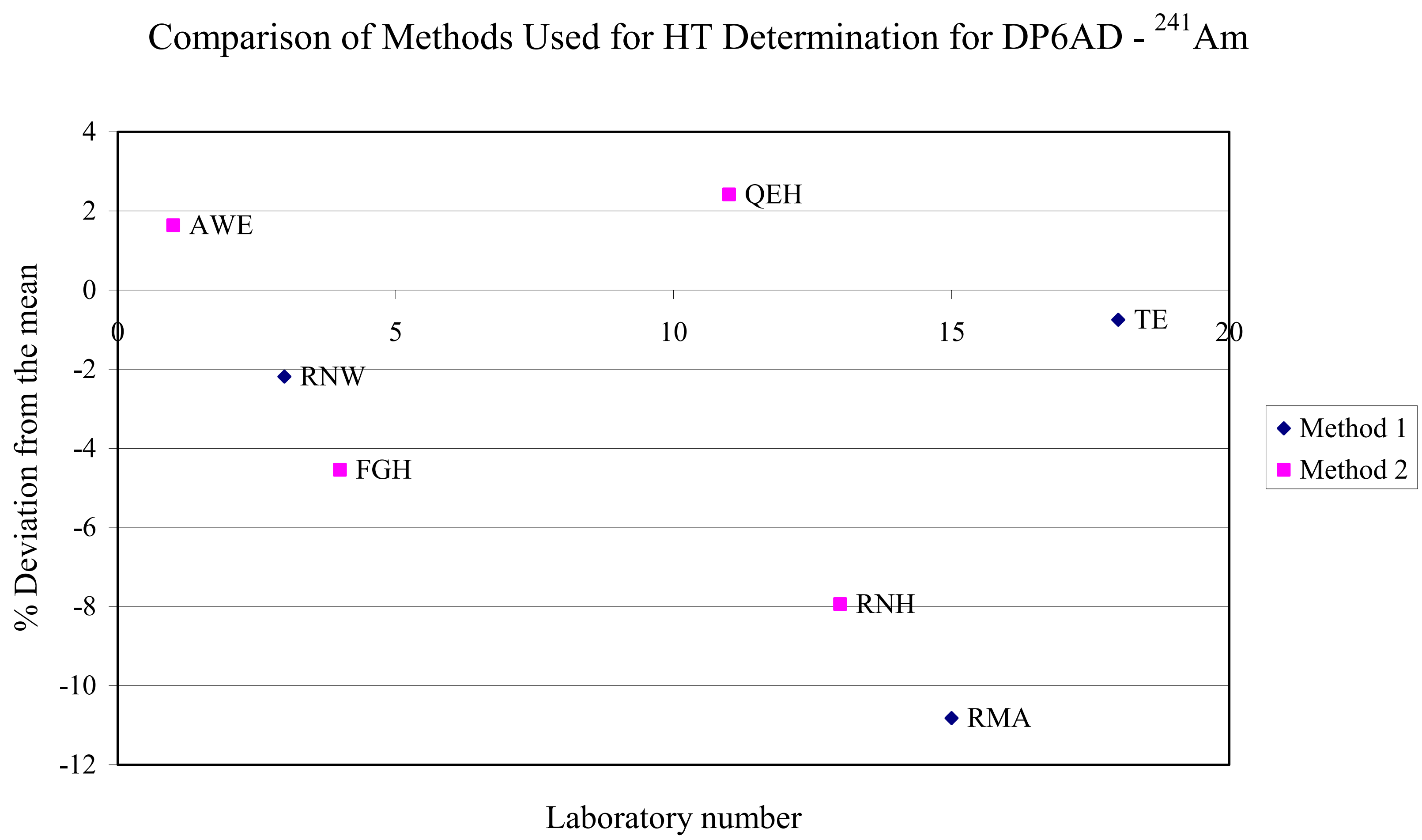

Comparison of Methods Used for HT Determination for DP6AD - ^{36}Cl
10
5
0
-5
-10
-15
% Deviation from the mean
0
5
10
15
20
Laboratory number
QEH
RM
RNW
AWE
TE
RNH
RMA
Method 1
Method 2

Figure 18


Comparison of Methods Used for HT Determination for DP6AD - 241Am
4
2
0
-2
-4
-6
-8
-10
-12
% Deviation from the mean
0
5
10
15
20
Laboratory number
AWE
QEH
TE
RNW
FGH
RNH
RMA
Method 1
Method 2